A cordon count program for pedestrians and bicycles commuting to/from a winter city university campus

By

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ABSTRACT

Pedestrian and bicycle traffic monitoring programs generate data that can be used to improve safety, promote healthy lifestyles, and improve design of non-motorized facilities. Traffic monitoring is well established for motorized vehicles, but is still developing for pedestrians and bicycles (non-motorized modes). Specifically, there is a need to establish systematic and flexible monitoring programs that capture the unique travel patterns of pedestrians and bicycles for various land uses and demographics.

The purpose of this research is to design and implement a pedestrian and bicycle cordon count program in the context of a university campus in a winter city. The approach to the research was to design the data collection plan, collect and process the data, and analyze it to calculate the simultaneous cordon counts, daily volumes, and average weekday traffic statistics at each data collection site. Automatic equipment counts and manual counts by video were used to collect data throughout the year to determine patterns for each season-semester combination.

Findings provide insight into modal, temporal, and spatial characteristics of pedestrians and bicycles at the University of Manitoba Fort Garry campus. Specifically: 1) pedestrian patterns seem more affected by semester than weather, 2) bicycle patterns seem more affected by weather than semester, and 3) the spatial distribution of traffic does not remain constant at the sites throughout the year. The research assists jurisdictions in planning data collection programs for similar urban activity areas, develops a novel approach to pedestrian and bicycle traffic data collection within a cordon count program, and provides data inputs for transportation infrastructure planning and design decisions in the campus area.

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1 INTRODUCTION

1.1 BACKGROUND AND NEED

Pedestrian and bicycle traffic monitoring programs provide data to make informed transportation decisions regarding road safety, traffic operations, infrastructure investment, sustainable transportation policies and practices, the promotion of healthy and liveable communities, and modal prioritization (Federal Highway Administration, 2016; Ryus et al., 2014b). While best practices for monitoring motorized traffic are well-established, the monitoring of pedestrians and bicycles is still an emerging field in need of research about effective program design, development, and implementation (Federal Highway Administration, 2016; Regehr et al., 2017).

Relative to motorized traffic, key challenges for monitoring pedestrians and bicycles arise because of differences in behaviour (e.g., lane adherence and directionality), physical characteristics (e.g., pedestrians cannot be detected using sensors such as inductive loops), and temporal variations (e.g., pedestrians and bicycles are more sensitive to weather conditions) (Budowski, 2015; Klassen, 2016; Ryus et al., 2014b). These challenges affect the type and performance of monitoring equipment, the placement of equipment, data screening practices, and data summarization techniques (Regehr et al., 2017; Ryus et al., 2014b). Moreover, there is increasing justification for counting pedestrians and bicycles separately, as these modes have different motivators and barriers (Delmelle & Delmelle, 2012; Rybarczyk & Gallagher, 2014).

In the North American context, three major documents have distilled available research on pedestrian and bicycle traffic monitoring into best-practice guidelines.

- *NCHRP Report 797* (Ryus et al., 2014b) is a best-practice guidebook on collecting and analyzing pedestrian and bicycle volume data. It outlines the procedures for planning and implementing a traffic monitoring program using proven methods developed by both researchers and practitioners (Ryus et al., 2014b).

- The Federal Highway Administration (FHWA) *Traffic Monitoring Guide* (2016) provides guidance on establishing system-wide pedestrian and bicycle traffic monitoring programs, principally directed toward state departments of transportation. The *Guide* includes details on best practices for pedestrian and bicycle monitoring including technology, characteristics of pedestrians and bicyclists, steps to implement traffic monitoring programs, and a standard format for pedestrian and bicycle data.
- The Transportation Association of Canada (TAC) *Traffic Monitoring Practices Guide for Canadian Provinces and Municipalities* (Regehr et al., 2017) provides recommendations on pedestrian and bicycle traffic monitoring program design, data collection, analysis, dissemination, and program evaluation. Like the FHWA *Guide*, it focuses on the implementation of system-level programs designed to monitor pedestrian and bicycle traffic throughout a defined network.

The methods described in these three documents have been widely-used to conduct research requiring pedestrian and bicycle volume data on a network or segment level (Klassen, 2016; Lu et al., 2017, 2018; Nordback et al., 2013). However, they do not contain guidance on methods to conduct cordon counts of pedestrian and bicycle traffic (Federal Highway Administration, 2016).

Cordon counts occur at entry points along an imaginary boundary around a major urban activity area to determine the number of vehicles or people entering/exiting the area in a day (Robertson, Hummer, & Nelson, 2000). These counts are ideally-suited to provide information about mode split and the unique trip generation characteristics for urban activity areas that have specific traffic data needs, yet may not have resources to implement a system-wide traffic monitoring program. Examples of activity areas include campuses, parks, tourism districts, or other specific-use areas. An evident limitation of most cordon counts is that they only capture information for a particular period (usually one week or less); thus, they cannot characterize the unique temporal variations in mode split or traffic generation patterns relevant to an activity area (City of Calgary, 2019b; University of British Columbia, 2018).

University campuses are one prominent activity area present in most major urban centres. Consideration of transportation planning, operation, design, and management on university campuses is instructive because these campuses offer an opportunity to study a city at a smaller scale and have distinct features that differentiate it from typical networks (Huang et al., 2012). Many campuses are physically isolated (or semi-isolated) from surrounding land uses. Demographically, university communities include faculty, students, staff, and other visitors. Despite this diversity, people on campuses are relatively young. For example, a campus-wide survey revealed that McMaster University had a median age of 21 years (Whalen, Páez, & Carrasco, 2013). From a travel perspective, relative to the general population, a large proportion of university students commute using active transportation modes (e.g., walking, cycling) (Delmelle & Delmelle, 2012; Whalen, Páez, & Carrasco, 2013). Most universities are progressing towards more sustainable environments in part by promoting the use of active transportation modes (Rybarczyk & Gallagher, 2014). In addition to modal differences, academic schedules and seasonality generate unique temporal traffic patterns as semesters and weather change throughout the year. This is particularly evident for campuses in winter cities (Budowski, 2015).

Despite the recent establishment of guidance for system-wide pedestrian and bicycle traffic monitoring programs and the well-understood practice of conducting cordon counts, there is a knowledge gap concerning the design and implementation of a cordon count program that adequately captures temporal traffic variations throughout a year. This research addresses this gap by designing and implementing a cordon count program to monitor variations in pedestrian and bicycle traffic accessing a university campus in a winter city throughout a year. Specifically, the research considers:

- cordon count monitoring locations (i.e., where to count);
- an appropriate counting schedule and duration (i.e., when and how long to count);
- the type of equipment needed to conduct the counts (i.e., automatic and/or manual); and
- pedestrian and bicycle traffic data screening, fusion, and analysis techniques.

1.2 OBJECTIVES AND SCOPE

The objectives of this research are:

1) to synthesize the state of practice regarding pedestrian and bicycle volume data collection plans, including equipment, count duration, and adjustment factors;
2) to design and implement a data collection plan for monitoring pedestrians and bicycles commuting to/from a university campus in a winter city; and
3) to determine and apply methods to screen, factor, and fuse the data to estimate average weekday pedestrian (AWDPT) and bicycle (AWDBT) traffic throughout a year.

The scope of this research is constrained geographically and temporally. The research designs and implements a cordon count program for pedestrians and bicycles entering and exiting the University of Manitoba Fort Garry campus. This campus is a semi-isolated urban activity area located in the southwest quadrant of the city of Winnipeg, Manitoba, Canada. Although the scope is limited to this campus, the methods and procedures used in this thesis are applicable to other urban activity areas, including other campuses, parks, or other unique areas with limited entry points and unique traffic patterns. To capture temporal traffic variations generated by academic schedules and weather, the research implemented the cordon count program for an entire year (September 2018 to August 2019). While the findings presented in the thesis pertain specifically to this timeframe, they provide general insights applicable beyond this temporal scope.

The research focuses on program-level traffic monitoring considerations. The research applies standard equipment installation, calibration, and verification procedures but does not attempt to produce specific findings on these issues.

1.3 APPROACH

Figure 1.1 shows the high-level approach applied in this research. The approach comprises four major steps:

1) the design and development of a pedestrian and bicycle traffic data collection plan for a university campus in a winter city;
2) implementation of the data collection plan using both automatic equipment and manual counts;
3) data screening, adjustment, and fusing of data sources; and
4) analysis and visualization of results to produce AWDPT/AWDBT throughout the year.

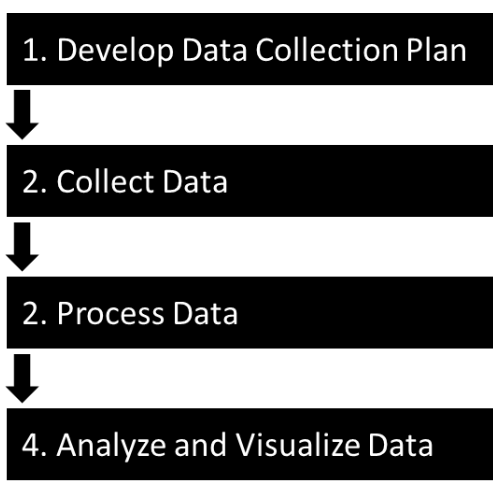


Figure 1.1: Basic flow chart of approach to research

The first step designs and develops a traffic monitoring program to determine AWDPT and AWDBT of commuters to/from the University of Manitoba Fort Garry campus for the duration of one year. Specifically, the objective of the data collection plan is to capture spatial and temporal variations in pedestrian and bicycle traffic. Design considerations include determination of the location, equipment, duration, resource allocation, and methods of data collection. The second step involves collecting pedestrian and bicycle traffic data using both automatic equipment and manual counts by video at six cordon count sites. The third step processes the automatic equipment and manual counts by video data to determine AWDPT and AWDBT commuting to/from the campus. Data processing includes screening and adjustment of raw data. The two sources of data are fused together to create a more robust estimation of AWDT by mode. The manual count data distinguishes between pedestrian and bicycle traffic and allows for detection on all facilities at all times of the year, but is limited in its collection duration. The automatic equipment allows for longer count durations, but is limited in distinguishing between pedestrians and bicycle traffic in all seasons and facilities. The final step involves the analysis and visualization of the data to reveal spatial and temporal characteristics of pedestrian and bicycle traffic on campus.

1.4 THESIS ORGANIZATION

The thesis comprises five chapters, including this introductory chapter.

Chapter 2 – Environmental Scan: This chapter reviews relevant literature in pedestrian and bicycle traffic monitoring programs and reviews 15 Canadian universities' sustainable transportation initiatives and traffic monitoring practices.

Chapter 3 – Methodology: This chapter describes the methodology of the research, including the data collection plan, implementation, and data processing procedures.

Chapter 4 –Analysis and Discussion: This chapter presents and discusses the results and limitations of the analysis.

Chapter 5 – Conclusion: This chapter summarizes the research and provides recommendations for future work.

1.5 KEY TERMS

Annual Average Daily Traffic (AADT) – the mean daily traffic volume in a given year at a site. Multiple methods to calculate AADT exist including the Simple Average Method and the AASHTO method (Regehr et al., 2017).

Automatic Equipment – technology that automatically collects traffic flow data in discrete periods. This includes permanent and temporary installments and applies to all modes (Federal Highway Administration, 2016).

Automated Pedestrian Counter (APC) – automatic equipment designed to count pedestrians.

Average WeekDay Traffic (AWDT) – the total volume during a given time period comprising of at least two but less than a year of whole weekdays, divided by the number of weekdays in that time period.

Average WeekDay Bicycle Traffic (AWDBT) – the Average Weekday Daily Traffic (AWDT) for bicycles.

Average WeekDay Pedestrian Traffic (AWDPT) – the Average Weekday Daily Traffic (AWDT) for pedestrians.

Bike-Specific Counter (BSC) – automatic equipment designed to count only bicycles (no other modes) (Ryus et al., 2014b).

Continuous Count Station (CCS) – a site where automatic equipment collects traffic data for 24 hours over 365 days (Federal Highway Administration, 2016).

Cordon Count – a count located at an entry point along an imaginary boundary around a major activity area conducted to determine the number of vehicles or people entering/exiting the area in a day (Robertson, Hummer, & Nelson, 2000).

Correction Factor – a factor that accounts for systematic inaccuracies in automatic equipment (Ryus et al., 2014b).

Expansion Factor – a factor applied to short duration counts to estimate traffic volume over longer periods (Ryus et al., 2014b).

Non-motorized Traffic – active modes of transportation including pedestrians, bicycles, skateboarders, scooters, etc.

Occlusion – the side-by-side positioning of multiple people (vehicles, pedestrians, and/or bicycles) passing a side-fire sensor at the same time, which results in bias due to undercounting (Federal Highway Administration, 2016).

Period – a homogeneous portion of time for each unique combination of academic semester and weather season.

Season – one of the four divisions of the year marked by changes in weather patterns in a winter city (winter, spring, summer, and fall). Astronomers define seasons by the earth's revolution around the sun using solstices and equinox to define the four seasons (generally at the end of March, June, September, and December) (National Centers for Environmental Information, 2016). Meteorologists categorize seasons into four different 3-month blocks beginning on the first of March, June, September, and December for consistency between years and alignment with civic months (National Centers for Environmental Information, 2016). This thesis defines seasonal transitions on March 1 (winter to spring), May 1 (spring to summer), September 1 (summer to fall), and November 1 (fall to winter).

Seasonal Average Daily Traffic (SADT) – a traffic statistic that includes months that contain at least 80% of the annual traffic (Federal Highway Administration, 2016). For example, the National Parks Service uses this metric to estimate its average daily traffic in the busier summer months (Federal Highway Administration, 2016).

Short Duration Count (SDC) – a count that is not a continuous count. Typical durations of these counts range from 24 hours to several weeks (Federal Highway Administration, 2016).

Semester – one of the three divisions of the year marked by changes in the post-secondary academic schedule. This thesis defines three semesters: (1) winter, from January to April; (2) summer, from June to August; and (3) fall, from September to December. The summer semester includes two-month courses offered in May-June and July-August.

Semi-Isolated Urban Activity Area – an urban area characterized by one or more distinct and unique features that distinguishes it from the surrounding area. Features may include demographics, temporal patterns, and predominant activities or land uses.

Winter City – a winter city has two definitions recognized by the Winter Cities Association. The first is a place where the average temperature is equal to or less than freezing (0°C) for the month of January (Rogers & Hanson, 1980). The second is a place where the average maximum daytime temperature is equal to or less than freezing (0°C) for a minimum period of two months (Pressman, 1995).

2 ENVIRONMENTAL SCAN

This chapter is an environmental scan that includes a review of literature relevant to pedestrian and bicycle traffic monitoring programs, a review of 15 Canadian universities' traffic monitoring programs, and a discussion of knowledge gaps in these areas. The literature review includes the importance of pedestrian and bicycle traffic monitoring programs, the design of a traffic monitoring program, conducting programs in urban activity areas, automatic equipment selection, data processing, and summarization of pedestrian and bicycle data.

2.1 PEDESTRIAN AND BICYCLE TRAFFIC MONITORING PROGRAMS

2.1.1 Need for Pedestrian and Bicycle Traffic Monitoring Programs

Regardless of mode, the determination of traffic volumes provides necessary information for many transportation planning, design, and management applications (Federal Highway Administration, 2016). These applications include safety and operational analyses, determining health outcomes in a community, assessing environmental impacts, and many others (Federal Highway Administration, 2016; Ryus et al., 2014b). Traffic volumes, often reported as average daily traffic (ADT) or annual average daily traffic (AADT), are crucial for informed decision-making regarding transportation systems, infrastructure, and policy.

Relative to motorized traffic monitoring programs, the implementation of monitoring programs for pedestrians and bicycles is less common, and questions remain about how closely such programs should mimic those implemented to monitor motorized traffic. Consequently, there is a need for ongoing research to support the development of best practices in the field of pedestrian and bicycle monitoring (Federal Highway Administration, 2016; Regehr et al., 2017).

Several prominent issues make non-motorized traffic monitoring programs unique from motorized traffic monitoring programs (Regehr et al., 2017; Ryus et al., 2014b):

- Other than ad hoc short duration counts, there is relatively limited historical non-motorized traffic data available.
- The behavioural and physical characteristics of non-motorized traffic make it more difficult to detect with current technologies than motorized traffic. Unlike motorized traffic, neither pedestrians nor bicycles are constrained to particular travel lanes or required to travel in a single direction in a particular lane. Physically, some types of detection equipment are ineffective for monitoring non-motorized traffic (e.g., inductive loops, which detect the presence of metal).
- Non-motorized traffic exhibits higher temporal variability and greater sensitivity to environmental conditions and, in some cases, lower volumes.

The foregoing issues underscore the need for more robust non-motorized traffic data and reveal areas requiring further research.

While much early work in the field focused on all types of non-motorized traffic (pedestrians, bicycles, skateboards, strollers, etc.) as a whole, there is increasing justification for counting pedestrians and bicycles separately, since these modes have different motivators and barriers. For example, motivators for cycling include the presence of bike racks and bicycle-specific infrastructure, whereas motivators for walking include better lighting (Rybarczyk & Gallagher, 2014). Trip distance is also a key differentiator between these modes, as people are more likely to walk than bike at shorter distances to their destination (Delmelle & Delmelle, 2012).

2.1.2 Traffic Monitoring Program Design

This section describes the general design process for collecting pedestrian and bicycle traffic data. It focuses on the design of network (or system) level pedestrian and bicycle traffic monitoring programs and discusses approaches for monitoring pedestrian and bicycle traffic in urban activity areas.

Design of Network-Level Pedestrian and Bicycle Traffic Monitoring Programs

Existing guidance on the design and implementation of pedestrian and bicycle traffic monitoring programs focuses on programs that aim to monitor traffic throughout an entire network or system (Federal Highway Administration, 2016; Regehr et al., 2017; Ryus et al., 2014b). In this context, the design process starts with the development of a comprehensive traffic monitoring plan directed at achieving the overall program objectives. Such a plan normally includes a data source inventory, a description of traffic patterns to monitor, data sampling strategies (i.e., where and how to monitor traffic and the resources required to do so), and priorities for data collection improvement (Regehr et al., 2017; Ryus et al., 2014b).

As with motorized traffic monitoring programs, achieving network level coverage with a non-motorized traffic monitoring program relies on the establishment of traffic pattern groups (TPGs). A traffic pattern group is a collection of continuous (or sometimes week-long) counts that exhibit similar temporal traffic variations (seasonal, day of week, or time of day). These groups generate average temporal factors (expansion factors) which can be applied to short duration counts to improve the quality of traffic statistics at short duration count sites. Important considerations in the development of TPGs for non-motorized traffic include determining the number of continuous count sites, determining the location of these sites, assigning short duration count sites to TPGs, and determining the location, duration, and frequency of short duration counts (Budowski, 2015; Olfert, Poapst, & Montufar, 2017; Regehr et al., 2017). Because of expected variations in pedestrian and bicycle traffic, existing guidance recommends count durations (at sampling sites) of between four and seven days (Regehr et al., 2017; Ryus et al., 2014b).

FHWA's *Traffic Monitoring Guide* describes two types for non-motorized traffic counts commonly deployed within network level monitoring programs: screenline counts and intersection counts (Federal Highway Administration, 2016). Screenline counts—both continuous and short duration—monitor traffic at a site on a single linear facility. Network level traffic monitoring programs deploy screenline counts to monitor spatial and temporal patterns throughout the defined network. Intersection counts provide information for safety and operations analyses and allow simultaneous collection of traffic counts for multiple streets (Ryus et al., 2014b). Currently, because of the complexity of movements at intersections, intersection counts are normally conducted manually or using automated video (Ryus et al., 2014b). Intersection counts are sometimes conducted on an ad hoc basis, but opportunities exist to integrate these within a network level traffic monitoring program.

As mentioned earlier, one of the major differences between non-motorized and motorized traffic monitoring is that pedestrians and bicycles are more sensitive to environmental factors, including seasonal variations in weather (Ryus et al., 2014b). Precipitation and temperature affect the number of pedestrians and bicycles throughout the year (Budowski, 2015; Klassen, 2016; Ryus et al., 2014b). For example, in the city of Winnipeg, which qualifies as a winter city according to the definitions by Pressman (1995) and Rogers (1980), research has shown that pedestrian and bicycle traffic is influenced by seasonal variables such as temperature and the amount of snow on the ground (Budowski, 2015; Klassen, 2016). In particular, pedestrians on pathways in Winnipeg were found to comprise between 64 and 77% of annual traffic in the months of May through October, inclusive (Klassen, 2016).

Count Programs in Urban Activity Areas

The *National Bicycle and Pedestrian Documentation (NBPD) Project* (Alta Planning & Design, 2005) recommends that activity areas for pedestrians and bicycles should be considered when selecting sites for short duration counts. Activity areas include places such as downtowns, parks, campuses and schools, tourism districts, or other specific-use areas that have distinct demographics or traffic patterns unlike those generated by commuter or recreational traffic. While many traffic monitoring programs emphasize city-wide or province-wide networks, there appears to be a gap in literature and practice regarding methods to monitor pedestrian and bicycle traffic in smaller activity areas.

The implementation of a cordon count program is one option for monitoring pedestrian and bicycle traffic accessing an activity area. Cordon counts create an imaginary boundary around a major activity area to count those entering and exiting the area at key access points (Robertson, Hummer, & Nelson, 2000). The counts are used for establishing modal split (i.e., vehicles, pedestrians, bicycles, transit passengers), analyzing traffic trends, studying origin-destination patterns, and supporting specific applications such as infrastructure development, parking, and congestion pricing (Liu et al., 2017; Robertson, Hummer, & Nelson, 2000). For example, a campus in California deployed a pedestrian cordon count program for to estimate crash risk in the fall and spring semesters. The data collection program included three continuous count stations and two-hour manual counts (Ryus et al., 2014b).

Normally, cordon counts comprise a set of screenline counts deployed simultaneously at midblock locations across major access points. Very low volume count sites can be ignored in cordon counts (i.e., less than 3% to 4% of total traffic) (Robertson, Hummer, & Nelson, 2000). While the deployment of screenline counts is common within network level non-motorized traffic monitoring programs (Lu et al., 2017), such screenline counts would not normally be situated at a cordon count boundary, they would seldom be conducted simultaneously, and they may be conducted for shorter durations than would be recommended for a network level traffic monitoring program. This is particularly true for traffic monitoring systems designed for pedestrians and bicycles (Day, Habib, & Miller, 2010; Schneider, Grembek, & Braughton, 2013; University of British Columbia, 2018). Consequently, despite some methodological similarities, disparate objectives and implementation practices result in a misalignment of the data produced by cordon count and network level traffic monitoring programs.

Alternatively, some large businesses, parks, and post-secondary institutions collect their own commuter data by means of surveys. Commuter/travel surveys are beneficial for determining characteristics of commuters, demographic patterns, and other factors that cannot be measured through traffic monitoring programs. Despite this use, surveys tend to be biased by those who feel strongly enough to participate and only capture a sample of the targeted population (Ryus et al., 2014b). Unless a precise origin-destination survey is conducted, surveys do not provide information on the more granular spatial characteristics of travelling to/from an activity area (e.g., particular points of access or streets utilized). Moreover, surveys typically fail to capture how traffic patterns and travel behaviours change throughout different seasonal periods.

In summary, the potential benefits of conducting cordon counts in comparison to network level counts or commuter surveys are:

- to determine the precise mode split at a specific point and into/out of a specified area, and
- to accurately determine the traffic generated by an urban activity area without bias or temporal limitations of surveys or extensive resources to deploy a network level count for all modes.

University campuses are one prominent example of an activity area present in most urban areas. Huang et al. (2012) note the distinct features that differentiate university campuses from typical networks and identify campuses as an opportunity to study a city at a smaller scale. Campus areas are communities that include faculty, students, staff, and other visitors and feature different demographic characteristics than other city neighborhoods. For example, a campus-wide survey at McMaster University's in Hamilton, Ontario found that the median age of people on campus is 21 years old (Whalen, Páez, & Carrasco, 2013). Universities are also progressing towards more sustainable environments and are attempting to promote active transportation (Rybarczyk & Gallagher, 2014). Specifically, relative to the general population, a large proportion of university students commute using active transportation modes (e.g., walking, cycling) and many live in shared accommodations (Whalen, Páez, & Carrasco, 2013). A study of bicycle traffic in Winnipeg, Manitoba provided evidence of the unique bicycle traffic patterns generated by the University of Manitoba Fort Garry campus (Budowski, 2015). Specifically, the study identified the unique temporal patterns of the "Winnipeg Post-Secondary" traffic pattern group, noting the higher proportions of bicycle traffic in September and October compared to the rest of the city.

2.1.3 Equipment

The selection of appropriate equipment for monitoring pedestrians and bicycles depends on the purpose of the count, various factors in the built environment, affordability, placement, human characteristics and behaviours, and technological limitations (Regehr et al., 2017). This section reviews the functions, advantages, and disadvantages of passive infrared sensors, inductive loops, pneumatic tubes, and manual counting by video. Although other types of equipment exist for counting pedestrians and bicycles, these four types of equipment are readily available and commonly used in the field (Glasgow, 2016; Klassen, 2016; Lindsey et al., 2013; Lu et al., 2017; Nordback, Marshall, & Janson, 2013).

Passive Infrared Sensors

Passive infrared sensors (Figure 2.1) count both pedestrians and bicycles by detecting humans as thermal objects relative to the ambient temperature. The equipment is portable and easy to install, which is an advantage when deployed for short duration counts (Eco-Counter, 2019). A limitation of the passive infrared sensor is that it cannot differentiate between pedestrians and bicycles. Pairing of the passive infrared sensor with manual counts or a bicycle-specific counter enables differentiation between pedestrians and bicycles. The sensor is subject to occlusion error when pedestrians or bicycles travel side-by-side. Passive infrared sensors can operate in extreme temperatures, though some insulating winter coats do not enable the sensor to detect human presence (Andersen et al., 2014). Ryus et al. (2014b) state that passive infrared sensors have an average absolute error of 20.11%. A follow-up study found an overall average undercount rate (APD) of 10% for passive infrared sensors and an average absolute percent deviation (AAPD) of 17% (Ryus et al., 2017). A Winnipeg study similarly found the average absolute error of Eco-Counter's PYRO Box® to range from 14 to 19% (Nytepchuk, 2015).

Figure 2.1: Eco-Counter passive infrared sensor (PYRO Box)

Inductive Loops

Inductive loops (Figure 2.2) are an intrusive type of automatic equipment that count bicycles by detecting their electromagnetic properties (Regehr et al., 2017). Most installations are permanent counters embedded in the pathway or pavement, with the exception of temporary inductive loops that adhere to the pavement for short-term use (Regehr et al., 2017). The use of inductive loops together with passive-infrared sensors is the most common method of counting pedestrians and bicycles separately (Ryus et al., 2014b). Inductive loops with no bypass error have an AAPD of 8.87% (Ryus et al., 2014b). The disadvantage of the inductive loops is that the embedded counter is not suitable for counts that require equipment portability (Ryus et al., 2014b).

Figure 2.2: Eco-Counter inductive loops (ZELT)

Pneumatic Tubes

Pneumatic tubes (Figure 2.3) consist of two rubber hoses laid across the bicycle travelway. Passing bicycles compress the tube, generating an air pulse stored by a data logger. The setup determines the direction of the bicycles based on which of the two tubes generates the first pulse. Pneumatic tubes are either general purpose counters (GPCs) or bike-specific counters (BSCs). Eco-Counter's Selective Tubes are GPCs and their Greenway Tubes are BSCs. The GPCs can span roadways and distinguish bicycles from motorized vehicles, whereas BSCs are smaller tubes used only on active transportation pathways (Ryus et al., 2014b). A study determined a negative correlation between the lateral distance a bike is from the sensor and the accuracy of the count. For Eco-Counter's BSC, bicycles that crossed the pneumatic tubes between a lateral distance of 0 to 15 ft (0 to 4.5 m) away from the sensor have a 0.0% overall error (n=246). Bicycles that crossed the pneumatic tubes at a lateral distance between 0 to 30 ft (0 to 9 m) from the sensor have a mean absolute percent error of 1.7% (Nordback et al., 2016). Ryus et al. (2014b) state that pneumatic tubes for BSCs have an average absolute error of 18.50%. A follow up study determined the AAPD for BSCs for three different products were 10.8%, 69.1%, and 16.6%, demonstrating that brand is an important factor in a data collection plan (Ryus et al., 2017). The disadvantage of the pneumatic tubes is that they are not suitable in temperatures below 0°C because the tubes have trouble compressing to count bicycles and snow clearing equipment could damage the equipment (Ryus et al., 2014b).

Figure 2.3: Eco-Counter pneumatic tubes (GPC)

Manual Counts from Video

In-field manual counts (either screenline or at an intersection) require a human observer. Manual counts from video are very similar to in-field manual counts with the exception that the human reviews video footage of the area from a camera instead of conducting the count in the field. Relative to in-field manual counts, counts from manual video review may be more reliable (video can be paused and replayed) and require less human exposure to the elements (e.g., rain, snow, extreme heat, and extreme cold). Multiple cameras can also be set up for a specific duration to count at several places simultaneously. Comparing manual counts from video to in-field manual counts, the counts from video are more expensive, as cameras require weather-resistant technology, high battery life, and ample storage to capture the video. Relative to automatic equipment, manually obtaining counts from video can be time-consuming and resource intensive (Ryus et al., 2014b). With proper camera installation (Figure 2.4), lighting, and weather conditions, manual counts from video can be the most accurate method of conducting short duration counts, as they enable 24-hour counts while limiting human fatigue (Regehr et al., 2017; Ryus et al., 2014b).

Figure 2.4: Miovision Scout camera used to collect video footage

2.1.4 Quality Assurance and Data Processing

This section describes common procedures and practices for processing pedestrian and bicycle volume data and summarizes research specific to screening and correcting pedestrian and bicycle data. It discusses equipment calibration and verification, data screening criteria and imputation, corrections, and expansion factors. After installation, calibration, and verification of automated equipment, the output data may be subject to three processes: 1) data screening and imputation, 2) application of correction factors to compensate for equipment limitations, and 3) application of expansion factors to short duration counts (Ryus et al., 2014b).

Equipment Calibration and Verification

Equipment calibration involves adjusting the sensitivity of the sensor to enable accurate counting of pedestrian and bicycle traffic volumes at the installation site. The calibration procedure depends on the automatic equipment being used and the users it is detecting (Regehr et al., 2017).

Verification, which follows equipment calibration, is the manual process of ensuring that the equipment is counting accurately. This involves comparing output data produced by the equipment with manually-collected ground truth data to confirm that the equipment is performing as intended (Regehr et al., 2017).

Data Screening Criteria and Imputation

Outputs from calibrated and verified automated equipment require screening to detect erroneous data. For pedestrian and bicycle traffic data, algorithms apply a set of screening criteria to automatically flag erroneous data which may be accepted or rejected based on manual review (Regehr et al., 2017; Ryus et al., 2014b). Existing guidance and research recommend developing algorithms that automatically flag (Olfert, 2017; Regehr et al., 2017; Turner et al., 2012):

- hours with zero volume during times of the day when traffic is expected (6:00 a.m. to 8:00 p.m.),
- consecutive identical hourly volumes,
- hours which exceed a pre-set maximum hourly volume for that site, and
- situations in which the 3:00 a.m. volume is greater than the 3:00 p.m. volume.

Application of these criteria identify potentially problematic data. The subsequent manual review process determines whether the data appears valid given applicable site-specific, environmental, and temporal factors. For example, hourly volume data may be rejected if there are more than four consecutive hours with irregular data (Regehr et al., 2017). Rejection of short duration count data should consider whether the count is representative of a "typical" (ideal) day, as counts reflecting non-recurring events (including weather) should be excluded when producing summary traffic statistics (Federal Highway Administration, 2016; Regehr et al., 2017). The outcome of the manual review process is either data acceptance or rejection.

Missing data may occur due to data rejection, equipment maintenance, equipment malfunctions, or other reasons. Analysts may choose to leave gaps in the data (exclude data) or to impute data. The *Traffic Monitoring Practices for Canadian Provinces and Municipalities* recommends exclusion unless special circumstances arise to impute the data (Regehr et al., 2017). For random anomalies, imputation may be used for a single interval of data (an hour) by computing the mean hourly volume from the previous and following hours and applying that mean to the missing hour (Regehr et al., 2017).

Correction Factors

Correction of non-motorized data is necessary due to occlusion, weather-related factors, and/or avoidance of equipment (bypass error) that may create a discrepancy between the output data and ground truth

(Regehr et al., 2017). Occlusion error occurs when two or more people pass by a side-fire sensor simultaneously (Ryus et al., 2014b). Environmental conditions can include extreme heat and cold in which infrared sensors that depend on body temperature may be unable to accurately detect those in insulated winter clothes or when the ambient temperature is near body temperature (Ryus et al., 2014b).

A variety of correction factors can be applied to compensate for the systematic inaccuracies stated above. Ryus et al. (2014b) provide adjustment factors for different sensor technologies including passive infrared sensors, bike-specific pneumatic tubes, and inductive loops. Ryus et al. (2014a) show that passive infrared correction factors range from 1.037 to 1.412 for different equipment brands and range from 1.127 and 1.520 for different bike-specific pneumatic tubes. Although Ryus et al. (2014b) provide correction factors for these devices, they recommend that correction factors be developed for each site installation as occlusion and environmental factors differ from site to site. Nytephcuk (2015) developed correction factors in Winnipeg, Manitoba for the Eco-Counter branded passive infrared sensor for different seasons.

Lastly, correction factors exist for mixed-traffic and bypass error due to equipment evasion and to distinguish traffic modes. Mixed-traffic and bypass factors are types of correction factors generated from ground truth data to adjust counts so that they better represent the traffic at the site (Ryus et al., 2014b). The mixed-traffic error applies to automatic equipment that count more than one mode and must distinguish between them. For example, pneumatic tubes used on a roadway to count vehicles and bicycles will have additional errors as the equipment may detect the incorrect mode. Bypass error arises when road users at an automatic equipment site avoid detection by travelling outside the detection zone (Ryus et al., 2014b).

Expansion Factors

Unlike correction factors, which aim to adjust the data to more accurately represent the ground truth, expansion factors extrapolate or apply the corrected data in a different application (Ryus et al., 2014b). Expansion factors include temporal, environmental, and land use factors.

- Temporal factors are used to expand short duration counts to different or longer time periods. For example, temporal factors can be used to expand hourly counts into daily counts, or to adjust a daily count to a different time of year given traffic patterns observed at a continuous count station expected to have similar temporal patterns as the short duration count site (Ryus et al., 2014b).
- Environmental factors account for the effects of adverse weather (e.g., unusually low or high temperatures, precipitation, wind speed, snow on ground) on pedestrian and bicycle volume by adjusting observed volumes during adverse weather to more closely reflect what would be expected on a normal day with close to ideal environmental conditions (Ryus et al., 2014b). Available research has shown mixed results about whether the inclusion of environmental factors improves volume estimates (Ryus et al., 2014b). More specifically, the temporal approach of day-of-year factors is preferred if an appropriate continuous dataset is available (Ryus et al., 2014b).
- Land use factors (e.g., residential vs. industrial areas, amount of mixed land use) consider the surrounding characteristics of an area and usually apply to pedestrian traffic (Ryus et al., 2014b).

2.1.5 Pedestrian and Bicycle Traffic Volume Statistics

It is useful to summarize pedestrian and bicycle data using standard traffic volume statistics. The types of statistics that can be generated depend on the type of count (continuous or short duration) used to collect the data. This section describes the purpose and applications for representing data as Average Daily Traffic, Annual Average Daily Traffic, and Seasonal Average Daily Traffic.

Average Daily Traffic (ADT)

Average Daily Traffic (ADT) is the total volume of traffic for a period of time divided by the number of days of data collection (Federal Highway Administration, 2016). This is a common statistic for short duration counts as it only requires a minimum of two full days of data to be calculated. The Average Daily Pedestrian Traffic (ADPT) and Average Daily Bicycle Traffic (ADBT) equation, when using a daily base time period, is

$$ADPT/ADBT = \frac{1}{n}\sum_{i=1}^{n} VOL_i$$

where n is the number of whole days of data and VOL_i is the daily volume for the i^{th} day.

Annual Average Daily Traffic (AADT)

The Annual Average Daily Traffic (AADT) is the mean daily traffic volume over an entire year at a site (Federal Highway Administration, 2016; Regehr et al., 2017). Existing guidance provides various formulae for calculating the AADT for pedestrians (AADPT) and bicycles (AADBT). The formulae are the same as those used for motorized traffic. Ideally, an AADT calculation would include a full 24 hours of data every day for the full 365 days a year. Calculating AADT by the Hourly American Association of Highway Transportation Officials (AASHTO) method requires a full 24-hour count for at least one day-of-week for each month from a continuous count. Although AADT is a common component of motorized traffic data collection, AADPT/AADBT is less common in practice especially in jurisdictions with fluctuations in seasonal weather (Nordback et al., 2013; Regehr et al., 2017). When using an hourly base time period, the *Traffic Monitoring Practice Guide for Canadian Provinces and Municipalities* (Regehr et al., 2017) recommends the use of the following formula:

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

where VOL_{ihdm} is the traffic volume for the i^{th} occurrence of the h^{th} *hour* on the d^{th} day of week within the m^{th} month; n_{hdm} is the number of data values for a specific hour, day, and month; i is each occurrence of an hour within a day of the week in the month, h is the hour of the day, m is the month of the year, and d is the day of the week.

Seasonal Average Daily Traffic (SADT)

AADT is a common metric for motorized traffic as vehicular traffic is relatively constant regardless of weather conditions. Since pedestrian and bicycle traffic is more sensitive to weather variations by season, the use of AADT to report average pedestrian and bicycle traffic may misrepresent actual activity. For example, in a winter city, it is common that bicycle traffic declines substantially in the winter season. If a count station in a winter city recorded an ADBT of 50 for the months of October through March and an ADBT of 600 for the months of April through August, the AADBT (approximately 325 bicycles per day) poorly represents activity in both periods. Therefore, some agencies prefer reporting seasonal average daily traffic for pedestrian and bicycle volumes (SADPT/SADPT). The FHWA defines Seasonal Average Daily Traffic (SADT) as a traffic statistic that includes those months that contain at least 80% of the annual traffic (Federal Highway Administration, 2016). The *Traffic Monitoring Practice Guide for Canadian Provinces and Municipalities* (2017) describes SADPT/SADBT as the mean daily traffic that occurs during peak months of a year and does not specify the 80% threshold used in the *NCHRP Report 797* and the *Traffic Monitoring Guide* (Federal Highway Administration, 2016; Ryus et al., 2014b). For example, the National Parks Service uses this metric to estimate its average daily traffic in the busier summer season (Federal Highway Administration, 2016). This is also a statistic used in regions where climate varies greatly throughout the year to better represent active transportation in warmer seasons (Budowski, 2015).

2.2 REVIEW OF TRAFFIC MONITORING PRACTICES AT CANADIAN UNIVERSITIES

To provide context about the state of the practice in traffic monitoring on university campuses, this section reviews efforts at 15 Canadian university campuses. The universities are from the U15 Group of Canadian Research Universities, which comprises Canada's most research-intensive universities. The review, conducted in October 2019, provides insight as to how universities encourage active modes of transportation and the traffic monitoring practices implemented on university campuses. The post-secondary institutional review includes a brief description of the main campus characteristics, identification of sustainable transportation strategies/initiatives, and the identification of internal (on campus) and external (off campus) sources of transportation or traffic data. Table 2.1 summarizes the results of the review; Appendix A provides additional details.

Table 2.1: Summary of review of traffic monitoring practices on U15 campuses (west to east)

University and City	Campus Description	Sustainability Initiatives	Internal Transportation Data	External Transportation Data
University of British Columbia, Vancouver (UBC) Vancouver, BC	• 50, 000 students. • Semi-isolated urban campus with minimal through traffic.	The campus has a *Sustainability Plan* that includes specific targets and actions to increasing transit, walking, and cycling.	The campus has been collecting transportation data since 1997. This includes data on vehicle, pedestrian, bicycle, and transit movements. Counts are conducted annually. The university has conducted travel surveys.	The City publishes vehicle traffic counts, conducts pedestrian and bicycle counts, and has produced an annual travel survey since 2013.

University and City	Campus Description	Sustainability Initiatives	Internal Transportation Data	External Transportation Data
University of Calgary (U of C) Calgary, AB	• 30, 000 students. • Semi-integrated urban campus with major city streets delineating the campus area and indirect internal through routes.	The campus has many sustainability initiatives, groups, and targets. The only reference to cycling and walking identified was in their *2019 Climate Action Plan*, which aims to improve the walking and cycling network on campus.	The campus conducted an online survey of bicycles to determine how to increase the bicycle mode share but does not appear to have a traffic monitoring or count program for any mode.	The City has an extensive traffic monitoring program with automatic counters for vehicles and bicycles, additional manual counts for vehicles, bicycles, and pedestrians as well as an annual central business district cordon count of all modes. The traffic data is available online. The City also conducts commuter surveys, mode split surveys, and bike-specific surveys.
University of Alberta (U of A) Edmonton, AB	• 40, 000 students. • Semi-isolated urban campus with no internal through roads.	The campus has a Sustainability Council, a *Sustainability Plan*, and a *Long Range Development Plan*. The plans discuss the promotion of walking and cycling without specific measures or targets. The campus also published a *2007 Travel Demand Management Plan* with a section on pedestrians and bicycles.	The campus does not appear to have any traffic monitoring system or internal transportation data sources such as traffic counts and/or surveys.	The City produces traffic statistics for vehicles, pedestrians, and bicycles and publishes these online. The City also conducted a household travel survey in 2015.
University of Saskatchewan (U of S) Saskatoon, SK	• 21, 500 students • Semi-isolated urban campus with one through road dividing the two campus areas.	The university has a sustainable mobility plan and a cycling infrastructure plan. The mobility plan involved a thorough review and survey process and provided recommendations. The plan recommends specific bicycle infrastructure projects but	The university conducted travel surveys in 2013 and 2016 in addition to the City's travel survey that included a separate study of the campus. This study included a travel	The City relies on household travel surveys as their source for transportation data. No evidence of a traffic monitoring program was found publicly online.

University and City	Campus Description	Sustainability Initiatives	Internal Transportation Data	External Transportation Data
University of Saskatchewan (Continued)		does not state specific targets or goals.	diary survey to determine trip characteristics and mode split.	
University of Manitoba (U of M) Winnipeg, MB	• 39, 000 students. • Semi-isolated urban campus with little through-traffic.	The university published a report on strategies specific to sustainable transportation on campus. It includes guiding principles, strategies, actions, and implementation. It also includes infrastructure, education, and programming to support these initiatives.	The university conducted campus commuter surveys in 2016 and 2018. The campus owns two sets of pedestrian and bicycle counters for traffic monitoring.	The City has an annual traffic flow map for vehicles and owns equipment for counting pedestrians and bicycles. The data from the equipment is not publicly available. The City conducted a household travel survey in 2007.
University of Western Ontario (Western) London, ON	• 30, 600 students. • Integrated urban campus with internal through roads and a bridge to access the area.	The university has a *Campus Masterplan* that restricts vehicular traffic in the core of campus. It recommends improvement to infrastructure but does not state specific measures or targets.	The university conducted commuter surveys in 2009 and 2016. Results were not readily-available.	The City has an extensive vehicle traffic monitoring program. The City owns 13 counters for bicycles and supplements these counts with Strava® data. The City conducted a *Household Travel Survey* in 2016.
University of Waterloo Waterloo, ON	• 45, 600 students. • Semi-isolated urban campus in the centre of the city. It has few internal roadways for pass-by traffic.	The university has a specific target to increase sustainable commutes to 90% by 2025 (previously 85% in 2016). The campus has sustainability reports identifying cycling events and infrastructure. The *Campus Master Plan* prioritizes pedestrian and bicycle infrastructure projects and aims to create a *Transportation Demand Management* strategy.	It appears that the university relies on City transportation data through the household travel survey.	The City has open data for pedestrian and bicycle travel at 13 trail count locations. The City also collects and disseminates vehicular AADT estimates. The City conducts a household travel survey every 5 years.

University and City	Campus Description	Sustainability Initiatives	Internal Transportation Data	External Transportation Data
McMaster University Hamilton, ON	• 32, 000 students. • The campus is a semi-isolated urban area.	The university's *Sustainability Report* emphasizes increasing sustainable transportation but does not mention measurable targets.	The university conducts transportation surveys (2010, 2016). There is no evidence of a traffic monitoring program.	The City participates in the *Transportation Tomorrow Survey* (TTS), a household travel survey. The City has 21 counters for pedestrians and bicycles and publishes their data online.
University of Toronto (U of T), St. George Campus Toronto, ON	• 90, 000 students. • St. George Campus is an integrated campus with through roads allowing for pass-by trips.	The *Campus Master Plan* emphasizes the need for pedestrian and bicycle infrastructure to/from and within campus. The campus does not have specific measurable targets for walking and cycling in terms of sustainability or planning.	The campus does not appear to have its own traffic monitoring program. The St. George campus conducted a commuter survey in 2017.	The City conducts vehicle, pedestrian, and bicycle counts using different methods. The bicycle data is available online and includes permanent and short duration counts that use automatic equipment or intersection counts. The City uses the *Transportation Tomorrow Survey* (TTS), a household travel survey.
Queen's University Kingston, ON	• 25,000 students. • The main campus is integrated into the urban area near downtown. It is bounded by the lake and major roads and has internal roads to allow for pass-by trips.	The university's sustainability and campus planning documents state that it encourages cycling and walking and has plans for future networks and infrastructure. It does not have any measurable targets or goals to increase the mode share or decrease greenhouse gas emissions.	The university does not have a traffic monitoring program and conducted a travel survey only for employees.	The City does not have information publicly available on a traffic monitoring program. The City conducted a Household Travel Survey in 2008 and is currently conducting an updated survey.

University and City	Campus Description	Sustainability Initiatives	Internal Transportation Data	External Transportation Data
University of Ottawa (U of O) Ottawa, ON	• 40, 000 students. • The main campus is integrated into the urban area. It has internal roads likely used by residents in the area.	The university promotes cycling through bike parking and walking through a car-free campus core.	The university conducts commuter surveys every few years. There is no evidence of a traffic monitoring program.	The City provides data for over 20 bicycle counters in the city via an online data portal. The City conducted a 2013 survey on travel attitudes that did not collect travel data.
Université de Montréal Montréal, QC	• 67, 000 students. • The campus is mostly a semi-isolated urban area, but has a few buildings outside the main campus area.	The university promotes cycling through resources and programs including showers, maintenance, and bike-matching.	The university conducted a travel survey in 2011 but does not appear to implement a traffic monitoring program.	The City conducts frequent surveys related to mobility. The City publishes bicycle count data online. The online data portal contains real-time traffic data and bicycle trips.
McGill University Montréal, QC	• 40, 000 students. • Semi-integrated urban campus with little through-traffic.	The university is finalizing a *Transportation Master Plan* and has published documents including a *Sustainability Report* with transportation programs. The campus does not have specific goals or targets for transportation. The university created a guide to help students and staff make sustainable mode decisions.	The university conducts campus commute surveys every two years.	The City conducts frequent surveys related to mobility. The City publishes bicycle count data online. The online data portal contains real-time traffic data and bicycle trips.

University and City	Campus Description	Sustainability Initiatives	Internal Transportation Data	External Transportation Data
Université Laval Québec City, QC	• 43, 000 students. • A semi-isolated urban campus. It is bounded by major roadways and has few internal roadways.	The university has two documents on sustainability initiatives. Items on sustainable transportation include promotion of educational events such as “Sustainable Transportation Week” and measuring the amount of new bicycle infrastructure installed. It does not have any specific targets for cycling and walking.	No formal evidence of vehicular data collection at the university was identified, although it is expected that such collection occurs in some form. There is no evidence of a commuter or travel survey.	The City collects and disseminates their traffic data using an online platform since 2017. This is not a conventional traffic monitoring program as it uses real-time data and measures congestion more so than volumes.
Dalhousie University Halifax, NS	• 19, 000 students. • Mostly-integrated urban campus with major city streets delineating three campus areas. It has few internal roads to allow pass-by trips.	The campus Sustainability Office emphasizes the need for sustainable transportation. The department has produced over 20 reports related to transportation. It has measurable goals and targets and reports on progress made towards them.	The university conducts frequent commuter surveys and counts pedestrians and bicycles in partnership with the City.	The City uses 12 pedestrian and bicycle counters downtown. There is currently a travel survey underway for the province of Nova Scotia.

In general, the results of the university campus review show that although many campuses claim they want more students and staff to commute by walking, cycling, or transit, many do not have measurable targets or means to measure the growth of sustainable transportation on campus. Universities that do collect travel data primarily rely on travel surveys, except for two campuses that conduct traffic counts. The cities of these universities vary in their traffic monitoring practices and the information made available online. Some cities implement extensive count programs that include permanent counting equipment for multiple modes, cordon counts, and additional manual counts. Other cities do not have easily accessible information about their traffic monitoring programs.

2.3 SUMMARY AND GAPS IN KNOWLEDGE

Following research and practice relevant to motorized traffic monitoring and recently published guidance (Federal Highway Administration, 2016; Regehr et al., 2017; Ryus et al., 2014b), certain cities have established network level monitoring programs for pedestrians and bicycles. These programs typically do not offer the level of spatial granularity required to monitor pedestrians and bicycles in urban activity areas like university campuses. Cordon counts are a common approach to capturing motorized traffic in these types of urban activity areas but have seldom been deployed to monitor pedestrian and bicycle traffic specifically. Moreover, cordon counts typically fail to represent the temporal variations evident in non-motorized traffic patterns. As cordon counts are resource-intensive, they are often conducted for one or two days a year. Pedestrian and bicycle traffic exhibits high temporal variability due to sensitivity to inclement weather conditions and lower volumes (Federal Highway Administration, 2016; Regehr et al., 2017; Ryus et al., 2014b). This creates potentially unrepresentative estimates of pedestrian and bicycle traffic, particularly when monitoring these modes in winter cities. Consequently, there is a knowledge gap concerning how best to deploy a pedestrian and bicycle monitoring program for an urban activity area—particularly a university campus—that generates information about mode splits entering the area, traffic volumes on specific streets, and the temporal variations of traffic volume by mode. This thesis fills this knowledge gap.

To verify this gap, the scan included a comprehensive review of traffic monitoring programs at the U15 Group of Canadian universities. The review revealed that some universities have no access to traffic data, some gather it through commuter travel surveys, and two collect data using automatic equipment or manual count methods. The campuses that do collect count data are in non-winter cities and/or count primarily once a year in the fall. The only campus to use automatic equipment to count pedestrians and bicycles year-round is Dalhousie University; however, this is done in partnership with the City of Halifax as the Dalhousie Campus is integrated into the downtown. The University of British Columbia (UBC) Vancouver campus conducts annual cordon counts using a mix of automatic equipment and manual counts once per year. Thus, the scan confirmed the need for a novel approach for conducting a year-round pedestrian and bicycle traffic data at university campuses in a winter city.

3 METHODOLOGY

This chapter describes the methodology for the data collection plan, data collection, methods for data processing, and the visualization and analysis of data, as illustrated in Figure 3.1. The figure depicts how multiple data sources are utilized to gather information on modal, spatial, and temporal pedestrian and bicycle traffic trends on campus, as presented in Chapter 4. The figure depicts the relation between the purpose of the data collection plan (Section 3.1) and the representation of the results (Chapter 4). Specific elements of the methodology apply to the University of Manitoba Fort Garry campus, but the general approach has applications to other campuses or urban activity areas.

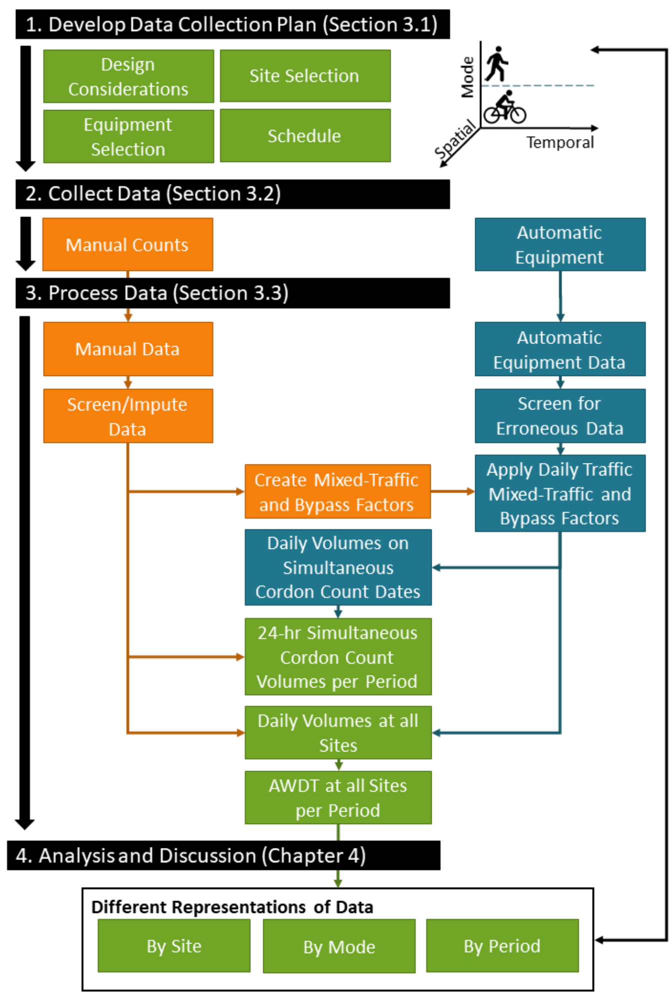


Figure 3.1: Flow chart of the research methodology

3.1 DATA COLLECTION PLAN

The data collection plan comprises general planning considerations, equipment selection, site selection and specific design considerations at each site, and temporal considerations that influenced data collection (see Figure 3.2). As depicted in the figure, the purpose of the data collection plan is to gather information on spatial and temporal characteristics of pedestrian and bicycle traffic at the University of Manitoba Fort Garry campus.

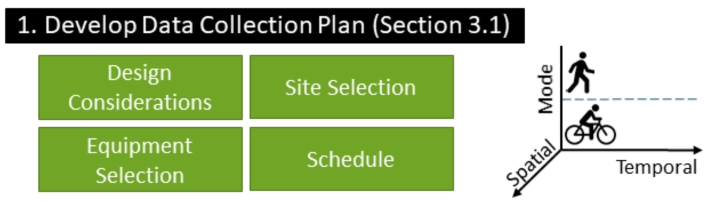


Figure 3.2: Data collection plan

3.1.1 General Planning Considerations

Description of the University of Manitoba Fort Garry Campus

The University of Manitoba is in the southwest quadrant of the city of Winnipeg, Manitoba, Canada. Winnipeg has a population of approximately 705,200 people (Statistics Canada, 2016). Commuter statistics from the 2016 census show that 4.9% of Winnipeggers commute by walking and 1.8% commute by cycling [n=342,220] (Statistics Canada, 2016). In contrast, an earlier 2007 study of travel within the Winnipeg area states that 9.5% of all trips within Winnipeg are by walking and 0.7% by cycling [n=1,625,680] (iTRANS Consulting Inc., 2009).

The University of Manitoba has approximately 40,000 students, professors, and staff members across the Fort Garry and Bannatyne campuses (University of Manitoba, n.d.). The Fort Garry campus occupies 2.70 km^2 of property, including 0.50 km^2 of land that was formerly a golf course (Southwood Lands), 0.94 km^2 of land designated as a research and technology park (Smartpark), and a stadium (IG Field) used for professional sports and other major events. The Fort Garry campus is semi-isolated, as it is bounded by perimeter roadways (Freedman Crescent and Pembina Highway) and the Red River.

The campus demographic is different than the broader urban area. From a recent commuter survey at the Fort Garry campus, 78% of students (undergraduate and graduate) report their age between 16 and 24 years old (n=4807) (Green Action Centre, 2018). At the time of the commuter survey (2018), the University of Manitoba had an estimated 29,254 students enrolled (full-time combined graduate and undergraduate) at both campuses, comprising 74% of the people that commute to/from the campus (Green Action Centre, 2018). Two campus commuter surveys conducted in 2016 and 2018 provide recent information on travel to and from campus. Figure 3.3 and Figure 3.4 show the results of the commuter mode split at the Fort Garry campus during the regular academic season (September through April) and summer (May through August). A universal university transit pass (U-Pass) was implemented in 2017 (i.e., between the survey periods); this may be one of the factors that contributed to the increase in transit mode share.

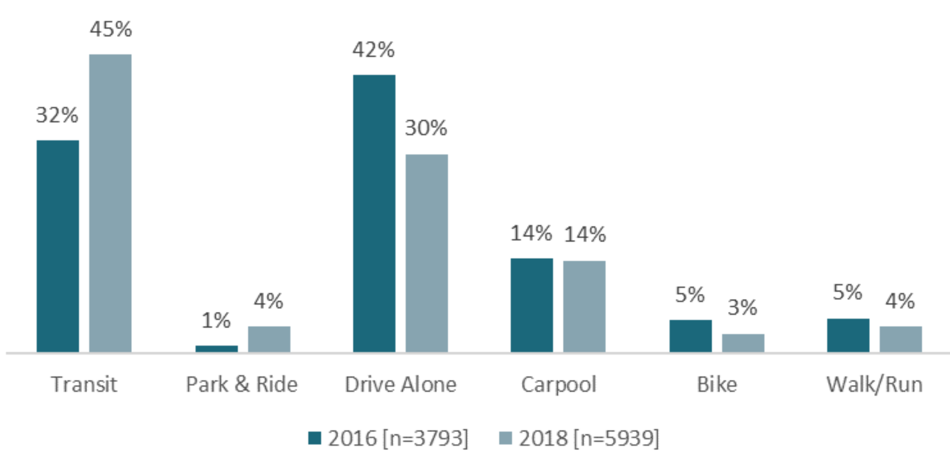


Figure 3.3: Mode split at Fort Garry campus between September and April (data sourced from Green Action Centre, 2016, 2018)

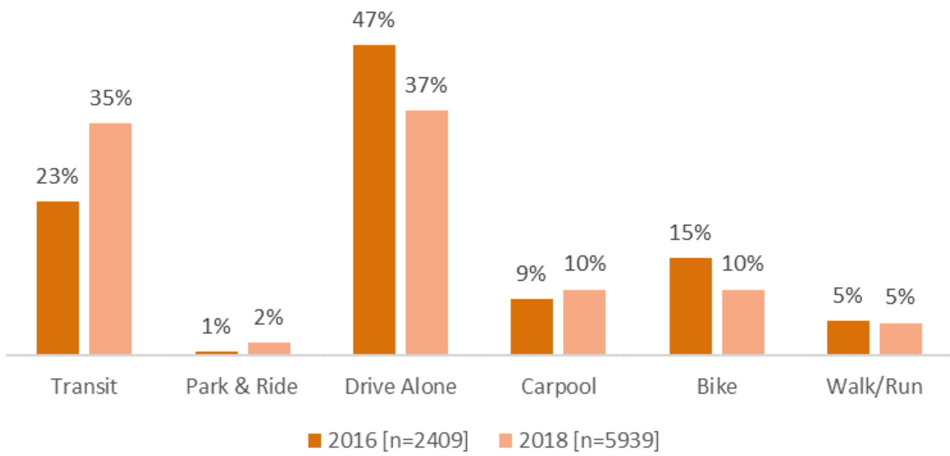


Figure 3.4: Mode split at Fort Garry campus between May and August (data sourced from Green Action Centre, 2016, 2018)

The data collection plan accounts for differences in travel modes and patterns generated by the campus' five main areas, shown in Figure 3.5:

- Core campus: This area includes most of the academic buildings in which classes are held, the University Centre, and the main administration building. The area also features the Active Living Centre, hockey rink, and several gymnasia, all of which attract the general public. A network of local roads provides access for vehicles and buses. Pathways and sidewalks provide access for pedestrians and bicyclists.
- Sports complex: This area includes the main stadium (IG Field), a track, outdoor practice facilities, and an indoor soccer complex. IG Field hosts large events throughout the year, including professional and amateur football games, other sporting events, and concerts. Arterial roads provide access to this area for vehicles and transit buses, and several pathways and sidewalks facilitate pedestrian and bicycle access.
- Research and technology park (Smartpark): Businesses located in Smartpark primarily employ professional researchers and some University of Manitoba staff. Few students enter the buildings in Smartpark, but students do travel through the area to access the core campus. The area is

accessible by vehicles and transit buses and has some pathways and sidewalks for pedestrians and bicyclists.

- Former golf course (Southwood Lands): This is a parcel of undeveloped land that is currently used recreationally by nearby residents and contains pathways used to access the core campus area.
- Agricultural plots: This isolated area is used to conduct agricultural research. Very little traffic can access this area, regardless of mode.

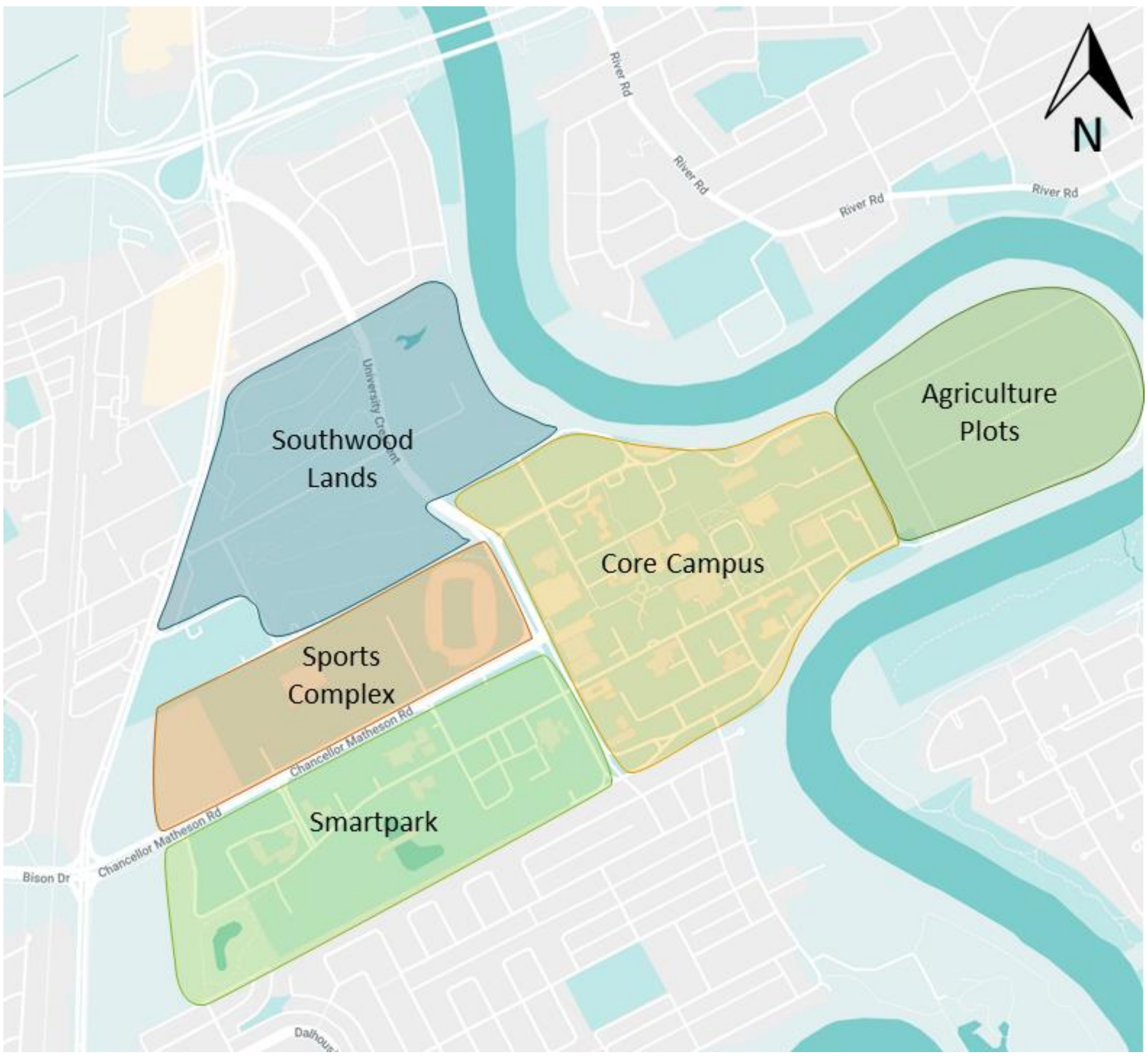


Figure 3.5: Main areas of the University of Manitoba Fort Garry campus

Integration of Modal, Spatial, and Temporal Considerations

The design of the data collection plan accounts for three integrated considerations: modal characteristics, spatial characteristics, and temporal characteristics. These three areas of consideration are inter-related since the design of one affects the design of the other two. For instance, site selection (a spatial issue) affects how equipment can be deployed to monitor the two modes, the number of sites affects the schedule and timing of counts, and some modes require different equipment throughout different weather seasons of the year. Key modal, spatial, and temporal characteristics are listed below. The following sections (3.1.2, 3.1.3, and 3.1.4) provide more details of modal (equipment selection), spatial (site selection), and temporal (defining periods and count durations) considerations in the design of the data collection plan.

- Modal: Only pedestrians and bicycles are considered in the data collection plan. The monitoring program deploys automatic equipment (passive infrared sensors and pneumatic tubes) to distinguish between the modes. Manual counts are used to supplement the automatic equipment counts.
- Spatial: A cordon count boundary is established to count all pedestrians and bicycles travelling in/out of the University of Manitoba Fort Garry campus. At each site, equipment is deployed to detect as many pedestrians and bicycles as feasible given site-specific constraints.
- Temporal: To determine different modal patterns throughout a year of data collection, two-month periods are established to determine AWDT for six combinations of semester and weather season.

Fusing Manual Counts by Video and Automatic Equipment Data

This research uses both automatic equipment and manual counts by video to collect data for pedestrian and bicycle traffic. Figure 3.6 and Table 3.1 illustrate the disadvantages and advantages of automatic equipment data and manual count data and how the two can be used to address the limitations of the other. The manual counts by video are used to develop factors to adjust the automatic equipment volumes to address some of the inherent limitations of this equipment. The automatic equipment data supports the manual counts by video by providing a longer duration count that provides more confidence in the AWDPT/AWDBT for each period. Although the automatic equipment volumes are influenced by the manual count factors, the two datasets provide an informal self-validation in that the AWDPT/AWDBTs at each site for each period should be similar. Combining multiple sources of data collection also allows for a simultaneous cordon count to determine the pedestrian and bicycle volume entering/exiting campus on a typical day. This approach fuses the traditional simultaneous cordon count with aspects of traditional network-wide approach to traffic monitoring (i.e. combining simultaneous counts with a rotation of automatic equipment for short duration counts). The fusion of data is described in more detail in Section 3.3.

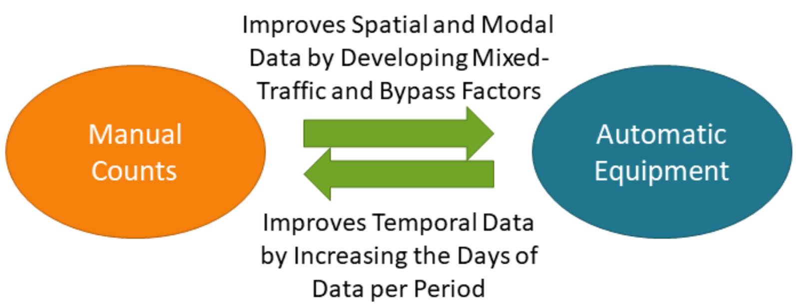


Figure 3.6: Data fusion of automatic equipment and manual counts by video

Table 3.1: Description of advantages and disadvantages of automatic equipment and manual counts by video

	Manual Counts	Automatic Equipment
Advantages	• No mixed-traffic or bypass error • Simultaneous cordon count	• Longer duration enables better representation of temporal variability • Fewer human resources consumed
Disadvantages	• Shorter duration inhibits representation of temporal variability • More human resources consumed	• Mixed-traffic and bypass error • Not a simultaneous cordon count

3.1.2 Equipment Selection

The University of Manitoba's Office of Sustainability selected the equipment prior to the initiation of this research. The Office of Sustainability purchased two sets of Eco-Counter's passive infrared sensors (PYRO Box) for monitoring mixed pedestrian and bicycle traffic and two sets of Eco-Counter's pneumatic tubes (one set each of Selective Tubes and Greenway Tubes) for bicycle-specific traffic. The passive infrared sensors detect any object that has a higher temperature than its surroundings, including pedestrians and bicyclists (Ryus et al., 2014b). Setting up passive infrared sensors with pneumatic tubes distinguishes between the two modes. The pneumatic tubes collect data in temperatures above 0°C on mixed active transportation pathways. Cold temperatures and snow clearing equipment may damage the rubber tubes; therefore, the tubes require removal in the winter season. Twenty-four-hour manual counts by video substitute for pneumatic tubes in the winter season months to provide modal splits between pedestrians and bicycles. The assumption is that the pedestrian and bicycle modal splits vary throughout the year in a winter city.

3.1.3 Site Selection and Description

Figure 3.7 shows the Fort Garry campus, the boundary of the cordon count, the six access points to enter/exit campus, and the general classification of each access. The cordon count boundary includes all internal parking lots to minimize the potential for capturing internal park-and-walk traffic. The boundary does not extend beyond the campus property to ensure that unrelated traffic is captured within the area. Of the six access points, two are active transportation only pathways, two are local roadways with narrow sidewalks and no bicycle-specific infrastructure, and two are arterial roadways with separated pathways for pedestrians and bicycles. Table 3.2 shows the facilities for all modes at each site.

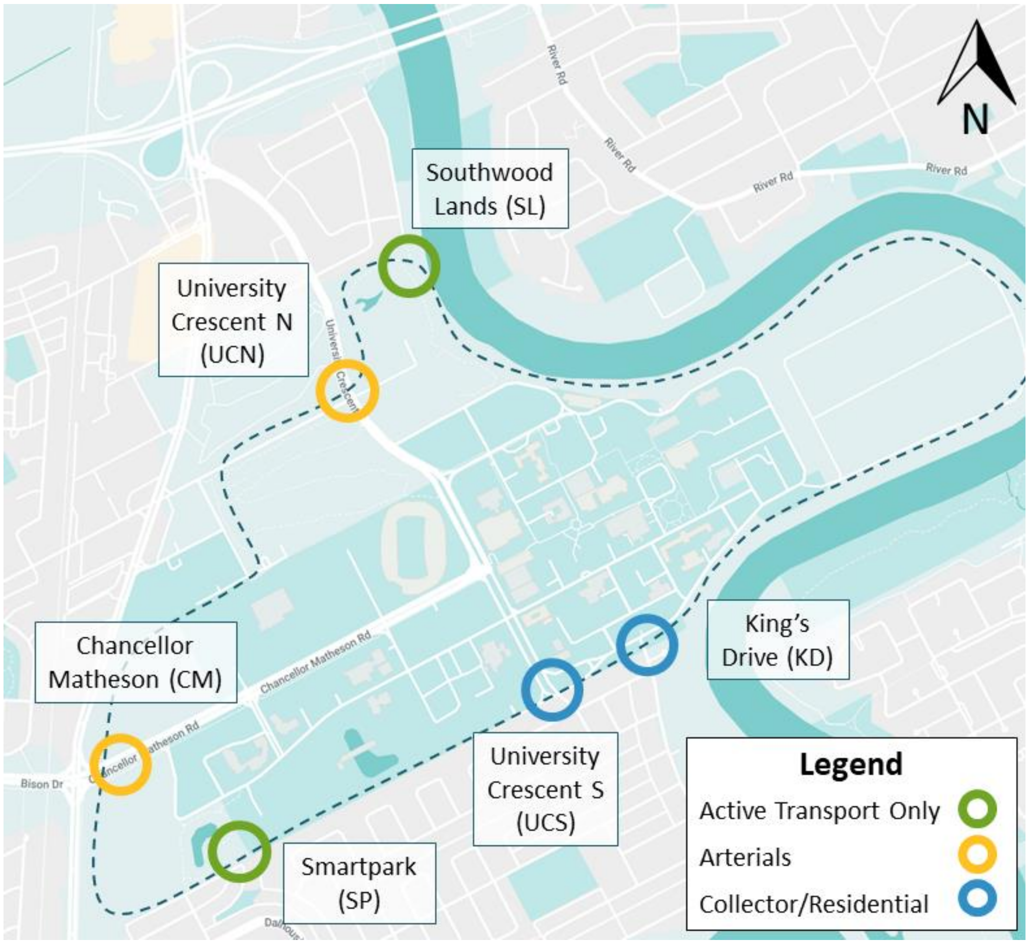


Figure 3.7: Cordon count screenline at the Fort Garry campus

Table 3.2: Description of transportation facilities at each site by mode

Site	Pedestrian Facilities	Bicycle Facilities	Vehicle Facilities
Southwood Lands	One shared multi-use path	One shared multi-use path	None
King's Drive	One sidewalk	No bicycle-specific facilities	Two lane collector roadway (50 km/h)
University Crescent S	Two sidewalks	No bicycle-specific facilities	Two lane collector roadway (50 km/h)
Smartpark	Three shared multi-use path	Three shared multi-use path	None
Chancellor Matheson	Two shared multi-use paths	Two shared multi-use paths	Four lane divided arterial roadway (70 km/h)
University Crescent N	One sidewalk and one segregated multi-use path	One segregated multi-use path and roadway shoulders	Four lane divided arterial (50 km/h)

Each of the sites has unique facilities and characteristics that influence the approach to collecting pedestrian and bicycle traffic data. The following subsections describe each site's facilities, the reasoning for the site location, site-specific challenges, and the final design and deployment of the equipment.

Southwood Lands (SL)

The Southwood Lands (SL) site consists of a pedestrian and bicycle use only facility at a bottleneck entrance in the northeast area of the Fort Garry campus. The gravel multi-use pathway connects a City of Winnipeg residential area to different areas of the Fort Garry campus. Because the pathway splits off to three different locations on campus, the counting site is located at the bottleneck at D'Arcy Drive to reduce the amount of resources required to count at multiple locations. Local residents often use the access point to enter/exit the Southwood Lands park area for recreational use. Including these recreational users is justified as these residents are entering/exiting the University's property and represent the diverse use of the campus area. There are no transit stops near this site. The setup of equipment includes the use of one passive infrared sensor on a pole just outside the University property and one set of pneumatic tubes across the gravel pathway. Manual counts by video are appropriate for use in the winter season to distinguish between pedestrian and bicycle traffic because pneumatic tubes are not feasible. Figure 3.8 shows the plan view of the site area and the location of the equipment. Figure 3.9 provides a ground view of the site with equipment in place for the winter and summer seasons.

Figure 3.8: Southwood Lands data collection plan

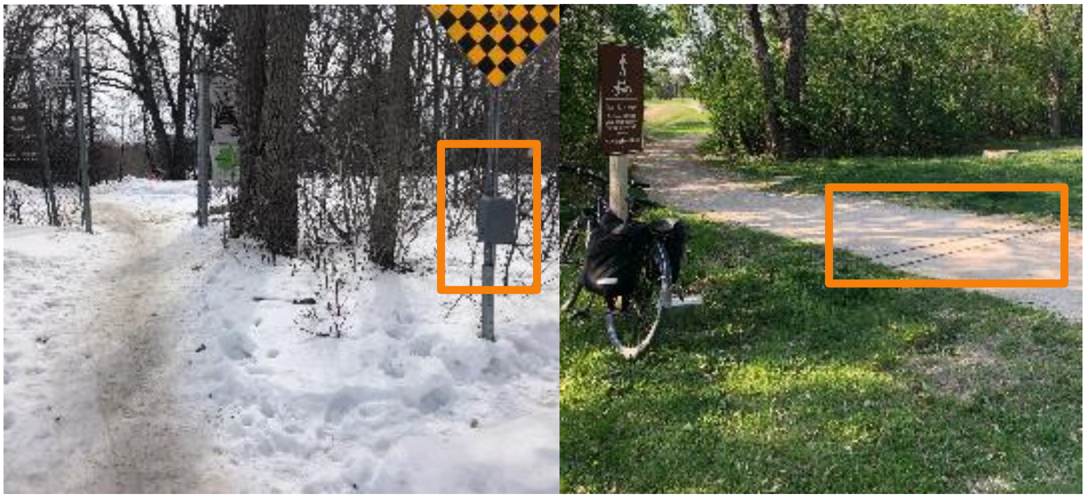


Figure 3.9: Southwood Lands ground view facing south (left: passive infrared sensor, right: pneumatic tubes)

King's Drive (KD)

The King's Drive (KD) site is a low volume collector, two-lane, undivided roadway entering the south part of the Fort Garry campus. The residential area south of this site has limited one hour parking on most streets with no parking restrictions on evenings and weekends. At approximately 500 m from the site, some parking restrictions allow for two hour parking. There is a sidewalk for pedestrians on the east side of the roadway and bicycles travel on the roadway with vehicles. The sidewalk leads into a narrow pathway north of the site into the campus core area. The sidewalk also connects to an east-west multi-use path. The location of equipment (passive infrared sensor) is south of the campus boundary, the transit stop, and the staff parking lot. This ensures that no pass-by trips from people parking and walking within campus are counted. One passive infrared sensor attached to a sign counts (combined) pedestrians and bicycles entering/exiting campus. Data collection challenges with this site include the following:

- Pneumatic tubes cannot record bicycles on the roadway due to property restrictions.
- Pneumatic tubes cannot record bicycles on the sidewalk due to property restrictions.
- Pedestrians on the roadway and walking on the grass area to the west evade the single passive infrared sensor.

To address the site challenges, manual counts by video provide a factor for bicycles that use the sidewalk (mixed-traffic factor) as well as pedestrians and bicycles that are not on the sidewalk (bypass factor). The video camera was set up on the same infrastructure as the passive infrared sensor to capture the entire cross-section of the roadway. Because pneumatic tubes were not used at this site, the equipment set up was consistent year-round. Figure 3.10 shows the plan view of the site area and the location of the equipment. Figure 3.11 provides a ground view of the site with equipment in place.

Figure 3.10: King's Drive data collection plan

Figure 3.11: King's Drive ground view facing north (passive infrared sensor)

University Crescent South (UCS)

The University Crescent South (UCS) site has similar characteristics to the KD site (low volume, two-lane, undivided roadway). This includes the parking restrictions in the residential area south of the site. There are no transit stops near this site. The site has sidewalks on both the east and west side of the roadway. The west sidewalk ends as it reaches the campus boundary (Freedman Cres) and the east sidewalk continues north into the campus area. The equipment was installed south of the campus boundary to ensure only pedestrians and bicycles entering from outside the campus boundary were counted. A set up on the north side of Freedman Cres would have excluded bicycles on the roadway. The east sidewalk used one passive infrared sensor attached to a stop sign to count (combined) pedestrians and bicycles entering/exiting campus. Data collection challenges with this site include the following:

- Pneumatic tubes cannot record bicycles on the roadway due to property restrictions.
- Pneumatic tubes cannot record bicycles on the sidewalk due to property restrictions.
- Pedestrians on the roadway and walking on the west sidewalk evaded the single passive infrared sensor.

To address the site challenges, manual counts by video provide a factor for bicycles that used the sidewalk (mixed-traffic factor) as well as pedestrians and bicycles that were not on the sidewalk (bypass factor). The video camera was set up on the same infrastructure as the passive infrared sensor to capture the entire cross-section of the roadway. Because pneumatic tubes were not used at this site, the equipment set up was consistent year-round. Figure 3.12 shows the plan view of the site area and the location of the equipment. Figure 3.13 provides a ground view of the site with equipment in place.

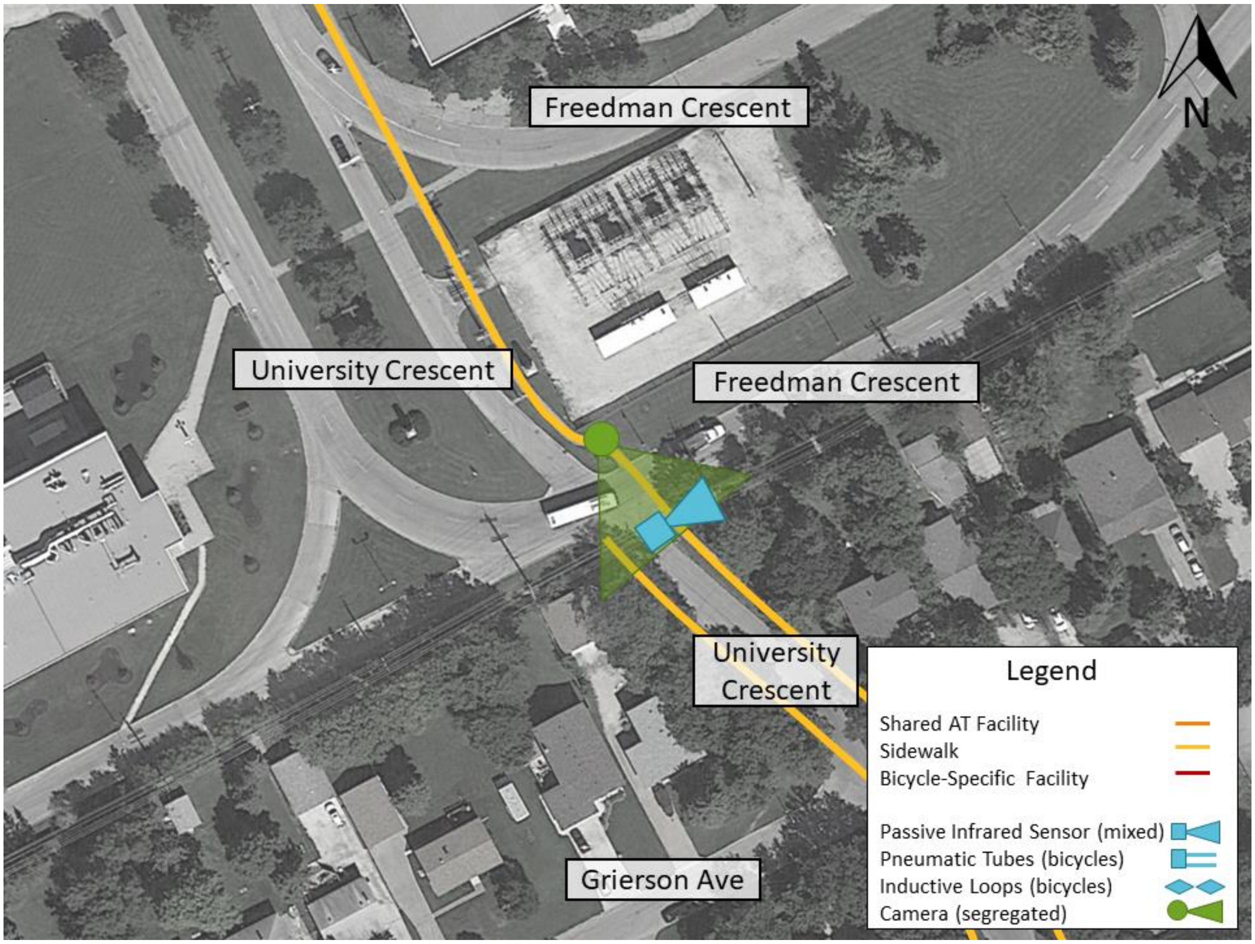


Figure 3.12: University Crescent South data collection plan

Figure 3.13: University Crescent South ground view facing south (passive infrared sensor)

Smartpark (SP)

The Smartpark (SP) site is similar to the SL site as it accommodates only pedestrians and bicycles using gravel multi-use pathways. The pathways connect a back-lane off Bayridge Ave to the Fort Garry campus/Smartpark area. This site provides access to campus for people residing in the southwest area of Winnipeg. The pathways are marked with signs to indicate the access is for pedestrians and bicycles only. There do not appear to be parking restrictions on the residential roads in this area. There are also no transit stops near this site. Observations during site visits indicated that this is the least travelled of the six access points. This site has three separate pathways with no point of confluence (unlike the SL site). The west and centre pathways are not maintained in the winter season and therefore do not attract as much traffic (Figure 3.14). Equipment resource constraints necessitated installation of monitoring equipment at only one of the three pathways. Based on site observations, the pathway with the highest traffic volume and the only pathway with occasional winter maintenance—the pathway to the east—was selected for equipment installation (passive infrared sensor and pneumatic tubes). The one passive infrared sensor was at the campus boundary fixed to a post and the one set of pneumatic tubes were 30 m east of the passive infrared sensor where the ground is even. Figure 3.15 shows the plan view of the site area and the location of the equipment. Figure 3.16 provides a ground view of the site with equipment in place for the summer season.

Figure 3.14: Lack of winter maintenance at the centre pathway at the Smartpark site

Figure 3.15: Smartpark site plan

Figure 3.16: Smartpark ground view (left: passive infrared sensor facing west; right: pneumatic tubes facing east)

Chancellor Matheson (CM)

The Chancellor Matheson (CM) site is one of the two major accesses to the Fort Garry campus. The roadway, Chancellor Matheson Rd, is a four-lane divided minor arterial with a speed limit of 70 km/h and an AWDT of 18,200 vehicles (City of Winnipeg, 2018). There is no free parking near this site. There are two paved, shared, multiuse pathways on the north and south sides of the roadway. On the south pathway, the location of the passive infrared sensor and pneumatic tubes is east of the transit stop located on Chancellor Matheson Rd to avoid detecting transit passengers. On the north pathway, the location of the passive infrared sensor and pneumatic tubes is east of Research Rd because there is no feasible installation site west of the intersection. This created a situation where pedestrians and bicycles may have been double counted or may have evaded the equipment on the north pathway. Winter season maintenance is an additional limitation as snowfall and snow clearing created snowbanks covering the equipment. The university-owned shared multiuse pathway provides a suitable environment for counting bicycles with pneumatic tubes in the summer season. Due to the high volumes of pedestrians and bicycles observed, this is the only site that simultaneously deployed both sets of pneumatic tubes and passive infrared sensors. In the winter season, only the passive infrared sensors were used. Manual counts by video determined the proportion of pedestrians and bicycles in winter season (mixed-traffic factor) as well as pedestrians and bicycles that evaded the equipment by travelling on the roadway or along the dike (bypass factor). Figure 3.17 shows the plan view of the site area and the location of the equipment. Figure 3.18 and

Figure 3.19 provide ground views of the two site set ups.

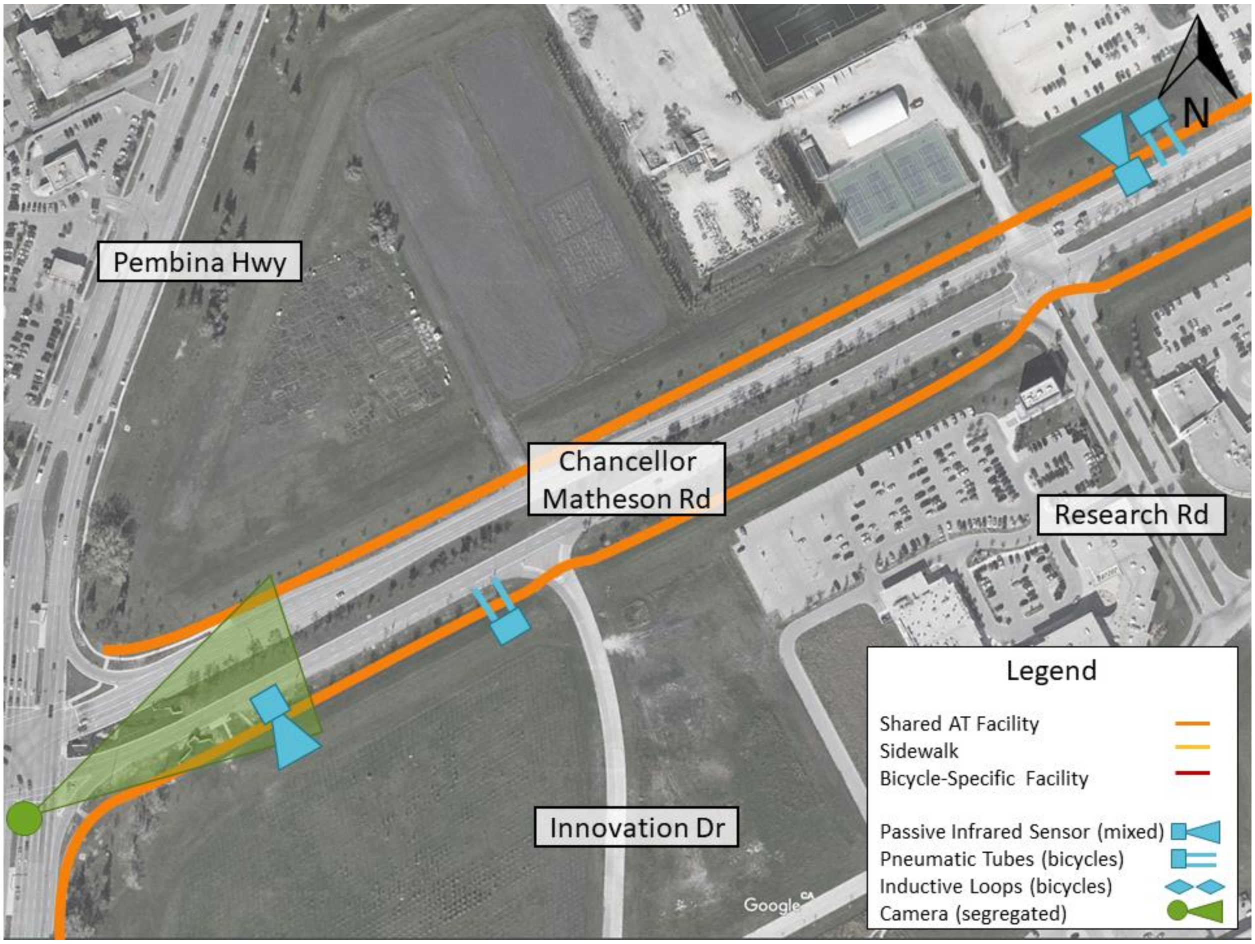


Figure 3.17: Chancellor Matheson data collection plan

Figure 3.18: Chancellor Matheson ground view on north pathway facing west (passive infrared and pneumatic tubes)

Figure 3.19: Chancellor Matheson ground view on south pathway (left: passive infrared sensor facing west; right: pneumatic tubes)

University Crescent North (UCN)

The University Crescent North (UCN) site roadway is a four-lane minor arterial with two-way traffic separated by a median, a speed limit of 50 km/h, and an AWDT of 18,800 vehicles (City of Winnipeg, 2018). The active transportation facilities at this location include a segregated multi-use path with a sidewalk and bidirectional bike path on the west side of the road, a sidewalk on the east side, and roadway shoulders where bicycles travel. The multi-use path has a transit stop south of the intersection of University Cres and Markham Rd and the east sidewalk has a transit stop north of the same intersection. The site also has a pedestrian corridor that both pedestrians and bicycles use to cross to/from the gravel pathways in the Southwood Lands area to the east.

This site location can capture pedestrian and bicycle traffic using Markham Rd and University Cres as it consolidates two campus access points. Pedestrian and bicycle traffic use the segregated multi-use path to enter/exit campus or park on Markham Rd and walk into the campus area using gravel pathways. There are no parking restrictions on Markham Rd. Pedestrians and bicycles accessing campus along University Cres either the west sidewalk or the roadway to approach the Markham Rd and University Cres intersection.

This site presents installation challenges as there is no infrastructure on which to install a passive infrared sensor and property restrictions preclude the use of pneumatic tubes on all pathways at this site. It is also complex as bicycles travel on the bi-directional path, the shoulders of the roadway, and in the motorized vehicle travel lanes. Infrastructure exists south of the pedestrian corridor to attach the passive infrared sensor, but many pedestrians and bicycles cross into/out of the Southwood Lands area and would not be detected with a setup at that location. Consequently, no automatic equipment was set up at this site; rather, the site was monitored periodically by video. The screenline for counting pedestrians and bicycles is north of the pedestrian corridor to capture the pedestrians and bicycles that travel into the Southwood Lands. The placement is also south of the two transit stops to ensure transit passengers were not captured. Figure 3.20 shows the plan view of the site area and the location of the video screenline. Figure 3.21 provides a ground view of the site.

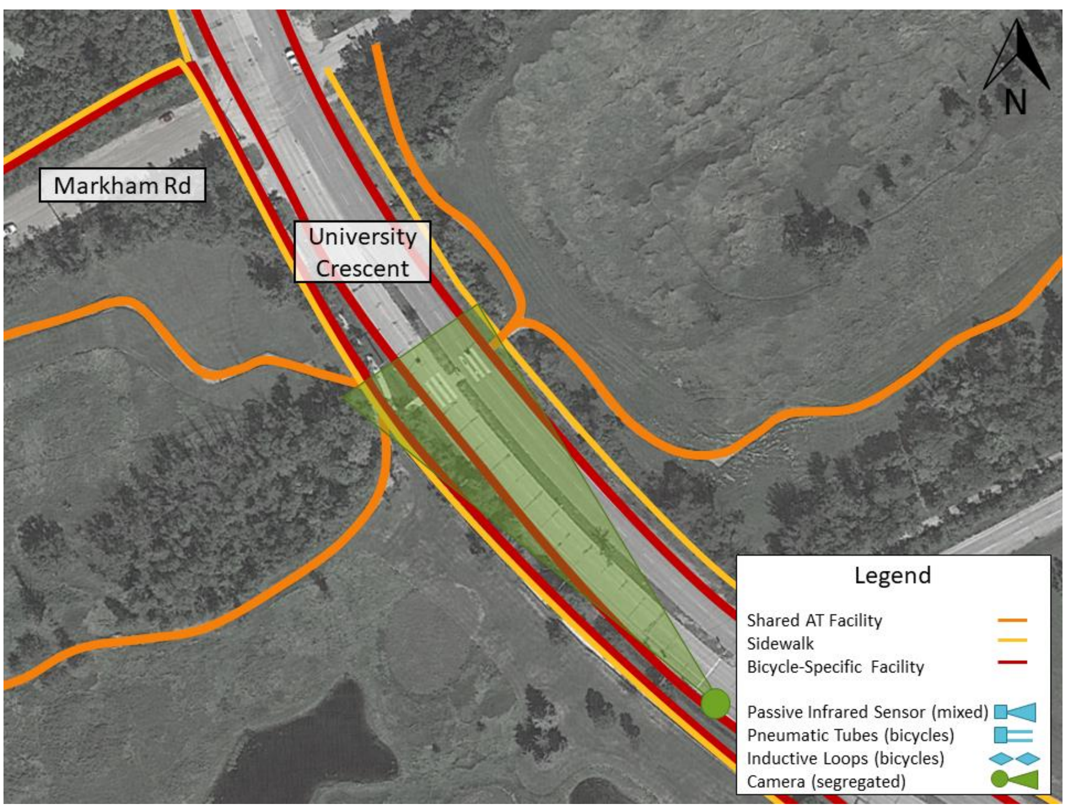


Figure 3.20: University Crescent North data collection plan

Figure 3.21: University Crescent South ground view segregated multi-use pathway (left: facing south; right: facing east)

3.1.4 Temporal Characteristics and Design

Temporal considerations are the third major design element of the data collection plan. This section describes the definition of periods to appropriately represent the varied traffic volumes at a university campus in a winter city throughout a year, the scheduling and allocation of resources to collect data, and the dates excluded from the data collection plan.

Definition of Periods to Monitor

The typical academic year comprises three semesters. The fall semester begins in September and ends in December with final examinations taking place during the second and third weeks of December. The winter semester begins in January and ends in April with final examinations taking place during the second and third weeks of April. Both the fall and winter semesters include a one week break for undergraduate students in November and February, respectively. The summer semester begins in May and ends in August, but differs from the fall and winter semesters as courses have varying durations and starting times. While most courses are offered from May to June, others are from July to August, May to July, May to mid-August, or may be one month in duration. Most classes run Monday through Friday during the day and evening.

In conjunction with academic semesters, four distinct weather seasons occur in Winnipeg each year (winter, spring, summer, and fall). Winnipeg is considered a winter city, as it has average temperatures equal to or less than freezing in January (Rogers & Hanson, 1980) and experiences maximum daily temperatures equal to or less than freezing for at least two months (Pressman, 1995). Several seasonal definitions were considered in this research. Astronomers define seasonal transitions on (approximately) March 20 (winter to spring), June 21 (spring to summer), September 23 (summer to fall), and December 21 (fall to winter) (National Centers for Environmental Information, 2016). In contrast, meteorologists use three-month intervals starting on the first of the month to define the four seasons (spring begins March 1, summer begins June 1, fall begins September 1, and winter begins December 1) (National Centers for Environmental Information, 2016). Another seasonal definition of relevance for pedestrian and bicycle traffic relates to snow accumulation or average temperatures around 0°C. Analysis of historic weather data for Winnipeg from 2008 to 2017 (Figure 3.22) shows that the months of May through October have consistent minimum daily temperatures above 0°C and the months of between mid-March through mid-November have consistent maximum daily temperatures above 0°C. Figure 3.22 also shows that snow accumulation begins in October and lasts through April. Given these definitions and the objective of capturing seasonal pedestrian and bicycle traffic patterns, this research sets seasonal transitions on the following dates: March 1, May 1, September 1, and November 1.

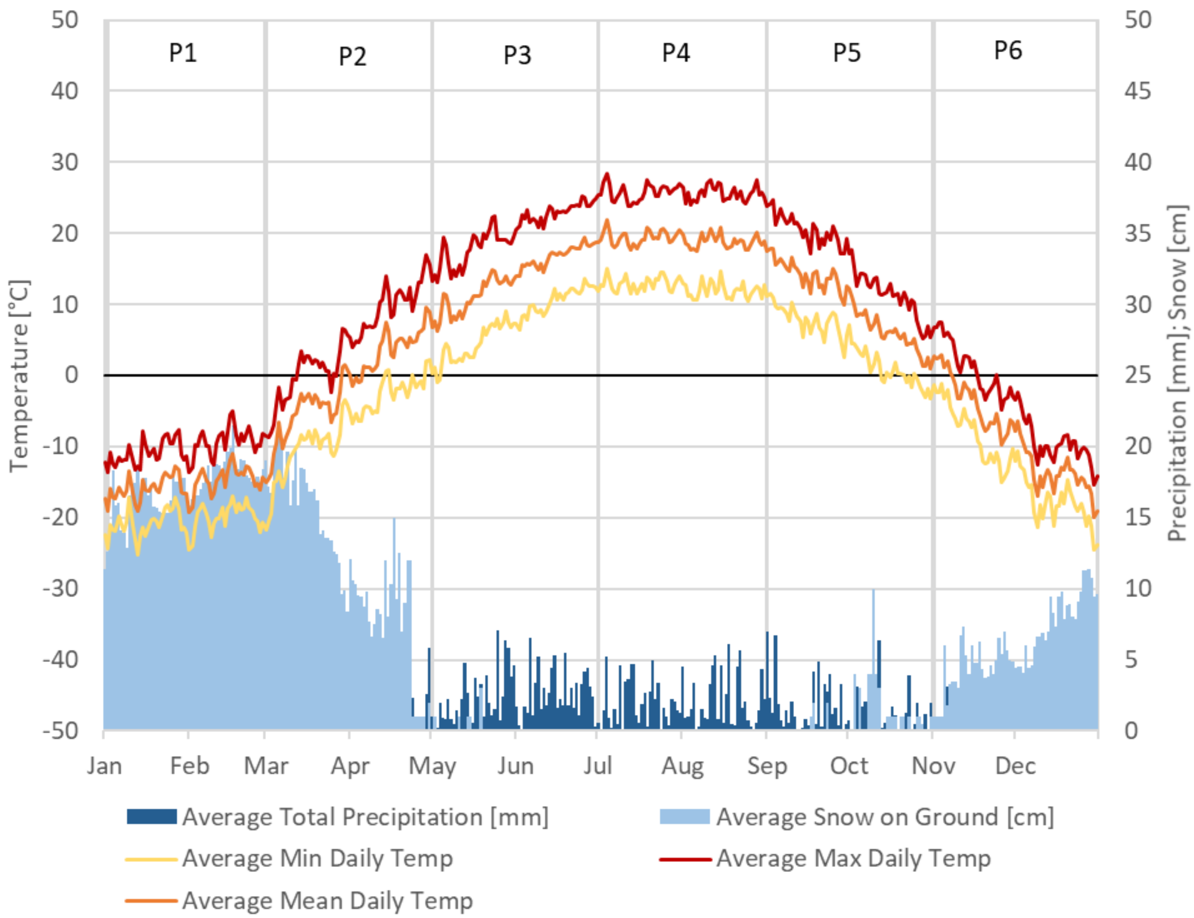


Figure 3.22: Historic weather data from 2008-2017 (data sourced from Environment Canada)

Combining the academic semesters and weather seasons creates six two-month periods during which pedestrian and bicycle traffic is expected to be reasonably homogeneous within each of the six periods. It assumes that pedestrian and bicycle traffic will vary with a change in semester and a change in season, but that traffic would remain more consistent throughout the same semester and season for the full duration of the two-month period. Table 3.3 defines the start and end dates of these six periods.

Table 3.3: Description of the six homogeneous periods throughout the academic year in a winter city

Period	Months	Semester	Season
1	January 1-February 28	Winter	Winter
2	March 1-April 30	Winter	Spring
3	May 1-June 30	Summer 1 (May-June courses)	Summer
4	July 1-August 31	Summer 2 (July-August courses)	Summer
5	September 1-October 31	Fall	Fall
6	November 1-December 31	Fall	Winter

Resource Allocation and Schedule

The design of a data collection plan involves the management of resources and scheduling short duration counts with automatic equipment and recording video for manual counts. An ideal system would count all pedestrians and bicycles commuting to/from a university for one year at every facility at every site for 24 hours a day for a full year (365 days). This is infeasible due to the cost of equipment, physical limitations at each site, and technological limitations of the equipment. The available automatic equipment includes two sets of passive infrared sensors for mixed active traffic and two sets of pneumatic tubes for bicycle traffic. The available resources for manual counts by video include two mobile cameras and two permanent cameras.

Equipment management and scheduling for each period involves the following activities: 1) rotating the automatic equipment for short duration counts at five of the six access points for a minimum of five days in each period, 2) conducting a simultaneous 24-hour cordon count in each period in which manual counts by video are used at four sites and the automatic equipment at the remaining two, and 3) conducting an additional 24-hour manual count by video at the site without the automatic equipment counts. Section 3.2 discusses the details of the data collection process and describes which sites collect automatic equipment data and/or manual counts by video data.

Exclusion Dates

The data collection plan excludes event days at IG Field because these days do not represent the normal university commuting activity. Event-generated traffic peaks create additional challenges, including pedestrians stepping on bicycle tubes, which causes overcounting, and pedestrians walking in groups, which causes occlusion error (undercounting). Other exclusions include dates when academic classes are not in-session (i.e., holidays, exam period, mid-semester breaks, and time in between semesters). Although these dates may represent "true" pedestrian and bicycle traffic on campus, the data are expected to misrepresent typical commuter travel patterns. Further, because the output is AWDPT/AWDBT for each period, the event days and non-session days would skew average traffic statistics. *Traffic Monitoring Practice Guide for Canadian Provinces and Municipalities* recommends conducting short duration counts on typical days only (Regehr et al., 2017).

3.2 DATA COLLECTION

The data collection process gathers data from both automatic equipment and manual counts by video (Figure 3.23).

Figure 3.23: Flow chart of the data collection process

The automatic equipment calibration was performed prior to this study by the Office of Sustainability with support from Eco-Counter. Verification of the automatic equipment used manual checks to ensure the equipment counts pedestrians and bicycles accurately. The verification process for the automatic equipment involved confirming that no potential obstructions existed at the site, checking the reasonableness of the equipment output, and monitoring the equipment for any malfunctions over time. The verification of the equipment output included conducting manual counts for a period of at least 15 minutes at the site and comparing these counts to those obtained from the automatic equipment during the same time period (Ryus et al., 2014b). This was done for each site at varying times throughout the year.

The manual counts by video produce daily volumes of pedestrians and bicycles on each facility at each site. The disaggregation of data provides information as to how many pedestrians and bicycles use facilities where automatic equipment is set up and the proportion of bicycle traffic where only a passive infrared sensor exists. This also provides valuable information to the University of Manitoba and the City of Winnipeg as to how the facilities are being used by active transportation modes.

Table 3.4 summarizes the type of count deployed at each of the six cordon sites and the duration of the count per period. The SL site only has one manual count by video as automatic equipment is sufficient when pneumatic tubes are feasible and a single manual count by video is used to show the proportion of bicycle traffic on the snow-covered pathway. The SP site does not use any manual counts by video as only automatic equipment is used when pneumatic tubes are feasible. It is also unnecessary to use manual counts by video to create a mixed-traffic factor for winter bicycle traffic because the pathway was not snow-cleared in the winter season and no bicycles accessed this site in the winter season. The UCN site does not have any automatic equipment counts because physical constraints of the site make the equipment infeasible to install.

Table 3.4: Summary of automatic counts and manual counts by video use at each site

Sites	Duration of Data Collection per Period	Southwood Lands	King's Drive	University Crescent S	Smartpark	Chancellor Matheson	University Crescent N	Total Sites
Automatic Count	>5 Days	✓	✓	✓	✓	✓	✗	5
Manual Counts	24 Hours	*	✓	✓	✗	✓	✓	5*

* Manual Count conducted in one period only

Note: University Crescent N uses two 24-hour counts

3.3 DATA PROCESSING

This section describes the processing of the automatic equipment and manual count data. Figure 3.24 shows the data processing steps. These include screening and imputation, developing and applying adjustment factors, and the fusion of data sources to create final outputs. The outputs from the data processing step include a 24-hour simultaneous cordon count for pedestrians and bicycles in each period, daily volumes of pedestrian and bicycle traffic for one year, and estimates of the AWDPT and AWDBT at each site for each period. As described in Section 3.1.3, each site has a different data collection approach using manual counts by video and/or automatic equipment. Figure 3.24 shows the number of sites with data for each method of data collection and how many sites require adjustment factors. There are four sites with manual count data for each period and an additional site with a manual count conducted for a single period. The automatic equipment is set up at five sites to collect data in each period. The 24-hour simultaneous cordon count requires the four manual counts and two automatic equipment counts to calculate the total traffic at all six sites.

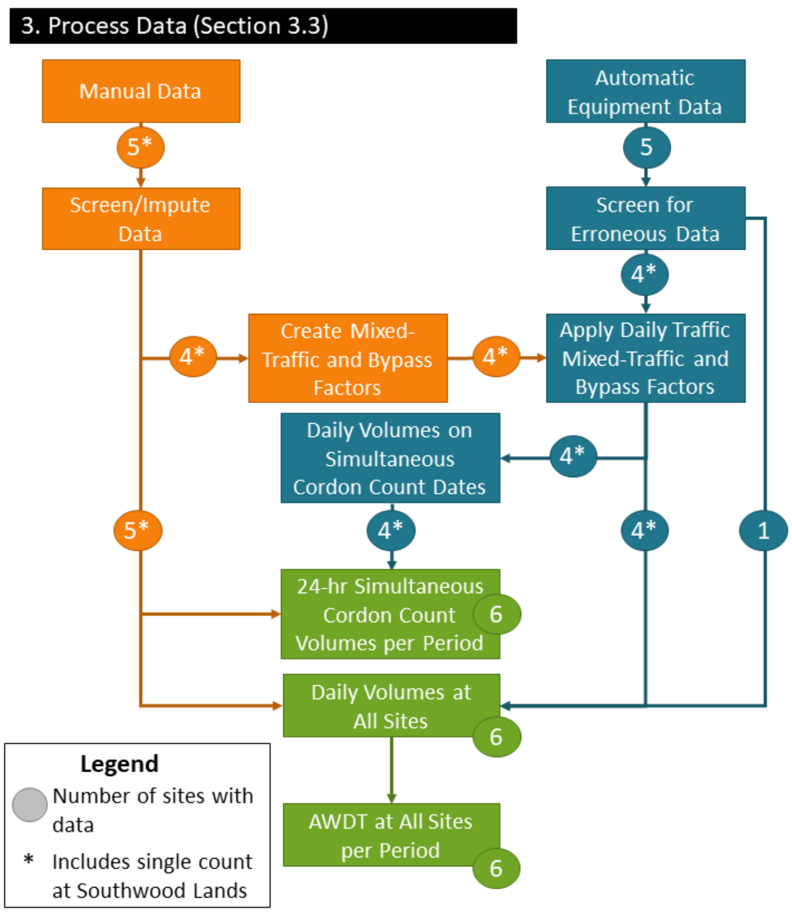


Figure 3.24: Data processing flow chart

3.3.1 Screening and Imputing Automatic Equipment and Manual Counts by Video

Despite their relative reliability, manual counts by video are prone to some data loss caused by equipment malfunctions. Data imputation may be needed to compensate for data loss if a full 24-hours of data are unavailable (Regehr et al., 2017; Ryus et al., 2014b). For missing data up to two consecutive hours, imputation methods include averaging the previous and next hour to estimate the missing hour volume. For more than two hours of consecutive missing data, a similar 24-hour manual count for that site and period can be used to create hourly factors to expand the desired date with missing data. If a similar 24-hour manual count is unavailable at the site for the period, then imputation is not used and the site and period will have no manual count data.

Automatic equipment produces less accurate data than manual counts by video and requires screening to ensure data quality. The data is downloaded from Eco-Counter's Eco-Visio website as hourly volumes at for each of the four sensors. There is a four-step process to organize, clean, and screen for erroneous errors. The four steps are listed below and described in the following paragraphs.

- Assign each sensor's hourly data to a specific site and equipment location.
- Remove exclusion dates outside of the scope of this research.
- Differentiate between pedestrian and bicycle traffic.
- Apply an algorithm to automatically flag hourly volumes that require manual review.

Step 1: Assign each sensor's hourly data to a specific site

An algorithm uses a database of the sensor's location to sort the volumes from each sensor to each site. This determines if the volume is mixed-traffic or bicycle traffic.

Step 2: Remove days of data that are not typical university days

The list of excluded dates includes weekends, holidays, event days at IG Field, and dates when classes are not in session (exam period and closures).

Step 3: Pedestrian and bicycle differentiation

The passive infrared sensor collects data for both pedestrian and bicycle traffic. Pneumatic tube volumes must be subtracted from the passive infrared sensor data to determine pedestrian traffic. For instances when no pneumatic tube volumes are available, volumes are considered "mixed" and factored using the correction process to determine separate pedestrian and bicycle volumes.

Step 4: Create an algorithm to flag potentially erroneous data

The dataset for hourly pedestrian, bicycle, and combined traffic uses the following algorithm to flag any

- hours with zero volume when traffic is expected (6:00 a.m. to 8:00 p.m.),
- consecutive identical hourly volumes,
- hours that exceed a pre-set maximum hourly volume for that site, or
- hours with volumes 75% greater than or less than the following hour.

These criteria only flag potentially problematic data. The manual review process confirms or rejects the validity of the data (Lu et al., 2017). Rejected data is not imputed as there are many days of automatic equipment data in each period for each site.

After the automatic equipment hourly volume data is accepted or rejected, the hours are aggregated to create daily volumes for pedestrians, bicycles, and mixed-traffic for each site. This automatic equipment data cleaning process creates a dataset of raw daily pedestrian, bicycle, and mixed volumes at each site to be corrected for mixed-traffic and bypass conditions. The manual counts by video imputation creates daily volumes for pedestrians and bicycles for each site and period except at the SL and SP sites.

3.3.2 Data Adjustment

This section describes various correction and expansion factors and their applicability to this research. It discusses the rationale for not using specific factors as well as the development and application of mixed-traffic and bypass factors. Adjustment of the counts includes using spatial and mode split data from the manual counts and extrapolating those trends to the automatic equipment for the sites. The adjustment factors allow for a more comprehensive dataset that accounts for the exclusion of pedestrians and bicycles that evade common automatic equipment.

Section 2.1.4 describes correction factors including occlusion/equipment, environmental, mixed-traffic and bypass, as well as expansion factors for temporal, environmental, and land use conditions. Despite their use in other research, the factors listed below were not applied for the following reasons:

- Occlusion/Equipment Correction Factor: Studies on the accuracy of passive infrared sensors and bike-specific pneumatic tubes provide a wide range of results depending on the brand of equipment (Ryus et al., 2017). The passive infrared study found the total deviation ranged between 1.6% and 27% for different products. The bicycle-specific pneumatic tube deviation ranged between 10.8% and 69.1% for different products (Ryus et al., 2017). These studies were conducted without specifying the manufacturer of each product (Ryus et al., 2017). A Winnipeg study determined that the accuracy of passive infrared sensors varies with both spatial and temporal characteristics (Nytepchuk, 2015). Both Ryus et al. (2014b) and Nytepchuk (2015) recommend developing site-specific factors. For this research, this would require an additional 36 manual counts at each site for each period because none of the manual counts by video occurred at the same time as the automatic equipment counts at a site. Instead, the video cameras and automatic equipment are located separately at all sites with no ground-truth reference. This trade-off is justified by the benefits of conducting a simultaneous cordon count and the use of mixed-use and bypass errors that can be produced without ground-truth data. The application of a general occlusion factor derived from other research would be subject to error due to (1) the large range of error associated with the brand of automatic equipment used; (2) the seasonal changes that affect occlusion; and (3) spatial discrepancies between sites. Although previous research generally agrees that passive infrared sensors and pneumatic tubes commonly undercount both pedestrian and bicycle traffic, the exact amount of undercounting is unknown in the context of this research. Therefore, no general occlusion factor was applied to this research; this results in a conservative estimate of pedestrian and bicycle traffic.

- Weather Correction Factor: Weather correction is not applicable to this research as the short duration counts were conducted at each site throughout the year and had a minimum of five days of data within each period. This allows for a representational AWDT for typical weather in each period.
- Temporal, Environmental, and Land Use Expansion Factors: Expansion factors are not applicable to this research as the data collection program captures the temporal, environmental, and spatial data necessary. There is no need to expand any volumes to a full day, different times of the year, or to other areas with similar land use. Moreover, no attempt was made to annualize daily volume statistics (i.e., produce an estimate of AADPT or AADBT).

The factors applied in this research follow:

- Mixed-traffic Factor: This is a necessary factor because the winter season and certain sites do not allow for pneumatic tubes to distinguish between pedestrian and bicycle traffic.

- Bypass Correction Factor: This is a necessary factor as the KD and UCS sites are unable to collect data on bicycles and pedestrians at locations other than on the sidewalk with the passive infrared sensor (i.e., roadway or other pathways).

Developing Factors

The data to develop correction factors is the sum of a 24-hour manual count by video at four sites separated into 1) pedestrians travelling where the automatic equipment is installed ($VOL_{ped@AE}$), 2) bicycles travelling where the automatic equipment is installed ($VOL_{bike@AE}$), 3) pedestrians that bypass the automatic equipment sensor ($VOL_{ped@bypass}$), and 4) bicycles that bypass the automatic equipment sensor ($VOL_{bike@bypass}$). The manual count is collected hourly, but is summed into a daily volume as the hour-to-hour volatility is too high to create representative hourly factors. Therefore, all factors developed and applied are for daily volumes. As an example, Figure 3.25 illustrates the camera and automatic equipment configuration and the monitored and bypass travel paths of pedestrians and bicycles at the University Crescent South site.

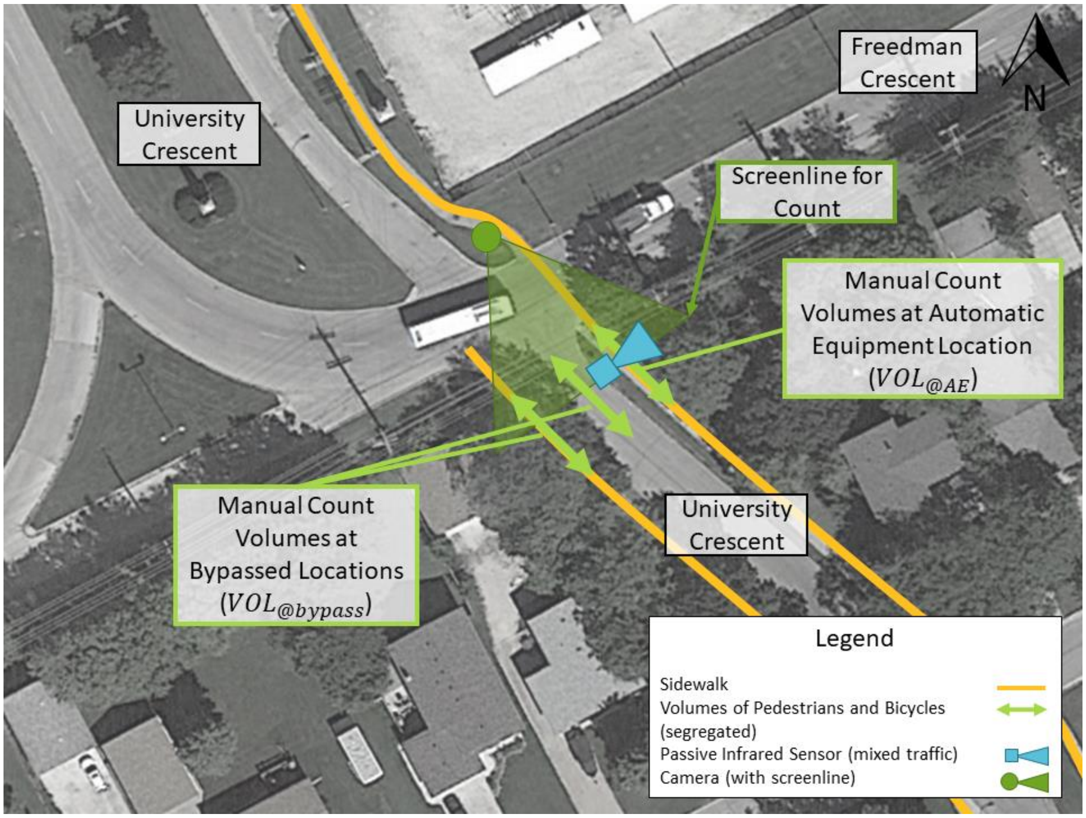


Figure 3.25: Definition of manual count by video data outputs at the University Crescent S site

No clear guidance exists on developing mixed-traffic and bypass factors (Ryus et al., 2014b). Therefore, the following equations are developed to calculate mixed-traffic and bypass factors for the specific characteristics of this research. A series of equations are developed to calculate the various adjustment factors applied to the combined volumes from the passive infrared sensor. The adjustment factors are produced using volumes from the manual counts by video as illustrated above in Figure 3.25. All mixed-traffic and bypass factor equations are calculated using the same denominator in order to create factors that relate to the automatic equipment data that requires factoring. This method of factoring is simple and consistent with the manual counts by video data.

Below are the equations for the mixed-traffic factors that determine the proportion of pedestrians (M_{ped}) and bicycles (M_{bike}) at the location of the automatic equipment.

$$M_{ped@AE} = \frac{VOL_{ped@AE}}{VOL_{ped@AE} + VOL_{bike@AE}}$$

$$M_{bike@AE} = \frac{VOL_{bike@AE}}{VOL_{ped@AE} + VOL_{bike@AE}}$$

Where $M_{ped@AE}$ and $M_{bike@AE}$ are the mixed-traffic factors for pedestrian and bicycle traffic at the location where automatic equipment counts are collected, $VOL_{ped@AE}$ is the daily volume of pedestrians from the manual count by video at the location of automatic equipment counts, and $VOL_{bike@AE}$ is the daily volume of bicycles from the manual count by video at the location of automatic equipment counts. The mixed-traffic factors, which sum to one, represent the proportion of each mode travelling on the facility where the automatic equipment.

Below are the equations for the bypass factors that determine the proportion of pedestrians (B_{ped}) and bicycles (B_{bike}) at the bypassed locations.

$$B_{ped@bypass} = \frac{VOL_{ped@bypass}}{VOL_{ped@AE} + VOL_{bike@AE}}$$

$$B_{bike@bypass} = \frac{VOL_{bike@bypass}}{VOL_{ped@AE} + VOL_{bike@AE}}$$

Where $B_{ped@bypass}$ and $B_{bike@bypass}$ are the bypass factors for pedestrian and bicycle traffic at the bypassed locations, $VOL_{ped@bypass}$ is the daily volume of pedestrians from the manual count by video at the bypassed locations, $VOL_{bike@bypass}$ is the daily volume of bicycles from the manual count by video at the bypassed locations, $VOL_{ped@AE}$ is the daily volume of pedestrians from the manual count by video at the location of automatic equipment counts, and $VOL_{bike@AE}$ is the daily volume of bicycles from the manual count by video at the location of automatic equipment counts. The mixed-traffic and bypass factors for all sites periods can be found in Appendix B.

To illustrate the application of the foregoing equations, consider the following example using data collected at the UCS site on June 12, 2019. In this case, there were an observed 516 pedestrians at the location of automatic equipment ($VOL_{ped@AE}$), 60 bicycles at the location of the automatic equipment ($VOL_{bike@AE}$), 221 pedestrians that bypassed the automatic equipment ($VOL_{ped@bypass}$), and 204 bicycles that bypassed the location of the automatic equipment $\left(VOL_{bike@bypass}\right)$. This results in the following factors for Period 3 at the UCS site:

$$M_{ped@AE} = \frac{VOL_{ped@AE}}{VOL_{ped@AE} + VOL_{bike@AE}} = \frac{516}{516 + 60} = 0.896$$

$$M_{bike@AE} = \frac{VOL_{bike@AE}}{VOL_{ped@AE} + VOL_{bike@AE}} \frac{60}{516 + 60} = 0.104$$

$$B_{ped@bypass} = \frac{VOL_{ped@bypass}}{VOL_{ped@AE} + VOL_{bike@AE}} \frac{221}{516 + 60} = 0.384$$

$$B_{bike@bypass} = \frac{VOL_{bike@bypass}}{VOL_{ped@AE} + VOL_{bike@AE}} \frac{204}{516 + 60} = 0.354$$

Applying Factors

After screening, the hourly automatic equipment data is summed into daily volumes and then adjusted for correction using the above factors. The following equations calculate the adjusted automatic equipment volume for each mode using the data from a passive infrared sensor (combined traffic). In this research, the KD and UCS sites were the only sites that required the bypass factor in all seasons. The SL and CM sites only required the mixed-traffic factors in the winter season and did not have bypass. The SP and UCN sites conducted counts using either automatic equipment or manual counts by video and therefore no factors were developed or applied at these sites.

$$VOL_{peds\ at\ site} = VOL_{raw\ AE\ count} \times \left(M_{ped@AE} + B_{ped@bypass}\right)$$

Where $VOL_{peds\ at\ site}$ is the daily volume of pedestrians at the site using only automatic equipment, $VOL_{raw\ AE\ count}$ is the raw daily volume of combined pedestrian and bicycle traffic from the automatic equipment, $M_{ped@AE}$ is the mixed-traffic factor for pedestrians at the location of the automatic equipment, and $B_{ped@bypass}$ is the bypass factor for pedestrians at the bypassed locations. The factors are added as they use the same denominator of combined traffic at the location of automatic equipment to provide separate factors for different travel lanes.

$$VOL_{bikes\ at\ site} = VOL_{raw\ AE\ count} \times \left(M_{bike@AE} + B_{bike@bypass}\right)$$

Where $VOL_{bikes\ at\ site}$ is the daily volume of bicycles at the site using only automatic equipment, $VOL_{raw\ AE\ count}$ is the raw daily volume of combined pedestrian and bicycle traffic from the automatic equipment, $M_{bike@AE}$ is the mixed-traffic factor for bicycles at the location of the automatic equipment, and $B_{bike@bypass}$ is the bypass factor for bicycles at the bypassed locations.

Continuing with the previous example at the UCS site, given a daily volume from the automatic equipment within the same period of 453 people per day at the automatic equipment location, the estimated pedestrian volume is 580 and the bicycle volume is 208, as shown below.

$$VOL_{peds\ at\ site} = 453\ (0.896 + 0.384) = 580$$

$$VOL_{bikes\ at\ site} = 453\ (0.104 + 0.354) = 208$$

3.3.3 Data Fusion and Calculating Results

This section describes the process of fusing the automatic equipment and manual count volumes to create 1) simultaneous cordon count volumes in each period; 2) weekday daily volumes at all sites; and 3) average weekday traffic at all sites for each period.

- Simultaneous Cordon Count Volumes per Period: A 24-hour simultaneous cordon count requires manual counts by video at four sites (KD, UCS, CM, and UCN) and adjusted automatic equipment counts at two sites (SL and SP). Combining these data sources allows for a daily volume of all pedestrian and bicycle traffic entering/exiting the Fort Garry campus on a typical weekday in each period. This provides a self-validation of data to ensure the AWDT from the short duration automatic equipment counts represents the spatial distribution determined in the simultaneous cordon counts. For example, if the simultaneous cordon count determined 20% of pedestrian traffic to be at a specific site in a period, the AWDPT at that site should be approximately 20% of the total AWDPT on campus in that period. This is not a ground-truth study and there is variability associated in the single-day count as well as the automatic equipment. Nevertheless, this provides a high-level, qualitative self-validation check to confirm volumes are similar between the two methods.

- Weekday Daily Volumes at All Sites: Weekday daily volumes are compiled from both the adjusted automatic equipment data and the manual counts by video volumes for pedestrian and bicycle traffic at each site. This allows for representation of temporal characteristics at each site with a minimum of five data points in each period.
- Average Weekday Pedestrian and Bicycle Traffic at All Sites per Period: Lastly, the weekday daily traffic volumes are averaged within each period for each site to determine the AWDPT and AWDBT at each site for each period. This allows for temporal and spatial findings for each mode.

4 ANALYSIS AND DISCUSSION

This chapter analyzes and discusses the results obtained from the processing of pedestrian and bicycle traffic count data collected at the University of Manitoba Fort Garry campus. Figure 4.1 sets the context of the analysis and discussion included in this chapter. The first section summarizes the data collection program implemented as per the plan described in Section 3.1 and identifies weather-related considerations. The second section presents the results of the analysis to fulfill the objectives of the data collection plan (modal, spatial, and temporal characteristics). This includes (1) a summary of pedestrian and bicycle traffic volumes; (2) pedestrian and bicycle traffic volumes by period; and (3) pedestrian and bicycle traffic volumes by site. The chapter closes with a discussion of the research limitations, a comparative analysis designed to contextualize the results, and the implications of the research.

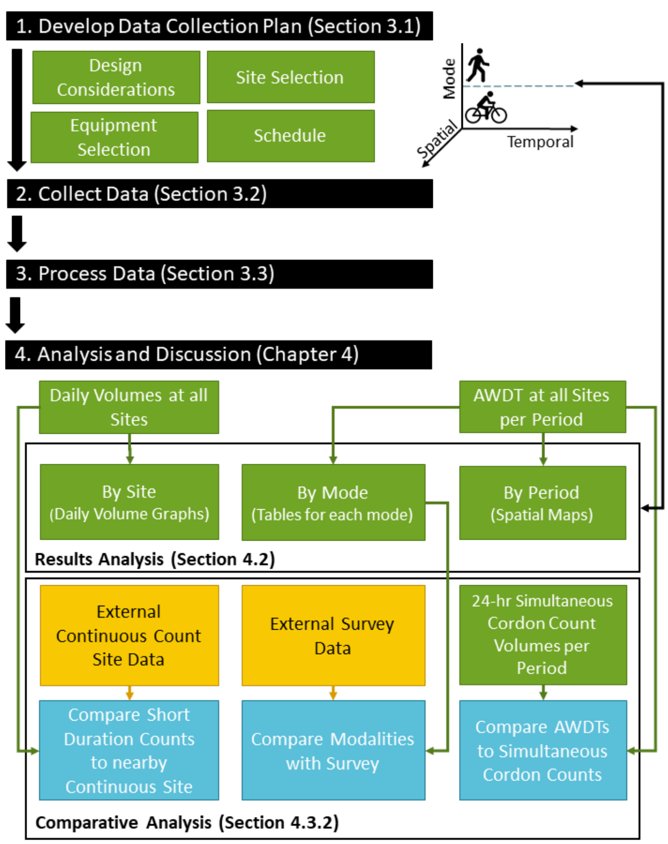


Figure 4.1: Flow chart of the analysis and visualization of data

4.1 SUMMARY OF PEDESTRIAN AND BICYCLE TRAFFIC DATA

This section describes the pedestrian and bicycle traffic data collected for this research. It discusses the number of days of data collection for each mode and period and identifies key weather-related considerations during the data collection period.

4.1.1 Data available from automatic equipment and manual counts by video

Data was collected for a full year from September 2018 through August 2019 using automatic equipment and manual counts by video. The two sets of automatic equipment (two infrared sensors each paired with a pneumatic tube for bicycles) were rotated through five of the six sites to gather a minimum of five days of data in each period. No data from automatic equipment were collected at the UCN site, since it was not feasible to deploy the automatic equipment at this site, as stated in Section 3.1.3. Table 4.1 and Table 4.2 show the number of days for which automatic equipment was used to collect pedestrian and bicycle data, respectively. There are more days of bicycle data than pedestrian data because the bicycle data is a combination of pneumatic tube counts and using mixed-traffic factors for passive infrared sensor data. When passive infrared sensors were installed at the KD and/or UCS sites, the pneumatic tubes remained at the CM, SL, or SP sites to continue collecting bicycle data.

Table 4.1: Automatic equipment days per period per site (pedestrians)

Pedestrians	P1	P2	P3	P4	P5	P6	SUM
Southwood Lands	14	14	13	11	17	8	**77**
King's Drive	4	6	12	8	5	5	**40**
University Crescent S	5	6	12	8	4	5	**40**
Smartpark	14	15	13	7	21	11	**81**
Chancellor Matheson	10	6	8	14	10	3	**51**
University Crescent N	No Data	No Data	No Data	No Data	No Data	No Data	**No Data**
SUM	**81**	**76**	**93**	**80**	**94**	**54**	**478**

Table 4.2: Automatic equipment days per period per site (bicycles)

Bicycles	P1	P2	P3	P4	P5	P6	SUM
Southwood Lands	14	14	26	19	17	8	**98**
King's Drive	4	6	12	8	5	5	**40**
University Crescent S	5	6	12	8	4	5	**40**
Smartpark	14	15	21	15	21	15	**101**
Chancellor Matheson	10	6	8	14	13	3	**54**
University Crescent N	No Data	No Data	No Data	No Data	No Data	No Data	**No Data**
SUM	**81**	**76**	**114**	**96**	**97**	**58**	**522**

As highlighted in the tables, for both pedestrians and bicycles, there are three sites with less than five days of data available in a period: (1) the KD site in Period 1 with four days of data available; (2) the UCS site in Period 5 with four days of data available; and (3) the CM site in Period 6 with three days of data available. All of these sites have an additional 24 hours of manual data on different days than those recorded automatically. Only the CM site in Period 6 falls short of the recommended minimum number of days (i.e., 5 days) required to compute average traffic volume statistics for pedestrians and bicycles (Regehr et al., 2017; Ryus et al., 2014b). Appendix C provides a complete list of the automatic equipment malfunctions.

The manual counts by video provided 24-hour counts for each period at the four pre-determined sites (KD, UCS, CM, and UCN), as well as an additional 24 hours at the UCN site in each period. Two separate equipment malfunctions precluded a manual count by video at the KD site in Period 2. Table 4.3 shows the dates for the simultaneous cordon counts.

Table 4.3: Simultaneous Cordon Count Dates

Period	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
Date	February 12, 2019	March 20, 2019	June 12, 2019	July 24, 2019	October 17, 2018	November 29, 2018

The total hours of video footage collected was 1846 hours. This included redundant counts and unusable footage due to extreme weather and equipment malfunctions. Of the 1846 hours of video collected, 693 hours were used to conduct the manual counts by video. The 693 hours of pedestrian and bicycle counts consists of 24 hours of footage at each of the four sites for each of the six periods, an additional 24 hours at the UCN site for each of the six periods, and a single 24-hour manual count at the SL site in the winter season to determine mixed-traffic factors. A total of 19 hours of footage (2.7% of the total used video) was imputed or supplemented using hourly factors from a manual count in the same period. In Period 2, the CM and UCN sites had an equipment malfunction for the first 9 hours of video for the simultaneous cordon count date. These hours were imputed by creating hourly factors from a 24-hour manual count by video conducted the following day.

4.2 RESULTS ANALYSIS

This section presents the principal research findings by representing the pedestrian and bicycle traffic in three ways. First, summary tables for pedestrian and bicycle traffic display the AWDPT and AWDBT for each site and each period. Second, a series of visualizations for each period show the total AWDPT/AWDBT in that period, the total pedestrian and bicycle traffic at each site, and the proportion of pedestrian and bicycle traffic at each site. Third, a series of graphs display temporal traffic trends for each mode at each site. Specifically, daily volume graphs for each site show the changes in both pedestrian and bicycle traffic throughout the year and distinguish between automatic counts and manual counts by video. These three representations of the data align with the objectives set out in the methodology by enabling modal, spatial, and temporal analysis of the data.

4.2.1 Summary of Pedestrian and Bicycle Traffic Volume

Table 4.4 and Table 4.5 show the AWDPT and AWDBT, respectively, at each site for each period. Table 4.6 shows the combined AWDPT and AWDBT at each site for each period. The highest volumes are highlighted in green and the lowest volumes are highlighted in yellow. The tables reveal the following:

- The KD site consistently exhibited the highest pedestrian traffic regardless of period, with AWDPTs ranging from 749 in Period 4 to 1365 in Period 5. The mean of the six period-specific AWDPTs was 1019 at this site.
- The SP site consistently exhibited the lowest pedestrian traffic regardless of period, with AWDBTs ranging from 24 in Period 2 to 200 in Period 3. The mean of the six period-specific AWDPTs was 115 at this site.
- The SL site exhibited the highest bicycle traffic in three of the six periods with AWDBTs ranging from 31 in Period 1 to 692 in Period 3. The mean of the six period-specific AWDPTs was 1019 at this site. The mean of the six period-specific AWDBTs was 282 at this site.
- The SP site exhibited the lowest bicycle traffic in five of the six periods with AWDBTs ranging from 0 in Periods 1 and 2 to 117 in Period 3. The mean of the six period-specific AWDBTs was 49 at this site.
- The KD site consistently exhibited the highest combined pedestrian and bicycle traffic regardless of period, with AWDTs ranging from 1072 in Period 2 to 1507 in Period 5. The mean of the six period-specific AWDTs was 1192 at this site.
- The SP site consistently exhibited the lowest combined pedestrian and bicycle traffic regardless of period, with AWDTs ranging from 31 in Period 1 to 317 in Period 3. The mean of the six period-specific AWDTs was 164 at this site.

Table 4.4: Average WeekDay Pedestrian Traffic for each site and each temporal period

AWDPT	P1	P2	P3	P4	P5	P6	Mean
Southwood Lands	179	186	316	254	248	206	**231**
King's Drive	1087	971*	874	749	1365	1068	**1019**
University Crescent S	625	317	705	452	577	736	**569**
Smartpark	31	24	200	134	182	119	**115**
Chancellor Matheson	172	186	459	375	436	195	**304**
University Crescent N	328	430	641	544	605	322	**478**
SUM	**2422**	**2113**	**3196**	**2508**	**3414**	**2645**	**2716**

* No manual count by video. Estimated value from automatic equipment counts and Period 5 factors.

Table 4.5: Average WeekDay Bicycle Traffic for each site and each temporal period

AWDBT	P1	P2	P3	P4	P5	P6	Mean
Southwood Lands	31	45	692	611	276	36	**282**
King's Drive	17	101*	397	366	142	18	**174**
University Crescent S	12	9	253	184	73	8	**90**
Smartpark	0**	0**	117	107	45	25	**49**
Chancellor Matheson	25	49	232	299	298	25	**155**
University Crescent N	20	28	463	398	178	37	**187**
SUM	**105**	**232**	**2154**	**1965**	**1012**	**149**	**936**

* No manual count by video. Estimated value from automatic equipment counts and Period 5 factors.

** No bicycles counted due to lack of snow clearing at the site.

Table 4.6: Average WeekDay Non-motorized Traffic for each site and each temporal period

AWDPT+AWDBT	P1	P2	P3	P4	P5	P6	Mean
Southwood Lands	210	231	1009	864	523	241	**513**
King's Drive	1104	1072*	1271	1115	1507	1086	**1192**
University Crescent S	637	326	958	637	651	744	**659**
Smartpark	31**	24**	317	241	227	144	**164**
Chancellor Matheson	197	235	692	674	734	220	**459**
University Crescent N	348	458	1104	942	783	359	**666**
SUM	**2527**	**2345**	**5350**	**4473**	**4426**	**2794**	**3653**

* No manual count by video. Estimated value from automatic equipment counts and Period 5 factors.

** No bicycles counted due to lack of snow clearing at the site.

Additional findings from the tables follow:

- The trends of the combined traffic (Table 4.6) align with the trends of the pedestrian traffic (Table 4.4) because the pedestrian traffic represents the majority of the overall non-motorized travel into/out of campus. This demonstrates the need to analyze pedestrians and bicycles separately.
- The consistently high total and pedestrian traffic at the KD site may indicate that the surrounding land use around the campus plays a considerable factor in pedestrian and bicycle travel. The major sites for vehicular traffic are UCN and CM, however pedestrian traffic is highest at the KD site. This may be due to the number of people that reside in the residential area south of the Fort Garry campus and commute via walking.

- This analysis shows the value of collecting spatially diverse data because the traffic trends throughout the year vary from site to site.

4.2.2 Weather-related considerations

Figure 4.2 shows the weather data collected in Winnipeg from September 2018 through August 2019. The graph shows both temperature and precipitation (as snow and rain) by period. The year featured the following unusual weather conditions:

- The months of January and February were lower than historic temperatures.
- March featured a relatively fast snow melt.
- The end of April featured unseasonably high temperatures.
- September was unusually cold and wet.
- There were a few unseasonably warm days in mid-October and mid-December
- There was no snow on the ground until late November (unseasonably late).

While no days were removed from the dataset, there was an attempt to collect manual counts by video and the cordon counts on "typical" weather days for each period.

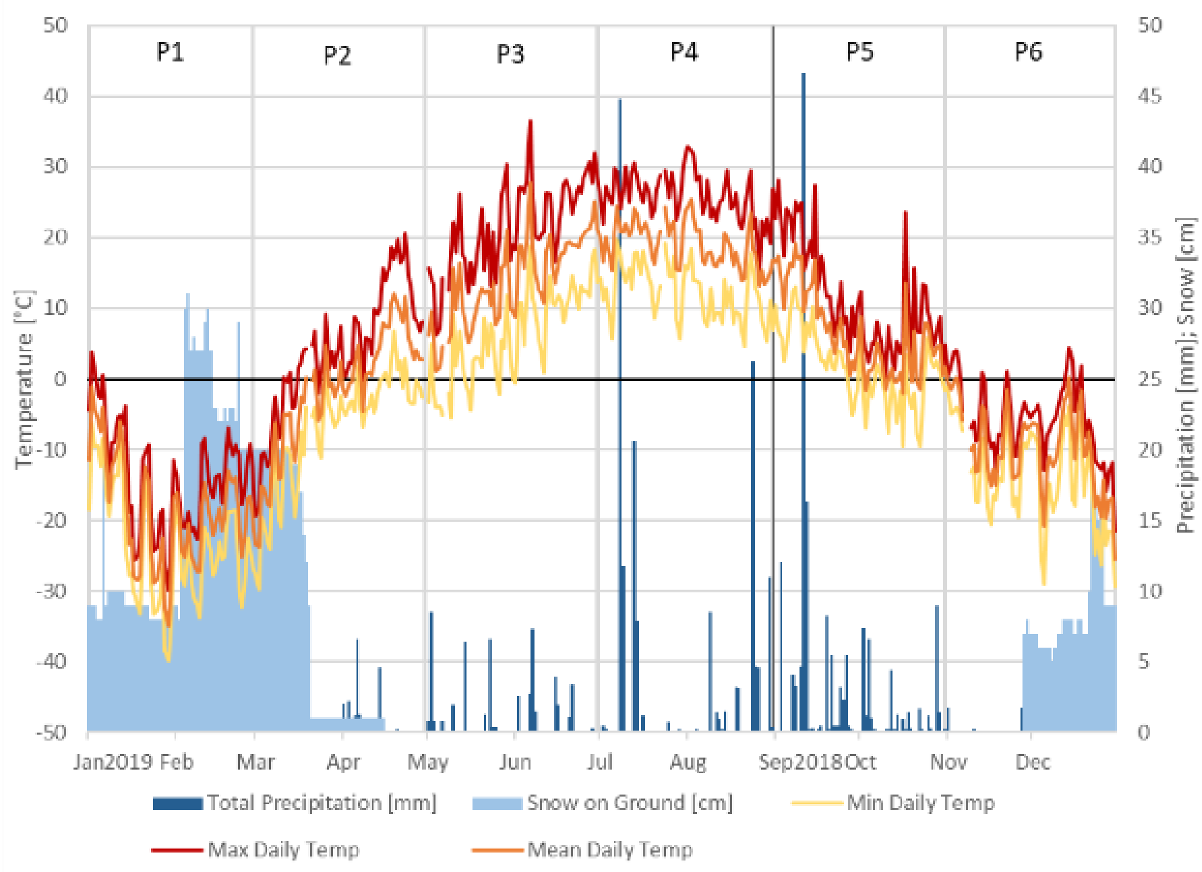


Figure 4.2: Weather recorded in Winnipeg from September 2018 through August 2019 [data sourced from Environment Canada]

4.2.3 Pedestrian and Bicycle Traffic Volume by Period

Figure 4.3 shows the total Average WeekDay Traffic for both pedestrians and bicycles in each period. The AWDPT is highest in Period 5 with a 36% increase from Period 4, which coincides with the start of the fall semester and fall season. The AWDPT is higher in the first period of each semester (Periods 1, 3, and 5) than the second period that coincides with the semester (Periods 2, 4, and 6). The AWDBT is highest in the summer season months (Periods 3 and 4) and declines in Period 5 when the fall semester begins. The 48% decrease in bicycle traffic in Period 5 (relative to Period 4) is noteworthy, since it coincides with an overall increase in the number of people accessing the campus. This graph also shows the decrease in pedestrian and bicycle traffic between Period 3 and Period 4. The weather in these two periods is similar so the decrease in pedestrian traffic may be attributed to the two main class sessions within the summer semester. The pedestrian traffic seems to be affected more by the academic semesters and the bicycle traffic seems to be more affected by weather.

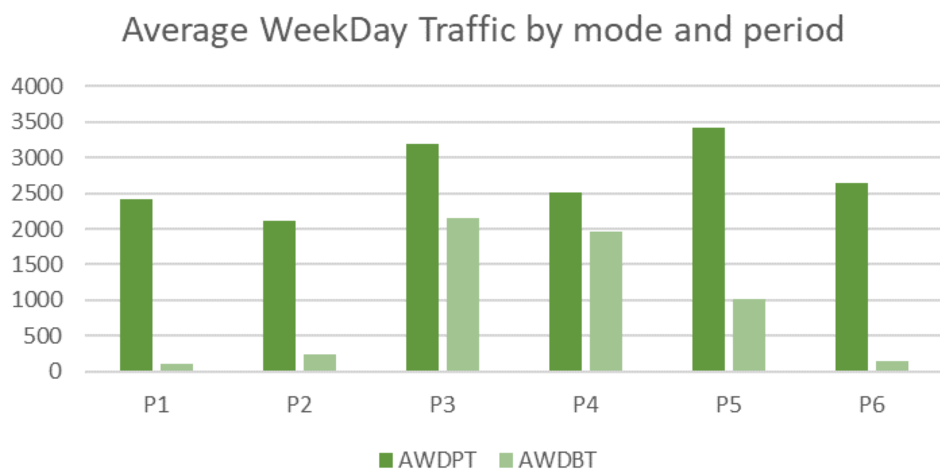


Figure 4.3: Total Average WeekDay Traffic by mode and period

Figure 4.4 through Figure 4.9 present the spatial and modal traffic volume distribution for each period. The areas of the circles are proportional to the total volume of pedestrian and bicycle traffic in that period (i.e., the scale is consistent within each figure, but inconsistent between the figures). The figures illustrate the relationship and differences between pedestrian and bicycle traffic at each site while providing a spatial reference to show where these sites are situated. This provides insight as to how the different access points are used by each mode at different times of the year and may impact the future deployment of automatic equipment to optimize resources. Principal findings from the figures follow:

- The KD and UCS sites do not provide bicycle-specific facilities and have a smaller proportion of bicycle traffic compared to other sites.
- The SL site is the only site to have more bicycle than pedestrian traffic (Figure 4.6, Figure 4.7, and Figure 4.8), despite the availability of bicycle facilities at the nearby UCN site. This may be because the SL site provides ready access for people using existing City of Winnipeg bicycle infrastructure north and east of the campus. The Pembina Hwy bike lanes and Bishop Grandin Greenway provide

direct access to the SL site. It may be used recreationally by bicycles as it is a gravel trail along the Red River.

- The colder periods (Periods 1, 2, 5 and 6) show higher combined AWDPT/AWDBT at the KD and UCS sites and traffic becomes more evenly distributed throughout the sites in warmer weather periods (Periods 3 and 4). This is likely due to land-use factors, with many people residing south of the campus choosing to walk during these periods. A consistent volume of people walk to campus regardless of the weather.

Comments on differences in spatial distribution for each of the six periods are listed below. For every period the highest combined AWDPT/AWDBT volumes are at the KD site and the lowest are at the SP site. The proportion of traffic at each site fluctuates throughout the year.

- Period 1 has an AWDPT of 2422 and an AWDBT of 105. The spatial distribution shows the highest traffic site is KD with 44% of the overall AWDT (1104 people). The lowest traffic site is SP with 1% of the overall AWDT (31 people).
- Period 2 has an AWDPT of 2113 and an AWDBT of 232. The spatial distribution shows the highest traffic site is KD with 46% of the overall AWDT (1072 people). The lowest traffic site is SP with 1% of the overall AWDT (24 people).
- Period 3 has an AWDPT of 3196 and an AWDBT of 2154. The spatial distribution shows the highest traffic site is KD with 24% of the overall AWDT (1271 people). The lowest traffic site is SP with 6% of the overall AWDT (317 people).
- Period 4 has an AWDPT of 2508 and an AWDBT of 1965. The spatial distribution shows the highest traffic site is KD with 25% of the overall AWDT (1115 people). The lowest traffic site is SP with 5% of the overall AWDT (241 people).

- Period 5 has an AWDPT of 3414 and an AWDBT of 1012. The spatial distribution shows the highest traffic site is KD with 34% of the overall AWDT (1507 people). The lowest traffic site is SP with 5% of the overall AWDT (227 people).
- Period 6 has an AWDPT of 2645 and an AWDBT of 149. The spatial distribution shows the highest traffic site is KD with 39% of the overall AWDT (1086 people). The lowest traffic site is SP with 5% of the overall AWDT (144 people).

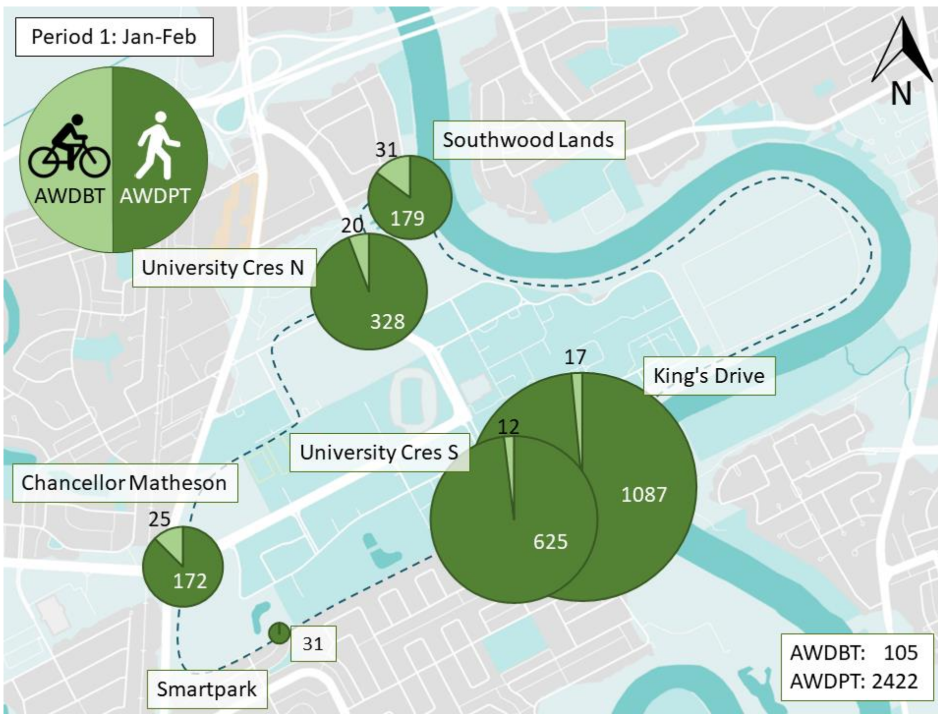


Figure 4.4: Proportional map of Average WeekDay Pedestrian and Bicycle Traffic in Period 1

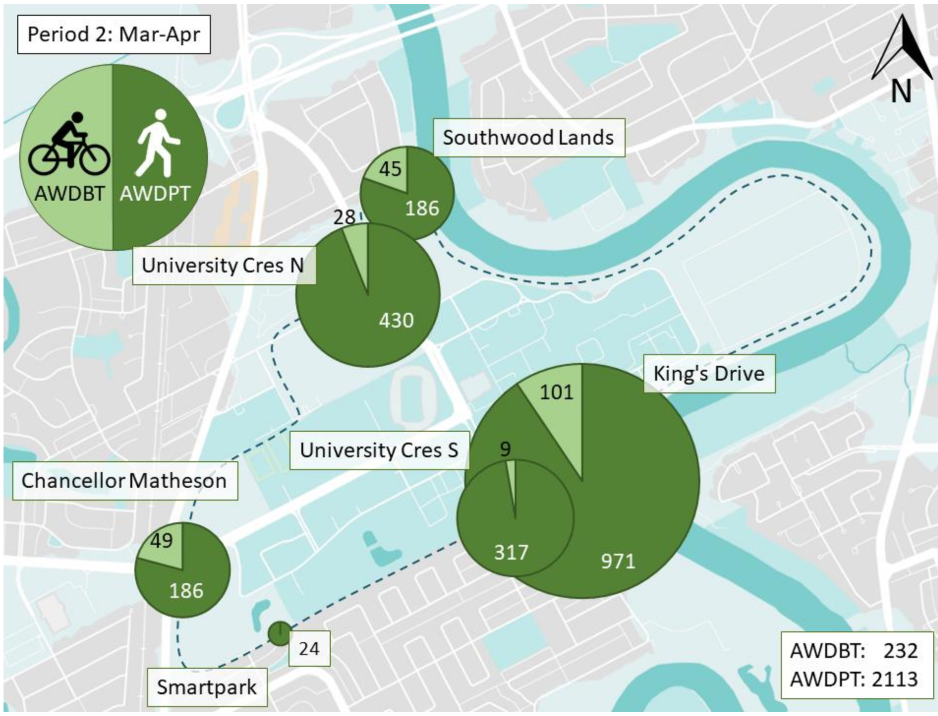


Figure 4.5: Proportional map of Average WeekDay Pedestrian and Bicycle Traffic in Period 2

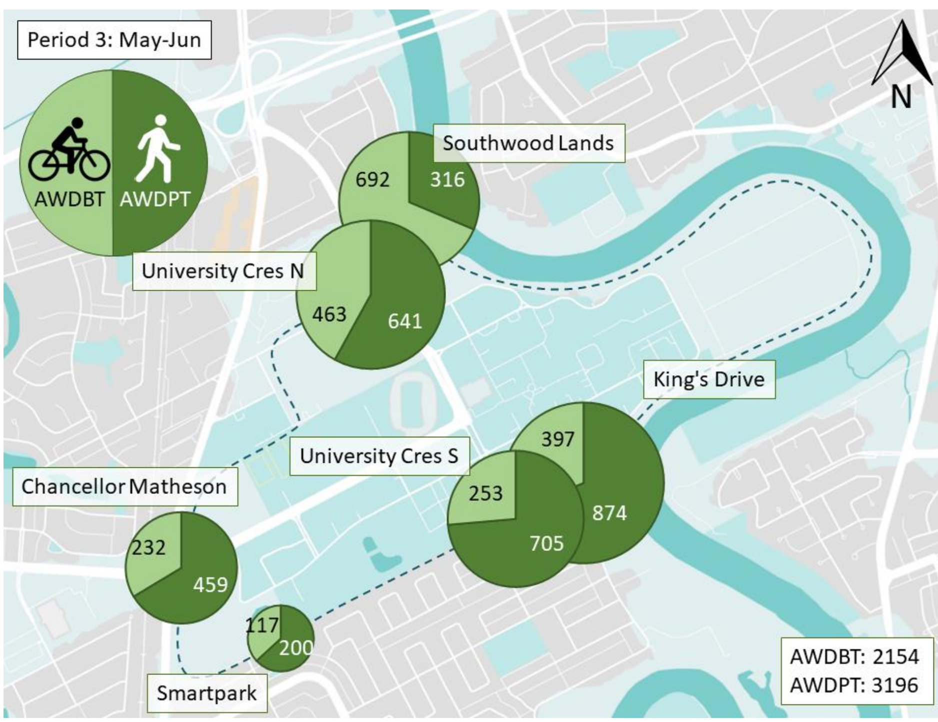


Figure 4.6: Proportional map of Average WeekDay Pedestrian and Bicycle Traffic in Period 3

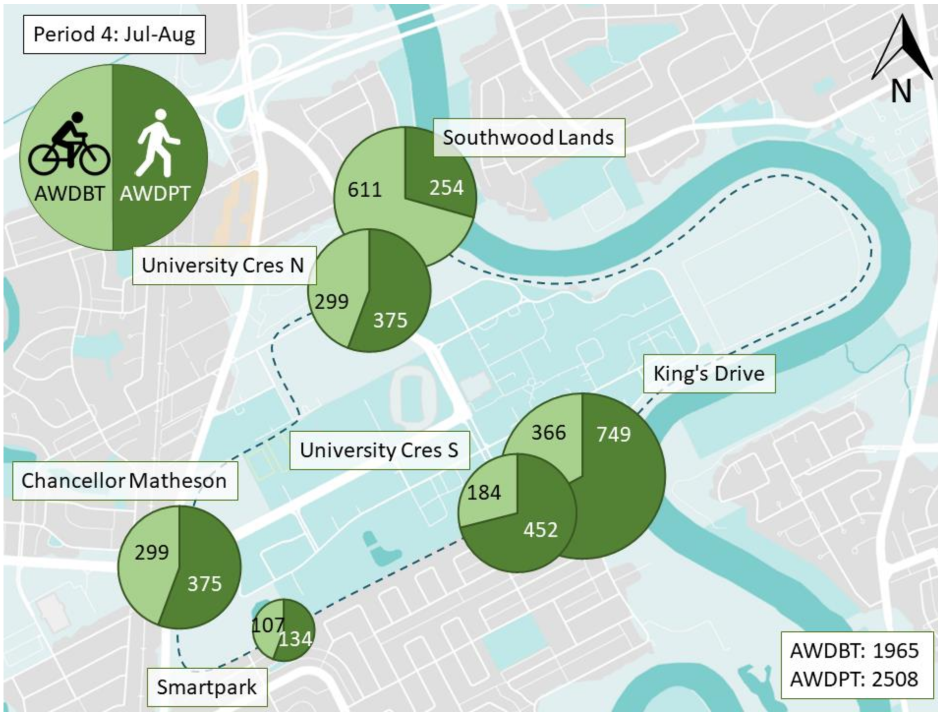


Figure 4.7: Proportional map of Average WeekDay Pedestrian and Bicycle Traffic in Period 4

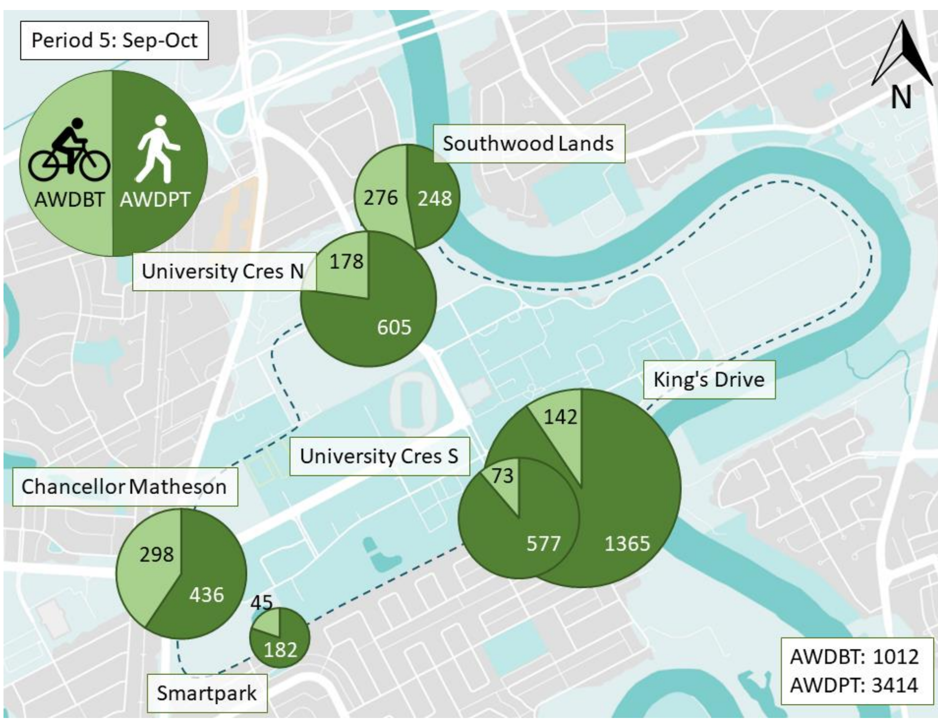


Figure 4.8: Proportional map of Average WeekDay Pedestrian and Bicycle Traffic in Period 5

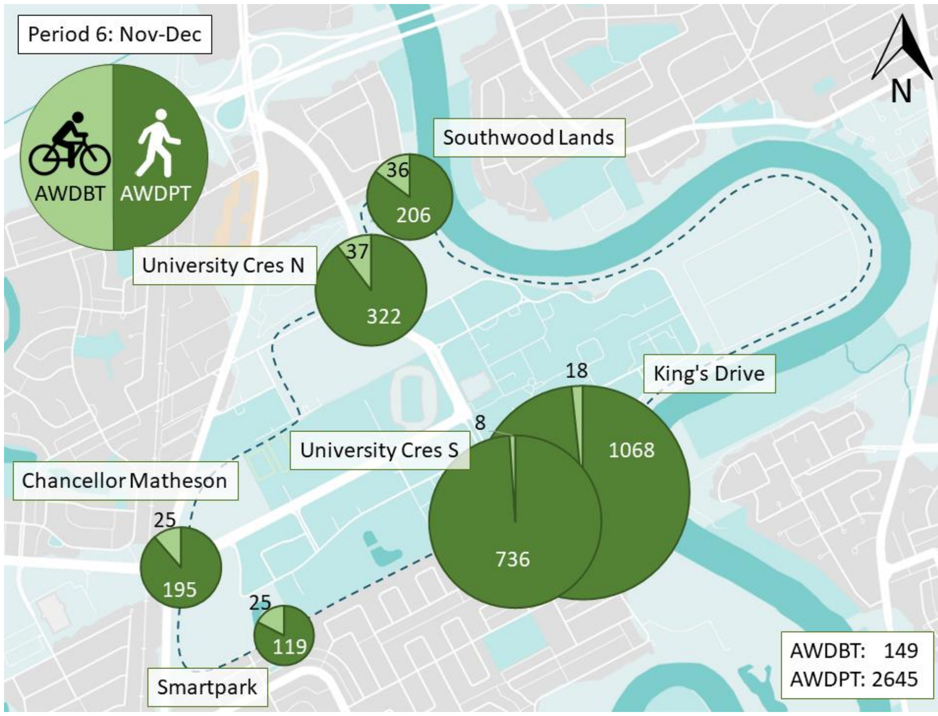


Figure 4.9: Proportional map of Average WeekDay Pedestrian and Bicycle Traffic in Period 6

4.2.4 Pedestrian and Bicycle Traffic Volume by Site

This section provides findings of pedestrian and bicycle volumes at each site. Information provided in each site analysis includes a graph of daily volumes that distinguishes between pedestrian and bicycles as well as between automatic equipment counts and manual counts by video; a table that compares the AWDPT/AWDBT to the single-day simultaneous cordon count volume in each period; and comments related to these results. The simultaneous cordon count volumes are sourced from either automatic equipment or manual count by video depending on the site. A more in-depth comparison between the simultaneous cordon count volumes and the AWDPT/AWDBT at each site is discussed in Section 4.3.2. Additional comments on the site-specific data collection process are also provided.

Southwood Lands (SL)

The site is located on the north end of campus and is a gravel multi-use trail. Figure 4.10 shows the daily volumes for both pedestrians and bicycles at the SL site. The single manual count by video was conducted on March 6, 2019 to determine the bicycle proportion of traffic in the snow-covered periods (1, 2, and 6). No pedestrian volume data was recorded in Periods 3 and 4; this does not necessarily mean that there were zero pedestrians at the site on those dates. Table 4.7 shows the AWDT and simultaneous cordon count volumes for pedestrians and bicycle traffic in each period. All simultaneous cordon count volumes were collected with automatic equipment on the dates specified in Section 4.1.1. The data shows there is a 251% increase in average combined AWDT from Periods 1, 2, and 6 to Periods 3, 4, and 5. There is also a 572% increase in AWDBT from Periods 1, 2, and 6 to Periods 3, 4 and 5.

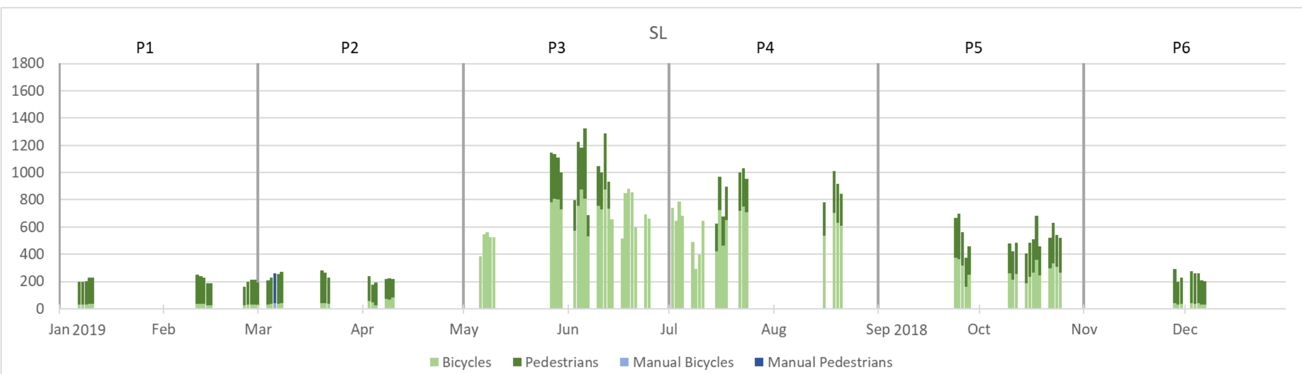


Figure 4.10: Southwood Lands daily volumes for pedestrian and bicycle traffic

Table 4.7: Summary of volumes (AWDT and automatic equipment simultaneous cordon count) at the Southwood Lands site

AWDT (Cordon Count)	P1	P2	P3	P4	P5	P6	Mean
Pedestrians	179 (203)	183 (241)	316 (408)	254 (242)	248 (245)	206 (170)	**231 (252)**
Bicycles	31 (35)	46 (42)	692 (877)	611 (711)	276 (266)	36 (30)	**282 (327)**
SUM	**210 (238)**	**229 (283)**	**1009 (1285)**	**864 (953)**	**523 (511)**	**241 (200)**	**513 (578)**

King's Drive (KD)

The site is located on the south end of campus and consists of a road for bicycles and a single sidewalk for pedestrians. Figure 4.11 shows the daily volumes for both pedestrians and bicycles at the KD site. Table 4.8 shows the AWDT and simultaneous cordon count volumes for pedestrians and bicycle traffic in each period. All simultaneous cordon count volumes were collected with manual counts by video on the dates specified in Section 4.1.1. The KD site is one of three sites to collect data using both automatic equipment and manual counts by video. Although the deviation between the manual count and the combined AWDT varies for each period, the overall mean deviation is 0% in comparing the mean manual counts (1193 people) relative to the mean combined AWDT (1197 people). The data shows there is an 82% increase in AWDPT from Period 4 to Period 5 and a 61% decrease in AWDBT from Period 4 to Period 5.

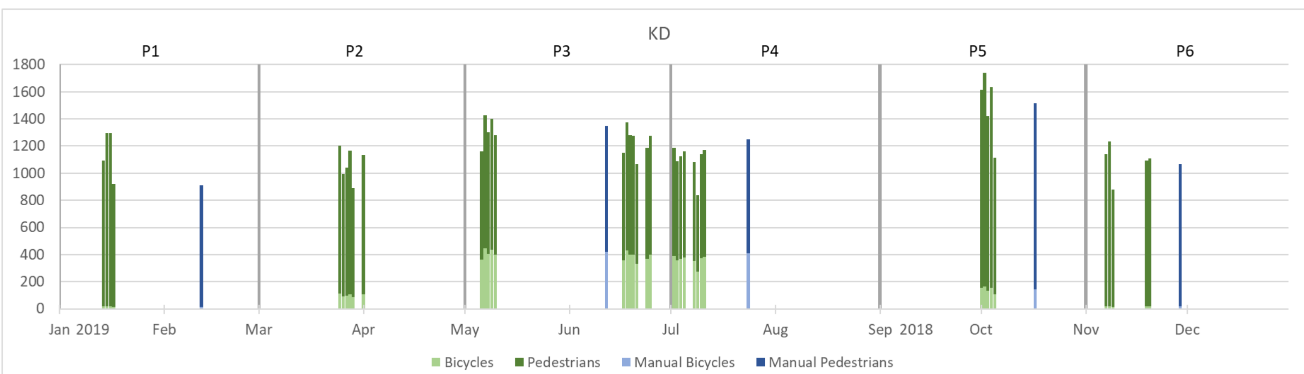


Figure 4.11: King's Drive daily volumes for pedestrian and bicycle traffic

Table 4.8: Summary of volumes (AWDT and simultaneous cordon count) at the King's Drive site

AWDT (Cordon Count)	P1	P2	P3	P4	P5	P6	Mean
Pedestrians	1135 (895)	971*	870 (926)	738 (838)	1363 (1374)	1072 (1049)	**1025 (1009)**
Bicycles	18 (14)	101*	395 (420)	361 (410)	142 (143)	18 (18)	**172 (184)**
SUM	**1153 (909)**	**1072***	**1265 (1346)**	**1098 (1248)**	**1505 (1517)**	**1090 (1067)**	**1197 (1193)**

*No simultaneous cordon count data available

University Crescent South (UCS)

The site is located on the south end of campus and consists of a road for bicycles and two sidewalks for pedestrians. Period 5 only has four days of automatic equipment data due to malfunctions. It has a total of five days of data when using the 24-hour manual count by video. Figure 4.12 shows the daily volumes for both pedestrians and bicycles at the UCS site. Table 4.9 shows the AWDT and simultaneous cordon count volumes for pedestrians and bicycle traffic in each period. All simultaneous cordon count volumes were collected with manual counts by video on the dates specified in Section 4.1.1. The UCS site is one of three sites to collect data using both automatic equipment and manual counts by video. The deviations between the manual count relative to the combined AWDT in Periods 2, 4, and 5 are +57% (730 relative to 326 people), +26% (860 relative to 637 people), and +31% (941 relative to 651 people). The spike in overall traffic on May 7, 2019 could not be explained by a malfunction or known event in the area and was therefore kept as part of the dataset. A 49% decrease in combined AWDT from Period 1 to 2 could not be explained after review of the data. The pedestrian and combined traffic at this site remains relatively consistent throughout the year with a 31% increase in average combined AWDT from Periods 1, 2, and 6 to Periods 3, 4, and 5.

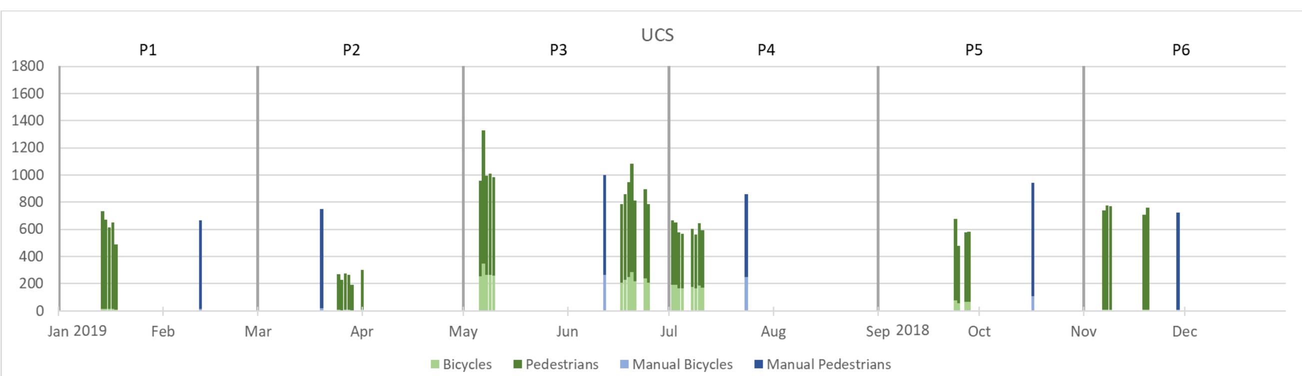


Figure 4.12: University Crescent South daily volumes for pedestrian and bicycle traffic

Table 4.9: Summary of volumes (AWDT and simultaneous cordon count) at the University Crescent South site

AWDT (Cordon Count)	P1	P2	P3	P4	P5	P6	Mean
Pedestrians	618 (655)	249 (730)	702 (737)	433 (611)	513 (835)	741 (715)	**543 (714)**
Bicycles	12 (13)	7 (21)	252 (264)	176 (249)	65 (106)	8 (7)	**87 (110)**
SUM	**631 (668)**	**256 (751)**	**954 (1001)**	**609 (860)**	**578 (941)**	**749 (722)**	**629 (824)**

Smartpark (SP)

The SP site is located on the southwest end of campus and consists of three small gravel pathways into the campus technology park. There are three access points at this site, but automatic equipment was only set up on the most trafficked path. Figure 4.13 shows the daily volumes for both pedestrians and bicycles at the SP site. No pedestrian volume data was recorded in Periods 3 and 4; this does not necessarily mean that there were zero pedestrians at the site on those dates. Table 4.10 shows the AWDT and simultaneous cordon count volumes for pedestrians and bicycle traffic in each period. No manual counts by video were used at this site and all simultaneous cordon count volumes were collected with automatic equipment on the dates specified in Section 4.1.1. SP is a low traffic site for both pedestrians and bicycles and had unique challenges for collecting data due to maintenance and other site-specific characteristics. The site was cleared for snow in Period 6 and early in Period 1, but the winter maintenance stopped and a large snowbank formed in front of the main walking path (see Figure 4.14). This may be why no bicycles were recorded for Periods 1 and 2. The other two pathways were not cleared in the winter season. The data shows there is a 294% increase in average combined AWDT from Periods 1, 2, and 6 to Periods 3, 4, and 5.

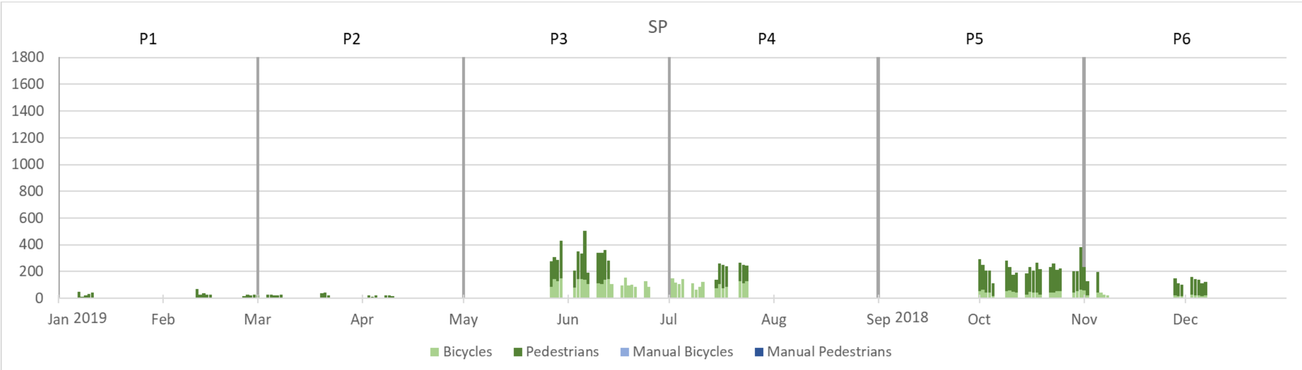


Figure 4.13: Smartpark daily volumes for pedestrian and bicycle traffic

Table 4.10: Summary of volumes (AWDT and simultaneous cordon count) at the Smartpark site

AWDT (Cordon Count)	P1	P2	P3	P4	P5	P6	Mean
Pedestrians	31 (27)	24 (35)	200 (225)	134 (118)	182 (163)	119 (94)	**115 (110)**
Bicycles	0 (0)	0 (0)	117 (138)	107 (127)	45 (43)	25 (18)	**49 (54)**
SUM	**31 (27)**	**24 (35)**	**317 (363)**	**241 (245)**	**227 (206)**	**144 (112)**	**164 (165)**

Figure 4.14: Smartpark pathway cleared (Left: Jan 5, 2019) and pathway blocked (Right: Feb 9, 2019)

Chancellor Matheson (CM)

The site is located on the west end of campus and facilitates pedestrians and bicycles with two multi-use paths alongside the arterial roadway. This site used two sets of automatic equipment for short duration counts. If a malfunction occurred at one of the two set ups, the data at the one site was factored to estimate traffic on both pathways. Figure 4.15 shows the daily volumes for both pedestrians and bicycles at the CM site. No pedestrian volume data was recorded in Period 5; this does not necessarily mean that there were zero pedestrians at the site on those dates. Table 4.11 shows the AWDT and simultaneous cordon count volumes for pedestrian and bicycle traffic in each period. All simultaneous cordon count volumes were collected with manual counts by video on the dates specified in Section 4.1.1. The CM site is one of three sites to collect data using both automatic equipment and manual counts by video. The overall mean deviation between the manual counts and the combined AWDT is -6% in comparing the mean manual counts (431 people) relative to the mean AWDT (459 people). The manual count comparison in Period 4 shows a -85% deviation from the manual count (400 people) relative to AWDT (734 people). The data shows there is a 223% increase in average combined AWDT from Periods 1, 2, and 6 to Periods 3, 4, and 5.

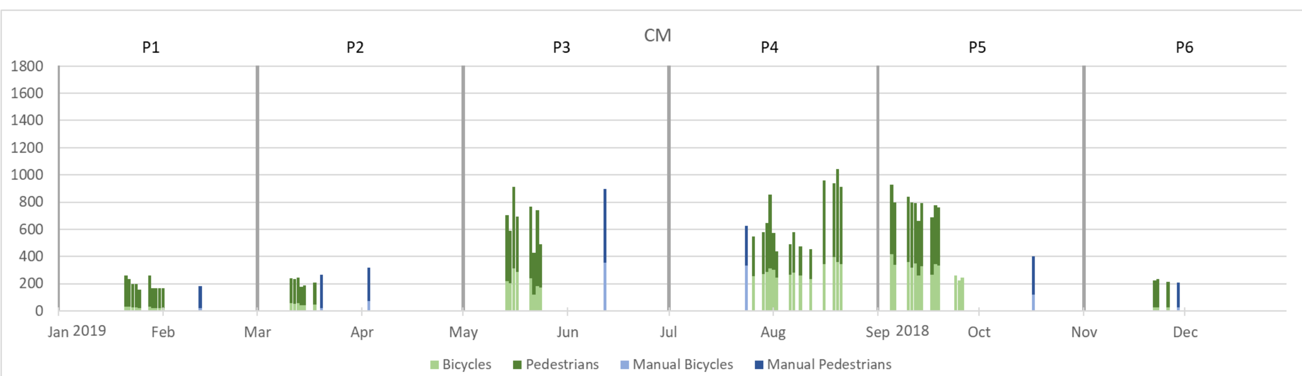


Figure 4.15: Chancellor Matheson daily volumes for pedestrian and bicycle traffic

Table 4.11: Summary of volumes (AWDT and simultaneous cordon count) at the Chancellor Matheson site

AWDT (Cordon Count)	P1	P2	P3	P4	P5	P6	Mean
Pedestrians	173 (161)	166 (249)	448 (546)	382 (290)	452 (278)	197 (186)	**303 (285)**
Bicycles	25 (23)	50 (19)	217 (353)	296 (336)	312 (122)	25 (24)	**154 (146)**
SUM	**198 (184)**	**215 (268)**	**666 (899)**	**678 (626)**	**764 (400)**	**223 (210)**	**457 (431)**

University Crescent North (UCN)

The site has a segregated multi-use path for pedestrians and bicycles, but this facility does not continue north on University Cres. Therefore, some bicycles travel on the four-lane divided roadway and pedestrians also use the east sidewalk instead of the pathway. The site is located on the north end of campus. No automatic equipment counts were conducted due to limitations of existing infrastructure at the site and the complex movements of pedestrians and bicycles at the count location. Figure 4.16 shows the daily volumes for both pedestrians and bicycles at the SP site. Table 4.12 shows the AWDT and simultaneous cordon count volumes for pedestrians and bicycle traffic in each period. At this site, the table represents the comparison between the single-day, simultaneous cordon count volume (collected using manual count by video) and the average of the 48-hours of manual count by video data that include the simultaneous cordon count date. The data shows there is a 143% increase in average combined AWDT from Periods 1, 2, and 6 to Periods 3, 4, and 5.

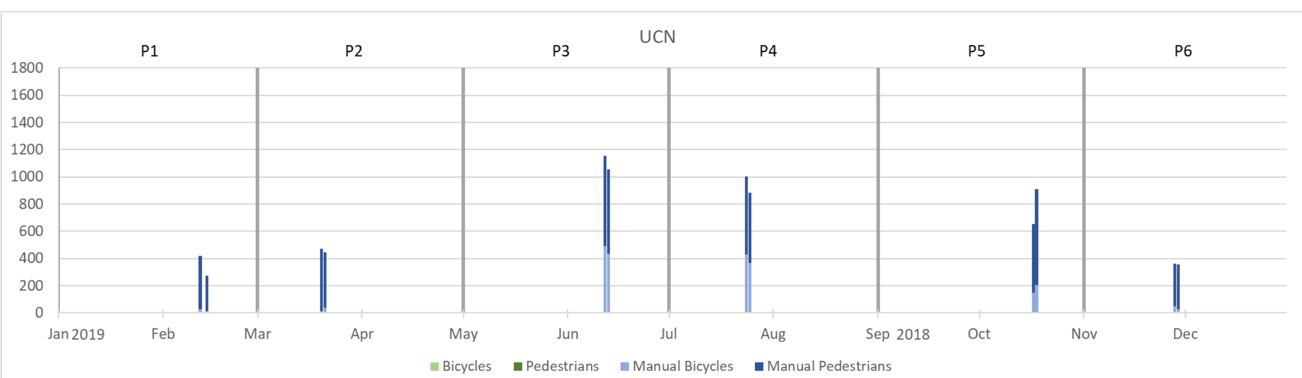


Figure 4.16: University Crescent North daily volumes for pedestrian and bicycle traffic

Table 4.12: Summary of volumes (AWDT and simultaneous cordon count) at the University Crescent North site

AWDT (Cordon Count)	P1	P2	P3	P4	P5	P6	Mean
Pedestrians	328 (396)	430 (455)	641 (662)	544 (572)	605 (505)	322 (328)	**478 (486)**
Bicycles	20 (26)	28 (15)	463 (491)	398 (430)	178 (149)	37 (27)	**187 (190)**
SUM	**348 (422)**	**458 (470)**	**1104 (1153)**	**942 (1002)**	**783 (654)**	**359 (355)**	**666 (676)**

4.3 DISCUSSION OF RESULTS

This section discusses the results. It begins by identifying key limitations relevant to this research. Next, it contextualizes the results by comparing: (1) the average weekday traffic for each period to the simultaneous cordon count (comprising two automatic equipment counts and four manual counts by video) in each period; (2) the counts obtained from the SL site with those obtained from a nearby permanent count station outside of campus; and (3) the traffic count program results with findings from a recent campus commuter survey. Finally, implications of the key findings are presented.

4.3.1 Limitations

This section identifies limitations relevant to this research, including those related to: (1) equipment and the physical characteristics of the sites; (2) weather and count program logistics; and (3) methodological constraints.

Equipment and Physical Characteristics of the Sites

All research performed in the field in uncontrolled settings has limitations related to equipment and the physical constraints of the research site. The following equipment and physical site limitations apply to this research:

- Equipment malfunctions affected the collection of data and limited the days of data that were collected. Appendix C provides a summary of equipment malfunctions. The malfunctions of the automatic equipment included: pneumatic tubes being cut by lawn mowing equipment, removal of the tree supporting the passive infrared sensor, and electromagnetic interference with the passive infrared sensor. The portable camera used to provide video footage for manual counts shut down multiple times prior to the end of the recording. The non-portable cameras also produced incomplete video footage. Since these cameras are controlled by the City of Winnipeg's Transportation Management Centre (TMC), they occasionally needed to be directed away from the study area to monitor a nearby incident. Lastly, some of the video files became corrupted or were inadvertently deleted in the transferring process. Conducting redundant manual counts by video and attempting to capture more than five days of automatic equipment data at each site aided in mitigating this limitation.

- The physical characteristics at certain sites limited the data collection in this research. The most important limitation was the inability to set up automatic equipment at the UCN site. This was due to the complex movements of pedestrians and bicyclists at this access point. As described in Section 3.1.3, pedestrians and bicyclists utilize all facilities/pathways and they frequently cross at the pedestrian corridor and into/out of the Southwood Lands pathways. There are a total of six facilities/pathways north of the pedestrian crossing corridor used by pedestrians and/or bicyclists, and five south of the corridor. There are also no trees or posts available to mount the passive infrared sensors and pneumatic tubes are not allowed on City of Winnipeg facilities, including the segregated multi-use path.
- Occlusion factors were omitted from the data adjustment of automatic equipment. As described in Section 3.3.2, the omission of this factor was justified because of the uncertainty of the value for this factor. This uncertainty arises because of expected variations in the factor value due to equipment brand, seasons, and site-specific characteristics. The development of mixed-traffic and bypass factors using the manual counts by video was prioritized.

Weather and Logistics

Weather conditions and data collection logistics play a role in data collection especially when pedestrians and bicyclists are influenced by the environmental conditions more than motorized traffic. The following weather and logistics limitations apply to this research:

- Weather was a considerable factor in deploying cordon counts. Cordon counts were conducted on non-event days with typical weather conditions and no precipitation (to facilitate video monitoring). Since some of the equipment was owned by external entities, it was not always available for use when the weather conditions were appropriate for counting.
- Both temperature and precipitation create physical barriers for pedestrians and bicyclists. In particular, at certain sites snow accumulation inhibited passage of pedestrians and bicyclists; nevertheless, days with significant snowfall were included in the dataset unless the snowfall interfered with the automatic equipment. While the snow was normally cleared in a reasonable time period at most sites, two of the pathways at the SP site were not maintained in the winter season and the third pathway was only maintained until mid-January. In the spring season, the melting of snow created puddles that resulted in pedestrians and bicyclists taking detours at certain sites and evading the sensors.
- The availability of automatic equipment presented a logistical limitation, since only two sets of equipment were used to monitor traffic at six sites. Ideally, there would be sufficient automatic equipment to monitor pedestrians and bicycles at each facility at each site for an entire year with no malfunctions. The impracticality of owning the ideal number of sensors, certain placement constraints, and the equipment's own limitations necessitated the design and implementation of a monitoring program that could meet stated objectives with available resources. Anticipating upcoming exclusion dates and developing a flexible schedule for the deployment of equipment aided in mitigating this limitation.

Methodological Limitations

In addition to the physical, environmental, and logistical limitations above, the following methodological limitations apply to this research:

- To capture the typical commuting activity on a campus and to reduce error associated with occlusion of high-traffic events, event days, weekends, exam week, and out of session dates were excluded from this research. Although the data collected on these dates may accurately represent the facility utilization on campus, inclusion of the data would affect the Average WeekDay Traffic results, which aim to represent typical commuter traffic on campus.
- The volatility of hourly pedestrian and bicycle traffic did not allow for the application of hourly mixed-traffic and bypass factors. There are hours where no pedestrians or bicycles were using the facility with the automatic equipment sensor (the sidewalk), but multiple pedestrians and bicycles would bypass the location of the equipment. An hourly factor cannot be developed if there is no hourly traffic at the location of the automatic equipment. This was addressed by developing daily factors of mixed-traffic and bypass to be applied to daily automatic equipment volumes.

4.3.2 Comparative Analysis

Despite the foregoing limitations, the results presented provide the first available observations of pedestrian and bicycle traffic at access points to the University of Manitoba Fort Garry campus. Ideally, an external data set would be used to validate the results presented; however, no such data set exists. Consequently, to contextualize the results, a comparative analysis was completed to assess the validity of the results. Three comparisons were examined: (1) a comparison of the estimated AWDPT/AWDBT and the simultaneous cordon counts obtained at each site and each period; (2) a comparison of the pedestrian and bicycle traffic volume observed at the SL site and the volumes observed at a nearby permanent count station; and (3) a comparison of the results with those obtained from a survey of commuters to campus.

Comparison of AWDT and Simultaneous Cordon Counts

The first comparison is of two data outputs (i.e., AWDPT/AWDBT and simultaneous cordon counts) that were used to determine the results presented in Section 4.2. Commonly, cordon counts comprise a set of screenline counts deployed simultaneously at midblock locations across major access points. The simultaneous nature of the cordon count reduces the variability of day-to-day traffic and enables determination of the modal split and proportion of traffic entering/exiting an area at certain access points. Unlike the simultaneous cordon count, collecting multiple days of data with short duration counts using automatic equipment and/or manual counts by video reduces the variability of pedestrian and bicycle traffic data.

This analysis compares the six simultaneous cordon counts conducted for each period with AWDPT/AWDBT data from each site. Table 4.13 and Table 4.14 show the comparison results for pedestrian and bicycle traffic. The table cells include values of the AWDPT/AWDBT, the single-day simultaneous cordon count volume (italicized), and the percent deviation of the single-day cordon count relative to the AWDPT/AWDBT. Although the single day simultaneous cordon count is included in the AWDPT/AWDBT calculation, this comparison is illustrative in showing how representative a single day count is within the two-month period. It provides high-level insight as to the appropriateness of conducting a single-day count for pedestrian and bicycle traffic. The values in the analysis below are those stated in Section 4.2.4. The greatest deviations are highlighted in yellow and the lowest deviations in green. The tables reveal the following for pedestrians:

- The UCS site exhibits the highest absolute mean deviation for pedestrian traffic (20%) and has absolute deviations ranging from 3% in Period 6 and 57% in Period 2.
- The KD site exhibits the lowest absolute mean deviation for pedestrian traffic (1%). The KD site has absolute deviations ranging from 1% in Period 5 to 21% in Period 1.

- Period 2 exhibits the highest absolute total deviation for pedestrian traffic (21%) and has absolute deviations ranging from 5% at UCN to 57% at UCS.
- Period 5 exhibits the lowest absolute total deviation for pedestrian traffic (0%) and has absolute deviations ranging from 1% at the SL and KD sites to 57% at CM.

The tables reveal the following for bicycles:

- The UCS site exhibits the highest absolute mean deviation for bicycle traffic (18%) and has absolute deviations ranging from 4% in Period 3 to 57% in Period 2.
- The UCN site exhibits the lowest absolute mean deviations for bicycle traffic (1%) and has absolute deviations ranging from 6% in Period 3 to 83% in Period 2.
- Period 5 exhibits the highest absolute total deviation for bicycle traffic (22%) and has absolute deviations ranging from 1% at KD to 144% at CM.
- Period 1 exhibits the lowest absolute total deviation for bicycle traffic (5%) and has absolute deviations ranging from 5% at UCS to 23% at UCN.

The below findings show the percent of cordon count to AWDPT/AWDBT comparisons within ranges of deviation. This calculation uses the by site and by period volumes for both pedestrians and bicycle traffic in Table 4.13 and Table 4.14 (n=68). This does not include the total volumes or mean volumes.

- 25% of the simultaneous cordon counts were within ±5% of the AWDPT/AWDBT,
- 38% of the simultaneous cordon counts were within ±10% of the AWDPT/AWDBT,
- 53% of the simultaneous cordon counts were within ±15% of the AWDPT/AWDBT,
- 65% of the simultaneous cordon counts were within ±20% of the AWDPT/AWDBT, and
- 75% of the simultaneous cordon counts were within ±25% of the AWDPT/AWDBT.

Table 4.13: Comparison of AWDPT and the single-day simultaneous cordon count volume

Pedestrian	P1	P2	P3	P4	P5	P6	Mean
Southwood Lands	179 *203* (12%)	186 *241* (23%)	316 *408* (22%)	254 *242* (-5%)	248 *245* (-1%)	206 *170* (-21%)	**231** ***252*** **(8%)**
King's Drive	1087 *895* (-21%)	971*	874 *926* (6%)	749 *838* (11%)	1365 *1374* (1%)	1068 *1049* (-2%)	**1019** ***1009*** **(-1%)**
University Crescent S	625 *655* (5%)	317 *730* (57%)	705 *737* (4%)	452 *611* (26%)	577 *835* (31%)	736 *715* (-3%)	**569** ***714*** **(20%)**
Smartpark	31 *27* (-16%)	24 *35* (32%)	200 *225* (11%)	134 *118* (-14%)	182 *163* (-12%)	119 *94* (-26%)	**115** ***110*** **(-4%)**
Chancellor Matheson	172 *161* (-7%)	186 *249* (25%)	459 *546* (16%)	375 *290* (-29%)	436 *278* (-57%)	195 *186* (-5%)	**304** ***285*** **(-7%)**
University Crescent N	328 *396* (17%)	430 *455* (5%)	641 *662* (3%)	544 *572* (5%)	605 *505* (-20%)	322 *328* (2%)	**478** ***486*** **(2%)**
TOTAL	**2422** ***2337*** **(-4%)**	**2113** ***2681*** **(21%)**	**3196** ***3504*** **(9%)**	**2508** ***2671*** **(6%)**	**3414** ***3400*** **(0%)**	**2645** ***2542*** **(-4%)**	**2716** ***2856*** **(5%)**

* No simultaneous cordon count is available.
Note: The italicized values are the simultaneous cordon count conducted in that period.

Table 4.14: Comparison of AWDBT and the single-day simultaneous cordon count volume

Bicycle	P1	P2	P3	P4	P5	P6	Mean
Southwood Lands	31 *35* (11%)	45 *42* (-8%)	692 *877* (21%)	611 *711* (14%)	276 *266* (-4%)	36 *30* (-19%)	**282** ***327*** **(14%)**
King's Drive	17 *14* (-21%)	101*	397 *420* (6%)	366 *410* (11%)	142 *143* (1%)	18 *18* (-2%)	**174** ***184*** **(6%)**
University Crescent S	12 *13* (5%)	9 *21* (57%)	253 *264* (4%)	184 *249* (26%)	73 *106* (31%)	8 *7* (-14%)	**90** ***110*** **(18%)**
Smartpark	0	0	117 *138* (15%)	107 *127* (16%)	45 *43* (-5%)	25 *18* (-40%)	**49** ***54*** **(10%)**
Chancellor Matheson	25 *23* (-7%)	49 *19* (-157%)	232 *353* (34%)	299 *336* (11%)	298 *122* (-144%)	25 *24* (-4%)	**155** ***146*** **(-6%)**
University Crescent N	20 *26* (23%)	28 *15* (-83%)	463 *491* (6%)	398 *430* (7%)	178 *149* (-19%)	37 *27* (-37%)	**187** ***190*** **(1%)**
TOTAL	**105** ***111*** **(5%)**	**232** ***198*** **(-17%)**	**2154** ***2543*** **(15%)**	**1965** ***2263*** **(13%)**	**1012** ***829*** **(-22%)**	**149** ***124*** **(-20%)**	**936** ***1011*** **(7%)**

* No simultaneous cordon count is available.
Notes: Due to the lack of winter maintenance at the Smartpark site, no bicycles counts were conducted.
The italicized values are the simultaneous cordon count conducted in that period.

Comparison of Southwood Lands Counts and Observations at a Permanent Count Station

The second comparison examines count data obtained at the SL site and data obtained at a nearby permanent count station outside of campus. Previous research determined that this count site exhibited a distinct “post-secondary” temporal traffic pattern unique to this area in comparison to nine other city sites (Budowski, 2015). Consequently, a comparison of the temporal patterns observed at this site and those observed at the SL site is instructive.

The City of Winnipeg operates a permanent count station comprising a passive infrared sensor (Eco-Counter’s PYRO Box) and an inductive loop (Eco-Counter’s ZELT) located 550 m north of the SL count site (Figure 4.17). The permanent count station, situated on the Bishop Grandin Greenway active transportation path on the west side of the Fort Garry Bridge, provides a continuous (year-round) count of pedestrian and bicycle traffic. This site captures pedestrian and bicycle traffic travelling between the bridge and Southwood Lands via D’Arcy Drive. It also includes those travelling between the bridge and University Cres but excludes those travelling to Southwood Lands via D’Arcy Drive that evade the bridge. Figure 4.18 shows the plan view of the data collection equipment set up at the site. Figure 4.19 provides a ground view of the site with equipment in place for the summer season.

Figure 4.17: Plan view of the Bishop Grandin (BG) and Southwood Lands (SL) sites

Figure 4.18: Plan view of the Bishop Grandin site

Figure 4.19: Bishop Grandin site ground view level (Left: inductive loop, Right: passive infrared sensor)

Figure 4.20 shows the daily pedestrian and bicycle traffic volumes at the Bishop Grandin (BG) site and the SL site from September 1, 2018 through August 31, 2019. As with the results from the six campus sites, event days and the non-session academic season are excluded from the BG site dataset to show traffic on typical in-session days. Screening of the BG data identified unrealistic (negative) pedestrian volumes for certain hours[1]. While no attempt was made to verify the BG equipment as part of this research, comparison of the two data sets reveals that although the BG site is directly linked to the SL site, the BG site had a smaller proportion of pedestrians in the summer season. This may be due to equipment malfunctions at BG and/or more people walking in the Southwood Lands greenspace for recreational use. This also demonstrates volatility of data between sites in near spatial proximity to each other. Glasgow (2016) noted volatility in pedestrian volumes between sites on the same corridor in Winnipeg, MB. Specifically, the results of this comparative analysis show that although the BG site has been a good indicator of

[1] Pedestrian volumes for the BG site are calculated the same way as with other sites with both passive infrared sensors and bike-specific counters. The pedestrian volume is the combined traffic from the passive infrared sensor minus the inductive loop data. If the passive infrared sensor undercounts or the inductive loops overcount, this results in a negative pedestrian volume.

differentiating traffic near the campus from other Winnipeg sites, it is not suitable in determining patterns in/out of the campus area (Budowski, 2015). Despite this site being characterized as having "post-secondary patterns" on a Winnipeg scale, the daily volume trends are not fully-consistent with those observed at campus sites. In particular, the campus sites seem to be more influenced by the academic semester than the BG site.

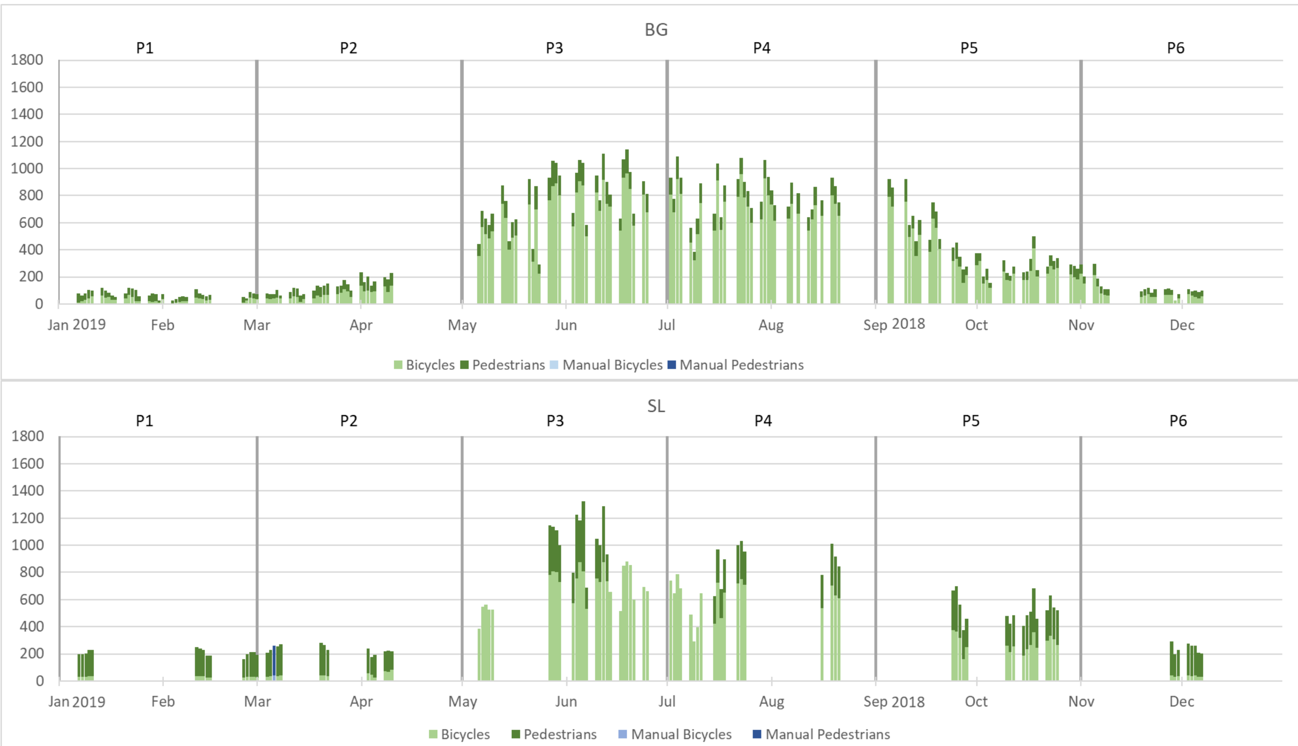
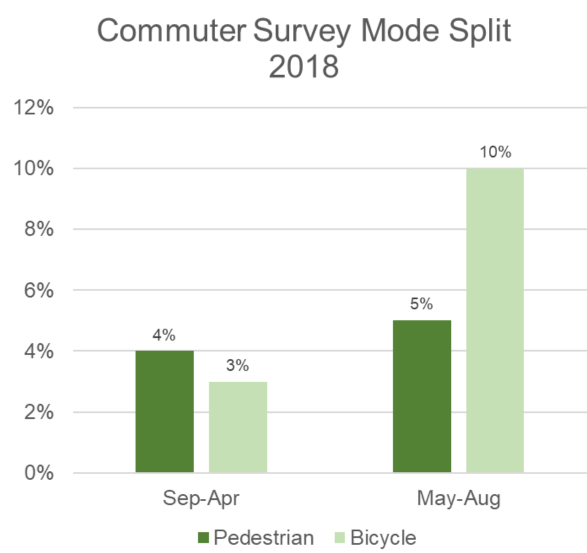


Figure 4.20: Bishop Grandin (above) and Southwood Lands (below) daily volumes for pedestrian and bicycle traffic

Comparison of Results with a Campus Commuter Survey

The third comparison examines the results from the campus traffic monitoring program with those obtained from a campus commuter survey conducted by the University of Manitoba's Office of Sustainability in 2018. The University of Manitoba has two main campus areas, the Fort Garry campus and Bannatyne campus. The survey disaggregates the data for each campus. However, the University as a whole does not provide information on how many students, staff, and faculty are at each campus and only provides a value for the entire University. If this information was available, a more direct comparison between results would be feasible. Figure 4.21 and Table 4.15 show the mode split results for pedestrians and bicycles from the 2018 Campus Commuter Survey for September through April and May through August as well as the AWDPT and AWDBT for the same time periods from this research (Green Action Centre, 2018). The data sources are compared by looking at the ratio of bicycle to pedestrian traffic for both times of year. From September through April, the survey estimates 1.3 pedestrians for every bicycle while this research estimates 6.2 pedestrians for every bicycle. From May through August, the survey estimates 0.5 pedestrians for every bicycle whereas this research estimates 1.4 pedestrians for every bicycle. Thus, for both time periods, this comparison reveals an over representation of bicycle traffic or an under representation of pedestrian traffic in the survey results relative to the traffic monitoring results presented in this thesis.



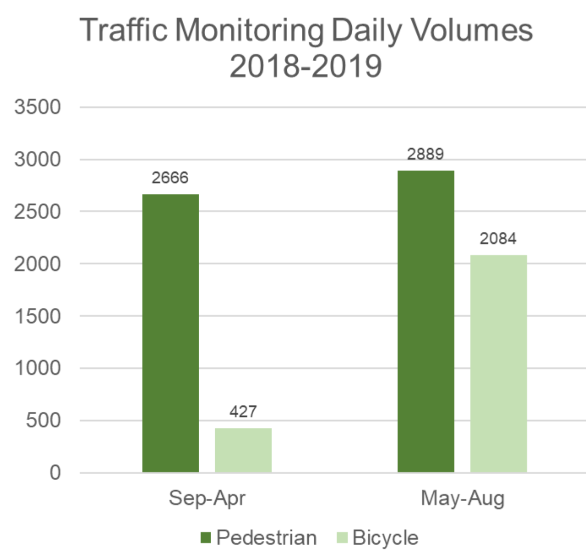


Figure 4.21: Comparison of the commuter survey results and traffic monitoring results (data sourced from Green Action Centre, 2018)

Table 4.15: Comparison of 2018 Campus Commuter Survey results and traffic monitoring counts (Green Action Centre, 2018)

Source of Data:	Commuter Survey Mode Split (% of all modes)		Traffic Monitoring Counts (AWDT)	
Time of Year:	Sep-Apr [n=3193]	May-Aug [n=2409]	Sep-Apr	May-Aug
Pedestrian	4%	5%	2666	2889
Bicycle	3%	10%	427	2084
Bicycle : Pedestrian Ratio	1 : 1.3	1 : 0.5	1 : 6.2	1 : 1.4

4.3.3 Implications of Results

The implications of this research extend to the University of Manitoba Fort Garry Campus, the surrounding City of Winnipeg area, and the academic community researching pedestrian and bicycle traffic monitoring. The four main implications pertain to 1) traffic monitoring trends at a university campus in a winter city, 2) the need for site-specific pedestrian and bicycle volumes to make informed transportation decisions, particularly on the Fort Garry campus and surrounding areas, 3) the implementation of a cordon count for pedestrians and bicycles for an urban activity area, and 4) the use of a combination of manual counts by video and short duration counts with automatic equipment to determine volumes for pedestrians and bicycles.

First, this research provides information on the trends of pedestrian and bicycle traffic commuting to/from a university campus in a winter city. At this campus, pedestrian traffic appears to be principally influenced by the academic semester and bicycle traffic appears to fluctuate by weather season. The pedestrian traffic peaks in Period 5 which is the start of the fall semester and the bicycle traffic peaks in Periods 3 and 4 which coincides with the summer weather months (May to August). This may influence when future counts are conducted for each mode. This research also provides justification for the need to distinguish between pedestrian and bicycle volumes as they have different trends throughout the year. This particular research offers a novel opportunity as the campus studied only has six access points for pedestrians to enter and exit campus. The findings related to traffic monitoring trends at a university campus in a winter city provide insight for future research and sustainable transportation policy decisions in similar campus environments and other winter cities.

Second, the spatial, temporal, and modal findings of this research benefit the University of Manitoba and the City of Winnipeg as follows:

- The research provides local data to make informed transportation planning, design, operations, and management decisions. For example, the relatively high volumes observed at the KD site may support the need for improving infrastructure and prioritizing maintenance at this site.
- The spatial distribution of pedestrian traffic demonstrates the influence of proximal student and staff housing on modal choices made by people accessing campus. The Fort Garry campus is in the southwest part of the city and therefore, without contrary evidence, one might expect the majority of pedestrian and bicycle traffic to enter/exit from the northern access points, similar to vehicular and transit traffic. However, the findings in this thesis contradict this expectation.
- This research provides the University with a data collection plan and adjustment factors to continue automatic equipment counts on the Fort Garry campus.
- The City's continuous count site on the Bishop Grandin (BG) Greenway and the nearby access to the campus at the Southwood Lands (SL) entrance do not have the same temporal trends for pedestrian and bicycle data. This demonstrates the need for site-specific data collection to appropriately capture pedestrian and bicycle traffic characteristics.
- The comparative analysis of the 2018 Campus Commuter Survey and the traffic monitoring results from this research suggest the need to be cautious when referencing the survey results in discussions about pedestrian and bicycle mode split on campus.

Third, beyond the University of Manitoba campus, the research offers insights for conducting similar traffic monitoring programs in other urban activity areas. Jurisdictions may elect to rotate automatic equipment for short duration counts and conduct short manual counts to determine the mixed-traffic and bypass factors for each site. Others may choose to conduct full manual counts at all access points for a desired season. This research shows that a combination of weather season and land-use characteristics (i.e., semesters for campus, tourism season, etc.) within the jurisdiction are crucial in determining the optimal time of year to conduct a cordon count. Areas such as parks should consider whether their pedestrian and bicycle traffic is mostly generated by residents or tourists.

Finally, there are advantages and disadvantages to rotating automatic equipment for short duration counts and conducting a single-day cordon count to determine the average weekday traffic in a given period. Section 4.3.2 discussed the quantitative comparisons between the simultaneous cordon count volumes and the AWDPT/AWDBT in each period. This is not an exact comparison between the automatic equipment data and simultaneous count, but provides a high-level assessment of the simultaneous cordon count and the AWDPT/AWDBT which comprises mostly automatic equipment counts (five of six sites). It is important to also note the qualitative differences of these approaches and the advantages and disadvantages of conducting simultaneous cordon counts and automatic equipment short duration counts independently and fused together. The automatic equipment was relatively easy to set up and the data analysis was straightforward. However, rotating the two sets of equipment on a weekly or bi-weekly basis was resource intensive and it was difficult to collect a full five days of data at each site in each period given equipment malfunctions and exclusion dates. The manual counts by video are either extremely resource intensive to manually review or expensive to out-source. However, only two days of data collection were required to set up and takedown the portable cameras in each period. In terms of the results, the manual counts provide a precise volume of pedestrians and bicycles regardless of mixed-traffic on sidewalks or bypass of equipment. This was particularly important at sites where it was not feasible to count road users or install pneumatic tubes. The automatic equipment results were more accurate in representing the trends in traffic within each period by reducing the influence of day-to-day variability with longer duration counts than the manual counts. Moreover, a simultaneous cordon count at all sites would not provide the consistent daily volumes that the automatic equipment provides, and the automatic equipment alone would have only counted a portion of traffic at each site due to limitations of the facilities and pneumatic tubes (mixed-traffic and bypass error). This research provides a novel option for collecting cordon count data to determine pedestrian and bicycle volumes.

5 CONCLUSION

This chapter summarizes the key findings and limitations of this research, provides recommendations for future research, and presents a brief conclusion.

5.1 SUMMARY OF KEY FINDINGS AND LIMITATIONS

This research develops a novel data collection plan to conduct a year-long cordon count program for pedestrians and bicycles at a university campus in a winter city. The data collection and adjustment methods and the analysis results contribute to research and practice in the traffic monitoring field. The following sections discuss key findings and the limitations of the research.

5.1.1 Key Findings

The findings presented in this thesis contribute to research in pedestrian and bicycle traffic monitoring as follows:

- Using a combination of automatic equipment and manual counts by video is a novel approach to reduce the limitations of both methods. The manual counts were used to develop site-specific and period-specific factors to adjust the automatic equipment data and the automatic equipment allowed for a minimum of five days of data in each period to reduce the temporal variability characteristic of pedestrian and bicycle volume data. In addition to the data fusion reducing limitations of each dataset, this also provides insight into the relationships between single-day simultaneous cordon count volumes and estimated AWDT for pedestrian and bicycle traffic in each period.
- While the deployment of screenline counts is common within network level non-motorized traffic monitoring programs, such screenline counts would not normally be situated at a cordon count

boundary and would seldom be conducted simultaneously. Consequently, despite some methodological similarities, disparate objectives and implementation practices result in a misalignment of the data produced by cordon count and network level traffic monitoring programs. This research implements a cordon count program that captures mode split throughout the year rather than the more common estimation of mode split using a single cordon count. This revealed that sites respond uniquely to varying academic activities and seasonal conditions throughout the year. Therefore, it is important that conventional traffic monitoring programs conduct short duration counts at different times of the year for each site, as the time of year variations differ between sites.

- The deployment of a cordon count program for pedestrians and bicycles at an urban activity centre—in this case a university campus—provides a case example for other jurisdictions that require traffic data for urban areas with unique geographic and demographic characteristics. This research provides results that show the variation in pedestrian and bicycle traffic in a year on a university campus in a winter city. The findings reveal the combined effects of changing academic semesters and the four weather seasons on pedestrian and bicycle volumes. Overall, the results show that pedestrians and bicycles do not have the same travel patterns throughout the year.

More specifically, the findings presented in this thesis support practical decisions and activities relevant to the University of Manitoba and the City of Winnipeg:

- The site with the highest pedestrian traffic is the KD access with an AWDPT of 1365 in Period 5 (September-October). The University of Manitoba Fort Garry campus should consider this in planning pedestrian networks on campus and providing maintenance. The high volumes at the KD site may be a reflection of the land-use south of the Fort Garry campus.

- The site with the highest bicycle traffic is the SL access with an AWDBT of 692 in Period 3 (May-June). The University of Manitoba Fort Garry campus should consider this in planning bicycle networks on campus and providing maintenance.
- The AWDPT/AWDBT at each site in Periods 1, 2, and 6 (November-March) provide information to both the City of Winnipeg and the University of Manitoba in the prioritization of snow-clearing maintenance on and around campus.
- The comparative analysis of the short duration count site (SL) and the nearby continuous count site (BG) site shows that pedestrian and bicycle volumes have temporal differences despite their close proximity. This supports the need for specificity in the location of counts and the assumptions made in spatial comparisons in urban areas.
- The development of mixed-traffic and bypass factors for each site and each period enables the University of Manitoba to continue collecting automatic equipment counts and factoring the data.
- The University of Manitoba Fort Garry campus has characteristic patterns for pedestrian and bicycle traffic that depend on weather season and academic semester. These patterns should be considered when determining when and where to conduct future counts on campus.
- The modal split observed for pedestrian and bicycle traffic differs from previously reported modal splits reported from the 2018 Campus Commuter Survey (Green Action Centre, 2018). This finding should be considered when making planning and engineering decisions based on commuter survey data.

5.1.2 Limitations

Section 4.3.1 discusses the limitations of this research that include equipment, weather and logistics, and methodological limitations. These limitations are summarized below:

- Equipment malfunctions of both automatic equipment (passive infrared sensors and pneumatic tubes) and the manual counts by video (stationary and portable cameras).
- Physical limitations at specific sites did not allow for a deployment of automatic equipment including infrastructure to install equipment and property restrictions.
- Omission of an occlusion factor for the automatic equipment data.
- Simultaneous cordon counts were only deployed on dates with typical weather for each period. This was not always possible given logistical limitations of multiple sources of equipment.
- Adverse weather in terms of both precipitation and temperature create physical barriers that also affect pedestrian and bicyclist travel.
- Logistical limitations of conducting short duration counts with two sets of automatic equipment at five sites within each of the two-month periods.
- The exclusion of weekends and event days limits the information gathered on travel patterns to/from the university.
- Daily factors for mixed-traffic and bypass error were applied because of high hour-to-hour volatility in the manual counts by video data.

These limitations provide opportunity to improve and expand on this research and apply this approach to pedestrian and bicycle traffic data collection in different scenarios. More specifically, the scope of this research is restricted to the University of Manitoba Fort Garry campus, has a cordon count focus (versus a network system), and only monitors pedestrian and bicycle traffic. There are areas outside of the scope and limitations of this research that allow for future work.

5.2 RECOMMENDATIONS FOR FUTURE RESEARCH

This research was possible because of all the previous research in the field of pedestrian and bicycle traffic monitoring including equipment testing, data collection program recommendations, travel patterns, data processing, and many other subject areas. This research develops and applies a high-level approach for deploying pedestrian and bicycle traffic monitoring and cordon count programs and provides opportunities for further contribution to traffic monitoring practice. Recommendations for future research to extend the results and address limitations of this work follow:

- Develop a multi-modal cordon count program for all modes (including motorized modes) at an urban activity area. This would provide a more robust approach for obtaining mode split to/from the urban activity area. As the number of equipment units, facilities, and modes increases, the ability to collect accurate data becomes more difficult and program implementation becomes more complex.
- Conduct a cordon count program at similar semi-isolated university campuses, but with different weather conditions (non-winter cities), semester structures, or policies that influence active transportation (such as universal bus passes). There is value in applying the principles identified in this thesis and applying them to different campuses, as they may see different temporal variations in pedestrian and bicycle traffic.
- Conduct a similar traffic monitoring program on a university campus that includes weekends, event days, and non in-session periods (exams, closures) to determine the variability of ADT on a campus and how to best represent ADT, SADT, or AADT.
- Conduct a ground-truth study to determine whether short duration counts using automatic equipment, manual counts by video, or a combination of the two provide the best results for traffic monitoring of pedestrians and bicycles under varying conditions. The ground-truth data would also allow for the development of occlusion factors and could measure the effect of their use.

- Conduct simultaneous traffic counts and a commuter survey for a semi-isolated urban activity area (such as a campus) to better identify and explain differences in results.
- Further investigate the relationship between simultaneous cordon counts and automatic equipment data by conducting an analysis to determine the relationship between the number of days of automatic equipment counts and the deviation between those counts and the simultaneous cordon counts. Such research could determine whether an increase in the duration of the short duration count affects the deviation between these data sources.

5.3 SUMMARY OF THE RESEARCH

In conclusion, this research determined time of year variations in average weekday pedestrian and bicycle traffic commuting to/from a university campus in a winter city. This research developed and implemented a data collection plan that included

- determining appropriate cordon count monitoring locations;
- use of automatic equipment and manual counts by video to collect data;
- a counting schedule and duration for both data collection methods for one year; and
- application of pedestrian and bicycle traffic data screening, fusion, and analysis techniques.

The results provide findings relevant for traffic monitoring research and practice and specific results applicable to the University of Manitoba and the City of Winnipeg. Many university campuses feature unique demographics and encourage sustainable transportation policy objectives. Determining traffic volumes for pedestrians and bicycles enables decision makers to make informed choices on transportation infrastructure, maintenance, safety, and policy.

6 REFERENCES

AECOM. (2015). *2015 Kingston Transportation Master Plan*.

Alta Planning & Design. (2005). *National Bicycle and Pedestrian Documentation Project*. 62. http://www.altaplanning.com/national+bicycle+and+pedestrian+documentation+project.aspx

Andersen, O., Gundersen, V., Wold, L. C., & Stange, E. (2014). Monitoring visitors to natural areas in wintertime: Issues in counter accuracy. *Journal of Sustainable Tourism*, *22*(4), 550–560. https://doi.org/10.1080/09669582.2013.839693

TTS 2016: 2016, 2011, 2006, 1996 and 1986 Travel Summaries for the Greater Toronto & Hamilton Area, (2018). http://dmg.utoronto.ca/transportation-tomorrow-survey/tts-reports

Ashby, B. (2018). *TTS 2016 Data Guide*. *February*, 1–132. http://dmg.utoronto.ca/pdf/tts/2016/2016TTS_DataGuide.pdf

BrookMcllroy. (2017). *McMaster University - Campus Master Plan Update*. *April*. https://www.mcmaster.ca/policy/Governance/Other/Campus_Master_ Plan.pdf

Budowski, A. R. (2015). *Developing Expansion Factors to Estimate Cyclist Seasonal Average Daily Traffic in Winnipeg, MB*.

Bunt & Associates. (2007). *Changing Our Travel Habits : Travel Demand Management at the University of Alberta* (Issue January).

City of Calgary. (n.d.-a). *Transportation Data*. Retrieved October 10, 2019, from https://www.calgary.ca/Transportation/TP/Pages/Planning/Transportation-Data/Transportation-Data.aspx

City of Calgary. (n.d.-b). *Travel and Activity Surveys*. https://www.calgary.ca/Transportation/TP/Pages/Planning/Forecasting/Forecasting-surveys.aspx

City of Calgary. (2007). *Calgary Downtown Commuter Cyclist Survey Report*.

City of Calgary. (2019a). *Bike Data*. https://www.calgary.ca/Transportation/TP/Pages/Cycling/Bike-Data.aspx

City of Calgary. (2019b). *Central Business District Cordon Count*. https://www.calgary.ca/Transportation/TP/Pages/Planning/Transportation-Data/Central-Business-District-Cordon-Count.aspx

City of Edmonton. (2015). *2015 Edmonton and Region Household Travel Survey*. *April 2018*.

City of Edmonton. (2017). *Traffic Flow Maps and Reports*. https://www.edmonton.ca/transportation/traffic_reports/traffic-reports-flow-maps.aspx

City of Hamilton. (2010). *Shifting Gears 2009* (Issue May).

City of Hamilton. (2017). *Bicycle Count Summary 2013 to 2017*.

City of Kingston. (2008). *City of Kingston 2008 Travel Survey*. https://qspace.library.queensu.ca/handle/1974/14014

City of Kingston. (2019). *Survey Questions*. http://www.kingstonmoves.ca/survey-questions.php

City of Kitchener. (2019). *Traffic Volumes*. https://rowopendata-rmw.opendata.arcgis.com/datasets/426089c5166c4f8f8f4000acb2fef840_0

City of London. (n.d.-a). *Maps London*. https://maps.london.ca/CityMap/?run=ToggleLayer&mapServiceId=14&ext=475460.10266395955%2C4757239.925100273%2C482106.4492899861%2C4761024.532669489

City of London. (n.d.-b). *Traffic Volumes*. Retrieved October 5, 2019, from https://www.london.ca/residents/Roads-Transportation/traffic-management/Pages/Traffic-Volumes.aspx

City of London, & MMM Group. (2016). *City of London Cycling Master Plan*. *4*.

City of Montreal. (2013). *Enquete Origine-Destination*.

City of Montreal. (2019). *Montreal Open Data Portal - Bicycles counting on bike baths*. the university’s

Transportation Research at McGill (TRaM) group conducts a commuter survey every two years (McGill University, n.d.-b). The only results that were readily available was the 2013 survey in a 136-page report and a questionnaire of over 260 q

City of Ottawa. (2019). *Bicycle Trip Counters*.

City of Toronto. (2019a). *About Bicycle Counts*. https://open.toronto.ca/dataset/bicycle-counts/

City of Toronto. (2019b). *About Traffic Counts - Cycling*. https://open.toronto.ca/dataset/traffic-counts-cycling/

City of Toronto. (2019c). *Attachment 7 - Maps of Cycling Analysis Results* (Issue March).

City of Toronto. (2019d). *King St. Transit Pilot - Detailed Traffic & Pedestrian Volumes*. https://open.toronto.ca/dataset/king-st-transit-pilot-detailed-traffic-pedestrian-volumes/

City of Vancouver. (n.d.). *Why we collect traffic count data*. Retrieved October 10, 2019, from https://vancouver.ca/streets-transportation/traffic-count-data.aspx

City of Vancouver. (2015). *2013 Pedestrian Volume and Opinion Survey* (Issue May 2015).

City of Vancouver. (2019a). *2018 Vancouver Panel Survey* (Issue April 2019). https://vancouver.ca/files/cov/2018-transportation-panel-survey.pdf

City of Vancouver. (2019b). *Walking + Cycling in Vancouver* (Issue September).

City of Waterloo. (2019). *City of Waterloo Trail Counter Data*. https://rowopendata-rmw.opendata.arcgis.com/datasets/City-of-Waterloo::city-of-waterloo-trail-counter-data?selectedAttribute=LOC_ID

City of Winnipeg. (2018). *2018 Traffic Flow Map*.

City of Winnipeg. (2019). *Traffic Data*. https://www.winnipeg.ca/publicworks/trafficControl/trafficData/default.stm

Dalhousie University. (n.d.-a). *Dal at a Glance*. Retrieved September 16, 2019, from https://www.dal.ca/about-dal/dal-at-a-glance.html

Dalhousie University. (n.d.-b). *Halifax Campuses*. Retrieved September 17, 2019, from https://www.dal.ca/about-dal/campus-experience/halifax-campuses.html

Dalhousie University. (2012). *Bikeways Plan: Urban Halifax Institutional District*.

Dalhousie University. (2013). *Sustainability Progress Report for Campus Operations*.

Dalhousie University. (2019a). *Climate Change Operations Plan 2019 V2*.

Dalhousie University. (2019b). *Office of Sustainability: Policies and Guidelines*. https://www.dal.ca/dept/sustainability/resources/publications_policies.html

Dalhousie University. (2019c). *SmartTripDalhousie*. https://www.dal.ca/dept/sustainability/smart-trip.html

DalTRAC. (n.d.). *NovaTRAC Survey*. Dalhousie University. Retrieved October 10, 2019, from https://www.dal.ca/sites/daltrac/novatrac-info.html

DalTRAC. (2019). *Publications*. https://www.dal.ca/sites/daltrac/publications.html).

Damianil, R.-M. (2008). *Planning Sustainable Suburban Communities in Calgary: Evaluation and Reporting Framework*. http://www.ucalgary.ca/cities/files/cities/Sustainable_Suburbs.pdf

Day, N., Habib, K. N., & Miller, E. J. (2010). Analysis of work trip timing and mode choice in the Greater Toronto Area. *Canadian Journal of Civil Engineering*, *37*(5), 695–705. https://doi.org/10.1139/L10-008

Delmelle, E. M., & Delmelle, E. C. (2012). Exploring spatio-temporal commuting patterns in a university environment. *Transport Policy*, *21*, 1–9. https://doi.org/10.1016/j.tranpol.2011.12.007

Eco-Counter. (2019). *PYRO-Box*. /pyro-box/

Fandrich, C. (2010). *2010 Summary of the McMaster Transportation Survey – Walkable and Cycleable Areas*. 1–37.

Federal Highway Administration. (2016). *Traffic Monitoring Guide* (Issue October). http://www.fhwa.dot.gov/policyinformation/tmguide/

Glasgow, M. (2016). *Analysis of Pedestrian Traffic along a Commercial District Corridor*.

Government of Quebec. (2019). *Quebec Data*. https://www.donneesquebec.ca/recherche/fr/dataset

Green Action Centre. (2016). *Transportation Survey Results & Recommendations Final Report*.

Green Action Centre. (2018). *Campus Commuting Survey 2018* (Vol. 4, Issue April).

GSP Group. (2012). *University of Waterloo Northwest Campus Development Design Guidelines*.

Halifax Cycling Coalition. (n.d.). *StreetSenseNetwork Project*. Retrieved October 10, 2019, from https://cyclehalifax.ca/streetsensenetwork-project/

Huang, S., Guo, L., Yang, Y., Casas, I., & Sadek, A. W. (2012). Dynamic demand estimation and microscopic traffic simulation of a university campus transportation network. *Transportation Planning and Technology*, *35*(July). https://doi.org/10.1080/03081060.2012.680818

IBI Group. (2018). *2016 Household Travel Survey*.

Ipsos Reid. (2014). *2013 Household Travel Survey*. https://www.saskatoon.ca/sites/default/files/documents/transportation-utilities/transportation/planning/Attachment3 Technical Report HTS_FollowUp_report.pdf

iTRANS Consulting Inc. (2009). *2007 Winnipeg Area Travel Survey Results - Final Report* (Issue July).

Klassen, S. (2016). *Analysis of Pedestrian Traffic on Multi-use Trails in Winnipeg*. 1 PDF file, 1.3 MB, 41p. https://www.cite7.org/wpdm-package/2016-kelowna-compendium/%0Ahttps://trid.trb.org/view/1434778

Koblents, H., & MacIssac, D. (2014). *Making Connections: 2014-19 Halifax Active Transportation Priorities Plan*.

Lay, J. (2012). *Stepping It Up – Final Report* (Issue June).

Lindsey, G., Hankey, S., Wang, X., & Chen, J. (2013). *The Minnesota bicycle and pedestrian counting initiative: methodologies for non-motorized traffic monitoring*. *October*, 57.

Liu, Z., Zhang, Y., Wang, S., & Li, Z. (2017). A Trial-and-Error Method with Autonomous Vehicle-to-

Infrastructure Traffic Counts for Cordon-Based Congestion Pricing. *Journal of Advanced Transportation*, *2017*. https://doi.org/10.1155/2017/9243039

Lu, T., Buehler, R., Mondschein, A., & Hankey, S. (2017). Designing a bicycle and pedestrian traffic monitoring program to estimate annual average daily traffic in a small rural college town. *Transportation Research Part D: Transport and Environment*, *53*, 193–204. https://doi.org/10.1016/j.trd.2017.04.017

Lu, T., Mondschein, A., Buehler, R., & Hankey, S. (2018). Adding temporal information to direct-demand models: Hourly estimation of bicycle and pedestrian traffic in Blacksburg, VA. *Transportation Research Part D: Transport and Environment*, *63*(May), 244–260. https://doi.org/10.1016/j.trd.2018.05.011

McGill University. (n.d.-a). *Factbook*. Retrieved September 19, 2019, from https://mcgill.ca/about/quickfacts

McGill University. (n.d.-b). *Transportation at McGill*. Retrieved September 19, 2019, from https://mcgill.ca/sustainability/topics/transportation

McGill University. (2017). *Vision 2020: Climate & Sustainability Action Plan 2017-2020*.

McGill University. (2019). *Sustainable Travel and Mobility Guide*.

McMaster Institute for Transportation and Logistics. (2016). *Travel Demand Management Plan 2016*.

McMaster University. (n.d.). *McMaster Fast Facts*. Retrieved September 19, 2019, from https://www.mcmaster.ca/opr/html/opr/fast_facts/main/about.html

McMaster University. (2016). *Sustainability Annual Report 2016*.

McMaster University. (2018a). *Annual Report 2018*.

McMaster University. (2018b). *Environmental Sustainability Plan 2018*.

Morency, C. (2014). *Recent development and analysis on Household Travel surveys , Quebec* (Issue October).

National Centers for Environmental Information. (2016). *Meteorological Versus Astronomical Seasons*. National Oceanic and Atmospheric Administration. https://www.ncei.noaa.gov/news/meteorological-versus-astronomical-seasons

Nordback, K., Kothuri, S., Phillips, T., Gorecki, C., & Figliozzi, M. (2016). Accuracy of Bicycle Counting with Pneumatic Tubes in Oregon. *Http://Dx.Doi.Org/10.3141/2593-02*, *2593*, 8–17. https://doi.org/10.3141/2593-02

Nordback, K., Marshall, W., & Janson, B. (2013). *DEVELOPMENT OF ESTIMATION METHODOLOGY FOR BICYCLE AND PEDESTRIAN VOLUMES BASED ON EXISTING COUNTS*.

Nordback, K., Marshall, W., Janson, B., & Stolz, E. (2013). Estimating Annual Average Daily Bicyclists: Error and Accuracy. *Transportation Research Record: Journal of the Transportation Research Board*, *2339*, 90–97. https://doi.org/10.3141/2339-10

Nytepchuk, N. J. (2015). *Operating Performance of Passive Infrared Counters Under Different Seasons*.

Olfert, C. (2017). *Analysis and Evaluation of Methods for Adjusting Pedestrian Counts*.

Olfert, C., Poapst, R., & Montufar, J. (2017). *Incorporating the Effect of Special Events into Continuous Count Site Selection for Pedestrian Traffic*. 1–13.

Pressman, N. (1995). *Northern Cityscape: Linking Design to Climate*. Winter Cities Association.

Queen’s University. (n.d.-a). *Campus Map - Overall*. Retrieved October 5, 2019, from https://www.queensu.ca/campusmap/overall

Queen’s University. (n.d.-b). *Quick Facts*. Retrieved October 5, 2019, from https://www.queensu.ca/about/quickfacts

Queen’s University. (n.d.-c). *Transportation - Cycling*. Retrieved October 5, 2019, from https://www.queensu.ca/sustainability/campus-initiatives/transportation/cycling

Queen’s University. (2013). *Active Transportation Strategy for Queen’s University* (Issue December).

Queen’s University. (2014). *2013 Survey of Commute Patterns among Queen’ s University Employees*.

R.A. Malatest & Associates Ltd. (2013). *City of Ottawa Commuter Attitudes Survey*.

Regehr, J., Poapst, R., Rempel, G., Montufar, J., & Hallenbeck, M. (2017). *Traffic Monitoring Practices Guide for Canadian Provinces and Municipalities*. Transportation Association of Canada.

Region of Waterloo. (2011). *Regional Transportation Master Plan* (Vol. 33, Issue 9).

Regional Municipality of Waterloo. (2017). *Regional Municipality of Waterloo Traffic Counts 2015*.

Robertson, D. H., Hummer, J. E., & Nelson, D. C. (2000). *Manual of Transportation Engineering Studies*. Institute of Transportation Engineers.

Rocchi, S., & Noxon, G. (2013). *Sustainable Mobility Strategic Plan*.

Rogers, W. C., & Hanson, J. K. (1980). *The Winter City Book: A Survival Guide for the Frost Belt*. Dorn Books.

Rybarczyk, G., & Gallagher, L. (2014). Measuring the potential for bicycling and walking at a metropolitan commuter university. *Journal of Transport Geography*, *39*, 1–10. https://doi.org/10.1016/j.jtrangeo.2014.06.009

Ryus, P., Butsick, A., Proulx, F. R., Schneider, R. J., & Hull, T. (2017). Methods and Technologies for Pedestrian and Bicycle Volume Data Collection: Phase 2. In *Methods and Technologies for Pedestrian and Bicycle Volume Data Collection: Phase 2*. https://doi.org/10.17226/24732

Ryus, P., Ferguson, E., Laustsen, K. M., Schneider, R. J., Proulx, F. R., Hull, T., & Miranda-Moreno, L. (2014a). *Methods and Technologies for Pedestrian and Bicycle Volume Data Collection*. https://doi.org/10.17226/23429

Ryus, P., Ferguson, E., Laustsen, K., Schneider, R., Proulx, F., Hull, T., & Miranda-Moreno, L. (2014b). *NCHRP Report 797: Guidebook on Pedestrian and Bicycle Volume Data Collection*.

Schneider, R., Grembek, O., & Braughton, M. (2013). Pedestrian crash risk on boundary roadways. *Transportation Research Record*, *2393*, 164–173. https://doi.org/10.3141/2393-19

Shaw, E., St-Louis, E., Lierop, D. Van, Grimsrud, M., Stewart, C., Tepavac, A., Manaugh, K., & El-Geneidy, A. (2013). *Findings from the 2013 McGill Commuter Survey*.

http://tram.mcgill.ca/Research//Publications/McGill_2013_travel_survey_full_version.pdf

Smart Commute Hamilton. (2019). *Smart Commute Month 2019*. https://smartcommute.ca/hamilton/survey/

SOM Recherches & Sondages. (2013). *Évaluation de la campagne de communication Mobilité Montréal 2013,*.

SOM Recherches & Sondages. (2014). *Campagne de Communication de Mobilite Montreal 2014*.

SOM Recherches & Sondages. (2016a). *Sondage Post Campagne par Internet Campagne de Communication de Mobilité Montréal 2015*.

SOM Recherches & Sondages. (2016b). *Sondage Post Campagne par Internet Campagne de Communication de Mobilité Montréal 2016*.

SOM Recherches & Sondages. (2019). *Sondage Post Campagne de Mobilité Montréal 2019*.

Statistics Canada. (2016). *Census Profile, 2016 Census: Winnipeg, Manitoba*. https://www12.statcan.gc.ca/census-recensement/2016/dp-pd/prof/details/page.cfm?Lang=E&Geo1=CSD&Code1=4611040&Geo2=PR&Code2=01&SearchText=4611040&SearchType=Begins&SearchPR=01&B1=Journey to work&TABID=3&type=0

Sustainability Council. (2018). *Uplifting People and Planet: Annual Report 2018-2019*.

Tremblay, P. (2014). *An overview of OD-Surveys in Québec*.

Turner, S., Qu, T. T., Lasley, P., Transportation, C. D. of, Manager, P., Abeyta, S., & Ph, D. (2012). *Strategic Plan for Non-Motorized Traffic Monitoring in Colorado*. 99.

Universite de Montreal. (n.d.-a). *Mon Campus un Velo*. Retrieved October 5, 2019, from https://velo-udem.com/

Universite de Montreal. (n.d.-b). *Velo Boulot*. Retrieved October 5, 2019, from https://velo-udem.com/velo-boulot/

Universite de Montreal. (2019a). *Campus Plan*. https://plancampus.umontreal.ca/montreal/

Universite de Montreal. (2019b). *In Figures*. https://www.umontreal.ca/en/udem/in-figures/

Universite Laval. (n.d.). *L'universite laval en bref*. https://www.ulaval.ca/notre-universite/luniversite-laval-en-bref

Universite Laval. (2010). *Sustainable Development Report 2009-2010*. www.mediclinic.com.

Universite Laval. (2013). *Institutional Sustainable Development Policy*.

University of Alberta. (2014). *Long Range Developmental Plan Ammendment* (Issue March).

University of Alberta. (2015). *Building a Sustainable Future 2016-2020*. http://eng.sinohydro.com/download/SINOHYDRO_Brochure(2015).pdf

University of Alberta. (2019a). *Aboust*. https://www.ualberta.ca/sustainability/about

University of Alberta. (2019b). *University of Alberta Campuses*. https://www.ualberta.ca/campus-life/our-campuses

University of British Columbia. (n.d.-a). *Bike Share Programs*. Retrieved September 19, 2019, from https://planning.ubc.ca/vancouver/transportation-planning/transportation-options/cycling/bike-share-programs

University of British Columbia. (n.d.-b). *UBC Campuses*. Retrieved July 23, 2019, from https://www.ubc.ca/our-campuses/index.html

University of British Columbia. (2010). *Vancouver Transportation Survey* (Issue February).

University of British Columbia. (2014a). *20-Year Sustainability Strategy*.

University of British Columbia. (2014b). *UBC Transportation Plan*. http://planning.ubc.ca/sites/planning.ubc.ca/files/documents/transportation/plans/UBC-Transportation-Plan-2014_Oct.pdf

University of British Columbia. (2018). *UBC Vancouver Transportation Status Report Fall 2017* (Issue March).
https://planning.ubc.ca/sites/planning.ubc.ca/files/documents/transportation/reports/UBC2014-

TransportationStatusReport-FINAL.pdf

University of Calgary. (n.d.-a). *Facts and Figures*. Retrieved September 19, 2019, from https://www.ucalgary.ca/about/our-story/facts-and-figures

University of Calgary. (n.d.-b). *Our Campuses*. Retrieved September 16, 2019, from https://www.ucalgary.ca/about/our-campuses/main-campus

University of Calgary. (n.d.-c). *Sustainability: Transportation*. Retrieved September 19, 2019, from https://www.ucalgary.ca/sustainability/discover/our-sustainable-campus/transportation

University of Calgary. (2011). *Institutional Sustainability Strategy*. 1–30.

University of Calgary. (2018). 2018 Sustainability Report. In *Volkswagon Group Sustainability Report*. https://ddd.uab.cat/pub/infsos/146241/isVOLKSWAGENa2011ieng.pdf

University of Calgary. (2019a). *2019 Climate Action Plan*.

University of Calgary. (2019b). *Human Dynamics: Key Initiatives, Research Groups and Centres*. https://www.ucalgary.ca/dynamics/research-action/key-initiatives

University of Manitoba. (n.d.). *Facts and Figures*. Retrieved July 9, 2020, from http://umanitoba.ca/about/factandfigures/#timeline

University of Manitoba. (2017). *MOVING FORWARD : Sustainable Transportation Strategy*.

University of Manitoba. (2018). Sustainability Strategy. In *University of Manitoba*. https://doi.org/10.1017/CBO9781107415324.004

University of Ottawa. (n.d.-a). *About*. Retrieved September 19, 2019, from https://www.uottawa.ca/about/

University of Ottawa. (n.d.-b). *Reports*. https://sustainable.uottawa.ca/reports

University of Ottawa. (n.d.-c). *Sustainable Transportation*. Retrieved October 5, 2019, from https://sustainable.uottawa.ca/sustainable-transportation

University of Ottawa. (2018). *2018 STARS Report*. https://reports.aashe.org/institutions/university-of-ottawa-on/report/2018-03-29/

University of Saskatchewan. (n.d.-a). *Cycling*. Retrieved October 5, 2019, from https://sustainability.usask.ca/programs/cycling.php#CyclingattheUofS

University of Saskatchewan. (n.d.-b). *UCommute*. Retrieved October 5, 2019, from https://sustainability.usask.ca/programs/ucommute.php#UCommuteCarpoolingandRideSharingMadeEasy

University of Saskatchewan. (2012). *Campus Sustainability Plan 2008-2012*. https://doi.org/10.1097/GME.0000000000000326

University of Saskatchewan. (2015). *2015 Cycling Infrastructure Report*.

University of Saskatchewan. (2017). *2016 STARS Report*. https://reports.aashe.org/institutions/university-of-saskatchewan-sk/report/2017-01-23/OP/transportation/OP-16/

University of Saskatchewan. (2019). *Enrolment Snapshot*.

University of Toronto. (n.d.). *University Life*. Retrieved October 5, 2019, from https://www.utoronto.ca/university-life

University of Toronto. (2011). *St . George Campus Master Plan* (Issue June).

University of Toronto. (2013). *2012/2013 Sustainability Report*. https://doi.org/10.1109/RCIS.2013.6577673

University of Toronto. (2017). *UCommute: Survey Results for Full-Time Undergraduates at the University of Toronto St. George Campus*.

University of Toronto. (2018). *2017–2018 Sustainability Yearbook*.

University of Toronto. (2019). *Low-Carbon Action Plan 2019-2024*.

University of Waterloo. (n.d.-a). *Transportation*. Retrieved October 5, 2019, from https://uwaterloo.ca/sustainability/projects-and-initiatives/transportation

University of Waterloo. (n.d.-b). *Transportation*.

University of Waterloo. (n.d.-c). *Who we are: Facts*. Retrieved October 5, 2019, from https://uwaterloo.ca/about/who-we-are/facts

University of Waterloo. (2009). *Sustainability Guide: Tips for living sustainably on campus and at home*.

University of Waterloo. (2016). *Transportation and Grounds*. https://uwaterloo.ca/sustainability-report/2016-0/feature/transportation-and-grounds

University of Waterloo. (2018). *Environmental Sustainability Report*.

University of Western Ontario. (n.d.-a). *Commuting Survey - Western Students*. Retrieved October 5, 2019, from https://sustainability.uwo.ca/news/commuting_survey__western_students.html

University of Western Ontario. (n.d.-b). *Sustainability - Cycling*. http://sustainability.uwo.ca/initiatives/transportation/cycling.html

University of Western Ontario. (n.d.-c). *Sustainability - Transportation*. http://sustainability.uwo.ca/initiatives/transportation/index.html

University of Western Ontario. (n.d.-d). *Who we are: Facts*. Retrieved October 5, 2019, from https://www.uwo.ca/about/whoweare/facts.html

University of Western Ontario. (2012). *Creating a Sustainable Western Experience*.

University of Western Ontario. (2015). *Campus Master Plan* (Issue June). http://www.allianceforwaterefficiency.org/Xeriscape_Water_Savings.aspx

Urban Strategies Inc., Rickes Associates, Stantec, Betty Dion Associated Ltd., & Willowbank. (2014). *Main Campus Master Plan*.

Urban Strategies Ltd., Paradigm Transportation Solutions, & GSP Group. (2009). *Campus Master Plan Update*. https://uwaterloo.ca/plant-operations/sites/ca.plant-operations/files/uploads/files/2009_campus_master_plan.pdf

Whalen, K. E., Páez, A., & Carrasco, J. A. (2013). Mode choice of university students commuting to schooland the role of active travel. *Journal of Transport Geography*, *31*, 132–142.

https://doi.org/10.1016/j.jtrangeo.2013.06.008

APPENDIX A: REVIEW OF U15 TRAFFIC MONITORING

Below is a comprehensive review of the U15 Group of Canadian universities' sustainable transportation practices. This includes a description of the campus area, any sustainable initiatives for pedestrians and bicycles, internal sources of transportation data, and external (city) sources of transportation data. The review uses publicly available data on the universities' and cities' website. The universities are organized in order from west to east.

University of British Columbia

Campus Description

The University of British Columbia (Vancouver Campus) has 44,000 undergraduate and nearly 10,000 graduate students (University of British Columbia, n.d.-b). The campus is semi-isolated in an urban area as a river surrounds most of the campus boundary. There is limited through traffic within the campus area.

Sustainability Initiatives

The University of British Columbia (UBC) has a 20-year sustainability plan that includes transportation initiatives (University of British Columbia, 2014a). The report states a goal to restrain automobile transportation and encouraging alternative modes of transportation. UBC's target is to reduce single occupancy vehicle trips to enable sustainable modes. UBC has over a dozen reports or resources on transportation planning alone. Reports include research capital project consultation, annual transportation status reports, land use, and transportation demand management (University of British Columbia, 2014b). In 2019, the campus launched a bikeshare (HOPR) to promote cycling on campus (University of British Columbia, n.d.-a).

In 2014, UBC published a transportation plan for the Vancouver campus (University of British Columbia, 2014b). The report details transportation trends and three measurable targets including 66% of commuting trips by active modes (walk, cycle, or public transportation) by 2044 as well as reducing single occupancy and private vehicles on campus. The document follows with multimodal policies and actions to achieve these targets including land use planning, traffic calming, facilities planning, operational changes, accessibility, and more (University of British Columbia, 2014b). The document focuses on both travelling to/from and within the campus area (University of British Columbia, 2014b).

Internal Transportation Data

The University of British Columbia's (UBC's) *Transportation Plan* includes a section on transportation monitoring stating these three targets: to conduct an annual survey of bicycle rack use, to monitor traffic from construction tricks, and to develop a transportation monitoring program (University of British Columbia, 2014b). The monitoring program will include mode share, speed and volume at key intersections, heavy truck origin-destination information, and trip generation in comparison to the Institute of Engineers (ITE) trip generation handbook (University of British Columbia, 2014b). In 2013/2014, UBC reports 71% of trips to campus made by transit, carpool, walking, and cycling (University of British Columbia, 2014a). UBC also conducts travel surveys (2007 and 2009) (University of British Columbia, 2010).

UBC has been collecting transportation data since 1997 described in their transportation status reports (University of British Columbia, 2014b). The most recent transportation status report describes UBC's traffic monitoring program as collecting data in the fall for year-to-year consistency with additional studies to determine seasonal variation (University of British Columbia, 2018). The Annual Transportation Data Collection consists of (University of British Columbia, 2014b):

- Vehicle screenline counts (7 days)
- In-campus vehicle traffic (2 days)
- Intersection counts (manual for 8 hrs)
- Vehicle occupancy & class (manual for 8 hrs)
- Transit ridership (manual 9.5 hrs)
- Pedestrians and bicycles (8 hrs)
- Construction trucks (contractor reports)
- Non-construction trucks (manual 12 hr)

External Transportation Data

The City of Vancouver conducts traffic counts and publishes them online (City of Vancouver, n.d.). The City uses data from their Mobi bikeshare and automatic bike counters to determine bicycles volumes (City of Vancouver, 2019b). The City also had a pedestrian counting program in 2013 together with an opinion survey (City of Vancouver, 2015)The City conducts annual Transportation Panel Surveys dating back to 2013, to track progress towards modal share. The survey includes travel diaries and using automatic traffic counts (City of Vancouver, 2019a). Translink also conducts travel diary surveys (City of Vancouver, 2015).

University of Calgary

Campus Description

The University of Calgary has four campus areas within the city of Calgary, Alberta. The main campus contains 11 of 14 faculties at the university (University of Calgary, n.d.-b). The university has 30,000 students, 1800 academic staff, and an additional 3200 employees (University of Calgary, n.d.-a). The main campus is a semi-isolated urban area with major streets delineating the campus property with private roads within the campus area (University of Calgary, n.d.-b).

Sustainability Initiatives

The University of Calgary (U of C) produces an annual sustainability report from their Office of Sustainability. The most recent 2018 report focuses on students groups, projects, and waste. The only metric related to transportation is a reduction in GHG emissions which is likely a combination of building energy use and transportation (University of Calgary, 2018). U of C's Institutional Sustainability Strategy provides specific goals and strategies to improve sustainability on campus. It focusses on student education and does not explicitly discuss sustainable transportation (University of Calgary, 2011). The University of Calgary has over 300 secure bike parking stalls, a student-run bikeshare, a bicycle repair shop, bicycle rentals, and end-trip facilities for bicycles (University of Calgary, n.d.-c). The 2019 Climate Action Plan is the first documentation to address sustainable transportation and includes a non-specific reduction in emissions through implementing pedestrian and cycling network (University of Calgary, 2019a). The University of Calgary has over a dozen research groups and centers on campus. Groups related to transportation engineering and planning include the *Cities, Policy, & Planning Lab* and *The Urban Lab* (University of Calgary, 2019b). The U of C's Cities, Policy, & Planning group produced 10 studies for sustainability for different organizations, but did not produce a report on the campus sustainability (Damianil, 2008).

Internal Transportation Data

The university conducted a bicycle-specific commuter survey in 2006 (City of Calgary, 2007). There was no evidence of a traffic monitoring or counting program for any mode.

External Transportation Data

The City of Calgary has a traffic monitoring program that includes vehicles, pedestrians, and bicycles (City of Calgary, n.d.-a). The vehicle counts are mostly permanent count stations, bicycle counts are a mix of automatic (approximately 30) and manual, and pedestrian counts seem to be manual. They conduct annual bicycle counts starting in 2013 and now include pedestrians (City of Calgary, 2019a). The bicycle volumes are displayed as traffic flow maps (City of Calgary, 2019a). The 2016 manual counts looked at gender and other characteristics with each dataset is integrated into an interactive map (City of Calgary, n.d.-a). The counts also include an annual cordon count at 31 locations over a three-week period that include all modes. This data is available online through the City's Open Data Portal (City of Calgary, 2019b).

The City conducted bicycle-specific surveys in 2006 and 2010 (City of Calgary, n.d.-a, 2007). The City also conducted a number of reports on mode split over multiple years (City of Calgary, n.d.-b).

University of Alberta

Campus Description

The University of Alberta has 40,000 students and 14,400 employees at their five campus locations (University of Alberta, 2019b). The largest campuses are the North and South campuses located in Edmonton (University of Alberta, 2019b). Both campuses are semi-isolated urban areas within the city with little through traffic within the campus boundaries.

Sustainability Initiatives

The University of Alberta emphasizes its efforts to integrate sustainable and accessible transportation systems in their planning office. Their strategy for active transportation is to reduce the number of people driving to create a bike-friendly and walkable campus (University of Alberta, 2015). They also encourage carpooling and access to public transit (University of Alberta, 2015). The University of Alberta's Travel Demand Management analyzes parking, traffic, transit, and active modes. This report lacks information on pedestrian and bicycle activity, stating only that the North campus promotes walking to and from campus (Bunt & Associates, 2007). The University of Alberta has a Long Range Developmental Plan (LRDP) that includes an update to create a more pedestrian/bicycle friendly environment through a plan for intra-campus circulation (University of Alberta, 2014). No information on specific or measurable targets is readily available.

The University of Alberta has a Sustainability Council that is an "academic leadership unit" comprised of faculty members and students. The Council is a successor to the Office of Sustainability. It develops annual reports on the university's sustainability status and graduates students with sustainability certificates

(University of Alberta, 2019a). The 2018-2019 Annual Report focused on the academic program and did not specify any measures or progress in sustainability as it relates to transportation (Sustainability Council, 2018).

Internal Transportation Data

The University of Alberta does not seem to have any traffic monitoring system or internal transportation data sources including traffic counts and/or surveys.

External Transportation Data

The City of Edmonton records vehicular, pedestrian, and bicycle volumes and displays it publicly (City of Edmonton, 2017). The City of Edmonton has vehicular AAWDT traffic flows around, but not within the University of Alberta campus (City of Edmonton, 2017). The City also collects pedestrian and bicycle volumes using Eco-Counter equipment (City of Edmonton, 2017). The equipment is located in the downtown area and not in the campus area (City of Edmonton, 2017). The City has a household travel survey that shows that approximately 34,000 people walk and over 11,500 people bicycle within, to, or from the University Sector (City of Edmonton, 2015). The University Sector bicycle volumes were higher than the other 12 sectors (City of Edmonton, 2015).

University of Saskatchewan

Campus Description

The University of Saskatchewan is a semi-isolated campus located in the northeast corner of Saskatoon, Saskatchewan. The campus is bordered by a river, a railway, and two major roads. One major road divides the north and south campus areas and would require two cordon count areas. The university has over 21,500 students as of fall 2019 (University of Saskatchewan, 2019).

Sustainability Initiatives

The University of Saskatchewan (U of S) has broad goals to create transportation systems that benefit the health of their community and environment. The U of S also hosts events like Bike to Work Day, donating bikes to community groups, and bike maintenance workshops to encourage active modes on campus. The U of S has also implemented the following initiatives to support walking and biking on campus (University of Saskatchewan, n.d.-a):

- Actively maintaining bike racks,
- Creating high-security bike parking options in multiple locations,
- Maintaining a network of multi-use paths

The U of S also runs a program that can match up carpools and bike-pools (University of Saskatchewan, n.d.-b). The sustainability office published a document on sustainability initiatives that has a section related to transportation that includes “sustainable mobility plan implementation”, “bicycle sharing program”, and creating a transportation demand management plan (University of Saskatchewan, 2012).

In 2013, the university published a mobility strategy and supplemented it in 2015 with a report on bicycle infrastructure (Rocchi & Noxon, 2013; University of Saskatchewan, 2015). The sustainability mobility strategy is a comprehensive report that includes ground surveys, online surveys, implementation plan, safety, and recommended actions for all modes (Rocchi & Noxon, 2013). The report provides detailed actions, costs to implement recommendations, and delegates responsibilities to different campus departments (Rocchi & Noxon, 2013). Specific to walking and cycling, the report recommends fixing broken sidewalk links, more bike parking, a cycling code of conduct, and a bike repair shop (Rocchi & Noxon, 2013). The *Cycling Infrastructure Plan* consults stakeholders to identify challenges in the current system such as congestion, access to cross streets, and bicycle parking (University of Saskatchewan, 2015). The report recommends installation of bicycle racks, to create a dedicated bike facility, and to conduct further research on campus cycling (University of Saskatchewan, 2015).

Internal Transportation Data

The University of Saskatoon (U of S) does not seem to conduct any counts of vehicles, bicycles, or pedestrians on campus (traffic monitoring). The campus appears to gather all of its transportation data through a number of surveys conducted by the campus sustainability office (2013 and 2016), the City of Saskatoon (2013). The U of S's sustainability mobility strategy included ground and online surveys to determine how people on campus travel (Rocchi & Noxon, 2013). The City of Saskatoon conducted a Household Travel Survey with an additional survey for U of S students. The survey concludes that walking and cycling made up 9% each for the mode split (Ipsos Reid, 2014). As a follow up to the campus' 2013 Transportation Demand Management Survey, in 2016 the U of S conducted an additional survey to determine current mode split (University of Saskatchewan, 2017). The survey found that 78% of students and 50% of employees commute to campus by walking, biking, transit, or carpool (University of Saskatchewan, 2017). More specifically, 24% of students and 20% of employees walk or cycle to campus (University of Saskatchewan, 2017).

External Transportation Data

The City of Saskatoon does not have pedestrian or bicycle data available in their Open Data Portal. It does not appear that the City has a traffic monitoring program that is publicly available (no traffic flow maps). The City of Saskatoon conducted a Household Travel Survey in 2013 that includes travel diaries for citizens. With this data, the City found a mode split of 4% bicycles and 8% walking (Ipsos Reid, 2014).

University of Manitoba

Campus Description

The University of Manitoba has two campuses in Winnipeg, Manitoba. The main campus (Fort Garry) is a semi-isolated urban campus located in the south part of the city and the other campus (Bannatyne) is integrated into the downtown area. The university has 29,600 students enrolled in fall 2018 and 9400 staff members (University of Manitoba, n.d.). The Fort Garry campus is semi-isolated as it is bounded by a river and external roadways. There would be minimal through traffic given the surrounding infrastructure.

Sustainability Initiatives

The University of Manitoba (U of M) has a sustainability strategy that has transportation listed as one of the six areas of goals (University of Manitoba, 2018). The University of Manitoba (U of M) Office of Sustainability published a 63-page report on Sustainable Transportation (University of Manitoba, 2017). The strategy discusses solutions and goals multiple modes including a section on pedestrian and bicycle improvements (University of Manitoba, 2017). In this section there are seven strategies aimed at improving pedestrian and bicycle activity. The below strategies are complete with performance measures for each strategy:

- Identify high-traffic pedestrian and bicycle routes
- Create pedestrian and bicycle facilities on campus to meet current and future demand
- Focus on accessibility for all campus users (universal design)
- Expand on-campus bike parking options
- Provide and promote additional end-of-trip bicycle amenities.
- Work with internal and external partners
- Communicate current and future available route options.

The below targets to obtain the goals support these strategies.

- Reduce drive alone rate by students, faculty, and staff by 5% in five years.

- Decrease the carbon intensity of average passenger trips by 15% from baseline
- Increase campus walkability

These targets are encouraged by bi-annual transportation surveys, investment in automatic counting equipment for pedestrians and bicycles, reports on people's travel preference, and a transportation advisory committee.

Internal Transportation Data

The U of M conducted a transportation survey in 2016 and again in 2018 to understand how people travel and what may change those behaviours (Green Action Centre, 2016, 2018). The U of M Office of Sustainability owns two sets of pedestrian and bicycle automatic equipment for traffic monitoring purposes.

External Transportation Data

The City of Winnipeg conducts vehicular traffic counts and publishes a traffic flow map as well as manual pedestrian counts (City of Winnipeg, 2019). The City of Winnipeg owns a number of pedestrian and bicycle counters, but there is no readily available information on their current use or data (Budowski, 2015; Klassen, 2016). The City conducted a travel survey in 2007 (iTRANS Consulting Inc., 2009).

University of Western Ontario

Campus Description

Western University's main campus is integrated into the urban area of London, Ontario. The majority of campus buildings are in an area between the Thames River and a major roadway. However, there is a bridge on the roadway that may introduce through traffic to the area. The university enrolled over 30,600 students in the fall 2018 semester and employed 1400 faculty members (University of Western Ontario, n.d.-d).

Sustainability Initiatives

Western Ontario University (Western) has policies to support active transportation and transit for people (University of Western Ontario, n.d.-c). They are conducting a pilot to provide bicycles to their faculty (University of Western Ontario, n.d.-b). They also advertise that they are a rollerblade friendly campus with paths for bicycles and rollerbladers. Western's *Campus Master Plan* states a need to improve pedestrian and bicycle facilities within and surrounding the area as well as improvements to public transit (University of Western Ontario, 2015). The plan aims to focus vehicular traffic around the perimeter of campus and have the centre area focused on pedestrian, bicycle, and transit networks (University of Western Ontario, 2015). The plan states that pedestrian and bicycle connectivity requires improvement, but does not state their plan to accomplish this task. The section on the future of transportation states Western will work with the City of London to create connected active transportation corridors. The report does not state any defined targets or measures for pedestrian and bicycle traffic. Western's sustainability report states a goal for green infrastructure that includes collaborating with the City of London to increase access for pedestrians and bicycles to campus in five years (University of Western Ontario, 2012). The definition of "increase access" is not clear in the text.

Internal Transportation Data

Western University conducted commuter surveys in 2009 and 2016 (University of Western Ontario, n.d.-a). The results were not readily available online.

External Transportation Data

The City of London has been collecting vehicle volumes since 1981 (City of London, n.d.-b). An interactive map displays vehicle AADT and pedestrian/bicycle pathways (City of London, n.d.-a). The City does not have AADT for roads within the campus and shows two bicycle facilities that enter the campus area. The City also owns 13 bicycle counters and uses Strava data to gather volumes (City of London & MMM Group, 2016). The City of London conducted a Household Travel Survey in 2016 found that 1.2% of residents commute by bicycle and 10% by walking (IBI Group, 2018). In addition to the City survey, a targeted survey was distributed to Western University and Fanshawe College students with almost 1600 responses making up 3.34% of students (IBI Group, 2018).

Waterloo University

Campus Description

The University of Waterloo has a semi-isolated urban campus located in the centre of the city of Waterloo, Ontario. It has a few indirect internal roads for pass-by trips. The campus had 45,600 students enrolled in the fall 2017 semester (University of Waterloo, n.d.-c).

Sustainability Initiatives

Waterloo University produced a Sustainability Guide to assist students and staff to practice sustainable habits (University of Waterloo, 2009). The guide recommends walking and cycling as a mode that is good for the environment as well as physical and mental health (University of Waterloo, 2009). Waterloo has measurable targets such as increase sustainable commutes from 85% in 2016 to 90% in 2025 (University of Waterloo, n.d.-a). The South Campus has a bicycle repair shop and a bikeshare (University of Waterloo, n.d.-b). The university celebrates cycling through their third annual Bike Month (University of Waterloo, 2018). The *Campus Master Plan* proposes a strategy to reduce parking on campus, pedestrian circulation in the core campus area, providing weather-protected walking areas, developing a transportation demand management program, and implementing bicycle infrastructure (Urban Strategies Ltd., Paradigm Transportation Solutions, & GSP Group, 2009). The plan emphasizes the importance of sustainable transportation as over half of the eight key initiatives are related to transportation (Urban Strategies Ltd., Paradigm Transportation Solutions, & GSP Group, 2009). For pedestrians, the plan lays out directions to create a pedestrian-only street through the centre of campus, limit vehicular traffic to a ring road, and create pedestrian bridges (Urban Strategies Ltd., Paradigm Transportation Solutions, & GSP Group, 2009).

For bicycles, traffic calming will make the ring road more comfortable, bicyclists will be restricted from the pedestrian spine network, and more bicycle parking will be installed (Urban Strategies Ltd., Paradigm Transportation Solutions, & GSP Group, 2009). The campus plan was updated for the Northwest Campus in 2012 (GSP Group, 2012).

Internal Transportation Data

The University of Waterloo states current mode split and has specific goals for future years. To measure this change, it appears as though the university uses the Transportation Tomorrow Survey conducted in central Ontario (University of Waterloo, 2016).

External Transportation Data

The City of Kitchener has AADT traffic available to the public from 1979, but this excludes the Waterloo region (City of Kitchener, 2019). The Regional Municipality of Waterloo reports AADT for vehicular traffic in a report (Regional Municipality of Waterloo, 2017)The City of Waterloo publishes their trail counter data for pedestrians and bicycles collected using 13 sets of Eco-Counter equipment from 2014-2019 (City of Waterloo, 2019). Together with traffic monitoring, the region also collects survey data through a household survey conducted every 5 years (TTS 2016: 2016, 2011, 2006, 1996 and 1986 Travel Summaries for the Greater Toronto & Hamilton Area, 2018; Region of Waterloo, 2011). The most recent survey was conducted in 2016 (TTS 2016: 2016, 2011, 2006, 1996 and 1986 Travel Summaries for the Greater Toronto & Hamilton Area, 2018).

McMaster University

Campus Description

McMaster University is a semi-isolated urban campus located in the city of Hamilton, Ontario. The campus is bounded by a body of water, a major roadway, and a residential area. There is little through traffic because of the indirect roadways within the campus. McMaster has almost 32,000 students and 1,000 faculty members (McMaster University, n.d.).

Sustainability Initiatives

McMaster University publishes an annual sustainability report describing their different areas of sustainability initiatives and strategies (McMaster University, 2016, 2018a). In 2016, the university participated in annual bike to work day and installed city bikeshare stations on their campus (McMaster University, 2016). The 2018 Annual Report mentions transportation as one of its seven areas of focus (McMaster University, 2018a). The report states objectives to raise awareness and encourage use of sustainable transportation without measureable targets or actions (McMaster University, 2018a). The campus has seen an increase in bikeshare from 404 members in 2015 to 1052 members in 2017 (McMaster University, 2018a). The *Environmental Sustainability Plan* forecasts campus GHG and describes plans to reduce emissions, but does not directly mention transportation (McMaster University, 2018b). The McMaster *Campus Master Plan* states the desire to have a car-free campus core (BrookMcllroy, 2017).

Internal Transportation Data

McMaster produced a Travel Demand Management plan in 2016 that included a ravel survey (McMaster Institute for Transportation and Logistics, 2016). McMaster also published a pedestrian and bicycle specific transportation survey (Fandrich, 2010). There was no evidence of a traffic monitoring program outside of travel surveys.

External Transportation Data

The City of Hamilton participates in the frequent Transportation Tomorrow Survey (TTS 2016: 2016, 2011, 2006, 1996 and 1986 Travel Summaries for the Greater Toronto & Hamilton Area, 2018). Hamilton is also conducting its own commuter survey in 2019 (Smart Commute Hamilton, 2019). In 2012, the City conducted some pedestrian and bicycle counts to support active and sustainable school transportation (Lay, 2012). A 2009 report states that the City counts bicycle traffic, but not consistently (City of Hamilton, 2010). Since then, the City has installed 21 pedestrian and bicycle counters and published their data from 2013 to 2017 (City of Hamilton, 2017).

University of Toronto

Campus Description

The University of Toronto's St. George campus is located in the centre of Toronto, Ontario. The two other campuses are outside of Toronto in Mississauga and Scarborough (University of Toronto, n.d.). The campus is integrated into the downtown with some through roads allowing for pass-by trips. In 2019, the university had over 90,000 students, 14,400 faculty, and 7300 staff (University of Toronto, 2019).

Sustainability Initiatives

In an effort to increase cycling activity, the University of Toronto launched a community bike shop on campus and purchased bikes for a staff bikeshare/ bicycle fleet (University of Toronto, 2013). The sustainability office launched a low-carbon action plan for 2019-2024 that does not include efforts to reduce emissions through sustainable transportation (University of Toronto, 2019). The St. George Campus has a sustainability office that produces an annual progress report. In terms of sustainable transportation, the most recent report only references the new location of the bicycle repair shop (University of Toronto, 2018). The St. George Campus also released a *Campus Master Plan* recommends more bicycle parking and to work with the City to introduce more sustainable transportation and increase infrastructure (University of Toronto, 2011). The plan requires additional bike amenities and infrastructure with all new construction (University of Toronto, 2011). The 357-page report describes many priorities to include pedestrian and bicycle infrastructure (University of Toronto, 2011). The report uses the words "pedestrians" or "walk" almost 400 times (University of Toronto, 2011). Priorities for 2030 include safe pedestrian crossings, linking gaps in pedestrian network, reduce vehicle parking, and increase bicycle parking (University of Toronto, 2011).

Internal Transportation Data

The University of Toronto (U of T) did not seem to have readily available information on a campus traffic monitoring plan or its possible use of City count data. U of T's Data Management Group produces the report for the Transportation Tomorrow Survey that acts as the travel household survey for the GTA (Ashby, 2018). The St. George Campus has its own campus commute survey that concludes the primary mode of transportation is 21.4% for walking and 0.72% for cycling (University of Toronto, 2017).

External Transportation Data

The City publishes 8-hr vehicular traffic volumes on their open data web portal The City collects traffic volumes of bicycles using automatic equipment and turning movement counts to conduct short term and permanent counts (City of Toronto, 2019b, 2019a). The data is available from the City's Open Data Portal. For pedestrian data, the City conducted traffic volume counts at 31 intersections on a street in 2017 and 2018 as part of a specific study (City of Toronto, 2019d). The City of Toronto uses the Transportation Tomorrow Survey (TTS) as a household travel survey to determine mode split, trips, etc. (Ashby, 2018). This information was used to produce a current and potential cycling demand map (City of Toronto, 2019c).

Queen's University

Campus Description

Queen's University had almost 25,000 students enrolled in their fall 2018 semester with a total of 9000 faculty and staff in fall 2017 (Queen's University, n.d.-b). The university has three campus areas (Main, West, and Isabel) (Queen's University, n.d.-a). The main campus area is integrated into the urban area near downtown Kingston, Ontario. It is bounded by Lake Ontario and major roadways, but allows for pass-by trips with internal roadways.

Sustainability Initiatives

The Queen's University campus has a bike share on campus. It works towards encouraging sustainable modes through end-trip facilities, bike parking, and a campus bike repair shop (Queen's University, n.d.-c). Queen's Main Campus Master Plan states it promotes sustainable and active transportation. The plan recommends continuing to build the pedestrian network. The plan provides specific recommendations for various pedestrian and bicycle infrastructure projects, but it does not have measurable targets or goals (Urban Strategies Inc. et al., 2014).

Internal Transportation Data

Queen's University recommended the City of Kingston adopt a pedestrian counting program and recommends itself to register bicycles as a measure of counting bicycles on campus (Queen's University, 2013). A single survey was completed to determine Queen's employees travel preferences for use in assessing public transit use, no other transportation surveys were publicly available (Queen's University, 2014)

External Transportation Data

The City of Kingston mentions traffic data collection in their transportation master plan, but not made publically available in any format (open data portal, traffic flow maps, details on pedestrian or bicycle data) (AECOM, 2015). The City conducted a Household Travel Survey in 2008 and is currently conducting a survey for 2019 (City of Kingston, 2008, 2019).

University of Ottawa

Campus Description

The University of Ottawa is bilingual university located in Ottawa, Ontario. The university has over 40,000 students and 5000 employees (University of Ottawa, n.d.-a). With the canal acting as a boarder, the campus is integrated within Ottawa's Sandy Hill neighborhood... Although a major road delineates one of the campus boundaries, it is used by pass-by traffic. Through roads also allow for pass-by traffic for residents near the campus.

Sustainability Initiatives

The University of Ottawa has goals to create sustainable transportation alternatives. They have implemented VeloGo, Bike Coop, and connecting the entire campus with bike lanes (University of Ottawa, n.d.-c). The Office of Sustainability has published a number of reports related to sustainable practices, but the majority relate to water and waste reduction (University of Ottawa, n.d.-b). The university provides bicycle parking facilities (University of Ottawa, 2018). The University of Ottawa works with the City of Ottawa on transportation planning (STARS). The university's campus master plan promotes walking through creating a car-free campus core and implementing bike lanes over the next 30 years (University of Ottawa, 2018).

Internal Transportation Data

The University of Ottawa conducts commuter surveys every few years to determine mode split on campus via a third party organization (University of Ottawa, 2018). The survey is produced in collaboration with the university's Institutional Research and Planning Group (University of Ottawa, 2018). Employees that walk or cycle to campus make up 24% of the mode split and 54% take transit (University of Ottawa, 2018). Their STARS Report indicates that 87% of students commute using sustainable modes. Of this 87%, 26% walk or cycle to campus (University of Ottawa, 2018).

External Transportation Data

The City of Ottawa has over 20 permanent count stations for bicycles with data available online (City of Ottawa, 2019). The City does not appear to have the same data source for pedestrian or vehicle data.

In 2013, the City conducted a Commuter Attitudes Survey that gathers resident's opinions instead of travel data (R.A. Malatest & Associates Ltd., 2013).

Université de Montréal

Campus Description

The Université de Montreal's main campus is a mostly semi-isolated urban campus with the exception of a few buildings in the city of Montreal, Quebec. It has other campus areas in Laval, Longueil, Saint-Hyacinthe, Repentigny, Trois-Rivieres, and others (Universite de Montreal, 2019a). The campus is bounded by major roadways and a cemetery and discourages pass-by trips with indirect internal roads. The Université de Montreal has over 67,000 students and 2,400 professors and researchers (Universite de Montreal, 2019b).

Sustainability Initiatives

The Université de Montreal has an office of sustainability that provides programs and resources to encourage cycling and walking on campus (Universite de Montreal, n.d.-a). This includes bike racks, bike maintenance, bike showers, active transportation maps, and a program that matches experienced bicycles with less-experienced ones to get more people cycling to campus (Universite de Montreal, n.d.-b, n.d.-a). The French website limits the amount of information gathered.

Internal Transportation Data

The Université de Montreal conducted its first travel survey in 2011 (Morency, 2014). No evidence of a traffic monitoring program for vehicles, bicycles, or pedestrians was found in English.

External Transportation Data

The City of Montreal publishes bicycle count data online (City of Montreal, 2019). Quebec's Open Data Portal contains datasets for real-time traffic data and bicycle trips made using the Bike Rover app (Government of Quebec, 2019). The City and the Province of Quebec publish most of their content in French. This limits the information gathered, however eight reports show surveys conducted about mobility including a origin-destination survey (City of Montreal, 2013; SOM Recherches & Sondages, 2013, 2014, 2016a, 2016b, 2019).

McGill University

Campus Description

McGill University is an English-language university in the city of Montreal, Quebec. It is mostly a semi-integrated campus with some buildings outside of the campus boundary and integrated into the city. It has few direct through routes through campus and would not see a lot of pass-by traffic. The campus is integrated with the south-most roadway on campus acting as a boundary and a major roadway for through traffic. The university enrolled over 40,000 students and 1700 faculty members in fall 2018 (McGill University, n.d.-a).

Sustainability Initiatives

McGill University (McGill) includes Transportation as one of it's eight sustainability topics and converted the downtown campus into a pedestrian zone in 2010 (McGill University, n.d.-b, 2017). McGill's sustainable transportation strategy aims to reduce greenhouse gas emissions and has its own carbon calculator tool online (McGill University, n.d.-b). The Sustainability Office published a 2020 Vision for climate and sustainability that includes transportation initiatives (McGill University, 2017). The plan includes finalizing a Transportation Master Plan, developing transportation programs to encourage sustainable modes, and increasing bike parking (McGill University, 2017). The plan did not specifically mention any performance indicators or targets related to this strategy. The Sustainability Office also released a guide for students and staff to make sustainable transportation decisions by choosing environmentally friendly modes and reducing travel (McGill University, 2019). To encourage cycling on campus, McGill has Montreal's bikeshare, BIXI on campus and provides students with discounts (McGill University, n.d.-b).

Internal Transportation Data

The university's Transportation Research at McGill (TRaM) group conducts a commuter survey every two years (McGill University, n.d.-b). The only results that were readily available was the 2013 survey in a 136-page report and a questionnaire of over 260 questions (Shaw et al., 2013).

External Transportation Data

The City of Montreal publishes bicycle count data online (City of Montreal, 2019). Quebec's Open Data Portal contains datasets for real-time traffic data and bicycle trips made using the Bike Rover app (Government of Quebec, 2019). The City and the Province of Quebec publish most of their content in French. This limits the information gathered, however eight reports show surveys conducted about mobility including a origin-destination survey (City of Montreal, 2013; SOM Recherches & Sondages, 2013, 2014, 2016a, 2016b, 2019).

Université Laval

Campus Description

Université Laval is a semi-isolated urban campus located in Quebec City, Quebec. It is bounded by major roadways and has few internal roadways. It is a French-language university with 43,000 students enrolled in the fall 2018 semester and over 3000 staff members (Universite Laval, n.d.).

Sustainability Initiatives

The Université Laval has a number of sustainable initiatives on campus to help the environment. In 2009, they had a sustainable transportation week in September in which over 711 people participated. Laval Université did not have readily accessible information on sustainable transportation goals or strategies (Universite Laval, 2010). The university addresses reducing greenhouse gas emission in their Sustainable Development Report (Universite Laval, 2010). Specifically, it mentions initiatives to improve campus bicycle paths and more shelters/bicycle racks accompanied with performance indicators such as number of new sections added to the bicycle path system and number of racks installed (Universite Laval, 2010). Université Laval published an Institutional Sustainable Development Policy that mentions promoting sustainable means of travel without mention of specific modes or targets (Universite Laval, 2013).

Internal Transportation Data

Université Laval seems to have some vehicle data as it calculates GHG emissions. However, the reports are only in French and limits this assessment. No evidence of a commuter or travel survey was found.

External Transportation Data

Research into Quebec City's transportation data practices is limited due to the language barrier. The City conducted a origin-destination survey in 2011 that included a cordon count survey (Tremblay, 2014).

Dalhousie University

Campus Description

Dalhousie University has three campuses located in the downtown of Halifax, Nova Scotia and two smaller campuses two other communities (Dalhousie University, n.d.-b). The three Halifax campuses are semi-integrated into the downtown area with many campus buildings next to residential housing. The Studley campus downtown has a few internal roads to allow pass-by trips and is bounded by major roadways. Dalhousie University has over 19,000 students and 1,000 faculty members (Dalhousie University, n.d.-a).

Sustainability Initiatives

Dalhousie University has produced over 20 reports related to sustainability and transportation on campus dating back to 2009. The publications include analyses comparing five commuter surveys, travel demand management, a cycling master plan, and an active transportation end-of-trip guide (Dalhousie University, 2019b). Dalhousie has also collaborated with SmartTrip program to promote transit, car-pools, and cycling to campus (Dalhousie University, 2019c). In 2012, Dalhousie worked with collaborators to create a report on bikeway identify priority infrastructure for downtown Halifax (Dalhousie University, 2012). The report is comprehensive in outlining its vision for Halifax, identifying barriers (public engagement), designing a network, and additional programming and elements to support a cycling culture (end-trip facilities, education, etc.). Dalhousie University publishes annual sustainability reports that state the progress of each target. It has met the sustainable transportation targets of updating the TDM strategy, creating an annual commuter survey, and developing active transportation guidelines for the university (Dalhousie University, 2013). In 2019, Dalhousie University released its Climate Action Plan that includes a number of transportation-related strategies including the TDM strategy and a green fleet of vehicles. The TDM program consists of bus passes, ride-share, and increasing pedestrian and bicycle infrastructure (non-specific). The target for sustainable transportation is for 0 tonnes of GHG emissions by 2040 (Dalhousie University, 2019a).

Internal Transportation Data

Dalhousie University's transportation research group, DalTRAC, has published seven documents related to commuter surveys and travel behaviours analysis on campus (DalTRAC, 2019). DalTRAC operates 12 pedestrian and bicycle counters throughout the city and is supported by the City of Halifax and the Halifax Cycling Coalition (Halifax Cycling Coalition, n.d.). This includes a bicycle counter totem on University Avenue.

External Transportation Data

The City of Halifax supports DalTRAC and the Halifax Cycling Coalition in their StreetSenseNetwork Project that installed 12 pedestrian and bicycle counters mostly located in the downtown area (Halifax Cycling Coalition, n.d.). The City's Active Transportation Plan states it requires more data collection of modal share (Koblents & MacIssac, 2014). That plan used stats Canada census data to determine the amount of pedestrians and bicycles (Koblents & MacIssac, 2014). The City appears to collect vehicle counts, but were not readily available online. DalTRAC is currently analyzing a travel activity survey for the province of Nova Scotia (DalTRAC, n.d.).

APPENDIX B: MIXED-TRAFFIC AND BYPASS FACTORS

Southwood Lands

Factor	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
Mixed-Traffic Pedestrians	0.851*	0.851	None	None	None	0.851*
Mixed-Traffic Bicycles	0.149*	0.149	None	None	None	0.149*
Bypass Pedestrians	0.113*	0.113	None	None	None	0.113*
Bypass Bicycles	0.017*	0.017	None	None	None	0.017*
*Factors derived from Period 2 as only one manual count was conducted with snow on the ground. No factors required for Periods 3, 4, and 5 as they had both passive infrared sensors and pneumatic tubes and only one location to count.						

King's Drive

Factor	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
Mixed-Traffic Pedestrians	0.994	0.968*	0.885	0.878	0.968	0.997
Mixed-Traffic Bicycles	0.006	0.032*	0.115	0.122	0.032	0.003
Bypass Pedestrians	0.025	0.071*	0.084	0.084	0.071	0.038
Bypass Bicycles	0.010	0.076*	0.324	0.349	0.076	5.000
* Factors derived from Period 5 because there was no manual count.						

University Crescent South

Factor	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
Mixed-Traffic Pedestrians	0.998	0.996	0.896	0.875	0.977	1.00
Mixed-Traffic Bicycles	0.002	0.004	0.104	0.125	0.023	0.00*
Bypass Pedestrians	0.294	0.291	0.384	0.161	0.228	0.239
Bypass Bicycles	0.024	0.034	0.354	0.297	0.130	7.000
*There were no bicycles recorded at the location of automatic equipment in Period 6.						

Smartpark

Factor	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
Mixed-Traffic Pedestrians	1.00*	1.00*	0.744	0.694	0.862	1.00*
Mixed-Traffic Bicycles	0.00*	0.00*	0.256	0.306	0.138	0.00*
Bypass Pedestrians	None	None	1.295	1.295	1.503	None
Bypass Bicycles	None	None	0.362	0.362	2.623	None
*The mixed-traffic factor for bicycles is 0.00 because it was assumed that no bicycles would use the facility when the pathway was not cleared for snow. The factors in Period 3 and 4 were developed using multiple automatic equipment set ups on two of the three pathways at the site to provide an estimate of bypass at the site.						

Chancellor Matheson North

Factor	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
Mixed-Traffic Pedestrians	0.813	0.791	0.724	0.385	0.667	0.867
Mixed-Traffic Bicycles	0.188	0.209	0.276	0.615	0.333	0.133
Bypass Pedestrians	None	0.104	0.111	0.050	0.009	0.019
Bypass Bicycles	None	0.045	0.018	0.006	0.026	0.250

Chancellor Matheson South

Factor	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
Mixed-Traffic Pedestrians	0.897	0.763	0.483	0.485	0.713	0.905
Mixed-Traffic Bicycles	0.103	0.238	0.517	0.515	0.287	0.095
Bypass Pedestrians	None	None	None	None	None	None
Bypass Bicycles	None	None	None	None	None	None
There are no bypass factors because bypass is incorporated in the Chancellor Matheson North factors.						

Chancellor Matheson bypass if one of two sites is down

Factor	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
North Bypass Pedestrians	0.287	0.221	0.606	0.158	0.280	0.354
North Bypass Bicycles	0.066	0.058	0.232	0.252	0.140	0.054
South Bypass Pedestrians	2.542	2.731	0.576	1.184	1.701	2.217
South Bypass Bicycles	0.292	0.851	0.618	1.257	0.684	0.233
These factors are used when one of the two Chancellor Matheson sites malfunctions to account for the proportion of traffic between the two facilities. The bypass factor is calculated the same as for the other sites. For example in Period 1, for every one person that passes the automatic equipment at the north site, there would be 2.542 pedestrians and 0.292 bicycles at the south site.						

APPENDIX C: EQUIPMENT MALFUNCTION RECORDS

Manual Counts by Video

Date	Period	Site	Imputation/malfunction
12-Feb-19	1	UCN	Imputed midday 2 hours with average hours
20-Mar-20	2	UCN	Missing hours 0:00-8:00. Used a full day in same period to create hour of day factors for missing data.
20-Mar-20	2	CM	Missing hours 0:00-8:00. Used a full day in same period to create hour of day factors for missing data.
20-Mar-20	2	KD	Missing hours 7:00-0:00. Created a rough estimated based off of Automatic Equipment and factors from Period 5
12-Jun-20	3	UCN	Missing 17:00-0:00. Used a full day in the same period to create hour of day factors to expand to 24 hours.
24-Jul-20	4	KD	Missing 9:15-9:30. Imputed with average hours.

Automatic Equipment Errors (from log)

Start Date	Period	End Date	Period	Site	Equipment	Malfunction
20-Jan-19	P1	02-Feb-19	P1	CM 1	PYRO 1 (SL)	Possibly Covered by snowbank
20-Jan-19	P1	02-Feb-19	P1	CM 2	PYRO 2 (KD)	Possibly Covered by snowbank
24-Jan-19	P1	02-Feb-19	P1	CM 2	PYRO 2 (KD)	Malfunction
02-Feb-19	P1	10-Feb-19	P1	CM 1	PYRO 1 (SL)	Malfunction (extreme cold?)
02-Feb-19	P1	10-Feb-19	P1	CM 2	PYRO 2 (KD)	Malfunction (extreme cold?)
10-Feb-19	P1	10-Mar-19	P2	SL 1	PYRO 1 (SL)	Overcounting
10-Mar-19	P2	19-Mar-19	P2	CM 1	PYRO 1 (SL)	Overcounting
13-Aug-19	P4	13-Aug-19	P4	CM 1	PYRO 1 (SL)	Tree with sensor cut down
13-Aug-19	P4	13-Aug-19	P4	CM 1	S. Tubes (SL)	Tree with sensor attached cut down
01-Sep-18	P5	20-Sep-18	P5	CM 1	S. Tubes (SL)	Tubes were cut by maintenance staff
27-Sep-18	P5	27-Sep-18	P5	CM 1	S. Tubes (SL)	Malfunction

Automatic Equipment Errors (from data)

Start Date	Period	End Date	Period	Site	Equipment	Malfunction
20-Jan-19	P1	02-Feb-19	P1	CM 2	PYRO 2 (KD)	Malfunction
24-Jan-19	P1	02-Feb-19	P1	CM 2	PYRO 2 (KD)	Malfunction
02-Feb-19	P1	10-Feb-19	P1	CM 1	PYRO 1 (SL)	Malfunction (extreme cold?)
02-Feb-19	P1	10-Feb-19	P1	CM 2	PYRO 2 (KD)	Malfunction (extreme cold?)
12-Aug-19	P4	12-Aug-19	P4	CM 1	PYRO 1 (SL)	Malfunction (undercounting)
26-Sep-18	P5	26-Sep-18	P5	UCS	PYRO 2 (KD)	Overcounting by 256 per person.