Establishing baseline travel patterns from smart-phone and spatial data

by

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AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

Investment in public transit infrastructure and services is essential to providing effective transportation alternatives. It is important to monitor the progress of key performance indicators (KPIs) to ensure goals of major transit projects are being achieved. These key performance indicators provide replicable measurements related to different aspects of transportation and mobility. Through this thesis, data were collected and analyzed in relation to a set of key performance indicators in the context of Downtown Kitchener in the Region of Waterloo with the implementation of the ION Light Rail system to assess the current state of Downtown Kitchener, and its progression toward goals outlined in the Region of Waterloo's Community Building Strategy and the Kitchener Planning Around Rapid Transit Stations plan. Data related to transit ridership, modal splits, and active transportation networks were summarized from a collection of datasets to establish a baseline of data prior to the introduction of light rail. This thesis investigated the process to collect and analyze these types of data through smart-phone GPS data collection during February and March of 2017 and Python scripts, alongside demographic surveys and other datasets for Downtown Kitchener.

Overall, a sample of baseline indicators has been gathered and assessed for Downtown Kitchener that demonstrated a high propensity for transit and active transportation usage, supported by public policy, with some exceptions or areas of improvement. The process taken in this thesis may be applied to additional areas throughout the Region of Waterloo prior to and following commencement of ION Light Rail operation.

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Table of Contents

List of Figures

List of Tables

List of Appendices

List of Equations

List of Abbreviations

APC – Automatic Passenger Counter

AT – Active Transportation

CBS – Community Building Strategy

CRTC – Canadian Radio-television and Telecommunications Commission

CTC – Central Transit Corridor

CUTA – Canadian Urban Transit Association

GIS – Geographic Information System

GPS – Global Positioning System

GRT – Grand River Transit

LRT – Light Rail Transit

LTE – Long-Term Evolution (high-speed wireless communication)

PARTS – Planning Around Rapid Transit Stations

ROP – Regional Official Plan

RT – Rapid Transit

RTMP – Regional Transportation Master Plan

UGC – Urban Growth Centre

Chapter 1 Introduction

1.1 Investment in and Monitoring Sustainable Transportation in Canada

The period following World War II prioritized mobility via private automobiles, shifting development patterns to decentralized, sprawling designs connected by arterial roads and expressways. Automobiles provided cheap, convenient transportation, diverting traffic from mass transit to cars, stagnating any potential funding or improvements to public transportation; fewer transit riders equated to higher fares to recuperate operating costs and funding aimed at automobile travel often diverted funds away from transit (Malekafzali, 2009; Metrolinx, 2013). To support increased traffic associated with increased urbanization and population growth, the transportation network must too expand. Standard practices primarily widen roads to increase capacity for private vehicles. However, this method is subject to diminishing rates of return; traffic cannot be accommodated by expansion alone. With increasing fuel prices, health concerns, environmental concerns, and an aging population that may no longer be able to drive, the prioritization of the private automobile does not present a sustainable transportation system. Therefore, a shift to support a multimodal transportation network is essential in the success of mobility in the long-term (Litman, 2017).

Investment in public transit infrastructure and services is essential to providing effective transportation alternatives. As stated, while many Canadian cities have been growing at a rapid rate, the investment in public transit infrastructure and resources has not necessarily kept pace, until recent years. Increased investment and management in sustainable transportation has been made at an unprecedented level in the Province of Ontario through systems such as the BuildON infrastructure plan for Ontario, the Public Transit Infrastructure Fund (PTIF), and the Metrolinx Investment Strategy (Government of Ontario, 2017; Infrastructure Canada, 2018; Metrolinx, 2013). It is the intent of this new investment to provide reliable and sustainable transportation options and transit-oriented development opportunities in Canadian communities by way of major infrastructure projects. BuildON has committed to $190 billion over 13 years starting in 2014 for over 5000 infrastructure expansion and renewal projects in Ontario, 361 of which are transit projects (Government of Ontario, 2017). Created through the BuildON program, PTIF committed to $3.4 billion for 2016-2017 for Ontario transit infrastructure projects and intends to provide $8.3 billion over the next decade for transit projects (Infrastructure Canada, 2018). This investment more than doubles previously existing provincial funding for infrastructure.

Despite this increased investment, there are still concerns over the infrastructure improvements since resources are still limited. There are always trade-offs required when reallocating public funds, and so if one sector receives more funding, another will receive less funding, unless taxes are increased. Both where taxes are increased and where funding is reallocated, renewed attention to monitoring progress and impacts of large expenditures is at the forefront of public interest. Efficient and effective use of public funding in a transparent decision-making environment is best supported by data-driven monitoring and reporting as opposed to ad hoc or anecdotal decision-making. In this regard, the Metrolinx Investment Strategy indicates that improved efficiencies and monitoring methodologies “can significantly increase the return-on-investment of not just transit and transportation infrastructure, but other public investments in infrastructure and facilities.” (Metrolinx, 2013) Furthermore, not only are the funding sources identified above subject to public scrutiny, but the above are solely for infrastructure projects and do not account for operating and service costs, which make up the majority of public transit costs.

In line with the concerns identified above, when implementing a major transit project such as a light rail system, it is important to monitor the progress of key performance indicators (KPIs) to ensure goals of the project are being achieved. These goals include that customers are having positive individual experiences, that the operation of transit is working within its available budget, and that transit is maximizing community benefits while minimizing costs. These goals are typically developed as part of transportation policy alongside the introduction of the new transit service. These key performance indicators provide replicable measurements related to various aspects of transportation and mobility. Examples include the share of various transportation modes (mode share – the proportion of trips made by transit, cycling, walking, driving, etc.) and ridership numbers for a transit system. These indicators may reveal the method people use to reach a destination, if options for reaching these destinations are improving, and the overall attractiveness of the transportation system in relation to safety, accessibility, and connectivity (Cervero & Duncan, 2003; Metrolinx, 2013; Behan & Smith Lea, 2016). However, these conclusions can only be drawn with sufficient data and demonstrated analyses. Therefore, a set of KPIs must be both effectively developed to be relevant to the project at hand and must be well monitored to provide meaningful data. The desirable levels for each KPI is also relative to the agency doing the analysis, requiring benchmarks to be established prior to the introduction of new transit projects to observe if the KPI is improving. There is no “one-size-fits-all” number for a KPI to be considered “good”, but rather the measurement’s progression from the benchmark toward the goal is indicative of the level of success.

While KPIs are mostly universal within transportation monitoring, the methods of collecting data for monitoring these KPIs are variable, and often inefficient. In this sense, new methods for data collection continue to be explored, including automated and real-time data collection from sources such as smart-phones or GPS devices.

In keeping with investment and monitoring, it is the intent of this thesis to collect and evaluate data related to a set of relevant key performance indicators for a modern case study using enhanced data collection. The case study area is within Downtown Kitchener in the

Region of Waterloo with the implementation of the ION Light Rail system. The KPIs used in this thesis are meant to ensure the various aspects of this major infrastructure project are progressing toward desired characteristics, and the data collection methods are intended to provide enhanced information in relation to these KPIs.

1.2 Overview of Related Research

It is important to account for the previous work and considerations that have been taken in the development and monitoring of key performance indicators, and enhanced travel data collection methods. This section briefly summarizes the concepts that will be discussed further in Chapter 2 that will ultimately contribute to the development of the thesis methodology.

KPIs in transportation research have largely already been established for varying scales, from federal and provincial agencies (e.g., Metrolinx) to local municipalities. Through the development of KPIs, factors related to travel may be evaluated in their influence to shifting travelers to more sustainable modes of transportation (Lowe et al., 2013; City of Edmonton, 2016). In general, an agency will define selection criteria prior to selecting KPIs. These criteria may be that there is pre-existing data available, the measurements are easily replicable, and the measurements are appropriate to the scale of the project. Alongside general transit performance, common KPIs for transit projects are frequently related to liveability, sustainability, and complementary transportation options, indicating the metrics for success of transit projects are not confined to transit ridership or performance alone, but rather are interconnected to the greater community and its structure.

In consideration of data availability to monitor KPIs, the methods of data collection and benchmarks vary between agencies and projects. KPIs such as transit ridership or modal split have defined calculations for previously collected data, but the intermediary steps taken to gather the data needed for these calculations do not have a standard model (Maghelal & Capp, 2011; Frackelton et al., 2013; Lowe et al., 2013; Metrolinx, 2013; Region of Waterloo, 2016; City of Edmonton, 2016; Woldeamanuel & Kent, 2016; Galston, 2017; Litman, 2017). Traditional travel surveying via paper, online, or phone platforms has served as the primary source of travel data for quite some time. However, these data are subject to some limitations, including decreasing populations with a landline phone, forgotten trips from self-reporting, or other inaccurate descriptions of travel activities (Xu, 2010; Dunlop et al, 2014; Weiss et al, 2017). Therefore, the applicability of automated data collection has become increasingly common, including transit fare card data collection, specialized GPS surveying technology, and smart-phone based travel data collection. GPS-based data collection removes the burden from participants in the surveying process and will also decrease forgotten trips due to the real-time nature of GPS traces through smart-phones (Chung & Shalaby, 2005; Papinski et al., 2009; Xu, 2010; Dunlop et al., 2014).

Increasing numbers of travel studies are utilizing GPS-based data, especially data from smart-phones. The 2016 Canadian Radio-television and Telecommunications Commission (CRTC) annual Communications Monitoring Report reported that 73% of Canadians age 18 and over owned a smart-phone in 2015, representing an upward trend in ownership since 2011. 52% of Canadians also owned a tablet in 2015 (CRTC, 2016). Some previous studies have demonstrated that travel data collected via smart-phones as complementary or as a replacement to traditional travel surveys may provide meaningful data for a multitude of travel-related analyses, with some additional considerations required, such as the demographic distribution of respondents using smart-phones, and the reliability of GPS data (Dunlop et al., 2014; Weiss et al., 2016; Copperman et al., 2017; Flake et al., 2017; Li et al., 2017; Ritter & Greene, 2017).

1.3 Introduction to the Research Case Study

The Region of Waterloo, located in southwestern Ontario, Canada, is made up of three cities and four townships: Kitchener, Cambridge, and Waterloo, and Woolwich, Wilmot, Wellesley, and North Dumfries (see Figure 1-1). The three cities of the Region are all in a rapid state of growth (Statistics Canada, 2016). Kitchener's population is projected to increase by approximately 30% by the year 2031, with much of the growth projected to be within the downtown core (City of Kitchener, 2014; City of Kitchener 2015). In line with this growth, additional growth management strategies and projects have and will be undertaken. As such, in 2011, the Region announced it would be constructing the ION Rapid Transit System, a multiple phase transit infrastructure project, consisting of ION Light Rail between Conestoga Mall in north Waterloo to Fairview Park Mall in south Kitchener connected to ION Bus Rapid Transit between Fairview Park Mall to south Cambridge in Stage 1. Ultimately ION Light Rail will be constructed through Cambridge in Stage 2. This system is intended to provide large-scale improvements to the transit system for the Central Transit Corridor (CTC - an area approximately 800m from ION rapid transit, see Figure 1-1) as well as connecting Grand River Transit (GRT) bus routes, creating a central spine with direct cross-town routes feeding into the spine. ION is also intended to spur transit-oriented economic growth and intensification along the CTC (Region of Waterloo, 2016).

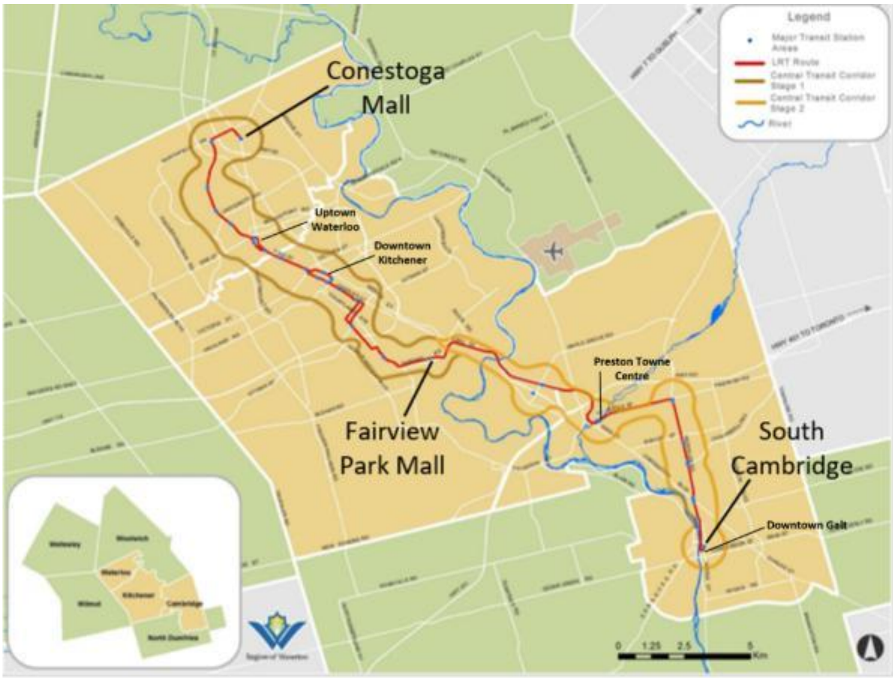

Figure 1-1. Region of Waterloo Central Transit Corridor (CTC) (Source: Region of Waterloo, 2016)

The Region of Waterloo's Rapid Transit initiative has two main goals: moving people and shaping the community, each of which is supported to varying degrees by the ION Light Rail Transit project (Region of Waterloo, 2016). Alongside ION, the Central Transit Corridor Community Building Strategy (CBS) is intended to guide the development of the CTC community and serves as the long-term approach to community planning (Region of Waterloo, 2013). The CBS contains various goals related to mobility, sustainable modes of transportation, vibrant communities, art and culture, heritage, investment, environment, crime and safety, and inclusive communities (Region of Waterloo, 2013). From these goals, KPIs have been developed by the Region of Waterloo in its Central Transit Corridor Baseline Monitoring Report, which was released in 2015 and updated in 2017. This report recognizes the importance of monitoring change in the CTC before, during, and after ION construction. It provides a comparison of a variety of economic, social, and environmental indicators in the baseline year of 2011 to the present and is intended to be updated to at least 2021. These indicators are also related to mobility, sustainable modes of transportation, compact and vibrant communities, art and culture, heritage, investment, environment, crime and safety, and inclusive communities (Region of Waterloo, 2016). For the purposes of this thesis, only mobility and sustainable modes of transportation indicators have been analyzed.

The Monitoring Report largely utilizes historical data to analyze mobility in the Region, such as the NEWPATH walkability index developed in 2009 and census data, which present potential accuracy issues due to data obsolescence (Region of Waterloo, 2016). With the ever-growing adoption of smart-phones and other smart devices, the ability to utilize new and often automated methods of data collection are becoming much more feasible. Other datasets used within the report can be updated with relative ease and can mainly be easily replicated. Therefore, this thesis will collect data related to the KPIs as defined in the Monitoring Report using enhanced data collection methods such as smart-phone surveys and GPS tracking alongside existing GIS datasets and transit ridership data.

1.4 Research Questions

Major investments in transit projects require the allocation of very scarce resources. To determine if this allocation is achieving its goals, key performance indicators are developed and applied to evaluate progress. Specifically, this thesis is intended to collect data on existing travel conditions in Downtown Kitchener based on a set of pre-defined KPIs, and to evaluate these data and relevant policy frameworks on the existing transportation system's ability to meet the ION's goal of moving people and shaping the community prior to the ION system opening.

This research objective is divided into the following explicit questions:

- For the following KPIs and their measurements defined below, what are the baseline results observed during the study period?

- Transit ridership: What are the daily average boardings and alightings per stop in the study area and what may have caused this distribution of boardings and alightings?
- Transit activity: What are the average daily boardings and alightings in the study area and CTC, how do they compare to previous years, and what may have caused any changes in activity?
- Transportation mode shares: For active modes (cycling and walking), the proportion of total active trips made by each mode is calculated. For transit, the total number of boardings in both the study area and the CTC are computed to establish a baseline. In future iterations, the difference in boardings can be calculated to quantify changing mode shares based on assumptions of total travel in the areas being studied.
- Competitiveness of the transit network[1]: Of the app-detected locations outside the study area that are part of travel connecting to the study area, how many currently have a competitive transit connection, and what amount will have a competitive transit connection with the network redesign?
- Walkability[2]: What percentage of travel by walking occurred along streets with sidewalks?
- Connectivity of the cycling network: What are the topological connectivity values of all cycling network intersections in the study area, and are cycling activities

[1] For the purposes of this thesis, a competitive transit connection has a comparable travel time to travel by car (a comparable travel time by transit is not greater than 50% longer than travel time by car), has the trip origin and destination within walking distance (450 metres) of a transit stop, headways are 30-minutes or shorter during peaks and midday, and transit operates 7 days a week.
[2] Walkability is a measure of what makes an area friendly to walking and its measurement is not constrained to sidewalks alone. The CTC Monitoring Report utilizes the NEWPATH walkability index that was developed in 2009 to identify which residents live in "high" or "very high" walkable areas, but this index has not been updated. Due to time, resource, and data constraints, walkability for this thesis has been scaled down to only analyze the proportion of observed walking that takes place on sidewalks.

correlated to high connectivity values? If a correlation exists, how strong is the correlation?

- What are the desired levels of these KPIs? Do the CBS and PARTS plan address improvements to KPIs that have not reached their desired levels?
- What other external factors or study design features may have influenced the KPI results observed?

1.5 Study Design

To achieve the objective of this thesis, several steps must be taken (see Figure 1-2). As per the above research questions, a literature review was completed to better understand the many processes that have been previously developed and analyzed in relation to the monitoring and implementation of major transportation projects. Smart-phone travel surveying and ubiquity research was briefly summarized to demonstrate the validity of smart-phone data collection as the primary data source. The development and selection processes for transportation project KPIs were compiled from different agencies and researchers to both compare and support the KPIs that would be used in this thesis; this section also discussed some aspects of travel behaviour or factors influencing KPIs. An analysis of the importance of public policy in implementation of transit projects was also completed to support the second research question's assumption that public policy will ultimately influence KPIs. This literature review provided the framework to support and guide the methodology and analysis sections of this thesis.

A set of KPIs were established by the Region of Waterloo and the relevant KPIs from the Region are used or adapted as the KPIs for this thesis. These KPIs are transit ridership, transit activity, transit and active transportation mode shares (measured at different scales based on data availability), walkability, transit competitiveness, and connectivity of the cycling network (orange box in Figure 1-2). These indicators were chosen since they are already considered significant to the case study area by their previous selection by the Region and are appropriate to the scale of this thesis.

The evaluation of these indicators is undertaken through the collection and analysis of qualitative and quantitative data administered through an online survey, smart-phone application and through the appraisal of existing GIS, automatic passenger count (APC) and policy data related to transportation in Downtown Kitchener (light blue box in Figure 1-2). Much of these data are readily available, which supports the common KPI selection criteria of availability of pre-existing data. Data that did not already exist, such as the smart-phone data, represent the chief enhanced data collection methods mentioned in the thesis objective.

The smart-phone application, called WatTrack, passively collected GPS data from volunteers during the study period. In addition to general data preparation and consolidation, the smart-phone application data were run through an automated Python script to automatically identify activity locations of participants. This would allow for general travel patterns to also be assessed in addition to the KPIs. Demographic data were also gathered through a survey to supplement the results observed, representing another enhanced dataset that is more focused than census data.

As identified in the literature review, public policy can impact the success of a project and may provide guidance for KPI measurements that meet the goals of the project. Where the goals each of the KPIs are intended to measure do not appear to have been achieved, additional analyses of the CBS and the Kitchener Planning Around Rapid Transit Stations (PARTS) plan are conducted to find support or solutions to reaching the desired levels for each indicator (green boxes in Figure 1-2); these two documents provide the framework for community development and transit supportive strategies in the case study area with regard to the goals of moving people and shaping the community. Where policy still does not address these shortcomings, the implications are identified (yellow box in Figure 1-2), and additional recommendations will be made to achieve the goals defined as part of the ION implementation (dark blue box in Figure 1-2).

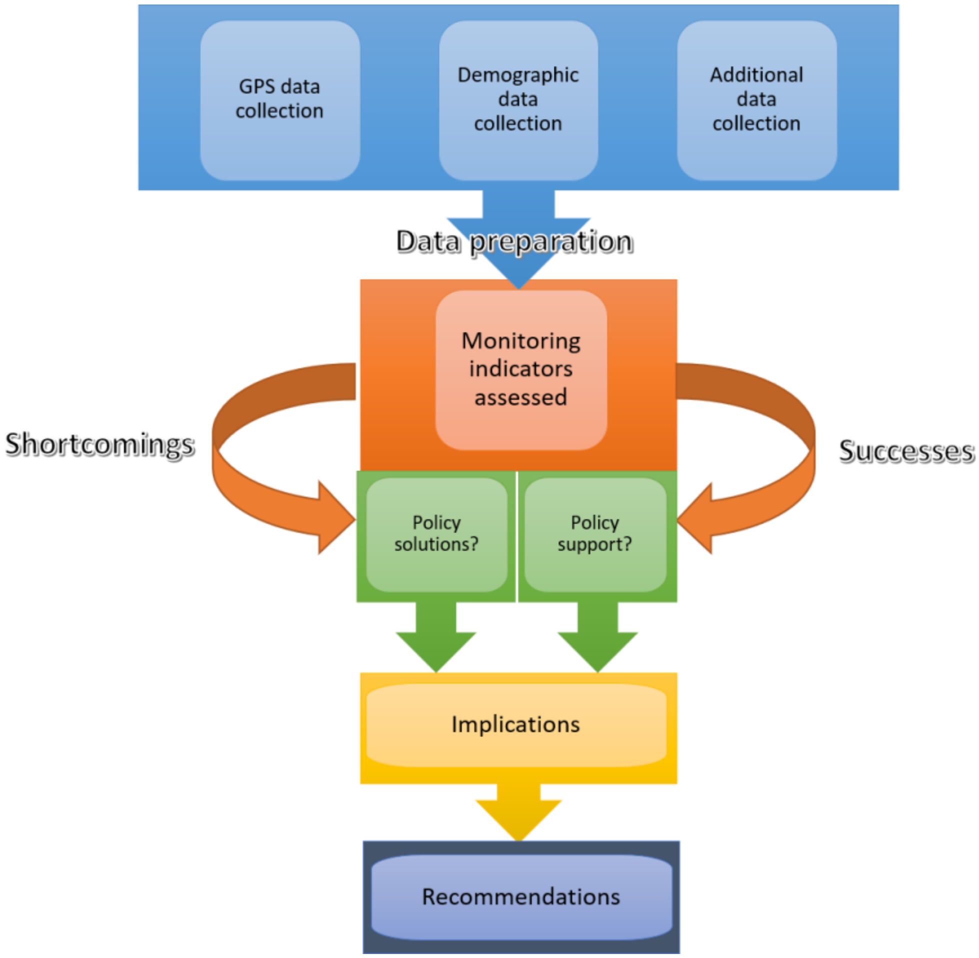

Figure 1-2. Study Process[3]

1.6 Thesis Structure

Chapter 1 has outlined the overall background and goals of this study. Chapter 2 summarizes and analyzes different literature on the subject of travel surveying methodologies,

[3] Demographic data include respondent residence and dwelling type, workplace and career, income, household characteristics, and travel needs

smart-phone ownership and data availability, electronic data collection methods, the physical appearance of travel behaviour for stop detection, key performance indicators, and the significance of effective public policy to establish what previous work has been done and how these methods may be applied to this thesis. Chapter 3 outlines the methods used within this study that was developed through the literature review, and the background of the case study area. Chapter 4 outlines the key results of the study, and analysis of the results. Chapter 5 provides the final conclusions of the study, as well as recommendations for improvements both to the research methodology, and for the case study area. Lastly, any additional supporting materials have been provided in appendices at the end of the thesis.

Chapter 2 Literature Review

2.1 Chapter overview

This chapter provides an outline of the previous work and considerations that have been taken in the development of enhanced travel data collection methods, the development and monitoring of key performance indicators, and other underlying topics that will ultimately contribute to the development of the thesis methodology. This chapter first outlines the ubiquity of smart-phones and their usage for travel surveys as an enhanced data collection method. The physical traits of activity locations based on GPS data are also discussed which can be used to create automated detection processes. This chapter also outlines the implications of developing key performance indicators in relation to travel and its associated goals. Several aspects of travel that are typically used as key performance indicators for transit-supportiveness are assessed in their influence on travel behaviour and how they have been monitored previously: transit ridership, activity and mode share, active transportation mode share, walkability, connectivity of active transportation systems, and efficiency of transit networks. Lastly the influence of policy is analyzed in its ability to support sustainable transportation and how mitigation of shortcomings may be applied.

2.2 Introduction to Smart-phones and Travel Data Collection

A review of travel surveying case studies and methods, smart-phone ownership facts, and travel characteristics from previous research is outlined in the following sections. These topics are intended to support the assumption that smart-phone-based data collection is viable, and what methods may be applied to make meaningful conclusions from smart-phone data based on a study's goals.

2.2.1 Electronic and Smart-phone Travel Surveys

Travel surveying is utilized to gather data directly from travelers on their travel patterns and how they are affected by a range of factors. Surveys typically are used to determine how and if travelers' travel needs are being met. Surveys typically provide origin and destination, mode of transportation, duration of travel, number of trips, number of activities completed in one trip, etc. Surveys may be large-scale (e.g. nation-wide) or highly focused (e.g. a neighbourhood in a city), depending on what the researchers wish to analyze and the availability of resources. Surveys may also observe a broad spectrum of sociodemographic groups, or just one, once again depending on what the researchers are looking for and the available resources (Chung & Shalaby, 2005; Papinski et al., 2009; Xu, 2010). Overall, a good survey will provide large, disaggregated data that will allow for multiple types of analyses. A good survey will also have as large a sample size and as many demographic groups represented as possible, and mechanisms in place to identify any omissions either intentional or unintentional among the methods to account for the influence these omissions may provide. Longitudinal data collection is also beneficial wherever possible (Weiss et al., 2016; Copperman et al., 2017; Ritter & Green, 2017).

The most common surveying method for detailed information has typically been a travel diary (Chung & Shalaby, 2005; Papinski et al., 2009; Xu, 2010). A travel diary is completed by travel survey participants in a physical diary or online for a pre-defined period of time in relation to their origin, destination, mode of transportation, etc., typically after they have completed their travel. The use of smart-phones and other electronic devices (e.g. tablets, GPS trackers, etc.) to collect travel data has become increasingly common in recent years (Dunlop et al., 2014; Widhalm et al., 2015; Ritter & Greene, 2017). Global Positioning System (GPS) based data collection provides automatic trip origin, destination, and route data without burden to respondents, which is the primary reason these data collection methods are complementary or even a replacement to traditional travel surveys. By retrieving real-time information from GPS data, self-reported travel data may be validated, or self-reporting is no longer necessary. GPS data may be appended to road map data to derive the route traveled. This automatic data collection also eliminates inaccuracies such as misreported or forgotten trips and trip duration. Trip speed and relevant land-use information may also be construed (Chung & Shalaby, 2005; Papinski et al., 2009; Xu, 2010; Dunlop et al., 2014). This section outlines a selection of these studies and the opportunities and challenges these studies faced.

Studies by Ritter & Greene (2017) and Flake et al. (2017) are two examples of standard smart-phone travel surveys in Ohio and North Carolina, respectively. Ritter & Greene sought to analyze passively-generated data for long-distance trips, which are only occasional occurrences, while Flake et al. used the smart-phone GPS data to supplement self-reported trips made by respondents online or by phone in a travel diary. Ritter & Greene's study featured voluntary participants over the age of consent with their own smart-phones. The app in this study successfully recorded 400 trips made by the 388 participants. The participants also identified 250 trips that had not been identified by the app, which were attributed to either technical malfunctions or a trip not meeting the threshold of a "long-distance trip". The Flake et al. study also had adults use their own smart-phones to complete the GPS portion of the travel survey. The study concluded that trip-level results of the GPS data were consistent with previous studies, with a 20% average increase in recorded trips per day per person when using smart-phones for data collection instead of travel diaries. It was also identified that the increase in trips recorded per person varied by demographic and trip type. Ultimately, the study used the GPS data to create a scaling factor to be applied to travel diary data to account for forgotten trips within a certain confidence level. These two studies demonstrate the ability of GPS-based surveys to both supplement and replace traditional paper travel surveys.

Weiss et al. (2016) sought to analyze how and to what extent differences in reported travel behaviour are influenced by recruitment and survey modes, primarily the difference between landline recruitment versus cell phone recruitment, and paper versus online surveys. It was estimated that this mixed recruitment method would increase the number of participants, but that the new participants may influence the results based on their demographics to an extent Weiss et al. were unsure of. Despite asking the same questions, the paper and online surveys varied in appearance and completion time. A propensity score weighting (technique used in controlling for selection biases in non-experimental studies through weighted distribution of probability of observed predictive variables) was applied to account for the variation in demographics of those recruited by different methods and which survey format they completed to define and describe survey mode effects related to socio-demographics and travel behaviour. Further analysis is required to determine to what extent those recruited by land line have the propensity to complete online surveys, as well as the cause of those completing online surveys to be more likely to forget short trips (Weiss et al., 2016). Overall, the survey and recruitment modes need to be considered when comparing survey results to ensure an accurate conclusion.

Copperman et al. (2017) also analyzed the differences in demographics and results as related to survey structure. However, in this case, the survey was entirely GPS driven alongside initial demographic survey questions, without traditional travel diaries. Those who owned a smart-phone were asked to download a smart-phone app to trace their movements, whereas those without a smart-phone were provided a GPS logger. Providing the logger was significantly more expensive than a smart-phone only survey. In general, this study found that those with higher income levels of working age were more likely to use the app, while those with fixed incomes and retired individuals tended to be overrepresented by those using a GPS logger. Additionally, the travel patterns observed were consistent with these demographics, where those using the app had more work-related trips because they represent a larger proportion of the population of working age.

Dunlop et al. (2014) as well as Li et al. (2017) used a smart-phone application to measure real time transit user experiences and satisfaction that may dictate an occasional or discretionary transit user's propensity to use transit. These studies determined that methods for enabling real-time troubleshooting and data upload or strategically placed signal beacons would improve results. Li et al. also discussed the difficulties associated with encouraging participation without meaningful external incentives, sustaining participation over the long-term, and incorporating certain demographics without the provision of equipment such as smart-phones with sufficient data availability.

Overall, as demonstrated by these numerous case studies, GPS-driven surveying may provide significant travel data, given several additional considerations. The demographics reached by solely smart-phone data collection methods may not be truly representative of the total population, but neither is traditional travel surveying (Weiss et al., 2016; Copperman et al., 2017). The propensity for individual demographics to utilize different survey platforms must be taken into account to truly represent the total population (Weiss et al., 2016; Copperman et al., 2017). Smart-phone based surveys were also subject to varying degrees of technical malfunction that must be accounted for when making conclusions (Dunlop et al., 2014; Li at al., 2017).

2.2.2 Smart-phone Ownership and Data Availability

The use of a smart-phone application to collect travel data, in addition to the above consideration, is only as useful as the availability of smart-phones and other smart devices by individuals participating in these studies. The Canadian Radio-television and Telecommunications Commission (CRTC) publishes an annual Communications Monitoring

Report. The 2016 edition of this information reported that 73% of Canadians age 18 and over owned a smart-phone in 2015; this represents a 7% increase from the previous year, and a 36% increase since 2011. As well, 52% of Canadians owned a tablet in 2015. Figure 2-1 shows this increase in smart device ownership. LTE and other mobile networks service 99% of Canadian households, covering 20% of the Canadian geographic area (CRTC, 2016). These data represent an ever-increasing penetration of smart devices and service coverage.

A report published by the Pew Research Center analyzed technology use in a variety of economies, including Canada. It was determined that smart-phone ownership was about 10% higher among men, and that those in higher income and higher education demographics were more likely to own a smart-phone. 94% of people under the age of 35 owned a smart-phone, while 58% of those over 35 owned a smart-phone. Therefore, most smart-phone users are highly educated, high income-earning individuals under the age of 35 (Poushter, 2016).

Despite the overall penetration rate of smart-phone ownership, the universality of smart-phone data collection still faces some exclusion of key demographics. Approximately 27% of people age 55 and over own a smart-phone, with ownership decreasing to about only 5% for those over the age of 80 and 10% for the 75-79 age groups. The reluctance of older individuals to own smart-phones is attributed to financial limitations, vision impairment and other cognitive decline, and lack of interest and technological savvy (Berenguer et al., 2017). Furthermore, even amongst the older individuals that own a smart-phone, these devices are often not used as smart devices. Most activity on smart-phones owned by older individuals is largely as a replacement to a traditional landline. Data from 11 different developed countries (not including Canada) indicated that 25% of smart-phone owners over 55 had never downloaded a mobile application to their smart-phone (Berenguer et al., 2017).

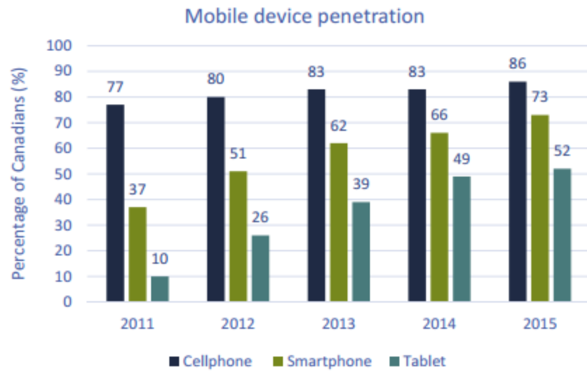

Figure 2-1. Percentage of Canadians that own a cellphone, smart-phone or tablet each year. (Source: CRTC, 2016)

The quality of data that may be collected via smart-phone GPS data will also affect the versatility of smart-phone-based travel studies. The quality of data pertains to accuracy, quantity, and accessibility. The greatest factor affecting accuracy is the number and position of GPS satellites, as well as the ability of the GPS device to communicate with the satellites. If the GPS signal is obstructed such as the device being underground or in an urban canyon, the accuracy will be greatly decreased (Zandbergen, 2009; Bauer, 2013; Hemminki et al., 2013). These are issues faced by all GPS enabled devices. An average smart-phone provides GPS traces that are accurate to within 10m 95% of the time, with some variation between the respective smart-phone, operating system, and GPS chipsets. However, the accuracy and granularity of GPS traces will also vary between different applications. (Zandbergen, 2009; Bauer, 2013)

2.2.3 Trajectories of Activity Locations and Other Stop Detection Methods

As mentioned in Section 2.2, GPS-based data collection removes the burden from participants in the surveying process and will also decrease forgotten trips due to the real-time nature of GPS traces through smart-phones. In addition to GPS providing the raw paths taken by individuals, it also provides the means to deduce intermediary stops or points of interest that will also lend themselves to conclusions on travel behaviour. By identifying where people are stopping, it can be determined what land uses are most frequented, how many stops a person makes in one trip, and what paths they take to get to these locations.

However, to deduce these conclusions, the trajectory of the paths must be analyzed. There is a visual difference between the trajectory of travel compared to stops or pauses in travel. Primarily, travel patterns are purposeful, maintaining a mostly consistent bearing at a consistent speed and displacement, independent of mode. In comparison, patterns of activity locations are anomalous and do not maintain a consistent bearing or displacement, often with inconsistent speeds as well. (Zheng et al., 2008; Zheng et al., 2009)

Many different methods have been used to detect destinations based on their GPS trajectories in recent years, each utilizing a varying number of additional external data sources to support their methods. Zheng et al. (2009) define stay points as "a geographic region where a user stayed over a certain time interval." Two parameters are considered in this study: time and distance. Zheng et al. define the distance threshold of a stay as 20 minutes and the distance threshold as 200 metres. That is to say, if a person remains in a location within a 200m radius for 20 minutes, then a stay is detected. This method filters out pauses in travel such as traffic lights or congestion.

Zheng et al. (2008) do not focus on stay locations, but rather segmentation of trips. However, this method of segmentation lends itself to stay detection as well. Zheng et al. assume that people must stop and then go when changing transportation modes and that walking is a transition between transportation modes, thus indicating that trip segments can partially be divided where walking is the detected transportation mode. Walk segments are detected using a speed threshold alongside analyzing the change in heading. Different transportation modes have different flexibilities to which they are able to change their heading, independent of traffic. For example, a pedestrian has the greatest flexibility to significantly change their heading in a brief time. Therefore, those with the greatest heading change rates are most likely walking segments. Lastly, pedestrians are assumed to have the greatest stop rates due to a number of factors identified by Zheng et al. including being attracted by the surrounding environment or waiting for a bus. Therefore, the number of GPS points below a certain speed and distance threshold will identify the stop rate, where the stop rate will be indicative of the mode type.

Widhalm et al. (2015) discuss the previous methods of defining a stay location to be where the position of an individual remains within a given radius for a given time; however, their ultimate methodology is a “low-pass filter with an incremental clustering algorithm”. This method consecutively observes the temporal order of GPS traces while incrementally creating or adding them to clusters where the points are within “small distances”. As well, a major part of the logic of this study’s clustering algorithm is that significant extra distances travelled are most likely incited by an activity (see Figure 2-22-2).

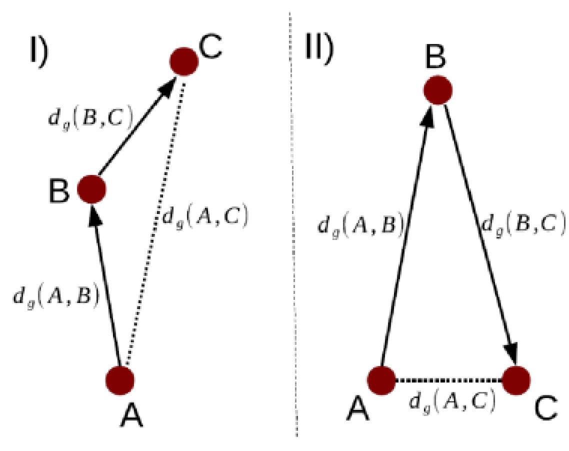

Figure 2-2. Widhalm et al. (2015) p. 604, primary physical identification of an activity location. “Detection of activity locations by the geometry of the trajectory: in I) B is not detected as activity location, while in II) B is probably as activity location, assuming that significant extra distances travelled are motivated by an activity.”

2.3 Key Performance Indicators

The previous section indicates there is potential for conclusions to be made about travel behaviour from smart-phone and GPS-based surveys. However, prior to gathering data and making conclusions, the desired goals and characteristics of travel behaviour must first be defined. The effects of factors on travel behaviour are broad and have variable influences for different travelers. Through the development of key performance indicators (KPIs), these factors may be evaluated in their influence to shifting travelers to more sustainable modes of transportation. KPIs are a measurement value of performance against a set of goals. These goals are typically developed as part of transportation policy, particularly when new transit or transportation projects are undertaken. In summary, goals of a new transit project would be identified (eg., percent modal shift), KPI measurements would be developed alongside policies intended to support these goals (eg., development of a KPI based on modal split alongside the new transit improvement), and the KPIs would be monitored using a pre-determined data source (eg., travel survey data).

KPIs in transportation research have largely already been established for varying scales. Transit performance needs to be measured to determine if customers are having a positive individual experience, operation of transit is working within its available budget, and transit is maximizing community benefits while minimizing costs (City of Edmonton, 2016). Transit performance also serves as a measurement to which the overall community contributes to the success of the transit service. By developing KPIs, disaggregated data such as that from travel surveys may be presented in an aggregated format that allows for conclusions to be made. Disaggregated individual responses from travel surveys cannot provide a clear trend or representation of reality, but the composite results of KPI measurements can be representative of reality and provide meaningful input to decision-making. Below are several examples of the methods involved in the development of KPIs for transportation or planning projects, followed by examples of common transit-related KPIs.

One example of KPI development was created as part of Melbourne's Place, Health and Liveability Research Program; a set of key indicators were identified in relation to liveability and sustainability (Lowe et al., 2013). This report indicates that a range of factors will influence the liveability of a community with a central focus on the health of the community and the sustainability of initiatives. The report asked four major questions: Is the indicator significant to liveability and/or the social determinants of health and wellbeing in urban areas? Is the indicator specific and quantifiable? Can the indicator be measured at the appropriate level(s) and scale(s), so that local areas within a city can be compared? Is the indicator relevant to urban policy? (Lowe et al., 2013). The questions related to the indicators provide a strong framework for developing KPIs of projects such as transit monitoring plans. The Melbourne program also indicates that indicators may be qualitative of quantitative.

Another example of KPI development is demonstrated by Metrolinx' handbook of KPIs for rapid transit monitoring plans as part of their "Big Move" plan. This plan identifies goals related to "an integrated transportation system that supports quality of life, our environment, and our prosperity." The plan also indicates that due to the complex nature of the goals defined in the plan, the KPIs developed may apply to more than one goal. KPIs identified in this document include Mode of Transportation, Transit Ridership, Transit Service per Capita, Length of Regional Rapid Transit, Living Close to Rapid Transit, Working Close to Rapid Transit, Transportation Choice for Low-Income Households, Accessibility of Transit, Transportation Choice for Children/Seniors, Road Safety, Air Quality, Emissions, Transit Between Urban Centres, Highway Travel, and Transit Efficiency (Metrolinx, 2014). Each KPI has an associated measurement system in place.

One final example of KPI development took place through the Region of Waterloo's Central Transit Corridor Monitoring Report, which was developed by the Region of Waterloo for the ION Light Rail project. The report identified several monitoring indicators, available and credible data sources, indicator methodologies, and a reporting timeline. The indicators chosen for the monitoring report were guided by the Region's Community Building Strategy and reflected a range of topics the Region expected would be most affected by transit improvements. The topics that were identified for monitoring were mobility, sustainable modes of transportation, compact and vibrant communities, art and culture, heritage, investment, environment, crime and safety, and inclusive community. As with the Melbourne research, the Region of Waterloo chose indicators that met a set of criteria, where the indicator: was "measurable repeatedly over time", has a "clear linkage to the impacts from investment in ION", "based on reliable and credible data sources that are updated regularly", has "limitations in data and methodology [that] are not likely to significantly impact results", is "relevant to a confluence of interests at the Waterloo Region level", and "reflects the intended level of geography". Indicators that did not fully meet these criteria were sorted into themes for further scoping in future (Region of Waterloo, 2016).

Overall, it appears that KPIs are typically selected based on which criteria are met, as defined by each agency. Agencies regularly select indicators that have pre-existing data available, are easily replicable, and are appropriate to the scale to which the agency is monitoring. In addition to KPIs that measure general transit performance, common KPIs for transit projects are often related to liveability, sustainability, and complementary transportation options. This is indicative of the fact that transit projects are not confined to transit ridership or performance alone, but rather are interconnected to the greater community and its structure.

2.3.1 Standard Transportation KPI Measurements

Following defining KPI development methods, the KPIs are selected and measurement methods are identified. This section outlines the measurement methodologies for some of the most common transit performance indicators as defined by several agencies.

Transit mode share, ridership, stop activity, and competitiveness are several common metrics for assessing general transit performance. Transit mode share, transit ridership, and transit activity are consistently measured by agencies. Transit mode share is the proportion of trips made by transit compared to other transportation modes (Metrolinx, 2013; Region of Waterloo, 2016; City of Edmonton, 2016; Litman, 2017). Transit ridership is the number of passengers that patronize a transit system in a given period (Metrolinx, 2013; Region of Waterloo, 2016; City of Edmonton, 2016; Litman, 2017). Transit stop activity is the number of passengers that board and alight transit at transit stops (Metrolinx, 2013; Region of Waterloo, 2016; City of Edmonton, 2016; Litman, 2017). Transit efficiency can be categorized in several ways: per capita operating costs of transit (Metrolinx, 2013), frequency, accessibility and speed of transit services (Litman, 2017), or other operational cost metrics such as vehicle utilization, passengers per vehicle per day, or kilometres per driver per day (Wei, et al, 2017). The desirable levels for each of these KPIs is relative to the agency doing the analysis (Metrolinx, 2013). A bus stop with 10 boardings an hour in Downtown Toronto may seem low, but a bus stop with the same boardings an hour in a smaller transit system may be considered high. Thus, it is important for benchmarks to be established to observe if the above KPIs are improving (Metrolinx, 2013). These KPIs are generally considered to be improving when transit mode share, ridership, stop activity, and competitiveness increase (Metrolinx, 2013). The magnitude to which these measures increase also indicate how much the system is improving (Metrolinx, 2013). A 10% increase in ridership indicates more improvement in KPIs than a 1% increase. There is no “one-size-fits-all” number for these KPIs to be considered “good”, but rather the

KPIs are intended to measure the transit agency's progression towards a particular goal (Metrolinx, 2013). For example, a transit agency may currently have a 5% transit mode share. This agency would like to see this mode share increased to 10% in the next 5 years. Over the next five years, the agency will check periodically to see if the mode share is increasing. If by year-5 the mode share has only reached 7%, the KPI has improved, but has not improved enough to have met the goal. This may indicate that either the goal was not reasonable, or the resources needed to achieve that goal were not provided, as a KPI is only as valuable as the action it inspires (Metrolinx, 2013).

Metrolinx identified mode of transportation and transit ridership (and activity) as fundamental to monitoring rapid transit networks as these indicators reveal the method people use to reach a destination and if options for reaching these destinations are improving (Metrolinx, 2013). Litman (2017) identified competitive travel as fundamental to monitoring transit projects as shorter and more convenient travel time by transit will be more competitive with private car travel, thereby reducing congestion and pollution costs associated with automobile traffic. Increased speed of transit service is crucial in promoting a modal shift from a personal vehicle to transit due to the inconvenience involved in longer travel times. On average, commute times in the USA by transit are twice as long as travel by car (Maciag, 2017). In this sense, for a consumer to patronize and re-patronize transit, a more comparable (similar) travel time would be required. The Metropolitan Transit Authority of Harris County in Texas even found that increasing the speed of a transit trip by 15% could spur increased transit ridership (Maciag, 2017). However, Wardman (2004) found that a car-users' in-vehicle travel time is more highly valued (50-60%) than that same user's in-vehicle travel time when using the bus. That is to say, the longer someone that normally drives must spend in a car is perceived more poorly than spending more time on a bus. This is likely due to the personal effort required in driving as compared to passively riding a bus.

The discussion above indicates that there are many variables that affect the attractiveness of a transit system, to varying degrees amongst individuals, but in general, competitive, reliable, and accessible transit service will encourage use. The effect of these traits can be observed in part through analysis of transit mode share, transit ridership, stop activity, and transit efficiency.

Additional complementary KPIs for transit projects are related to active transportation. More specifically, mode share, connectivity of the active transportation network, and the walkability of the area around transit stops. The mode share of active transportation is indicative of community structure and the overall attractiveness of the active transportation (travel by walking, cycling, and other human-powered modes) system in relation to safety and connectivity, as well as an indicator of the ability to access transit services, as cycling and walking are the primary methods of reaching transit service (Cervero & Duncan, 2003; Behan & Smith Lea, 2016). Active transportation mode share is largely influenced by connectivity of the active transportation network and walkability. Active transportation mode share is the proportion of trips made by active transportation compared to other transportation modes. Connectivity of the active transportation network is the number of connections that exist overall in the active transportation network, allowing for a traveler to have alternative routes. Walkability is a measure of what makes an area friendly to walking, including the number of sidewalks, proximity to services and amenities, and the feeling of safety. It has also been observed that cities with higher active transportation mode shares have a lower rate of pedestrians and cyclists being injured and killed in collisions with motor vehicles than cities with low active transportation mode share (Behan & Smith Lea, 2016). As before, there is no perfect number that an active transportation system should be striving for. Rather, the KPI measurements should be improving from a benchmark value, and the desired level of improvement would be pre-defined.

Analysis of active transportation mode share and the active transportation network's connectivity will indicate to some degree the safety and effectiveness of the network and will be indicative of the ability of people to reach transit stops. This is because the safety and risk to active transportation users will be affected by the active transportation infrastructure and network provided. There are several varieties of infrastructure for active transportation, with varying degrees of separation from other transportation modes. These include sidewalks, separated and non-separated on-street bike lanes, multi-use pathways (ie. for pedestrians and cyclists), sharrows (shared lane marking), and signed cycling routes (Behan & Smith Lea, 2016). For cyclists, the safest routes are separated or protected bike lanes, residential streets with bike routes and traffic diversion, bike lanes on major streets without on-street parking, off-street paths, and intersections with vehicle speeds below 30km/h. The highest risk routes are on streets with train or streetcar tracks, downhill grades, construction zones, sharrows, and traffic circles (Teschke, et al., 2012). This demonstrates that despite the connectivity of a cycling network, if it is solely made up of sharrows or non-separated infrastructure, it is not an ideal cycling network. However, given the inability to construct certain cycling paths due to space or cost constraints, it does not preclude the introduction of solutions such as sharrows to complete the cycling network.

In addition to active transportation mode share, walkability is another indicator that will be symptomatic of the safety, effectiveness, and connectivity of a pedestrian network and the ability of people to reach transit stops (Lowe et al., 2013; Litman, 2017). Walkability may be monitored in several ways with varying scales. Regardless of the measurement, walkability is correlated with liveability, sustainability, and healthy communities (Lowe et al., 2013; Region of Waterloo, 2016). Full scale walkability studies may monitor all or multiple aspects that contribute to a neighbourhood's pedestrian-friendliness, such as density, land use diversity, pedestrian linkages, provision of pedestrian crossings, provision of sidewalks, sidewalk widths and pavement types, lighting, slopes, and so on (Maghelal & Capp, 2011; Lowe et al., 2013; Region of Waterloo, 2016; Woldeamanuel & Kent, 2016). Smaller scale walkability studies may simply analyze pedestrian infrastructure, such as the availability of sidewalks, unevenness, maintenance, and width. This level of analysis provides more localized analyses without attempting to connect the indices to more generalized indices such as land use diversity (Maghelal & Capp, 2011; Frackelton et al., 2013; Woldeamanuel & Kent, 2016; Galston, 2017). As an example, a major walkability study was undertaken in the Region of Waterloo in 2009 that assessed the walkability of the entire Region in relation to the population that resides in walkable areas that were categorized through indices including walking audits of the quality of pedestrian environment, the intersection density, residential density, and retail design (Region of Waterloo, 2016). However, this study has not been fully updated since 2009; the population estimates have been updated on a yearly basis. The lack of updates may be attributed to the overall scale of the walkability study, and therefore smaller scale indicators may be warranted for monitoring in the short-term.

2.4 Transportation Policies and Impacts

In addition to general goals that may be outlined for a transit project, the project and its goals may also be influenced by transportation policies. Berg, et al. (2016) posits there are three policy instruments that will inform the interventions, outputs, responses, and outcomes in relation to transportation interventions: investment policies, price instruments policies, and regulations (see Figure 2-3). In this sense, a transportation policy instrument should both inform the type of and support the transportation intervention. However, implementation of these types of policies may be inhibited based on legal, institutional, financial, political and cultural, and practical and technological barriers (Rayle, 2008). As such, KPIs are a product of guiding policies and goals. As mentioned in Section 2.3.1, a KPI will identify whether progress is being made towards achieving a goal. However, it is required in the guiding policy that the goal is both reasonable to achieve, and the resources to achieve that goal are made available. Additionally, as discussed by Anas & Timilsina (2009), policies may also have unintended rebound effects. For example, reducing transit fares may attract those that normally drive to public transport, but it may also divert pedestrians to take the bus instead, which could increase the number of buses required (Anas & Timilsina, 2009).

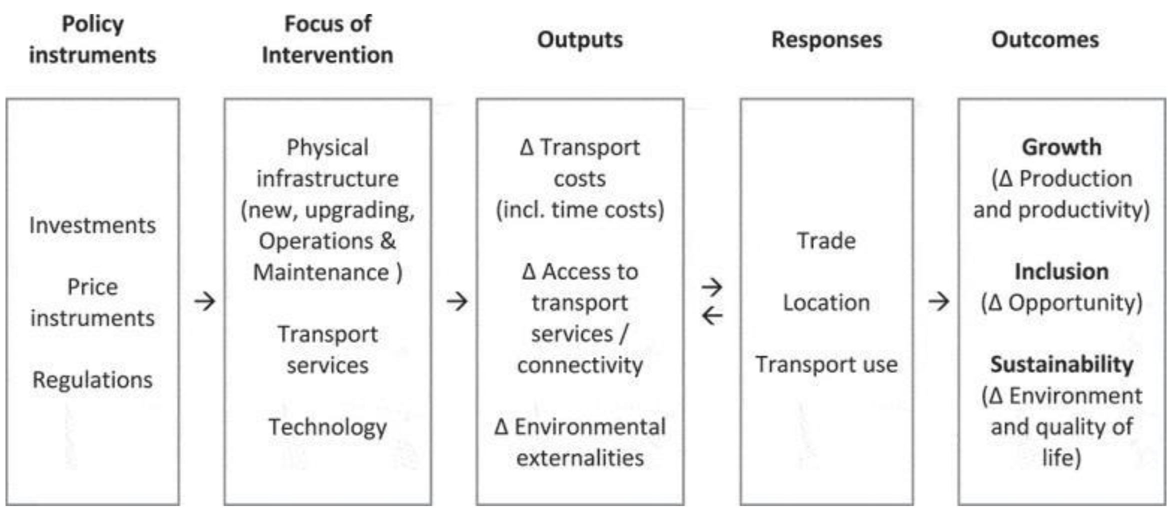

Figure 2-3. Impacts of transport policies: the mechanisms. (Berg, et al., 2016)

Given the potential barriers to implementation of transportation policies and unintended effects, the validity and effectiveness of transportation policies must be considered. Good transportation policies will be proactive as opposed to reactive, will prescribe clear solutions to issues that still allow for flexibility, and are representative of current and future transportation needs (Malekafzali, 2009; Litman, 2013). Where KPIs fall below desired or expected measurements, it may be indicative of insufficient public policies, either that do no exist, or do not provide the appropriate framework for proper implementation.

Transportation policies are not the only types of policies that influence the success of a transportation project. The most closely linked of these additional policies is related to land use. Land use patterns and transportation are inherently linked; land uses are the destinations that are connected by transportation networks. Higher-order transit systems will encourage density around that corridor, and physical separation and low-density development will create a sprawling transportation network (McEldowney, Scott & Smyth, 2003; Larson, Liu & Yezer, 2012). The relationships between land use and transportation, while clearly linked, are complex in nature, and require broad monitoring and analysis tools to properly assess.

In addition to land use policies, other policies that may influence transportation projects include health and wellness policies (e.g., encouraging physical activity) and environmental policies (e.g., carbon reduction policies or air quality improvement policies), which also may be related to land use policies (Larson, Liu & Yezer, 2012; Ulmer, et al, 2015; Sreedhara, et al, 2017). It is clear that the transportation network is interconnected with many social, environmental, and economic factors. The policy framework within which a transportation project is implemented can be highly complex. As a result, to properly account for this complexity, robust and diverse monitoring efforts are necessary; the scope of this work is beyond the goals of this thesis. The work completed here is limited to considerations of transportation infrastructure and high-level land use guidance documents.

2.5 Chapter Summary

This chapter discusses a number of topics related to travel surveying and transit monitoring. Given the increasing penetration of smart-phone and smart device ownership, their usage as either supplementary or alternatives to traditional paper surveys are considered an increasingly reliable method for travel surveying. However, smart devices are not entirely ubiquitous and the responses and demographics of respondents from these surveys may differ from those from traditional paper surveys. As such, the results must consider these discrepancies. Further, GPS travel trajectories have physical traits that can be automatically detected from data collection. From these data, key performance indicators may be monitored in relation to new transit projects. The most common key performance indicators, their relevance to monitoring transit projects, and their measurement methods have been identified. The ability of policy and regulation to support and define goals of transportation interventions, their key performance indicators, and the success of an intervention overall have also been discussed. Further, transportation interventions may be influenced by a number of policies beyond transportation policies, and these policies are beyond the scope of this thesis. The insights of this chapter will be used to develop the methodology and analysis sections of this study. Namely, the key performance indicators previously identified will be measured using smart-phone data collection methods and automated GPS analyses alongside other complementary data sources. Key performance indicators that are not reaching their desired levels will be assessed in comparison to existing policies for potential solutions or interventions. Where no solutions are identified, additional recommendations will be made in accordance with good policy development as described above.

Chapter 3 Methodology and Case Study

3.1 Chapter Overview

This chapter provides the methodology and case study background information. First the case study location, its demographics and any additional background information are outlined. The case study location's relevance to the area of study of monitoring transit projects is also identified. Then the study design is described, outlining the participant recruitment process, travel data and demographic data collection and analysis, and relevant guiding policy assessment in relation to the study area. This provides the overall process taken in this thesis. The key performance indicators are then outlined, grouped by transit performance indicators and active transportation performance indicators. These make up the majority of the data collection and analysis methodology. A full overview of the relevant policy documents is then provided. These documents are intended to address any shortcomings found in the results, and the intent of these documents is identified to support the key performance indicators.

Kitchener and its context within the Region of the Waterloo serve as contemporary and relevant case studies in the application of the use of technology-based surveys. The ION Light Rail system (ION) is an unprecedented undertaking for a mid-sized city, and its influence on local planning and behaviours presents a unique opportunity to be monitored. Furthermore, the Region of Waterloo is home to numerous large tech companies such as Google, D2L, and Blackberry, as well as multiple tech start-up companies, many of which are based in Downtown Kitchener. This appetite for innovation and technology development makes the area an ideal location to establish a monitoring method largely based in automated computer processes such as those in this study. In summary, this study will gather data based on the indicators below prior to the full implementation of the ION Light Rail Transit project through the collection of GPS, survey, GIS, and transit ridership data. These indicators as applied to this study, and their units of measure (defined further in Section 3.5), are:

- *Transit ridership (trips per unit of time)*
- *Transit activity (boardings and alightings from Grand River Transit per unit of time)*
- *Transit mode share (boardings) – the number of boardings that take place in a zone; comparisons can be made over different time periods. Mode shares can be calculated with assumptions on quantity of total travel occurring in the same zonal structure.*
- *Mobility*
    - *Competitiveness (unitless, calculated as the ratio of travel time by transit in minutes to travel time by auto in minutes)*
- *Active transportation - pedestrian and cyclist (percent of trip segments completed by an active mode (cycling or walking) from the total number of total trip segments as observed through the GPS data collected)*
- *Walkability (proportion of observed walking trips that occur on sidewalks)*
- *Connectivity of cycling systems (topological connectivity of cycling network nodes – see equation 1)*

These indicators were developed by the Region of Waterloo to measure change during periods prior to ION construction, during construction, service introduction, and early operation. All indicators as developed by the Region are directly related to the ION's goals of moving people and shaping the community (Region of Waterloo, 2016). The data are updated annually or every several years by the Region, but this thesis will be monitoring some of these indicators in a different manner with the use of enhanced data and analysis tools, which are outlined in more detail in this chapter. Transit ridership, activity, mode share and efficiency are expected to increase with the introduction of ION through an increased access to transit services.

A similar methodology will be used to monitor these transit indicators as the Monitoring Report but are primarily focused on Downtown Kitchener, and some adaptations have been applied. Active transportation measures including walkability and connectivity indicate the transit agency's ability to provide access both to transit services and to the general community. These indicators will be quantified in this thesis using enhanced data and analysis tools. The above indicators are all relevant to the goal of moving people. Indicators associated with building community, while having some relevance to travel behaviour, are not included in this analysis because they either cannot be measured by the resources within this study or provide a scope too large for this independent study. Furthermore, wayfinding as an indicator has not been included despite its presence in “moving people” in the monitoring report as no official inventory of wayfinding features currently exists.

The evaluation of these indicators is undertaken through the collection and analysis of qualitative and quantitative data administered through an online survey, smart-phone application and through the appraisal of existing GIS, APC and policy data related to transportation in Downtown Kitchener. Through this mixed-methods analysis, baseline data will be amassed to be compared against future data following completion of the ION LRT system as described below.

3.2 Location, Population, and Additional Background Information

The study area is located in the core of the City of Kitchener. Kitchener is the largest of three cities in the Region of Waterloo, with a population of 233,222 as of 2016 (See Figure 3-1). Kitchener’s population makes up more than 40% of the Region of Waterloo, the population of which in 2016 was 523,894. (Statistics Canada, 2016) As of 2012, the population of Kitchener within a 20-minute walk of the Downtown core was 42,300. Kitchener is projected to have a population of approximately 315,000 residents by the year 2031(a ~30% increase), with the largest growth projected to be within the Downtown core (City of Kitchener, 2012; City of Kitchener 2015).

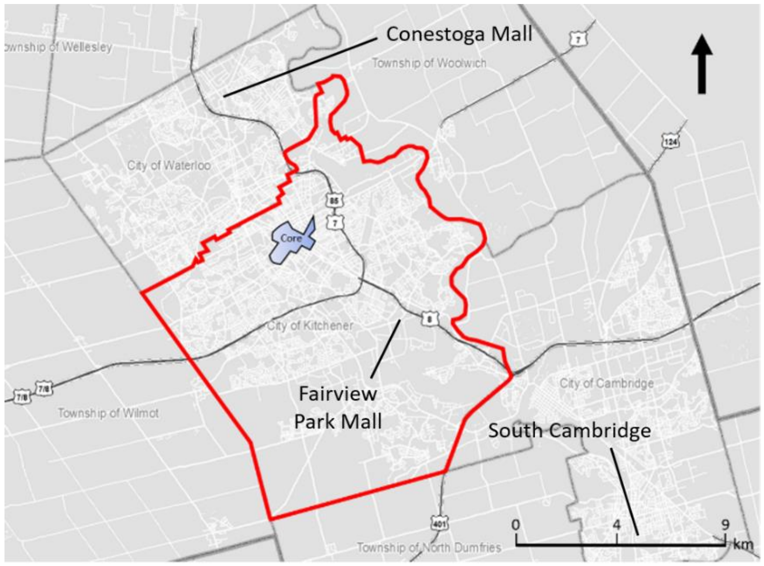

Figure 3-1. The City of Kitchener in the Region of Waterloo

Six ION stations have been constructed within the Downtown Kitchener Study area (see Figure 3-2), with all tracks running on-street in this area, within a separated right-of-way. The LRT tracks split into one-way tracks at the boundaries of the Downtown area, with the northbound tracks running along Duke Street and the southbound tracks running along Charles Street. These tracks meet at the northern border of Downtown at Victoria Street, and at the southern border of Downtown at Frederick/Benton Street. There are two northbound stations: Kitchener City Hall and Frederick, two southbound stations: Victoria Park and Queen, and two bidirectional stations: Central Station – Innovation District and Kitchener Market. Each ION stop will also be integrated with the local bus transit network – through bus route re-alignment, bus stop relocation and bus stops on or adjacent to LRT platforms (City of Kitchener, 2015).

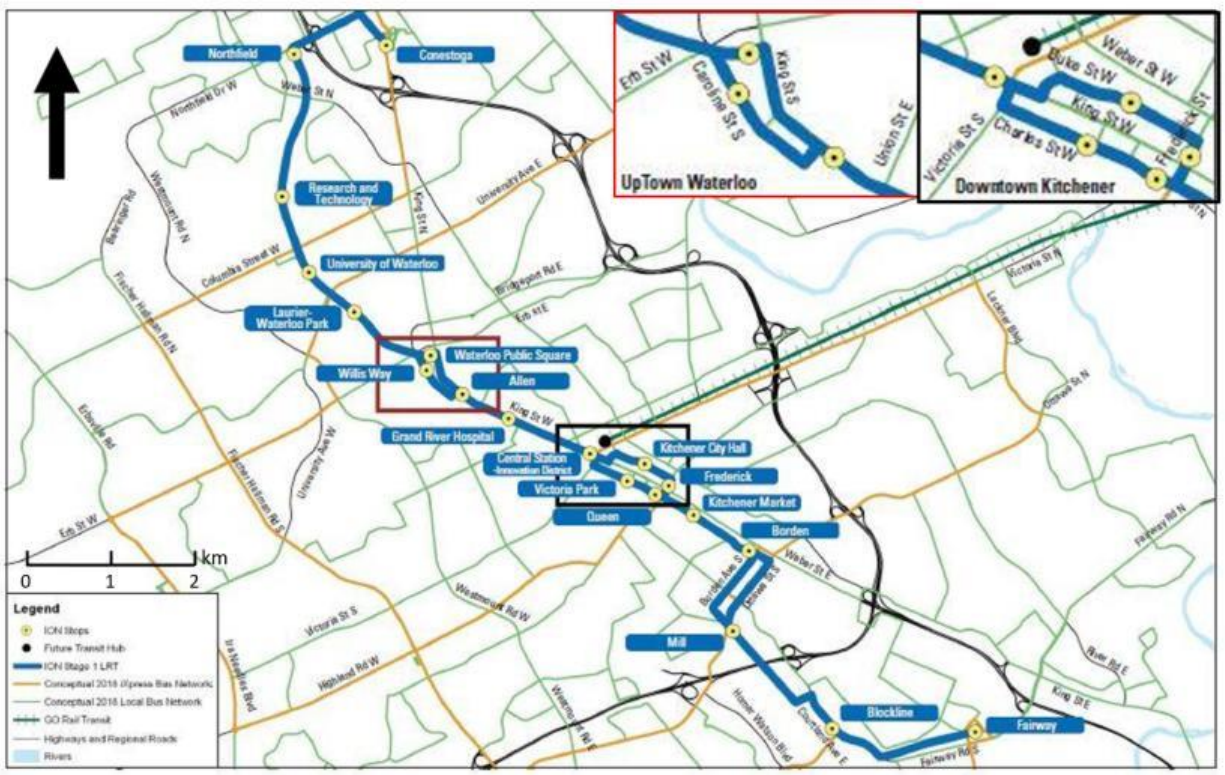

Figure 3-2. ION LRT route and stations (Source: Region of Waterloo, 2016)

This study is undertaken within the boundaries shown in Figure 3-3 which are based off four distinct existing neighbourhoods identified by the City of Kitchener: The Innovation District, City Centre District, Civic District, and Market District. The Innovation District, formerly known as the Warehouse District, contains several industrial heritage buildings which have been converted to office buildings and condos. This area encompasses the Lang Tannery which hosts D2L and other tech companies, the Kaufman Lofts which is a converted footwear factory, and the Breithaupt Block which has recently been redeveloped as the Kitchener Google office. The University of Waterloo's School of Pharmacy is also located in this district. The City Centre District contains a variety of key destinations, including Kitchener City Hall and Carl Zehr Square, the Regional Children's Museum, Charles Street Transit Terminal (current local bus terminal), and many restaurants and bars. This area is also adjacent to Victoria Park, described as the "jewel of the city" (City of Kitchener, 2012), which contains a lake, gazebo, banquet hall, playground and splashpad, basketball courts, a restaurant on the water, and the clock tower from the original Kitchener City Hall. The Civic District, in addition to some residential areas, contains a variety of government and cultural locations, including the Provincial Courthouse, Regional Police Headquarters, Region of Waterloo Headquarters, Centre in the Square (theatre), and the Kitchener Public Library. The Market District is the most underdeveloped district in Downtown Kitchener, with numerous vacant lots, and auto-oriented businesses and parking lots. However, it also contains the Kitchener Market that serves as a major destination, especially on Farmers' Market days (Saturdays) (City of Kitchener, 2012).

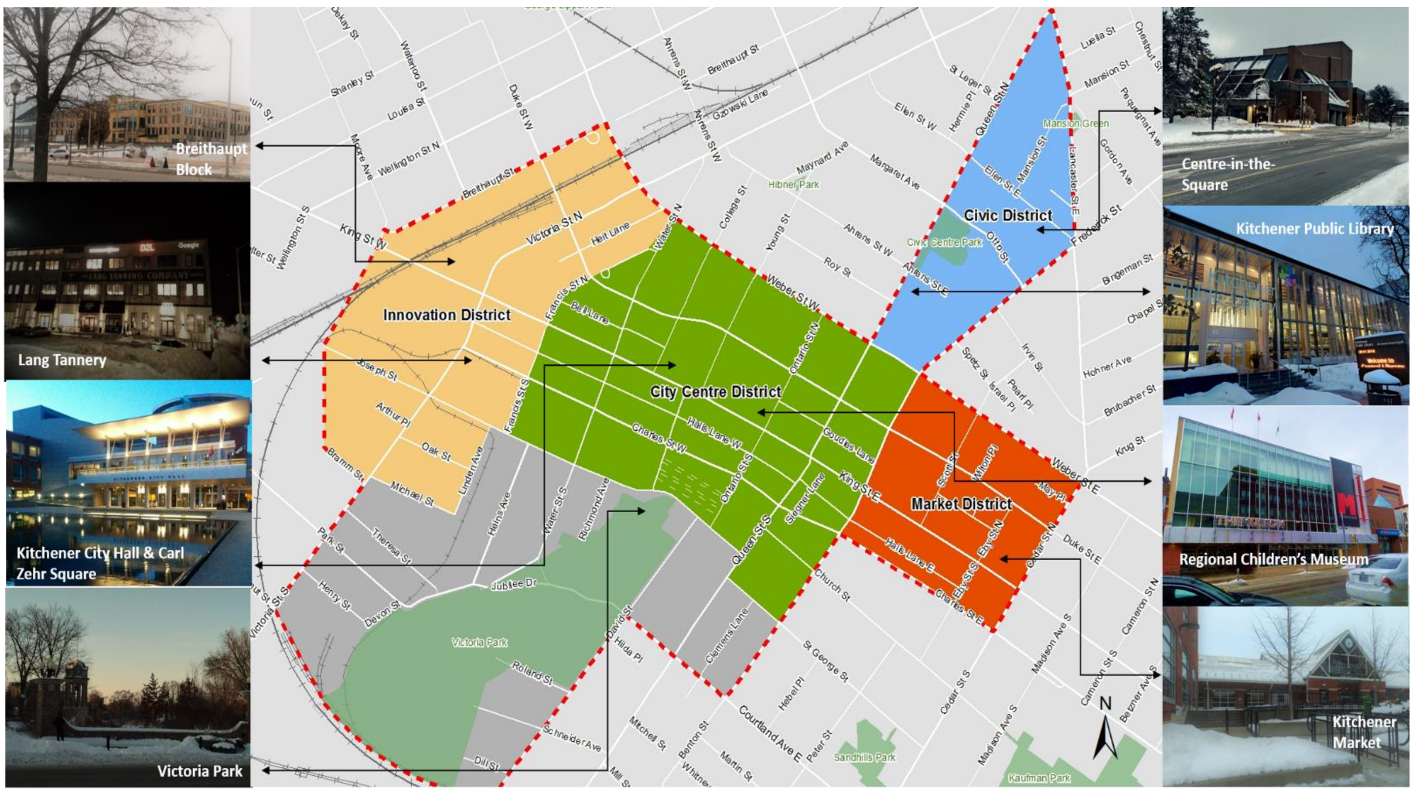

Figure 3-3. Downtown Kitchener Study Area and distinct neighbourhoods & landmarks. (Source: City of Kitchener Open Data; all photos taken by Andrea Mikkila)

3.3 Study Design

This study recruited participants that traveled in Downtown Kitchener and collected qualitative and quantitative data from the participants related to their demography and travel behaviour as well as from external data sources that would be used to assess the previously mentioned monitoring indicators. The results were further assessed through the analysis of additional policy documents to ensure plans are in place to address any shortcomings in the study area in relation to transportation planning.

The steps of this study, which are further outlined below, are as follows:

1. Participant recruitment
2. GPS data collection and demographic survey
3. Data download and cleaning; external data collection
4. Data consolidation and assessment
5. Policy analysis

3.3.1 Participant Recruitment and WatTrack App

Data collection was intended to collect spatial data from participants that would contribute to KPI assessment. The data for this research were primarily collected through a smart-device application titled “WatTrack” that was downloaded by volunteers onto their Android or iOS device (see Figure 3-4). The WatTrack software was developed by a team of transportation engineers at the University of Waterloo, in Ontario Canada under the company name iSYSIGN. WatTrack is a version adapted for the Region of Waterloo. WatTrack passively records a user’s latitude and longitude, altitude, the time, and the speed at which the user was traveling, which were used for travel analyses. The data were gathered on the participant’s phone and transmitted via internet to the WatTrack server to be stored securely in Montréal, Québec, Canada. WatTrack needed to be turned on each time the participant wanted to generate travel information. If the user did not wish to gather data, the app simply could be turned off. If the user were to lose internet connectivity (e.g., data signal fails, or data syncing is not enabled) WatTrack stored the information on the user’s phone until an internet connection became available. Once reconnected, multiple uploads would occur, so the phone could send the backlog of data. All of these data were used toward identifying travel routes and destinations.

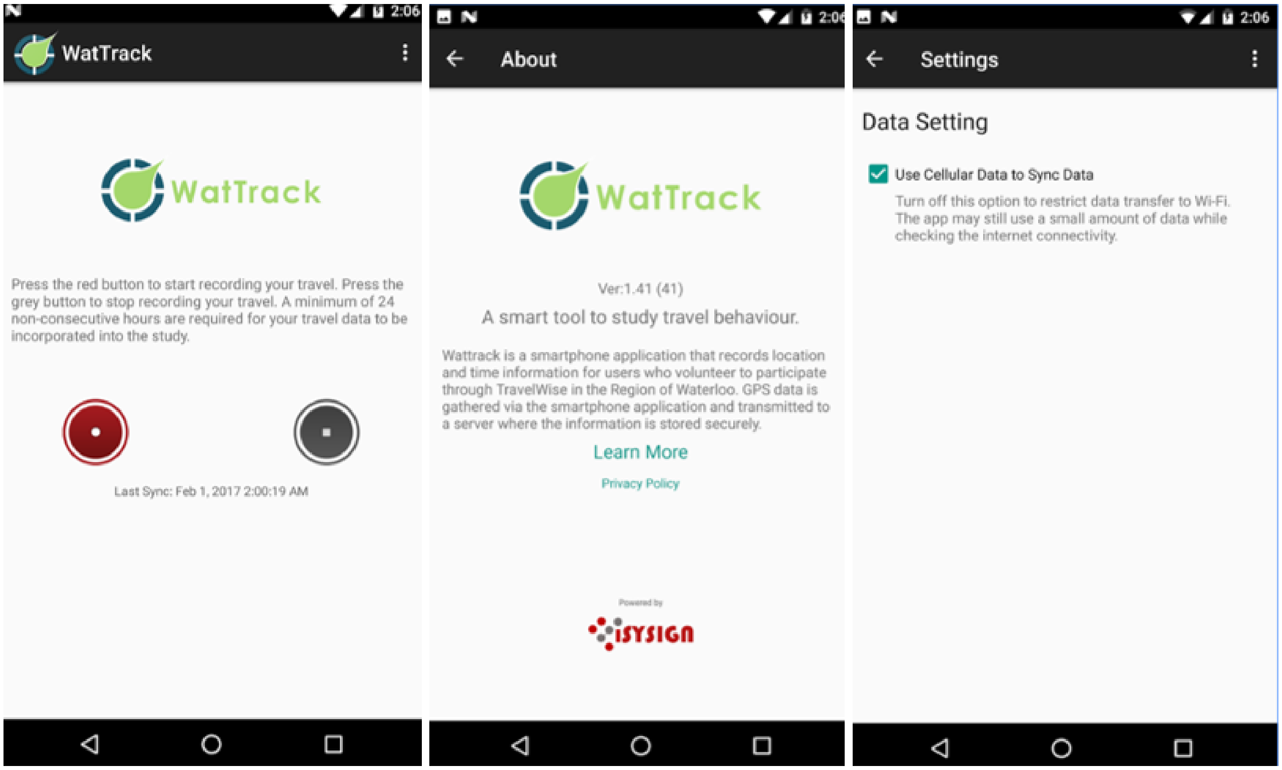

Figure 3-4. WatTrack User Interface

The accuracy within WatTrack may vary, as discussed in Chapter 2, with the ability of the phone to communicate with GPS satellites. As such, a confidence interval was provided for each GPS data point. Mobile data could be used to collect GPS data, but this option could be disabled within the app settings to limit data collection to WiFi for syncing.

Participants for this study were recruited through several methods that attempted to reach as many sociodemographic groups as possible with limited resources. As with Weiss et al. (2016) and Copperman et al. (2017), the influence recruitment methods have on results was considered, but due to the limited extent and resources of this study, some demographics were expected to be excluded, such as those without a smart-phone, or those that were not reached by the recruitment methods outlined below, and the implications of this exclusion are discussed further in Chapter 5.

Initial recruitment occurred through a presentation made to the TravelWise working group by the author and through the TravelWise e-newsletter sent to all TravelWise members. TravelWise is a Transportation Management Association that works with its member employers to encourage employees to bus, bike, walk, and carpool to work through membership benefits (TravelWise, 2017). The working group meets semi-regularly to discuss management strategies and other plans for transportation management. TravelWise was chosen for the presentation and primary recruitment platform due to its interest in transportation management, and the convenience of connecting with large groups of people to participate through a single outlet. This presentation requested that the representatives of this working group pass along information letters to interested employees, who could then anonymously register for the study on Wattrack.com.

The target participant group was those whose travel would both begin and end in the study area. However, the outreach and app allowed anyone to register and participate. If a traveler engaged in trips that began or ended outside of the zone, but contained some travel within the study area, only the data gathered from within the study area were analyzed in detail. It was recorded for these cases that the origin and / or the destination was outside of downtown; these trips served as candidate routes for which competitiveness was analyzed.

Participants were asked to record their travel movements for a minimum of 24 hours within the designated data collection period (February 13th - March 13th 2017). This period was selected as it followed the TravelWise meeting, which was the determining timing factor, since their meetings are only semi-regular. Unfortunately, this period of time reflects poor weather conditions in the study area. The e-newsletter provided the same information letter and encouraged those interested to register on Wattrack.com. Further recruitment occurred by placement of information posters in several Downtown businesses and through a live interview between the author and CBC Radio Kitchener on February 27 2017, outlining the study and how interested parties could register. This additional recruitment occurred due to limited participation in the first week of the study period. These additional methods reached those that may not have been aware of the study due to not being part of TravelWise. All participants were also incentivized to participate by the chance to win one of two $100 Amazon.ca gift cards, where they would receive a ballot for every 12 hours of data collected, thereby encouraging not only initial signup, but active participation in the study. Ultimately, there were 63 registrations, 40 of which provided usable GPS data.

3.3.2 Demographic survey

Concurrent with or following quantitative data collection via the WatTrack app, participants were encouraged to complete an optional supplementary demographic survey that allowed for additional information to contribute to the quality of the evaluation for assessment of the recruitment process, the accuracy of the GPS information, and the general characteristics of participants. This survey was administered through Simple Survey, an online survey system designed, developed, hosted and supported in Canada by OutSideSoft Solutions Inc. (See Appendix A and B for survey questions and results, respectively). 25 registrants completed this survey.

The questions in this demographic survey related to the participant's home and work locations, age, gender, education, income, household makeup, personal vehicle availability, and self-described travel patterns in Downtown Kitchener and the CTC. Overall, the questions provided an overview of those that participated in the study, allowing for an assessment to be completed in relation to the recruitment process (ie. if any demographics were excluded), and to allow for some connections to be made between demographics and travel patterns, if there were any. Not all of these questions are necessary to the completion of this thesis, but the results provide additional baseline information should future researchers wish to replicate or alter this study.

3.3.3 Data Collection, Download and Cleaning

GPS data collection of travelers' activities took place between Monday, February 13, 2017 and Monday, March 13, 2017. Participants could track their locations via the WatTrack app and fill out the demographic survey for the entirety of this period. Following the data collection period, two participants were randomly drawn to win the Amazon gift cards.

Additional spatial data were collected from the Region of Waterloo's Open Data platform that outlined the location of sidewalks and trails, neighbourhoods, roads and lanes, and bus routes and stops. Automatic Passenger Count (APC) data were also obtained from Grand River Transit for the bus stops in the study area during the same two-week period of the study. These additional data sources provided complementary and supplementary data to the GPS and demographic data.

Following the data collection period, the entirety of the collected data was downloaded from the server for analysis. The dataset downloaded from the server contained a spreadsheet of GPS points with timestamp (YYYY-MM-DD HH:MM:SS), incremental random numerical user ID, latitude, longitude, altitude, accuracy, speed (km/h), bearing, acceleration, battery usage data, and other supplementary data that are not relevant to this study. Anyone that provided a minimum of 12 hours of data collection were incorporated into the study; some participants would inherently provide more data than others, but all data for those that provided at least 12 hours of data were incorporated equally. The threshold for inclusion was established based on the expectation that it represented an opportunity for the traveler to have completed a full spectrum of activities – work, utilitarian shopping, recreational trips, etc. Data were also differentiated between travel that occurred inside or connected to the study area or occurred outside the study area with no connection to the study area.

The files went through initial data-cleaning that involved the deletion of any points whose accuracy value was greater than 50 metres (about 10% of all points were deleted due to their accuracy level). This accuracy deletion is based on the definition of accuracy as defined by Google and Apple where the value is the “estimated accuracy of this location, in meters … as the radius of 68% confidence. In other words, if you draw a circle centered at this location's latitude and longitude, and with a radius equal to the accuracy, then there is a 68% probability that the true location is inside the circle.”, as well as through the developer of the WatTrack app where “in the map/calculations we ignore any point with accuracy poorer than 50 meters.” No subsequent files mentioned contained inaccurate data points.

One of the goals of the research is to identify pedestrian tours. To do so, GPS data are processed using a Python script that identifies activities between which pedestrian trip segments take place. The Python script is described in the next section. In order to minimize the data files that need to be analyzed, an additional step was taken to eliminate those GPS traces that were clearly not completed by walking. To this end, any points that produced travel speeds more than 15km/h (well above average walking speeds) were deleted for the pedestrian analysis. These points constituted about 30% of all points.

The data were then saved into several different formats. One version was saved with all the (accurate and under 15km/h speed – see above) GPS data as a CSV in the required format to be run through a Python script (see Appendix B for code) that identifies activity locations in each tour that occur within the Downtown Core (which is outlined in further detail in Section 3.4). Another version was saved that contained only GPS data where the detected mode was on foot as identified using the built-in functionality of the app - see Appendix B for more information on the mode detection process). Lastly, another version was saved that contained only GPS data where the detected mode was cycling (detected from the app). These last two versions were first run through the Python script and then used to compare the travel patterns of these two modes as per the monitoring indicators outlined in Section 3.5.

There area a number of GPS data files. For clarity, those files and their purposes are summarized in Table 3.1.

Table 3-1. Consolidated Data Files Formats.

File	Content	Purpose
All accurate GPS data	CSV with all GPS points with inaccurate points deleted	Base collection of data points
All accurate GPS data around walking speed	CSV with all GPS points with inaccurate points and points traveling above 15kph deleted inside and outside study area	Used for Python script to detect activity locations for further analysis
All accurate GPS data for detected pedestrians	CSV with all GPS points with inaccurate points deleted and any points not identified as a pedestrian deleted; only points detected within study area are used	Used for Python script to detect activity locations of pedestrians and to divide travel into segments for further analysis
All accurate GPS data for detected cyclists	CSV with all GPS points with inaccurate points deleted and any points not identified as a cyclist deleted; only points detected within study area are used	Used for Python script to detect activity locations of cyclists and to divide travel into segments for further analysis

3.3.4 Data Consolidation and Assessment

The activity locations determined from the Python script were utilized to make a heat map of the most frequented locations in the Downtown Core, as well as a brief summary of the makeup of frequented land uses, the most frequently taken paths, and the most frequented land use types outside the Downtown area. These results provide a simple overview of the current travel patterns in Downtown Kitchener, as well as the most desired land uses in the area.

The spatial and demographic data were then assessed in comparison to the indicators described above (transit ridership, activity & mode share, active transportation, walkability, mobility, connectivity) as developed by the Region of Waterloo. The data were compared to what is considered a “good” level for each indicator, as described in Chapter 2, and discussed further in section 3.5 of this chapter. The indicators were measured in relation to transit trips, transit boardings and alightings, transit and active transportation mode share (measured at different scales), transit competitiveness, the provision of sidewalks, and the connectivity of the active transportation network in the study area during the study period of February 13 to March 13 2017.

3.3.5 Policy analysis

Lastly, the observed KPI results were assessed in comparison to policy documents pertaining to the Downtown Kitchener areas in proximity to future LRT stations, as discussed previously, since KPIs are developed from policy. The first document is the Region of Waterloo’s Central Transit Corridor Community Building Strategy (CBS) which provides directions and strategies for future growth around stations to shape the community. The second document is the City of Kitchener’s Planning Around Rapid Transit Stations (PARTS) document whose primary purpose is to provide direction for future development in station areas and infrastructure project recommendations that increase public interest in transit. Where the monitoring indicators show deficiencies, these policy documents will be checked for planned solutions in the policy documents.

3.4 Trajectories and Cluster Analysis Algorithm

The Python script mentioned in Section 3.3.4 was developed using trajectory and cluster analysis to identify activity locations in the study area, which assists in identifying travel patterns and key destinations related to transit and active transportation indicators. As discussed in

Chapter 2, a typical travel trajectory is observed to be a straight line with captured points evenly spaced from one another. This is because a traveler will be traveling from origin to destination at a mostly consistent speed (except for the occurrence of a mode change). Where pauses in travel occur such as stopping at a red light, the travel trajectory will not move and GPS that is captured will stay in one location. A trajectory of an activity is different from pauses and travel trajectories. An activity will typically have no discernible trajectory or may be observed as a temporary deviation from a trajectory (Zheng et al., 2008; Zheng et al., 2009; Widhalm et al., 2015). This is because a traveler will be limited to a single parcel of land for their activity but may move about the parcel throughout the time spent there. The traveler will either move around a central point location (as demonstrated where a trajectory is not discernible) or may deviate from their travel trajectory to quickly enter and exit an activity location (such as a drive-thru).

These two types of trajectories were detected using the script in Python, and additional spatial analysis in ArcMap following initial data cleaning as mentioned previously. All thresholds used in the script have undergone sensitivity testing to determine which thresholds provide the most realistic results.

For the purposes of this study, cluster analysis was undertaken to locate activities. A cluster is defined as a set of consecutive GPS points without a defined trajectory or that provides a temporary deviation from the observed trajectory and is confined to a limited spatial domain. The cluster analysis and detection was similar to Widhalm et al. (2015), whose methodology used an incremental algorithm to add points to a related cluster or create a new cluster as appropriate. Many of the other methodologies discussed in Chapter 2 are not as appropriate for this study. Zheng et al. (2008) and Yuan et al. (2015) look at trip segments rather than stay locations. Zheng et al. rely greatly on changes in heading, which is not readily available in this study’s dataset. Yuan et al. rely greatly on “characteristic points”, which have not necessarily been established for this study.

The clustering algorithm (Figure 3-5) looks at the trajectory of a set number of points and compares them to identify clusters of activity. An example of the cluster algorithm is outlined below for a set of points. For this sample analysis, it is important to define certain parts of the algorithm. First, there must be a differentiation between displacement and total travel. Displacement is the shortest path between two points, whereas total travel is the actual length of travel between two points. The *K* value shown in Figure 3-6 is the ratio of displacement over total travel that is used for cluster identification. An interval is also established beforehand of how many points are counted from the initial reference point for calculating displacement and total travel. In the below example, this interval is 6 (this value will be greater than 1 and less than the number of points being observed per person – this interval will typically fall within 5 and 15; this allows for a sufficient sample of points to be compared to one another that will be spatially and temporally close to one another; this value is a global parameter for the entire dataset of people; the interval will vary based on the dataset – datasets that cover a smaller spatial area will use a smaller interval). *W* is a distance threshold between clusters that is used for merging adjacent clusters.

1. There is a dataset of coordinates for 3 people: Person A, Person B, and Person C; Person A has the coordinates numbered 1 through 20, Person B has coordinates numbered 21 through 50, and Person C has coordinates numbered 51 through 75
2. Beginning with Person A, coordinates 1 through 20 are sorted in chronological order based on the timestamp associated with the coordinate. A straight line is drawn between point 1 and point 7 (bypassing any points in between), and this distance is calculated (displacement – $D_{1,7}$). Then a straight line is drawn between point 1 and point 2, point 2

and point 3, point 3 and point 4, point 4 and point 5, point 5 and point 6, and point 6 and point 7, and added together to calculate this distance (total distance – $T_{1,2,3,4,5,6,7}$).

3. If the value of displacement ($D_{1,7}$) over total distance ($T_{1,2,3,4,5,6,7}$) is less than *K,* point 1 is identified as part of a cluster and is assigned a cluster ID number of 1. If this ratio is greater than *K,* point 1 is not part of a cluster and is discarded. The process in step 2 is repeated for point 2 ($D_{2,8}$ over $T_{2,3,4,5,6,7,8}$). If point 1 was added to cluster 1 and point 2 is identified as part of a cluster, then point 2 will also be added to cluster 1. If point 1 was not part of a cluster, but point 2 was, then point 2 receives a new cluster ID number of 2. These steps are repeated for all points for Person A until a set of distinct clusters is established for all points.
4. The cluster data for Person A is then sorted in chronological order. The distance between all points in Cluster 1 are measured from all points in Cluster 2 (eg., point 1 in Cluster 1 is measured from points 1, 2, 3, 4, 5, 6, 7, 8, etc in Cluster 2, then point 2 in Cluster 1 is measured from points 1, 2, 3, 4, 5, 6, 7, 8, etc until all measurements are found). If any measurement between Cluster 1's points and Cluster 2's points is less than *W,* then these two clusters are merged into one cluster as they are physically and temporally close to each other. If the measurements are greater than *W*, the clusters are not merged. This process is then repeated for all temporally adjacent clusters for Person A (eg., Cluster 2 is compared to Cluster 3, Cluster 3 is compared to Cluster 4, etc.).
5. Steps 2 through 4 are repeated for Person B and Person C. The results are then exported as a dataset indexed by cluster ID.

Figure 3-6 provides a visualization of this algorithm. As shown, the Euclidean displacement (Green) between the first and last points of 'A' and the total distance traveled (Red) between these same points are very similar, thus indicating that it is not an activity location.

Comparatively, the total distance traveled between the first and last points of ‘B’ is much greater than the Euclidean distance between these same points, indicating it is likely a stop location.

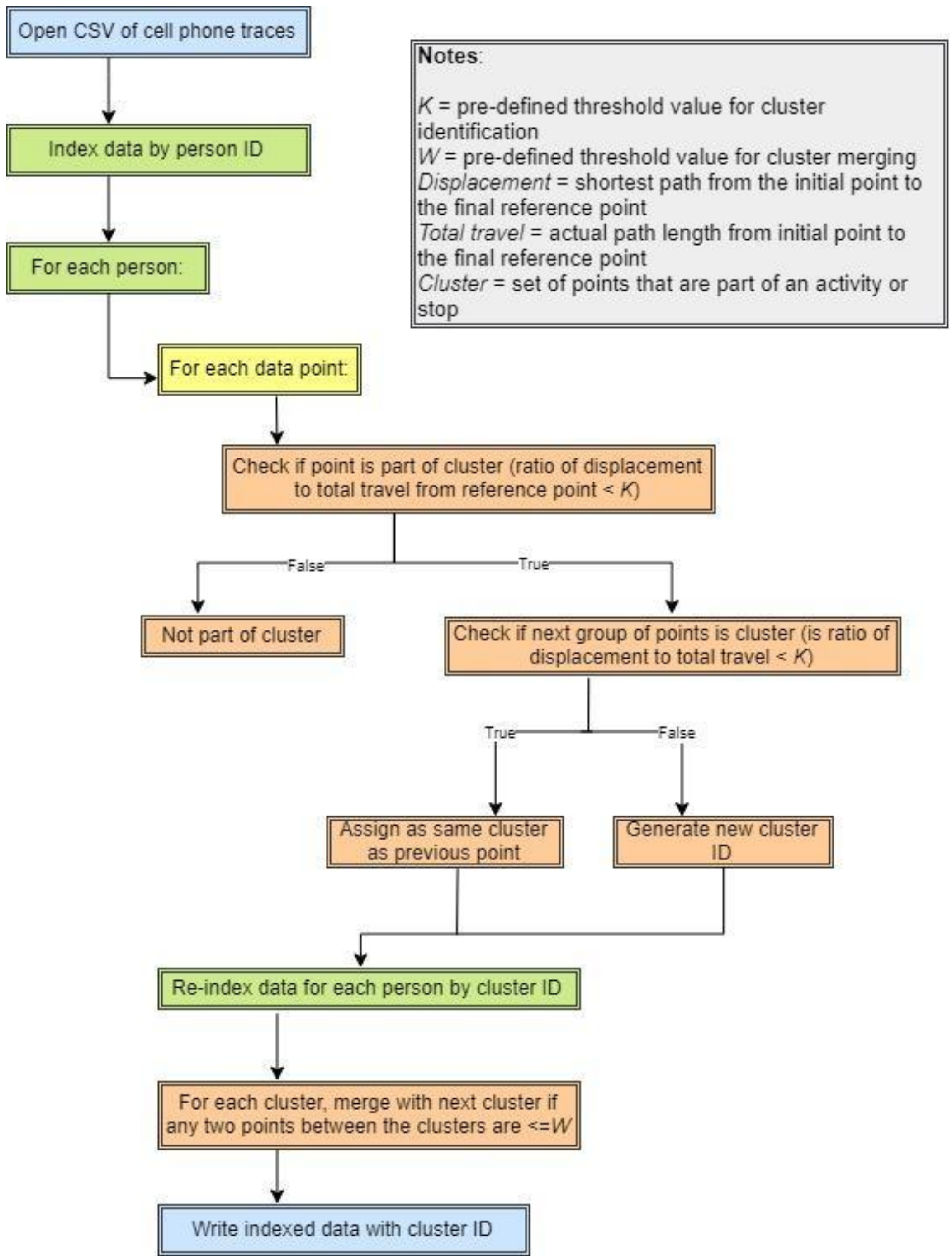

Figure 3-5. Cluster Algorithm. Defining stop activities by grouping GPS points based on comparison of Euclidean Distance versus distance of real path between points.

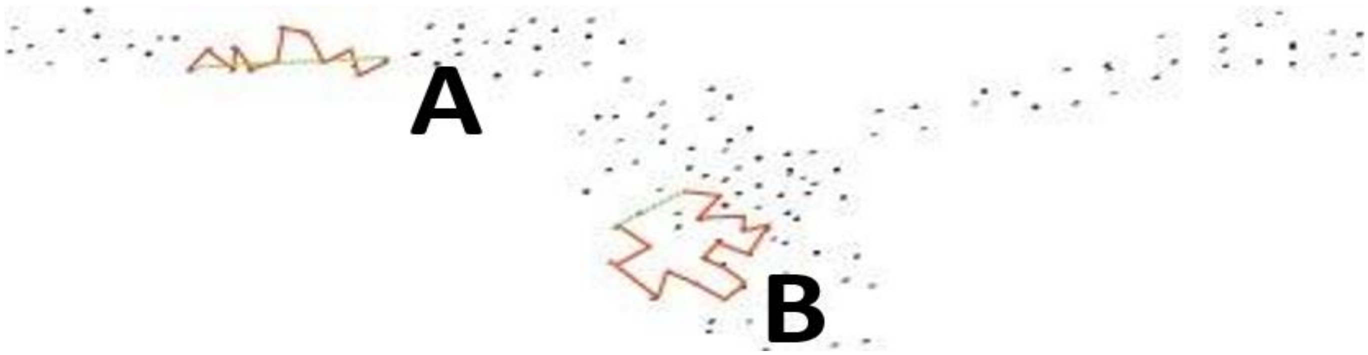

Figure 3-6. Visualization of clustering algorithm. The red line is the total distance and the green line is the displacement.

Preliminary analysis found that there was an over-representation of stop clusters (multiple clusters on a single land use) within the algorithm that could not be mitigated through adjusting iteration or distance threshold values in the algorithm. To address instances of over-representation, an additional threshold was created that analyzes the spatial locations of all points within a cluster and compares them to the spatial location of all points in another cluster (see Figure 3-5) while the initial ratio values and iteration intervals remained constant. Where any point in the first cluster is within a defined distance threshold of any point within the second cluster, the two clusters are combined into a single cluster. This method combines clusters that are spatially very close to each other.

One last step involved a spatial query in ArcMap. The GPS coordinates identified as being in a cluster were converted to a shapefile and a locational query was run where any points that fall within a road polygon shapefile were removed. This was done because there are occasions where high densities of points occurred around roads at intersections or highway interchanges that were in fact false positives, associated with possible problems with GPS accuracy that are plus or minus 10m of their true location. This spatial query removed these false positives.

3.5 Monitoring Indicators

Based on the availability of data from smart-phone collection, the indicators established in the Central Transit Corridor Monitoring Report - transit ridership, daily transit activity, transit mode share, active transportation mode share, walkability, connectivity of active transportation networks, and efficiency of the transit network – were evaluated using the data from the smart-phone app or using external data sources to provide a quantitative measurement of the functionality and value of active and public transportation systems, either within the study area, or larger parts of the Region of Waterloo. Smart-phone data do not differentiate between private vehicles and buses, and so transit usage cannot be monitored using the smart-phone app. These gaps were filled in using data from a variety of sources. The definition of each indicator, its relevance to the study and how it is evaluated is outlined below.

3.5.1 Transit Indicators

All transit indicators except for competitiveness are exclusive of the app-collected GPS data since transit is not a detected mode within WatTrack. Competitiveness uses the activity locations identified through the Python script to provide additional analyses. However, given the focus of monitoring indicators on transit and the effects of ION, transit indicators are still highly relevant to the study. As of February 2017, 12 different transit routes directly serviced Downtown Kitchener. All of these routes with the exception of the Route 20, travel to Charles Street Terminal. There were 74 transit stops in the study area during the study period (Charles Street Terminal counted as one), several of which were detour stops (Grand River Transit, 2017a). Stop activity data for the study period (boardings and alightings) were obtained from GRT. The ridership data are collected via Automatic Passenger Counters (APC) detection. This system automatically counts and records the number of people boarding and alighting a transit vehicle and is utilized in the analyses below. The desirable values for these KPIs and the reason for these desirable values are also outlined below.

3.5.1.1 Transit Ridership

Transit ridership is the number of trips (ie. boardings and alightings) made using Grand River Transit (GRT). This is a common and familiar measurement to the Canadian Urban Transit Association (CUTA) and other transit planning practitioners that clearly indicates transit usage (Metrolinx, 2013; Region of Waterloo, 2016). Transit ridership is expected to increase system-wide following the implementation of ION LRT due to the high-frequency and reliability of the system. Transit service level is linked to ridership increases due to GRT's annual ridership increasing in conjunction with the implementation of iXpress bus services over the past decade. Furthermore, the Region of Waterloo is expecting significant population growth which is also linked to increases in ridership. As such, transit ridership is a key indicator for analysis (Region of Waterloo, 2016). Using APC data, the total average number of boardings and alightings per stop that occurred daily were calculated for the study period. As of 2016, total transit ridership on GRT was 19,691,267 (Region of Waterloo, 2016). Overall, transit ridership has been decreasing since 2013 (ridership was 22,000,737 in 2013). The CTC Monitoring Report identified the possible reasons for this decline may include service impacts from construction detours, fare increases, the loss of school board funded high school trips, lower fuel prices, and shifts to ride-sharing services. Therefore, in order for the KPI to be considered to be improving, total transit ridership must increase.

As per the Regional Transportation Master Plan (RTMP) and the GRT Business Plan, the preferred transit ridership target for 2021 is 28,000,000 and the preferred transit ridership target for 2031 is 53,000,000. These values were determined based on stakeholder feedback, as well as the anticipated growth identified above (Region of Waterloo, 2011; Grand River Transit, 2017c). As of 2016, total transit activity in the CTC represents about 63% of total ridership for GRT (approximately 13,860,464) (Region of Waterloo, 2016). Assuming the proportion of ridership remains similar over the next several years, the total ridership within the CTC by 2021 should be around 17,640,000 and total ridership within the CTC by 2031 should be around 33,390,000. The intervals at which ridership will increase are not defined, and the largest ridership increases will likely occur after ION operation begins, but the ridership at least should be increasing during the period leading up to ION introduction to meet the target ridership. Since ridership is an annualized value, it cannot be fully evaluated within this thesis' cross-sectional study period. Therefore, the daily transit activity outlined below will be more indicative of the KPI's progress toward the 2021 ridership target.

3.5.1.2 Daily Transit Activity

Daily transit activity is the percent of daily average (mean) transit activity which occurred in the CTC. It is the sum of all daily boardings and alightings from all active transit stops that is averaged over the number of days for which data were collected. As of 2016, there were an average daily transit trips of 182,215 daily boardings and alightings on GRT. The percentage of transit activity that occurs in the CTC is indicative of the required investment in transit infrastructure. As such, in 2016, the percentage of transit activity that occurred within the CTC was 63%, (about 114,625) and this value is only expected to increase with the implementation of the ION LRT (Region of Waterloo, 2016). The percentage of transit activity that occurred in the study area was also calculated as a comparison to the total CTC activity. In order for the KPI to be considered to be improving, daily transit activity must increase. There is no defined target value for daily transit activity within the CTC Monitoring Report, the GRT Business Plan, or the RTMP. However, the values are related to total ridership, and so values that are increasing from the baseline 2016 transit trip number of 182,215 are indicative of progression toward the 28 million rides target in 2021.

3.5.1.3 Transit Mode Share

Transit mode share is the percent of total trips made within an analysis area which was on transit. The percentage of the total trips that utilize sustainable modes of transportation that are utilized in the Region of Waterloo is quite low, accounting for only about 15%, with transit only representing 5%. In accordance with the RTMP, the mode share for transit is anticipated to increase with the implementation of the LRT and complementary express and local bus routes (Region of Waterloo, 2016). As per the RTMP, the target mode share for transit is about 13% by 2021 and 17% by 2031. These values were determined based on stakeholder feedback, as well as the anticipated growth identified previously (Region of Waterloo, 2011; Grand River Transit, 2017c). An increase in transit mode share indicates that transit resources have been properly allocated, and that more sustainable transportation is being adopted over private auto use. Mode share cannot be calculated from the resources in this study, but it is assumed that if transit ridership has increased, so has the mode share, and if transit ridership has decreased, then so has the mode share, given that trends have followed this model for the years that have been monitored in the CTC Monitoring Report, and transit service has not changed significantly in the CTC since the Monitoring Report was established. There is the potential for ridership to increase while mode share decreases but given previous years where both have gone up or down in synchronicity, it is assumed that if one increases, so will the other.

3.5.1.4 Competitiveness

Competitiveness has not been discussed beyond identification as an indicator in the CTC Monitoring Report. The intent of the LRT is to serve as a central spine with frequent, cross-town routes connecting to this spine. As such, bus routes are planned to be streamlined, in accordance with GRT’s New Directions principles (Grand River Transit, 2017c): seamless connections to ION, new express routes running on key corridors, more frequent service on busy routes, more direct routes supporting a grid network, integrated fares, and improved rider amenities such as shelters. These principles dictate route planning that will be implemented with the launch of ION in 2018.

Transit competitiveness was measured in this study based on the quality of experience for a user as opposed to operational efficiency (eg. Passengers per vehicle, etc), due to the categorization of competitiveness as a mobility indicator in the CTC Monitoring Report (where competitiveness is labeled as “efficiency”). In essence, transit competitiveness in this thesis is how travel times by transit in the Region of Waterloo compare to those by private car. Competitiveness is measured as the proportion of transit routes that currently provide service between an origin destination pair for which the ratio of transit travel time to auto travel time is less than a threshold. Naturally, the proportion of routes that are providing competitive service will increase as the Region implements its New Directions principles that recommend increased directness and higher frequency. The origin and destination of participants dictate whether a participant has a direct and frequent route to and from these locations, and where improvements would be needed to provide competitive service to these participants. (See Appendix D for a map of the route configurations as of February 2017).

Directness implies that the travel time by transit is comparable to travel by car, where comparable, as discussed in Chapter 2, is a value choice transit riders would consider acceptable in order to switch from their personal vehicle in favour of public transit. There is no precise value that has been developed, but for the purposes of this study, a comparable travel time by transit would be no greater than 50% longer than travel time by car. In other words, a 10-minute trip by car should be no longer than 15 minutes by transit, or a 20-minute trip by car would be no longer than 30 minutes by transit. This obviously will not be applicable to all routes in the Region, but it presents a major issue with persuading choice transit riders to use public transit, because there is no clear benefit to riding transit if it takes them significantly longer. 50% was chosen as a rough estimate based on Wardman’s (2004) conclusion that valuation of in-vehicle travel time is roughly 50-60% less valuable when taking transit. This value was established based on two assumptions:

- Transit riders valuation of time is less than private drivers, so longer trips are more acceptable on transit trips than car trips, and
- Transit riders expect travel on transit to take longer. 50% longer is typical.

These assumptions are supported by the statements of: “The variations in the values of IVT and OVT according to mode are as expected. The ordering valuations is air, rail, car, and bus, and the values for the combined modes are largely consistent with the values for the modes separately.” (Wardman, 2004), and “...where public transportation is most prevalent, commutes average 1.5 times longer than driving (about 15 minutes).” (Maciag, 2017). Therefore, since it is expected and accepted that transit will take longer, to a certain extent, slightly longer transit trips are comparable to shorter driving trips due to in-vehicle-time (IVT) valuation. Therefore, adopting the average difference in travel time between transit and car of 50% will be representative of a comparable trip.

The origin and destination of participants outside the study area were identified using the Python script and assessed as to whether a participant has a direct and frequent route to and from these locations to the Downtown. As stated previously, there are 12 transit routes that service Downtown Kitchener. Each route’s attributes is outlined in Table 3-1. Isochrones were developed for peak times for each of these routes, with the study area boundary serving as the origin points, as well as another set of isochrones for travel by car, which can be seen in Chapter 4. Another set of isochrones was also developed for future transit service, which can be seen in Chapter 4.

Isochrones were created using a network dataset in ArcGIS that allowed for a Service Area calculation to be completed. An average route in the GRT network operates at an average speed of about 16km/h (this includes stops – value is established from internal assumptions GRT uses (personal communication from GRT staff)). The time interval of interest is then used to calculate the typical distance a route could travel in that time at that speed. For example, a 5-minute trip would get about 1800m away from a destination at a speed of 16 km/h. For bus trips in the study area, a network dataset of current bus routes was used in a Service Area calculation, and the desired distance for a certain time interval was used as the Impedance value in the Analysis Settings of the Service Area calculation to limit the polygons produced to traversable paths by bus and trimmed to a 450m buffer (a typical 5-minute walk). This same process was used with another network dataset of future route configurations. Isochrones for driving followed a similar process, but the average speed assumed was 21.5km/h (established from route travel time estimates from Google Maps) and the network dataset was made of roads. The polygons were once again trimmed to 450m.

Where the travel time is significantly greater (outlined further in Chapter 5) by transit – excluding time to travel to a bus stop - than it is by car, it is not considered competitive. Further, where service is limited, either in frequency or span of service, it is not considered competitive. Daily variations in service will also dictate whether a location has consistent competitive service or not. Lastly, if a transit stop is outside a 450m (about 5 minute) walk distance, it is not considered connected. No threshold has been established within the monitoring report of what proportion of transit trips should be comparable to driving trips, so this KPI is simply established as a benchmark value for the purposes of this thesis, where the current number of comparable trip times are identified. In future, the number of transit trips with comparable travel times to driving trips should increase.

Table 3-2. Downtown Kitchener Transit Connections. (Source: Grand River Transit, 2017a)

Route #	Route Name	Connections	Corridor(s)	Headways	Days of service/ span of service
1	Queen-River	Boardwalk shopping centre Charles Street Terminal Stanley Park Mall Fairview Park Mall	Midtown Kitchener	Mon-Fri Peak 15 min Mon-Sun Base 30 min	Mon-Sat 6am-1am Sun 8am-1am
2	Forest Heights	West Kitchener residential Charles Street Terminal	Midtown Kitchener	Mon-Sat 30 min	Mon-Fri 6am-10pm Sat 8am-10pm
3	Ottawa South	Charles Street Terminal GRT Strasburg Garage Forest Glen Plaza	Central and southwest Kitchener	Mon-Fri Peak 15 min Mon-Sat Base 30 min Sun 60 min	Mon-Sat 6am-1am Sun 10am-7pm
4	Glasgow	Charles Street Terminal Grand River Hospital Boardwalk shopping centre	Central and northwest Kitchener	Mon-Fri 30 min Mon-Fri evening 60 min Sat 60 min	Mon-Fri 6am-12am Sat 7am-11:30pm
6	Bridge	Charles Street Terminal Lancaster Street commercial & residential Conestoga Mall	East Kitchener East Waterloo	Mon-Sat 30 min Sun 60 min	Mon-Sat 6am-12am Sun 8am-11pm
7	Mainline	Fairview Park Mall Charles Street Terminal University of Waterloo/Laurier University Conestoga Mall	Central Transit Corridor	Mon-Fri 7 min Mon-Fri evening 15 min Sat 15 min Sun 15 min	Mon-Fri 5am-1am Sat 5:30am-3am Sun 8am-1am
8	Conestoga Mall- Fairview Park	University of Waterloo/Laurier University Belmont Village Sunnyside Home Fairview Park Mall	Central Transit Corridor	Mon-Sun 15 min with some variation	Mon-Sat 6am-1am Sun 7:30am-12am
11	Country Hills	Charles Street Terminal Country Hills neighbourhood Forest Glen Plaza	Central and southwest Kitchener	Mon-Fri Peak 15 min Mon-Sat Base 30 min Sun 60 min	Mon-Sat 6am-12am Sun 8am-12am
20	Victoria-Frederick	Boardwalk shopping centre Downtown Kitchener Eastern Kitchener	North Kitchener	Mon-Fri Peak 15 min Mon-Sun Base 30 min	Mon-Fri 5:30am-12:30am Sat 6am-12:30am Sun 8am-12am
22	Laurentian West	Charles Street Terminal Forest Glen Plaza Sunrise Shopping Centre Highland Hills Mall	Central and southwest Kitchener	Mon-Fri 30 min Sat-Sun 60 min	Mon-Fri 6am-11pm Sat 7am-8pm Sun 10am-7pm
200	iXpress/aBRT	Ainslie Street Terminal Cambridge Centre Terminal SmartCentres Cambridge	Central Transit Corridor	Mon-Fri Peak 10 min Mon-Sat Base 15 min Sun 30 min	Mon-Fri 5:30am-12am Sat 8am-12am Sun 8am-10pm

Route #	Route Name	Connections	Corridor(s)	Headways	Days of service/ span of service
		Sportsworld Crossing Fairview Park Mall Charles Street Terminal Uptown Waterloo University of Waterloo/Laurier University R&T Park Conestoga Mall			
204	Highland-Victoria iXpress	Boardwalk shopping centre Charles Street Terminal Lackner Centre	North Kitchener	Mon-Fri 15 min Sat-Sun 30 min	Mon-Fri 6am-12:30am Sat 6:30am-12:30am Sun 8:30am-10:30pm

183 unique origins/destinations (general aggregated regions) within the Region of Waterloo were identified from the GPS trace outside the study area, and 64 of those were part of a trip that connected to Downtown Kitchener (outlined further in Chapter 4). These locations were compared to the above outlined transit routes as to whether an competitive link exists between that location outside the study area and Downtown Kitchener, and, where there is not an competitive link, whether the proposed network redesign of GRT's transit network will provide a new competitive link.

3.5.2 Active Transportation Indicators

3.5.2.1 Active Transportation Mode Share

The indicator for active transportation is the percent of total travel which was pedestrian and cyclist. Total travel is the number of trip segments (defined as travel between activities) identified from the GPS points. This indicator is measured differently from transit mode share in terms of both the numerator and denominator as the transit calculations are based on data other than GPS. Therefore, the mode share of active transportation users can be calculated in the context of the study participants in the study area, as opposed to the entire Region. As with the transit mode share, active transportation only accounts for a small portion of the modal split in the Region of Waterloo, and an increase in active transportation mode share indicates that active transportation resources have been properly allocated, and that more sustainable transportation is being adopted over private auto use. In accordance with the RTMP and Regional Official Plan (ROP), the mode share for active transportation is also anticipated to increase with improved and increased connections to the LRT and additional complementary infrastructure (Region of Waterloo, 2016).

This indicator was evaluated as follows. The number of discrete active transportation users (walking, cycling) was calculated using the mode detection algorithm built into the smart-phone app. The total detection for the study period was calculated, as were daily averages. As per the RTMP, the target mode share for active transportation by 2031 is 12%. This target value was determined based on stakeholder feedback, as well as the anticipated growth identified previously (Region of Waterloo, 2011; Grand River Transit, 2017c). This value is for the entire Region of Waterloo, and so the mode share for active transportation in the CTC and Downtown Kitchener is likely to be higher.

3.5.2.2 Walkability

The indicator for walkability as defined by the CTC Monitoring Report is the percent of the population living in "high" or "very high" walkable areas. Walkable areas are those with high density residential, a mix of land uses, and grid-like and small blocks. More walkable areas lend themselves to increased active transportation and the availability of more efficient and effective transit services. Over half of the population within the CTC is considered to be in a walkable area, and the ION is intended to be pedestrian-accessible (Region of Waterloo, 2016).

For the purposes of this study, walkability was scoped down to a comparison of the detected chosen paths of pedestrians during the study period versus the presence or absence of sidewalks in order to test the hypothesis that more walkable areas (ie., those with sidewalks) would have higher pedestrian traffic. More specifically, by demonstrating that the largest proportion of walking trips occur on sidewalks, there is increased evidence that introducing more and more connected sidewalk infrastructure will likely generate more pedestrian trips and greater walkability. Figure 3-7 illustrates locations in the study area that have sidewalks (blue) or do not have sidewalks (black). (Region of Waterloo, 2017).

This indicator was evaluated using the GPS and GIS data collected by comparing the presence or absence of sidewalks to the paths chosen by participants identified as pedestrians in Downtown Kitchener.

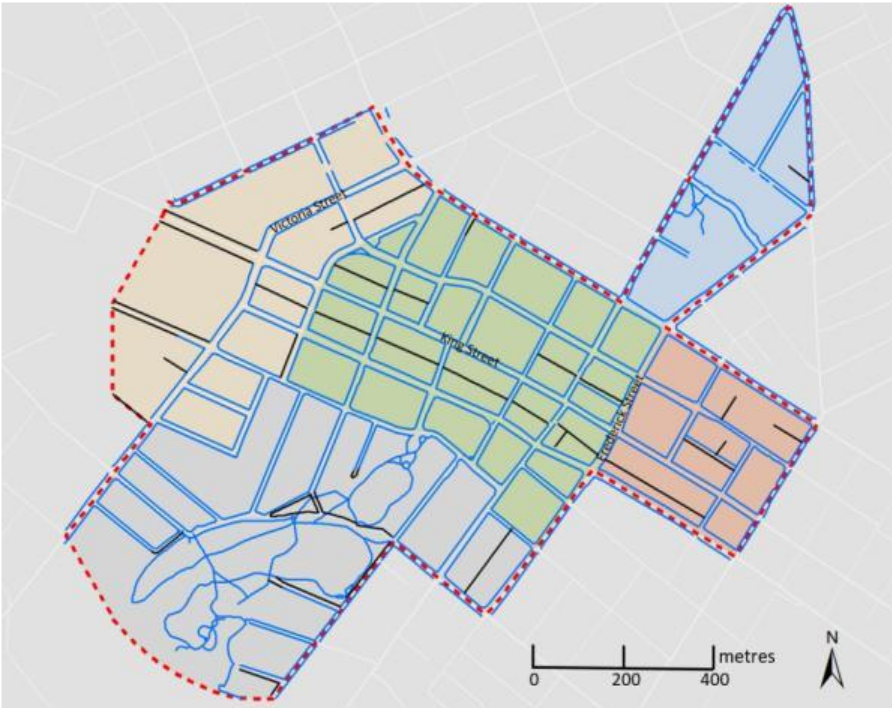

Figure 3-7. Location of sidewalks within the Downtown Kitchener study area. Blue indicates the presence of a sidewalk, while black indicates the absence of a sidewalk. Breaks in lines indicate a crossing or driveway. (Source: Region of Waterloo Open Data)

3.5.2.3 Connectivity of Cycling Network

Lastly, the connectivity of active transportation systems was identified within the CTC Monitoring Report as an indicator, but the methodology and purpose have not been identified. For the purposes of this study, active transportation systems were not analyzed; connectivity is limited to the cycling network: locations with multi-use trails, bike lanes, and other cycling infrastructure. Sidewalks are not included as they are assessed in the walkability section of this study

Connectivity is a unitless ordinal measure of accessibility independent of distance. In essence, a well-connected cycling network allows for multiple path options to be taken by cyclists, which will allow for them to modify their travel based on personal preference and needs. This lends itself to increased cycling activity. This is a difficult measure to compute, because for any given origin destination pair, even those that are relatively proximate, a very large number of alternate paths can exist.

Instead, for this thesis, an indicator was evaluated by developing a connectivity index (see Figure 3-8) that answered the following question: for any given node in the study area, how many links exist that provide direct connections to other nodes. Connectivity is based on topological connectivity – the number of direct paths or steps separating two nodes, a method of measurement for connectivity of transport systems that has been previously established amongst other connectivity indices and graph theory (Ducruet & Rodrigue, 2017). Topological connectivity may have varying Euclidean distances between nodes. For example, in Figure 3-8, only two links emerge from node C – connections to nodes A and D; there are five links emerging from node D – connecting to itself and all other nodes in the diagram. In this thesis, node C would have a connectivity index of 2, while node D has an index of 5.

A connectivity or adjacency index (see Figure 3-9) was developed using a network dataset in ArcGIS of all trails and cycling infrastructure in Downtown Kitchener to create junction points (nodes) to create a connectivity matrix of these nodes. The maximum connectivity value assigned to a node was 5, indicating a high level of connectivity at these locations. To analyze the network, the following additional observations are made. A second value is attributed to each node that reflects the observed volume of cycling trips that traverse that node (incidents).

If a GPS point labelled as a cyclist was part of a segment of travel that crossed a specific node, this point was attributed to that node it crossed, and the number of incidents were summed (the number of incidents per node ranged from 1 to 166). These assigned values are outlined in Chapter 4. A linear correlation was calculated for the connectivity index value of a node and its incidents count (see Equation 1).

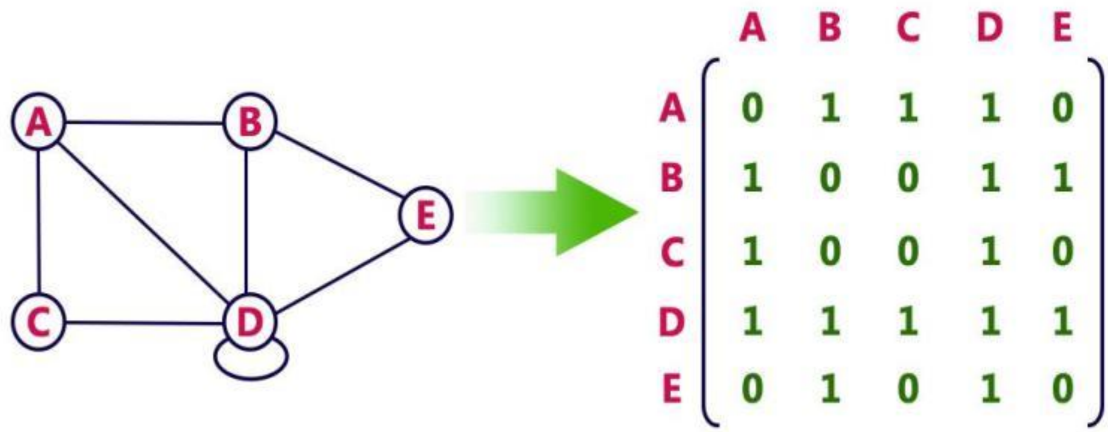

Figure 3-8. Creation of a connectivity index. (Source: http://btechsmartclass.com/DS/U3_T9.html)

$$r = \frac{\Sigma\,(x-\bar{x})(y-\bar{y})}{\sqrt{\Sigma\,(x-\bar{x})^2\,\Sigma\,(y-\bar{y})^2}}$$

where
$x = value\ from\ Array\ 1$
$y = value\ from\ Array\ 2$
$\bar{x} = average\ of\ Array\ 1$
$\bar{y} = average\ of\ Array\ 2$

Equation 1. Correlation coefficient equation. Array 1 is the number of incidents that occur per facility. Array 2 is the connectivity value per facility.

Figure 3-9. Connectivity of active transportation network

3.6 Policy Analysis

The CTC Community Building Strategy was developed as part of the Region of Waterloo's rapid transit initiative to help shape the community around rapid transit stations. It provides the vision for the community and prescribes the creation of station area plans by each of the three cities. This is where the development of the Planning Around Rapid Transit Stations initiative by the City of Kitchener was introduced to respond to place-specific community concerns, and guide infrastructure and resource investment for station area development. These two documents serve as the main framework for assessing the monitoring indicators in the study area. Where the indicators identify deficiencies, the CBS and PARTS were checked to determine if these policy documents have planned solutions for these deficiencies. These documents are also analyzed to determine if policies have been successfully implemented and are represented in the indicators.

The Region of Waterloo's Central Transit Corridor Community Building Strategy provides the Region's long-term community planning strategy. The CBS outlines the CTC existing conditions, key community building opportunities, transit-supportive frameworks, place-specific initiatives, station area snapshots and planning, parking strategies, priority initiatives, and implementation initiatives. The strategy provides higher level planning strategies that guide the station area plans for each of the Region's cities. The station area snapshots and the place-specific initiatives and implementation initiatives are the most relevant sources in the CBS for addressing any places within the Downtown Kitchener study area that do not currently meet the rapid transit initiatives. The station area snapshots provide summaries of all stations along the CTC from Ainslie in south Cambridge to Conestoga in north Waterloo. The relevant snapshots for this study are Cedar, Frederick/Benton, Young/Gaukel, and King/Victoria (Transit Hub). These snapshots outline existing policy framework, the future transportation network, and the plans for the station area and how that plan may be supported. The place-specific opportunities section catalogues areas in the study area that would benefit from streetscaping, connections, and integration with LRT. The implementation plan for these opportunities is also key in identifying the extent to which the CBS has provided solutions in the study area where transit and active transportation-supportive initiatives must be developed.

The PARTS plan is the City of Kitchener's station area plan for the CBS. When analyzing potential shortcomings in Downtown Kitchener through the travel survey and other data appraisal, the PARTS plan will provide a vision for how these shortcomings may be addressed specific to the City of Kitchener. The City of Kitchener's PARTS plan was initiated in 2013 and continues to be prepared and refined. The plan includes 5 station study areas: Central Station Study Area, Midtown Station Study Area, Rockway Station Study Area, Fairway Station Study Area, and Block Line Station Study Area (see Figure 3-100). For the purposes of this study, only the Central Station Study Area Plan applies. The plan includes the study area background and consultation process, existing conditions, ION stop profiles, vision and objectives, the preferred plan, streetscape profiles, parks and public realm vision and analysis, public art recommendations, transportation demand management strategies, transportation network existing and planned conditions, engineering infrastructure, and an implementation plan. In addressing any shortcomings identified through this travel survey study and data appraisal, the TDM strategies and transportation network conditions are most relevant, in addition to the park and public realm vision, streetscape profiles, and public art recommendations providing further opportunities for wayfinding and connectivity strategies.

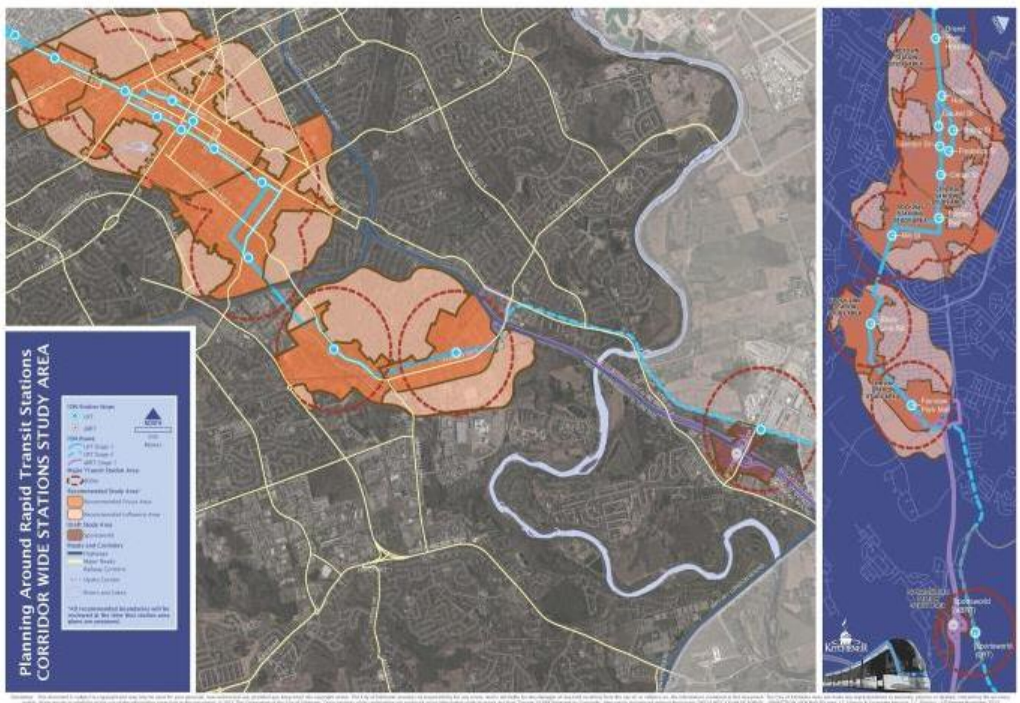

Figure 3-10. PARTS study areas. (Source: City of Kitchener, 2016)

3.7 Data Consolidation

In addition to the analysis in Chapters 4 and 5, the multitude of data collected through this study are displayed through visualizations to emphasize the overall travel patterns and results of this study. Heat maps were made for all travel in the Downtown area, as well as for cyclist and pedestrian travel only. These illustrate how much travel occurring in the Downtown is via active transportation. As well, summary charts of the major demographic data collected from survey respondents provide concise results of the demographic makeup of this study, and are provided in Appendix A.

3.8 Chapter Summary

This chapter provides context of the different political, social, and geographical characteristics of Downtown Kitchener and the methods used to analyze travel patterns in Downtown Kitchener. Qualitative and quantitative data are collected from participants related to their demography and travel behaviour through the WatTrack app, which passively records location and time information for volunteers in the study, and an optional supplementary demographic survey. The data are then run through an automated Python script that identifies activity locations in each tour that occur within the Downtown Core. The spatial and demographic data are then assessed in comparison to the Region of Waterloo's Central Transit Corridor Baseline Monitoring Report (2015). Lastly, the data are assessed in comparison to the Region of Waterloo's Central Transit Corridor Community Building Strategy (CBS) and the City of Kitchener's PARTS document where deficiencies within the monitoring indicators are found and determined if these policy documents have solutions planned for these deficiencies. All these data will be presented both in text and visually. The effect of these characteristics on the results of this study will be discussed further in Chapter 4 and 5.

Chapter 4 Findings and Analysis

In this chapter, the results of the WatTrack participants and external data consolidation are summarized and analyzed. These results are compared to the quantitative and qualitative transportation indicators as established by the Region of Waterloo's Central Transit Corridor Monitoring Report and described in Chapters 3 and the relevant policy documents.

4.1 Summary of Key Findings

Table 4-1. Summary of GPS data

Participants	Detected stops outside study area	Detected unique stops within study area	Detected trip segments connecting to or within study area	Unique locations outside study area with travel connecting to study area
40	183	26	504	64

25 participants completed the demographic survey. Overall, the average respondent resided outside the study area, although it is roughly even if they worked within or outside of the study area. Male and female respondents were equally represented, while the majority of respondents were between 18 and 29 years old. All respondents had a minimum of a post-secondary education. There were a range of occupation types, with Student being highest, followed by Computers and Technology, then Sales and Services and related, then Health/Education and related, and Other. Personal income also varied, with the most common range falling under $40,000, while still having respondents with personal income over $100,000. The majority of respondents lived in a single-detached home, while the remainder resided in a range of different dwelling types. Respondents typically had large households, with the majority of households having 4 or 5 people (it is not known if these people are related). Most respondents had at least one vehicle for personal use, while about a third had no vehicle. Most respondents travelled to the CTC by transit or personal vehicle; all other modes were represented. Most travel to the CTC was for work or shopping. Lastly, respondents claimed to typically complete 2 activities in

one trip to the CTC (weekday and weekend travel were not differentiated). These demographic results are outlined in detail in Table 4-2 below and in Appendix A.

Table 4-2. Summary of study participants' survey responses

Demographic Question	Results
Residence Location	64% - Outside Downtown 36% - Inside Downtown
Employer Location	48% - Outside Downtown 44% - Inside Downtown 8% - N/A
Gender	52% - Female 48% - Male 0% - Other
Age	52% - 18-29 24% - 30-39 12% - 40-49 12% - 50-59 0% - 60-64 0% - 65+
Highest Completed Level of Education	80% - Post-secondary 20% - Graduate education 0% - No certificate, degree or diploma 0% - High school diploma or equivalent 0% - Other
Employment Type	68% - Full-time 20% - Student 8% - Part-time 0% - Seasonal/Freelance 0% - Retired 0% - Not employed
Occupation Type	35% - Student 30% - Computers and Technology 15% - Sales and Services and Related 15% - Other 5% - Health/Education and related 0% - Construction/Manufacturing and related 0% - Agriculture, forestry, fishing and related 0% - Retired 0% - Not employed
Personal Income (before tax)	32% - Under $40,000 24% - $60,000-79,999 16% - $40,000-59,999 16% - $80,000-99,999 12% - $100,000+
Dwelling Type	44% - Single-detached house 24% - Apartment 16% - Townhouse 8% - Semi-detached/duplex 8% - Condo 0% - Other
Number of people in household	33% - 5 people

Demographic Question	Results
	27% - 4 people 20% - 3 people 13% - 2 people 7% - 1 person 0% - 6+ people
Number of minors in household	46% - N/A 42% - 0 minors 8% - 2 minors 4% - 1 minor 0% - 3+
In possession of a driver's license	84% - Yes 16% - No
Number of members of household with a driver's license	48% - 2 people 20% - 1 person 12% - 3 people 8% - 4 people 12% - N/A
Number of vehicles for personal use	52% - 1 vehicle 28% - no vehicle 8% - 2 vehicles 8% - 3 or more vehicles 4% - N/A
Frequency of Travel to CTC	32% - Multiple times daily 32% - Dailly 12% - Several times a week 12% - Several times a month 8% - Weekly 4% - Less than once a month 0% - Monthly 0% - Never
Transportation Mode to CTC	36% - Transit 28% - Personal vehicle 20% - Walk 8% - Cycle 4% - Taxi/Uber 4% - Carpool 0% - Other
Purpose of Travel to CTC	26% - Work 23% - Shopping 16% - Residence 13% - Visiting others 10% - Other 6% - School 6% - Volunteering
Activities completed in CTC	48% - 2 activities 20% - 1 activity 12% - 3 activities 12% - 5+ activities 4% - 4 activities 4% - N/A

The general travel patterns of pedestrians, cyclists, and all travel (the combination of all pedestrian, cyclist, and vehicle travel detected) are shown in Figure 4-1, Figure 4-2, and Figure

4-3 respectively, each indicating the different patterns for weekend versus weekday (except cycling; no cycling occurred on weekends). All travel data were used equally. That is to say, the GPS points from a person that provided 12 hours of data were weighted the same as a person that provided 4 weeks of data; however, the large amount of data from certain individuals create more defined patterns than those with short periods of data. Aside from residential locations, the major activitiy locations include Charles Street Terminal, several office employment locations, the Lang Tannery, Region of Waterloo Administrative headquarters, and Market Square. It would appear that the majority of travel is associated with home to work travel as opposed to leisure-based travel, which is to be expected and is consistent with the demographic survey, although there are marked differences in travel from weekdays to weekends. In general, there was much less travel in the study area on weekends. The most frequented paths for all modes were King Street between Frederick and College, Queen Street North and South, Jubilee Drive, and Victoria Street South between Park and King (see Figure 4-3), all of which are direct travel paths as opposed to leisurely paths.

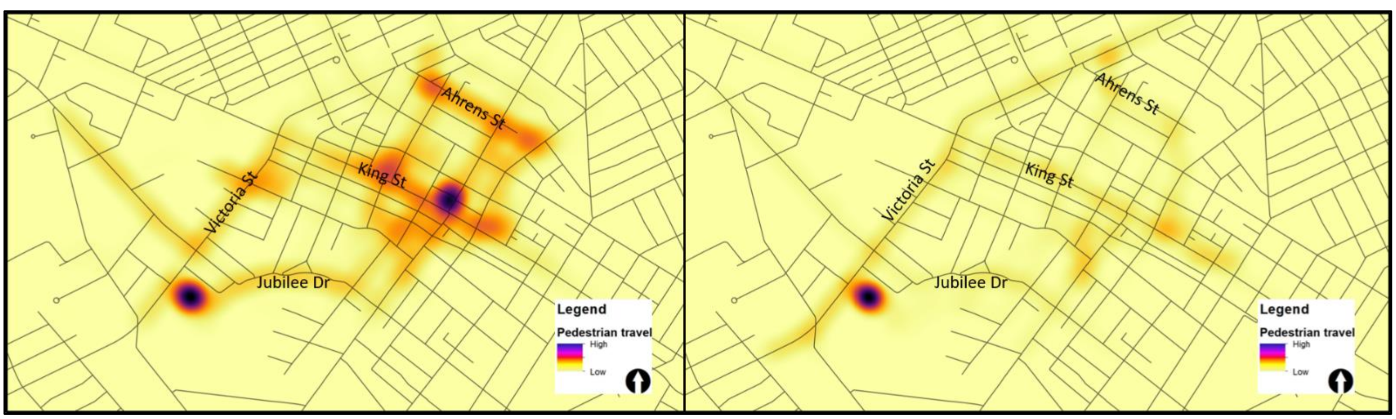

Figure 4-1. Pedestrian travel in Downtown Kitchener – Weekday vs. Weekend

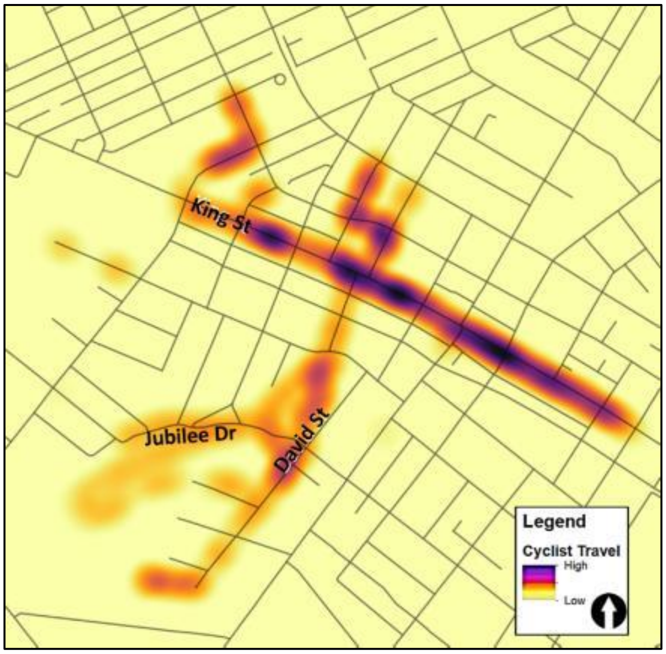

Figure 4-2. Cyclist travel in Downtown Kitchener – Weekday

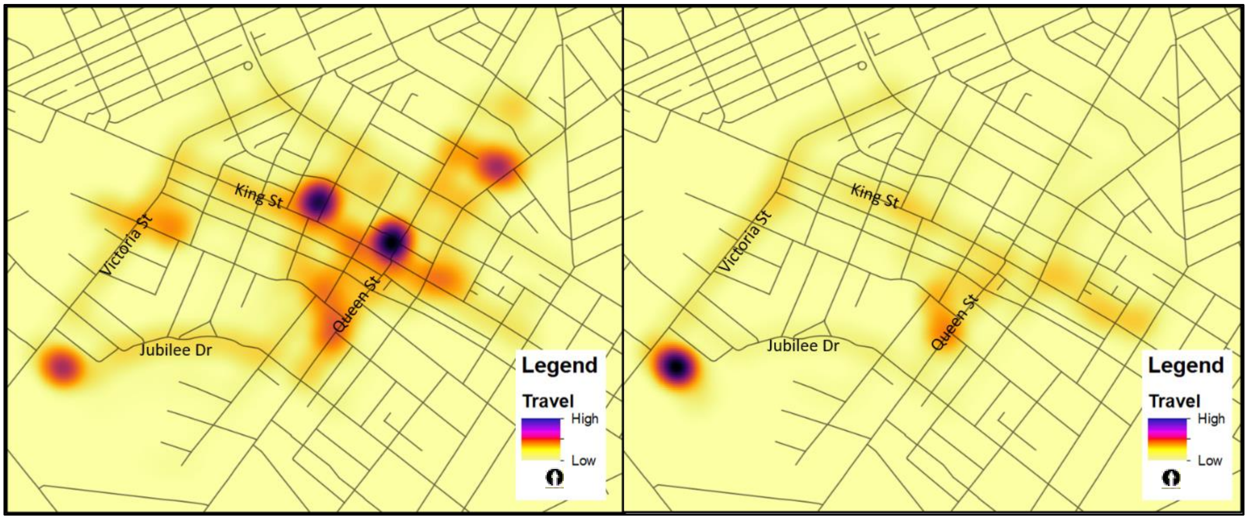

Figure 4-3. Total travel in Downtown Kitchener – Weekday vs. Weekend

4.1.1 Findings of Indicators

The findings of the different monitoring indicators that have been previously identified are outlined below.

4.1.1.1 Transit Ridership

Total ridership for the year could not be calculated as the period of study for this thesis is too brief. However, transit ridership in the study area (see Figure 4-4) during the study period was quite high, with a mean of about 140 boardings, 120 alightings, and 260 total activities at each stop daily, and a median of about 8 boardings, 9 alightings, and 20 total activity at each stop daily (see Appendix E for full summary of activity). The maximum boardings occurred at Charles Street Terminal EasyGO stop #2548 with 833 daily boardings, which is served by the 200 iXpress traveling to Cambridge. The maximum alightings occurred at Charles Street Terminal EasyGO stop #2549 with 590 daily alightings, which is served by the 200 iXpress to Waterloo. The minimum boardings (excluding those with a value of 0, where the trip ends at Charles Terminal) occurred at Weber Street and Ontario Street EasyGO stop #2502 with 2.5 daily boardings, which is served by the Route 4 toward Charles Street Terminal, and Route 20 toward Stanley Park Mall. The minimum alightings occurred at Benton Street and Courtland Avenue EasyGO stop #2714 with 0.7 daily alightings, which is served by the Route 3 toward Forest Glen, and Route 8 toward Fairview Park via Courtland.

It is not surprising that the highest activity occurs at Charles Street Terminal. It serves as a hub for transfers between many routes, including inter-city service, and serves as the terminus for several routes. Further, it is to be expected that the lower ridership activity occurs at locations in close proximity to the Terminal, as it would be inefficient for most riders to board or alight a bus at another location unless they do not need to transfer, or their origin/destination is adjacent to the bus stop. The Terminal serves riders better overall due to its high level of transit service and options, amenities, and transit information.

Figure 4-4. Bus stop activity in Downtown Kitchener

This distribution of transit activity will change significantly with the launch of ION light rail in 2018. Charles Terminal will be largely phased out. The majority of transfers will occur on street at ION stations until the completion of the multi-modal transit hub at Victoria Street and King Street by 2022, and fewer routes will end Downtown.

4.1.1.2 Daily Transit Activity

The benchmark value for daily transit activity in the Region of Waterloo was 182,215 boardings and alightings in 2016 and 114,625 boardings and alightings in the CTC in 2016. There were about 20,000 average daily boardings and alightings in Downtown Kitchener during the study period, or about 11,000 daily average boardings and 9000 daily average alightings. In addition, there were about 57,000 daily boardings and 57,000 daily alightings on average in the entire CTC during the study period for a total of 114,000 total boardings and alightings, marking similar daily transit activity to the 2016 value. Overall, activity in the CTC represents around

62% of total boardings and alightings in the entire Region of Waterloo, 1% lower than the activity from 2016 (Grand River Transit, 2017b). This is likely due to several reasons. Firstly, there was a large amount of ION-related construction taking place during the study period, resulting in road closures and bus route detours that either shifted people to streets outside the study area/CTC or deterred people from using transit. These situations were mentioned in local news articles, referring to the construction as “some pain”, and “bottlenecks” (CTV Kitchener, 2015; Desmond, 2015). Secondly, service continues to increase in areas outside the CTC that improves the ability of travelers to travel in areas outside the study area/CTC. Activity within the study area only makes up about 12% of total daily transit activity in the Region.

4.1.1.3 Transit Mode Share

As transit cannot be detected in the app, the mode share for the study participants in the study area is not calculated, and the following calculation is not associated with the collected GPS data. Given that ridership and daily transit activity within the CTC have decreased by 1% since 2015, it is likely that the mode share for transit for the CTC has either decreased or remained similar to the 5% reported in 2015. Yet, given the high ridership in the study area and the transit service in Downtown Kitchener, it is likely that the overall mode share in Downtown is higher on average than in the CTC in general and is likely supportive of achieving the target of 13% transit mode share by 2021.

4.1.1.4 Competitiveness

While transit cannot be detected as a mode within the WatTrack app, the presence or absence of an competitive bus route between Downtown Kitchener and the detected destinations outside the study area may be identified. As outlined in Chapter 3, a competitive bus route will provide a comparable travel time to car travel time (comparable meaning the transit trip is no more than 50% longer than travel by car, not including travel between the origin/destination and a bus stop) and will run on regular frequencies and with an effective span of service, which will be outlined further below. Of the 183 unique destinations identified outside the study area (but still within the Region of Waterloo), 155 are within 450m of bus service. Of these 155 areas in proximity to a bus route, 153 have 30-minute headways or better, with 62 having 10-minute or better bus service. Further, of the areas that are in proximity to a bus route, all of them have bus service 7 days a week. During weekdays and peak hours, the level of service at these locations is increased.

Sixty-four unique destinations were identified outside the study area that were part of travel that connected to Downtown. Of the identified locations, 62 are within 450m of bus service and 42 are within 450m of bus service with a direct connection (ie. no transfer required) to Downtown. Of these 42 areas, all of them have 30-minute headways or better, with 22 having 10-minute or better bus service (see Figure 4-5). With the introduction of the new GRT transit network in 2018, the same number of the 64 destinations connecting to Downtown will be within 450m of a bus route, but 10 will have a more direct trip (ie., either the route has been streamlined with a maintained connection to Downtown, or a new transfer is required but the trip overall will be shorter, not accounting for walk-time to the initial transit stop) and 4 will have a less direct trip. Of the 38 areas that will have either improved directness or maintained directness to Downtown, 8 will have improved headways (see Figure 4-6). Overall, the connections to Downtown for these locations will be slightly improved, with 36 having a comparable travel time by transit to bus whereas 34 had a comparable trip previously (see Figure 4-9, and 4-10).

There were three categories of destinations within these 64 locations: major trip generators such as the University of Waterloo, or GRT facilities/terminals, residential areas indicating participants either lived outside the study area or were visiting people outside the study area, and other land uses that create semi-regular travel requirements but are not provided within the study area, such as large-scale grocery stores or big box retail stores, indicating an absence of a certain type of use in the study area. This is not necessarily a negative aspect of the study area as big box retail is not a transit-supportive land use. However, a large-scale grocery store would be beneficial to Downtown residents.

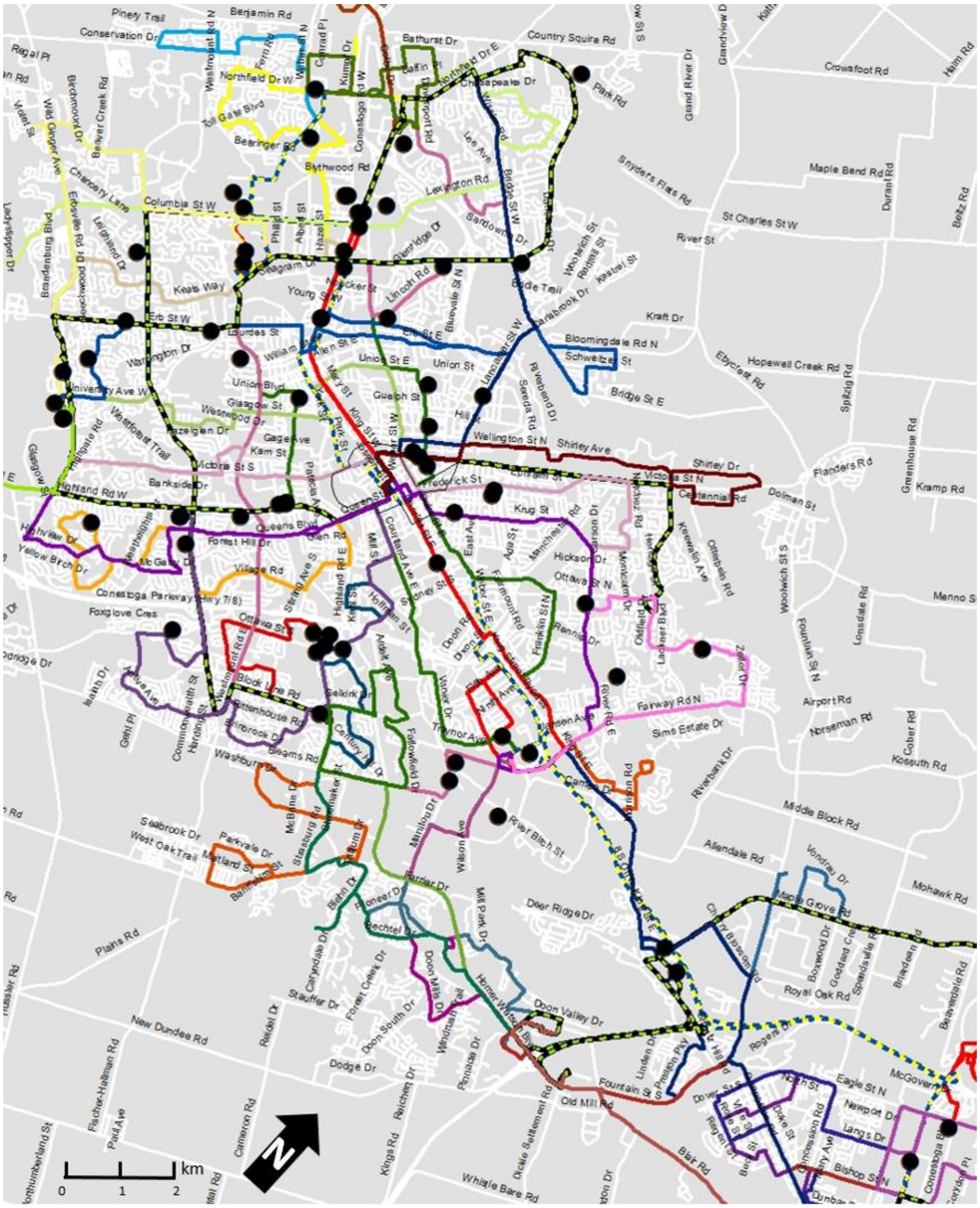

Figure 4-5. Origins/destinations of participants that travel to Downtown Kitchener and current bus routes

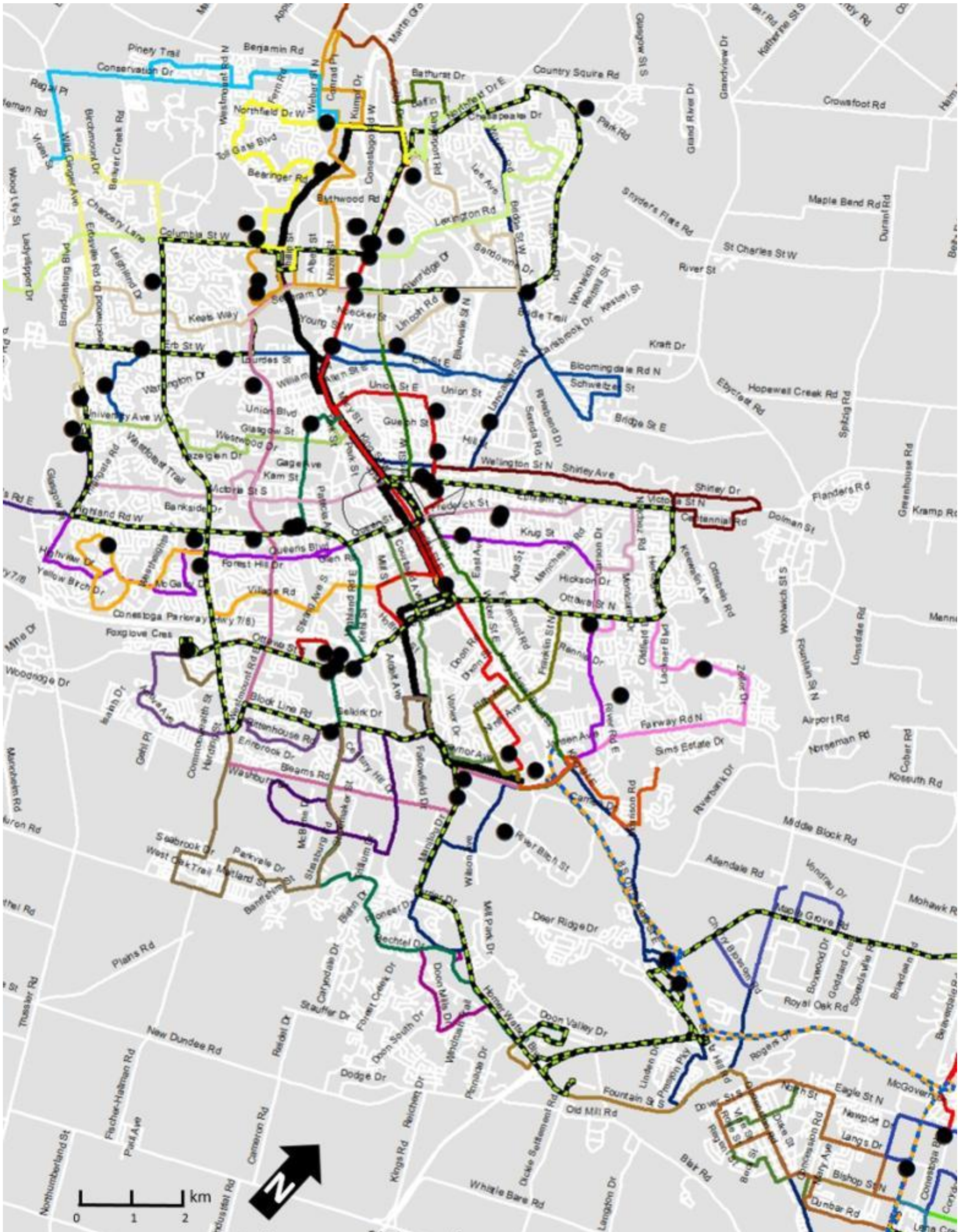

Figure 4-6. Origins/destinations of participants that travel to Downtown Kitchener and proposed bus routes

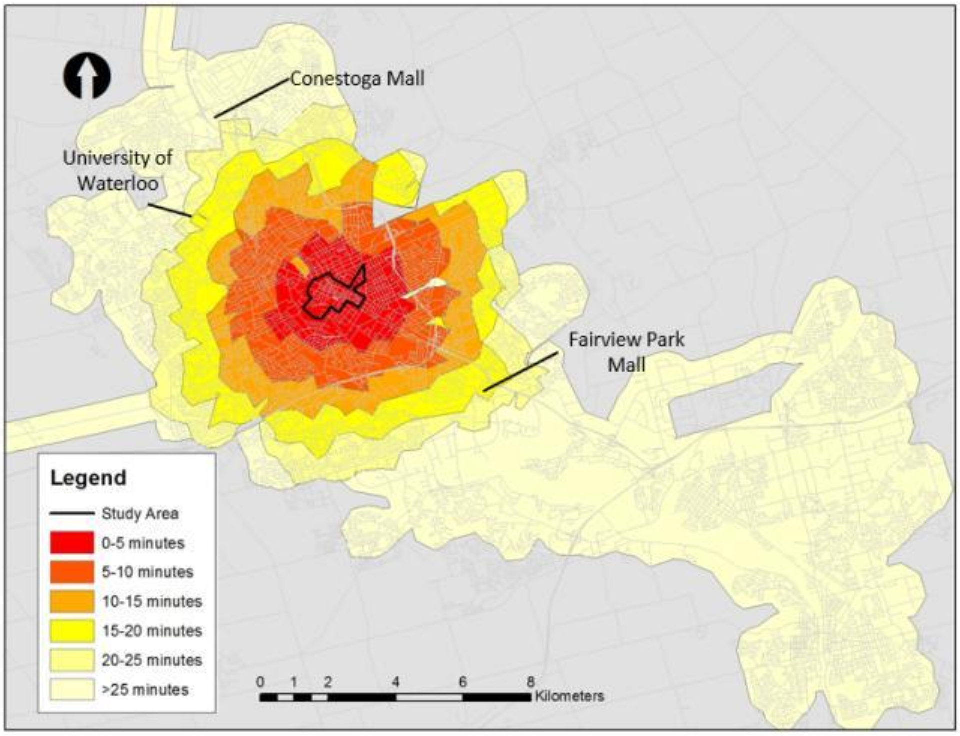

Figure 4-7. Travel time by current transit network – grey indicates the location is not accessible by transit

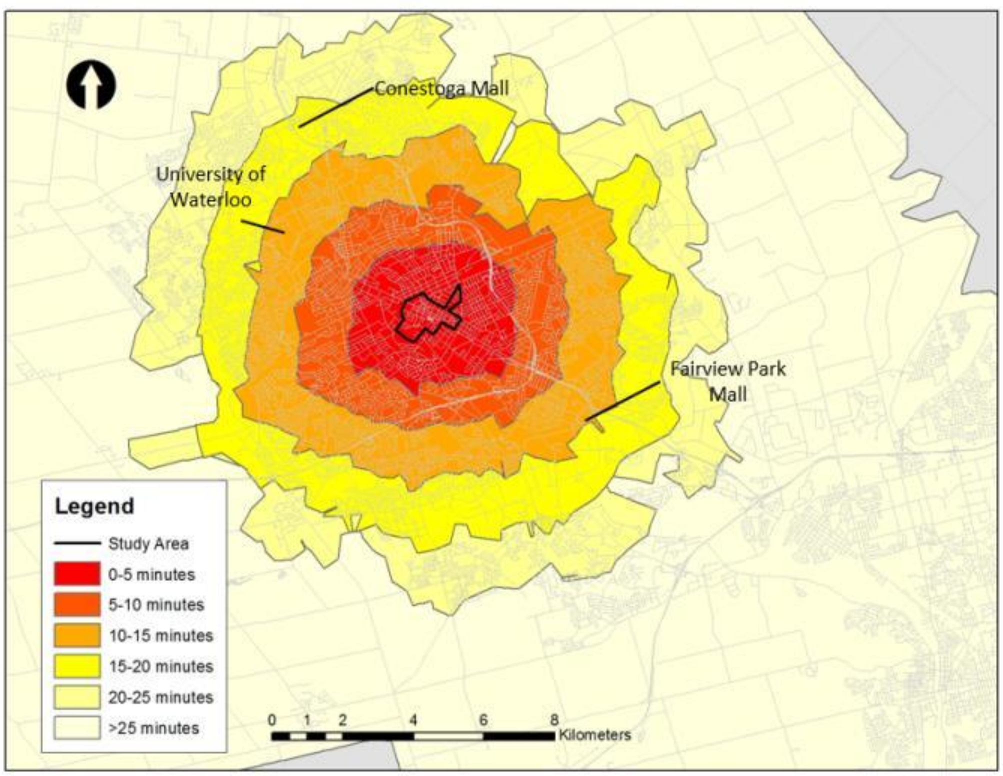

Figure 4-8. Current travel time by car

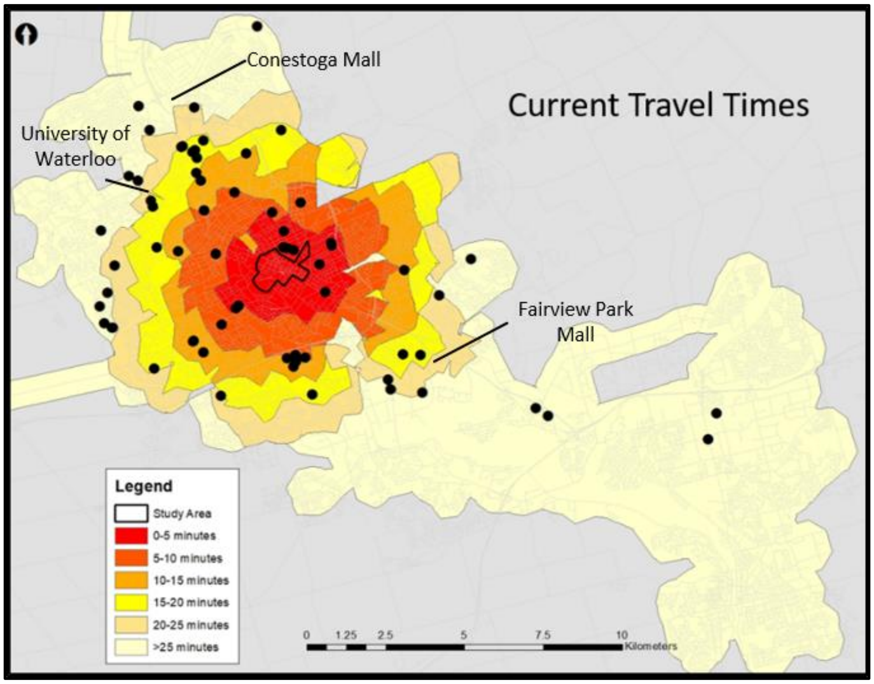

Figure 4-9. Travel time by current transit network versus origins/destinations of participants

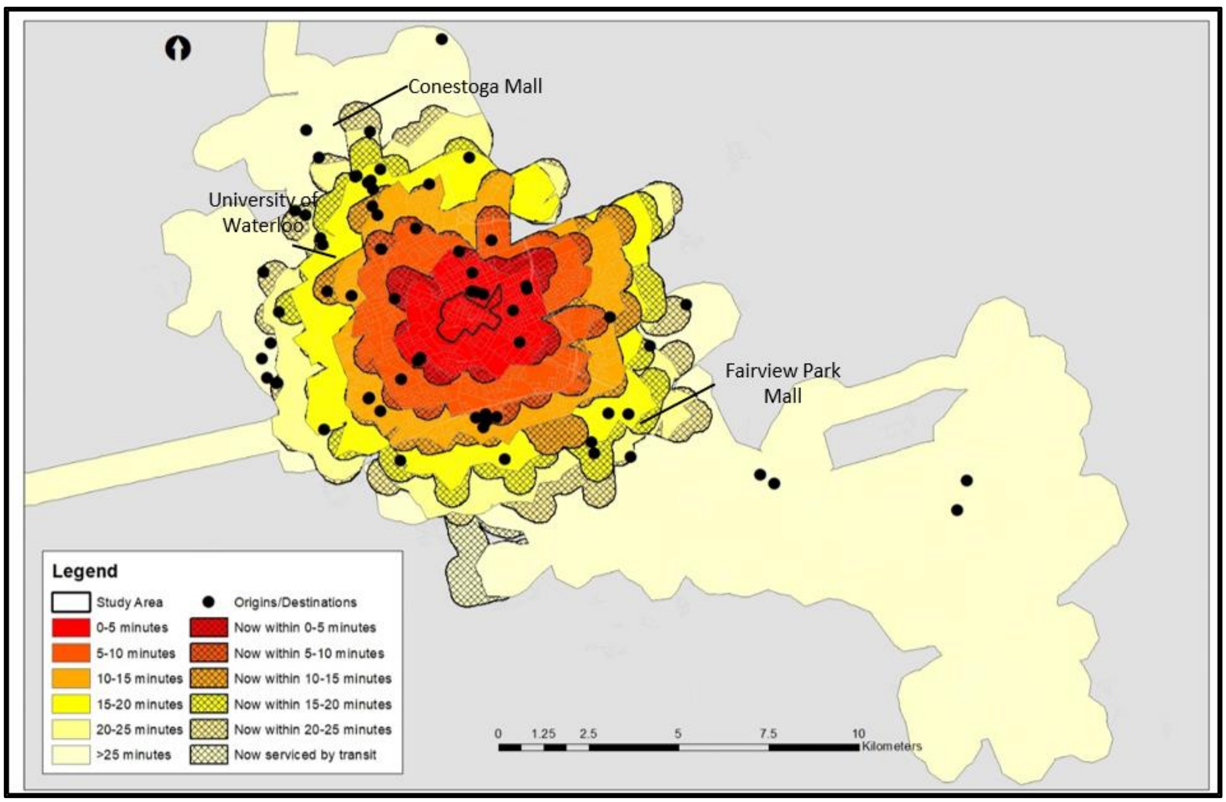

Figure 4-10. Comparison of previous travel times and travel times with network redesign versus origins/destinations of participants

4.1.1.5 Active Transportation Mode Share

Using the automated mode-detection algorithm built into the WatTrack app, the number of active transportation users was identified from study participants for the study area. The cycling detection algorithm's sensitivity was not completely accurate, so prior to analysis, those correctly identified as cyclists in the GPS traces were identified. This was done by analyzing my own GPS traces that had identified me as a cyclist, although I had not cycled during the study period. By observing the speeds and the number of consecutive points identified as cycling trips in these false positives, a proper estimate was made by renaming any points below a certain speed and those that were intermittently scattered in groups of other points identified as walking trips to walking trip segments. In total, 3 participants were correctly identified as using cycling for trip segments during the study period. This low number is not surprising as this study took place during winter months when cycling is not a highly viable mode of transportation. The daily average number of trip segments made by cycling in the study area was 18 or 1.3%, which is less than the average reported in the CTC Monitoring Report in 2015. Given the small sample size, and the winter conditions during the study period, this is likely not a true representation of cycling overall in the Downtown.

While all participants would have walked at some point in their travel, the total number of participants that used walking as their dominant mode of transportation in the study area (ie., they walked between identified stops, and the majority of their trip segments for a day were by walking) for a trip was 28. The daily average number of trip segments made by walking in the study area was 776 or 55% of total segments.

4.1.1.6 Walkability

Within the study area, there were 23,742m of road, and 35,561m of sidewalk, for a sidewalk to road ratio of 1.5. A value approaching 2 indicates sidewalk on all roads on both sides. The value identified here indicates a significant inventory of sidewalk, with some key gaps, including along Jubilee Drive in Victoria Park (as demonstrated in the GPS data), which, given its high pedestrian traffic, would warrant sidewalk on both sides of the road. Since this study was completed however, sidewalk has been partially installed along this stretch of road.

Of the detected travel of those identified as walking GPS points within the study area, about 98% of these points (detected from WatTrack) occurred in areas with sidewalk. The majority of travel occurring in areas without sidewalk appears to be cut-through travel through parking lots or other large parcels (see Figure 4-11). This indicates a very high propensity to walk where pedestrian infrastructure is made available.

Figure 4-11. Walking trips in areas without sidewalks in Downtown Kitchener

4.1.1.7 Connectivity of Cycling Networks

The areas with cycling infrastructure in Downtown Kitchener are limited overall. There are only 11,010m of total cycling infrastructure (trails, bike lanes, sharrows), of which only 43% (4700m) are either dedicated bike lanes or separated trails. As identified in the previous chapter, the highest connectivity value of a node in the study area was five. While this indicates a high connectivity value, it is not the average value. Fifty-five percent of nodes in the study area have a value of two or less. As well, the greater connectivity values occur in Victoria Park along separated but less direct trails. Bike infrastructure on roadways have lower connectivity values, indicating fewer alternative routes for commuter travel. As has been identified by many agencies and professionals before, sharrows are a superficial solution to providing active transportation routes, with very little differentiation between a sharrow and a regular street (Teschke, et al., 2012). As such, travel patterns do not necessarily preclude travel along regular streets.

Of the detected study participant cycling trip segments in the study area, 93% of cyclingtravel segments occurred along roads and trails with cycling infrastructure (see Figure 4-12). Of this travel, 25% occurred along separated trails, 3% along dedicated bike lanes, and 72% along sharrows or designated cycling routes. Another 7% of travel segments occurred along roads with no dedicated cycling infrastructure. Travel largely occurred on roads with some type of cycling infrastructure. Of the travel that did not occur in an area with cycling infrastructure, it appears that travel connected two separate locations with cycling infrastructure, thereby indicating a gap in the connectivity of the network. Bike lanes were underutilized in this sample, as indicated by the 3% usage of all travel by bike in the study period. Overall, the correlation coefficient of the connectivity of the active transportation network in comparison to the actual paths traveled is -0.23 (see Table 4-2), indicating little correlation between the provision of cycling infrastructure and the actual paths traveled. This correlation coefficient has a poor confidence interval due to the small sample size. However, while the sample size of cyclists is quite small in this study, this may indicate that there is a lack of bike lanes to be used, that they do not connect to desired destinations, and/or they are not properly maintained during winter months.

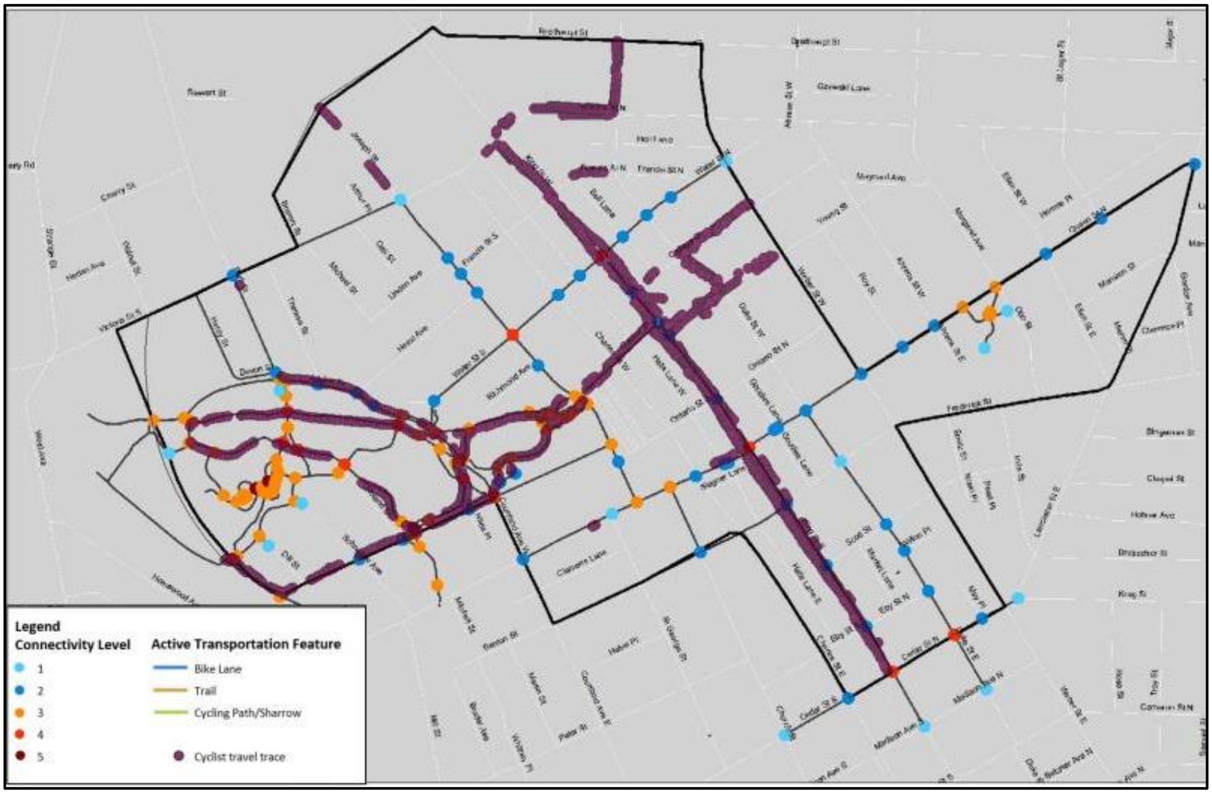

Figure 4-12. Cycling trips and connectivity of cycling infrastructure in Downtown Kitchener

Table 4-3. Values for calculation of correlation of cycling and cycling infrastructure (see equation 1 for calculation method). Incidents are detected point occurrences of cyclists from the GPS data.

	Array 1	**Array 2**
Intersection	**Number of Incidents**	**Connectivity Value**
1	6	3
2	27	4
3	6	4
4	8	4
5	12	3
6	8	4
7	4	3
8	17	4
9	1	3
10	5	3
11	10	4
12	10	3
13	11	3
14	1	5
15	1	5
16	9	4
17	15	3
18	4	3

	Array 1	Array 2
Intersection	Number of Incidents	Connectivity Value
19	7	4
20	6	3
21	6	3
22	22	4
23	13	3
24	13	4
25	166	2
26	5	3
27	6	3
28	22	3
29	1	3
30	7	3
31	1	3
32	6	3
33	21	3
34	77	4
35	12	4
36	68	2
37	87	2
38	108	2
39	4	2
40	3	2
41	2	2
42	1	2
43	24	2
44	24	3
45	7	3
46	7	2
47	10	2
48	11	2
49	1	3
50	10	3
51	15	3
52	1	3
53	88	2
54	4	2
55	48	2
56	59	2
57	140	2
58	139	4
59	42	1
60	1	2
61	26	1
62	25	2
63	16	2
64	21	3
65	23	4

4.1.2 Policy Analysis

The above analysis of the indicators reveals that there are a variety of strengths and weaknesses in the study area. In the study area, transit ridership is high within the current system, high volumes of cyclists were not observed, the active transportation network is lacking, while the existing sidewalk network is quite comprehensive with some key gaps, and transit to and from the study area is relatively competitive. A full summary of the desired levels for each KPI as compared to this study's results is provided in Chapter 5. The relevant policies that may mitigate the issues, and support the strengths and opportunities, or significant gaps are outlined below, since as previously discussed, KPIs are only as valuable as the action they inspire. If there are no plans within these guiding policies to bring KPI measurements to the target values identified in the monitoring plan, they simply will not be met.

4.1.2.1 Community Building Strategy

As previously stated, The Region of Waterloo's Central Transit Corridor Community Building Strategy is part of the rapid transit initiative to move people and shape the community and provides the Region's long-term community planning strategy. This plan is high-level, with a broad scope, but it still supports the improvements of the above indicators in many ways, with an increasing specificity as the document progresses.

The key sections of the plan and their relevance are outlined below (Table 4-4 & 4-5) where green text indicates successes that have been identified in the plan and red text indicates shortcomings that have been identified in the plan:

Table 4-4. CBS Sections and Relevance

Section	Intent	Successes and Shortcomings
1.3 The Region and Cities have been Planning for Enhanced Transit	Official Plan for Kitchener: • Intensification particularly in UGC, major transit station areas, nodes and corridors	• Encourages concept that higher proportion of residents would have access to transit → increase mode share, ridership

Section	Intent	Successes and Shortcomings
	• Higher frequency transit to achieve intensification targets	
1.5 The Mobility Network is Being Adapted to Support Growth in People & Jobs	• Reorientation of transit system from radial pattern to grid network with new iXpress corridors crossing RT line • Expand current level of services with improved access to important destinations • Complementary investments in AT Networks	• Encourages directness and competitive travel speeds → increase mode share, ridership, efficiency • Encourages supportive AT infrastructure to serve transit → increase mode share, connectivity, walkability • Investment strategy not defined • Important destinations not defined • AT network improvements not identified
2.4 Key Community Building Opportunities	• Enhanced mobility by completing gaps in cycling and trail networks • Target key destinations from RT corridor with improved connections by transit and AT • Coordination of RT stations and bus routes for integrated transit network • Identify and address barriers to accessibility systematically • Develop and promote programs to encourage AT • Develop inventory of parks, open spaces along corridor and improve AT connections	• Encourages improved AT network → increase mode share, connectivity, walkability • Coordination of RT and buses will allow for seamless transfers → increase efficiency • Removal of barriers increase walkability • Investment strategy not defined • Key destinations not defined • Improved AT connections only defined at high-level on map
3.1 Creating a New Land Use and Mobility Framework	• Transit system is easy to access by greatest number of people • Major land uses served by frequent, reliable transit • Convenient and well-connected transit • Direct routes that reduce travel times • Around immediate station areas, provide enhanced waiting areas, incorporate unique public art for each station, incorporate bike facilities • In station transfer zone provide AT facilities/amenities for transit users and to improve accessibility, improve safety, comfort, accessibility and wayfinding through streetscape and crossing enhancements, public art, integrate new development with station, redevelop surface parking to higher and better uses	• Encourages concept that higher proportion of residents would have access to transit → increase mode share, ridership • Direct routes → increase efficiency • Improved station areas and transfer zones encourage use → increase mode share, ridership • Investment strategy not defined • Specific major land uses not defined
3.2 Creating Transit-Supportive Places	• Support transit with a mix of uses and higher densities • Design streets for all users • Develop finer-scaled street and block pattern • Design buildings for pedestrian environment	• Encourages concept that higher proportion of residents would have access to transit → increase mode share, ridership • Streets for all users increases safety → increase AT mode share • Fine-scale block patterns increase connectivity and walkability

Section	Intent	Successes and Shortcomings
	• Support higher densities with new and improved public spaces • Balance parking with great place-making	• More specific identification of employment areas, neighbourhood types, campuses, UGCs, etc. • Sample street design not defined • “Support” not fully defined
4.1 Place-Specific Initiatives	• 69 place-specific initiatives identified, where 7 are specific to study area • Initiative 19: define Victoria Park as regional destination • Initiative 39: enhance access by transit to health and community facility clusters in Downtown • Initiative 44: improve walk between ION and Kitchener Market • Initiative 45: continue infill and revitalization of Downtown • Initiative 48: use redevelopment of Charles Street Terminal to connect Victoria Park to ION • Initiative 49: improve relationship of Victoria Park to Iron Horse Trail • Initiative 50: create integrated multi-modal hub at Transit Hub Station	• More specific identification of key locations and opportunities • Specifics of initiatives not truly defined
5.0 Station Area Snapshots	• Current (as of publication) conditions and what measures could be taken to improve the area • See Table 4-4 for summary of snapshots	
7.2 Enhancing Mobility Throughout	• Short-term: coordinate RT stations with iXpress corridors and Station Area Planning; prioritize and move actions forward; complete priority trailhead connections • Long-term: enhance existing areas to support AT and transit ridership through work with neighbourhood associations; complete trailhead connections in Kitchener	• Prioritization would enable for a project plan to be implemented • Neighbourhood associations would help with prioritization • Prioritization not yet completed • “Coordination” not fully defined

Table 4-5. Station Area Snapshots Summary

Station	Intent	Successes and Shortcomings
Kitchener Market (Cedar)	• Short-term: improved intersections and crosswalks at Cedar/Charles • Long-term: new streetscaping on Cedar to support market events; consolidation and redevelopment of large surface parking lots to mid-rise residential with retail at street and smaller streets and blocks; addition of bike facilities	• Improvements to pedestrian and cycling environment will encourage AT • Partial investment strategy identified through metre revenue • Employee passes would encourage transit usage • “Improvements” not fully scoped

Station	Intent	Successes and Shortcomings
	• Mobility improvements: dedicated cycling facilities along Charles south of Cedar; parking for new development in shared, structured facilities; dedicated metre revenue directed to CTC area improvements, district wide employee transit passes	• Dedicated cycling facilities not scoped out – what kind? Where on the street?
Frederick/ Queen (Frederick/ Benton)	• Short-term: new streetscaping along Frederick including intersection improvements • Long-term: redevelopment of surface parking over time to street level uses; renovation of existing buildings to activate streets such as Market Square • Mobility improvements: dedicated cycling facilities along Frederick; car-share parking in new developments	• Improvements to pedestrian and cycling environment will encourage AT • "Improvements" not fully scoped • Dedicated cycling facilities not scoped out – what kind? Where?
Kitchener City Hall/ Victoria Park (Young/ Gaukel)	• Short-term: attractive east/west pedestrian corridor by extending King streetscaping east on Young and Gaukel; intersection improvements with widened crossing at Charles/Gaukel and Young/Duke; create a master plan for redevelopment of Charles Street Terminal • Long-term: redevelopment of surface parking along Duke and Charles to active frontage uses; redevelop Charles Street Terminal with enhanced connection between Victoria Park and Downtown • Mobility improvements: preserve for extension of Goudies and Halls Lane; redevelop surface parking to new green public open space; dedicated metre revenue directed to CTC area improvements, district wide employee transit passes	• Improvements to pedestrian and cycling environment will encourage AT • Partial investment strategy identified through metre revenue • Employee passes would encourage transit usage • "Improvements" not fully scoped • Dedicated cycling facilities not scoped out – what kind? Where?
Central (King/ Victoria)	• Short-term: create technical Mobility Hub Study and Station Area Plan to integrate reurbanization opportunities with infrastructure; defined interface of ION, buses, GO Transit; sidewalk and intersection improvements at King/Victoria; enhanced streetscaping along King with bike lanes • Long-term: new infrastructure to strengthen connections between multiple modes; new commercial, institutional, residential around station to fill gaps in street created by surface parking • Mobility improvements: new development and streetscape improvements to preserve for AT routes on Victoria/King; dedicated metre revenue directed to CTC area improvements, district wide employee transit passes; car-share parking; significant bicycle parking for commuting and regional bikeshare program	• Mobility Hub Study completed in 2013 → comprehensive access analyses • Improvements to pedestrian and cycling environment will encourage AT • Partial investment strategy identified through metre revenue • Employee passes would encourage transit usage • "Improvements" not fully scoped • How will bike lanes be installed on King? Narrow street • Hub will not be built until 2022 – interim plan?

As demonstrated by the above synopsis of the CBS, much of the areas of concern are in some way mentioned and/or supported in the CBS. However, given the high-level nature of the document, it is difficult to specifically identify exact recommendations related to site-specific issues in the study area in full detail. However, the PARTS plan may provide further detail for improvements.

4.1.2.2 Planning Around Rapid Transit Stations (PARTS)

While the CBS provides some site-specific goals and objectives, the City of Kitchener's PARTS plan provides a refined vision and implementation plan of the goals outlined in the CBS. Much like the CBS, it begins at a higher-level and provides more refined relevant plans as it progresses. The key sections of the plan and their relevance are outlined below (Table 4-6) where green text indicates successes identified in the plans, and red text identifies shortcomings in the plan:

Table 4-6. PARTS Central Plan Summary and Relevance

Section	Intent	Successes and Shortcomings
4.0 Vision & Objectives	• Enhancing transportation choice & connectivity through: support of AT connectivity, convenience, access and mobility to and from ION; giving AT & transit priority over vehicular circulation; creating and maintaining AT friendly PARTS Central area; design street for all users by implementing pedestrian-scaled development principles; require barrier-free environment	• These are all good goals for transit-supportiveness
5.0 Preferred Plan	• Best practices for density around light rail: MTO recommends 160 people+jobs/ha within 800m of LRT station; Kitchener target of 225 people+jobs/ha in Downtown core	• Higher density goal set; feasible as density is already high in the City • Location of dense land uses identified on a map • Site-specific policy area proposed for more detail at certain locations • Implementation measures and recommendations are outlined through secondary plans and land use plans
9.0 Streetscapes	• Improved streetscaping: priority streets identified – Breithaupt, Victoria, Young, Queen, Frederick, Benton, Cedar, Charles, Courtland, Lancaster, Eby, Halls, Gaukel, King East; creation of a Streetscape Master Plan	• Improved streetscaping will encourage walking • Specific locations have been prioritized • As of late 2017, only partial streetscaping plans have been completed for upcoming capital projects in the very near future; some of the priority locations are in severe disrepair, do not have

Section	Intent	Successes and Shortcomings
		sidewalks or are not pedestrian friendly (see Appendix G for sample locations)
10.0 Parks & Public Realm	• Provide increased mid-block crossings, multi-use paths, and a pedestrian bridge over the rail lines	• Specific locations have been identified for improvements • Multi-use pathways only proposed between Kitchener Market & ION and between Central Station & Iron Horse Trail → more separated cycling infrastructure needed
12.0 Transportation Demand Management	• Provide street furniture and other AT amenities along sidewalks • Support route efficiency for AT to and from destinations and ION through linkages • Discourage surface parking • Encourage secure bicycle parking near stations • Implement these recommendations through completion of TDM checklist as part of development application to rate how TDM-friendly an application is	• All recommendations would support and encourage AT and AT connections to ION • Specific locations for new cycling infrastructure have been identified • Majority of proposed infrastructure is sharrow or signed routes instead of separated facilities
13.0 Transportation Network	• Increased local and inter-city transit service • Current inventory of sidewalks and AT infrastructure → areas of improvement: wider sidewalks with streetscaping on Young from Duke to Weber, sharrows on Young from King to Weber, contra-flow bike lane on Young from Weber to Maynard, sharrows on Water from Weber to King, wider sidewalks, cycling infrastructure and streetscaping on Duke from Breithaupt to Francis, extend sharrow on King from Madison to Ottawa, contra-flow bike lane on Duke from Cedar to Pandora, and more direct pedestrian connection from Walter/Wellington to King as the adjacent mixed use/commercial site redevelops	• All recommendations would support and encourage AT and AT connections to ION • Specific locations for new cycling infrastructure have been identified • As of late 2017, none of these improvements have been implemented, nor has timing been identified • Majority of proposed infrastructure is sharrow or signed routes instead of separated facilities

As with the CBS, it is difficult to ascertain exact recommendations to some extent due to the high-level of the PARTS plan. However, the PARTS plan does provide some highly specific recommendations. There are still some missing specific recommendations that should be addressed. For example, a streetscaping master plan has not been completed. A master plan would benefit streets that serve as major transit corridors and pedestrian transfer zones. As well, the areas of improvement for wider sidewalks or the provision of sidewalks at specific locations have been recommended, but not implemented.

Further, while many cycling network improvements have been proposed, the majority of those proposed are on-street facilities such as sharrows or signed cycling routes, which as discussed previously, are the highest risk cycling paths and largely superficial. The study area would benefit from true separated cycling facilities along key corridors. This could be achieved, for example, with installation of separated bike lanes through the removal of on-street parking along King Street, installation of multi-use pathways along Charles Street through the removal of left-turn lanes, conversion of wide sidewalks along Frederick Street to multi-use pathways, and/or closure of Halls Lane to vehicles except for delivery vehicles. While these proposals have not been assessed in their impact on traffic, they present more rigorous options for the cycling network as opposed to the bare minimum.

Another concern is that much of the improvements recommended are directed toward the multi-modal transit hub at King and Victoria. However, this hub has not been built yet, and it will be several years following ION operation commencement before it is constructed. There does not appear to be an interim plan for improved connections for all modes at this location.

4.2 Addressing Research Objectives

Through this thesis, the research objective has primarily been met. Demographic data and spatial data analysis have allowed for a small-scale analysis of travel behaviour in Downtown Kitchener. While the baseline data are likely too small to be truly representative, they still provide a granular sample of tours in Downtown, and provide a methodology that may be recreated in future.

Plans for implementing infrastructure or strategies to improve KPI measurements largely appear to be addressed in some detail in the CBS and PARTS plan. For example, there are many statements that support and encourage improvements to the active transportation network and transit network such as recommendations for more pedestrian mid-block crossings, additional cycling facilities throughout the Downtown Core, and improved integration of ION and bus stops. However, as previously mentioned, these documents are mostly high-level and even supportive statements do not fully explore potential improvements in most instances. Where specific improvements are identified, many have not been implemented, timing has not been identified for these improvements, and many are only minor changes in areas that would benefit from substantive changes (e.g., many new cycling connections are sharrows, while separated cycling facilities would be a better cycling path).

Lastly, in addition to the provision of infrastructure and transit in the area, it is likely that other factors may have influenced the results to some degree. These factors are discussed in more detail in Chapter 5.

4.3 Chapter Summary

This chapter outlines the results of the study in Downtown Kitchener in relation to travel and transportation infrastructure in Downtown Kitchener. There were a variety of respondents and a variety of travel patterns inside and outside the study area. Transit ridership and walking was high in the study area during the study period, while cycling was limited. Much of the study area will maintain a high level of competitiveness in transit connections within and without of the study area, while some locations will have more competitive connections, and others will have less competitive connections. It is difficult to assess whether the area will truly be improved through the application of GRT’s New Directions principles. There is a correlation between walking trips and pedestrian infrastructure, but the area is also already highly walkable, allowing for flexibility in travel on foot. However, cycling infrastructure is limited, and the travel patterns by bike did not have a definitive correlation between the availability of cycling infrastructure and cycling travel paths. Lastly, where deficiencies have been found within the monitoring indicators, the policies within the CBS and PARTS plan have largely addressed these deficiencies;

however, site-specific recommendations are somewhat lacking within these plans, and therefore solutions are discussed further in Chapter 5.

Chapter 5 Conclusions and Recommendations

5.1 Thesis Conclusions and Recommendations

This thesis has analyzed the viability of automated travel data collection, the process of monitoring large transit projects, and key performance indicators in the case study area of Downtown Kitchener. From these analyses, conclusions and recommendations can be made with regard to the CTC indicators, as well as the study design. Overall, travel behaviour can be correlated to many factors within the study area, and automated travel data collection serves as an effective method of travel analysis, with some flaws that would need to be addressed for improved analysis.

5.2 Addressing Research Questions

Three research questions were posed in Chapter 1:

1. What are the baseline results observed during the study period for each KPI?
2. What are the desired levels of these KPIs? Do the CBS and PARTS plan address improvements to KPIs that have not reached their desired levels?
3. What other external factors or study design features may have influenced the KPI results observed?

The results of each KPI and their desired levels are outlined in Table 5-1 below. Furthermore, it was determined the CBS and PARTS plans did address many improvements to the KPIs to some extent, with some areas for improvement, discussed in Section 5.2.7, Other external factors and study design features are also discussed in the following sections that may have influenced the observed KPI results.

Table 5-1. Summary of desired versus observed KPI results

Key Performance Indicator	Desired Result	Observed Result
Transit Ridership	Increase from 2016 ridership numbers of 19.69 million • CTC 2021 target: 17.6 million	Total ridership cannot be calculated for short-term study, but ridership in the study area is high (260 daily boardings and alightings per stop)
Daily Transit Activity	Increase from 2016 activity numbers of 114,625 boardings and alightings in the CTC	114,000 daily boardings and alightings in the CTC 62% of all activity on GRT in CTC 12% of all activity on GRT in study area

Transit Mode Share	2021 target for entire Region: 13%	Cannot be calculated Assumed to have decreased or remained similar
Transit Competitiveness	Increase in number of transit routes that provide comparable travel time to driving	10 observed origins will have improved travel times to study area 4 observed origins will have increase travel times to study area 8 observed origins with comparable or improved travel times will have improved route headways as well
Active Transportation Mode Share	2031 target for entire Region: 12%	1.3%* *small sample size, measured at Study Area scale
Walkability	Increase in provision of sidewalks and number of residents in walkable areas	Only baseline data has been established Sidewalk-road ratio of 1.5 98% of observed travel occurred on sidewalks
Connectivity of the cycling Network	Increase in provision of cycling routes Increase in topological connectivity in the study area	Only baseline data has been established 11,010m of cycling infrastructure 55% of nodes have connectivity of 2 or less 93% of observed cycling occurred on cycling infrastructure

5.2.1 Data Collection Review

First and foremost, it must be noted that the sample size for this study was small, and therefore cannot be truly representative of actual travel conditions. Rather, the main intent of this study has shown that the automated processes involved in this study allowed for passive collection of travel data from participants, somewhat comprehensive mode detection, and stop detection. The WatTrack app is an effective and simple interface and serves as a model of travel data collection that would be effective in future data collection as well. However, despite numerous tools in place to mediate battery-usage, it could still be observed to be draining on cell-phone battery. Furthermore, as discussed in Chapter 2, GPS reliability and signals vary between phones and carriers. It can be observed through the GPS data itself that signals were lost, or never connected in some situations, with some users having much more complete GPS traces than others. Further optimization may be warranted to improve the overall reliability of the application and battery usage. In addition to GPS reliability, results may also be skewed by participants that provided more data than others. Methods for automatically identifying those that provide more data for some type of weighting process would be beneficial in future to account for these different participants.

The data collected through the WatTrack app were also run through an automated mode detection algorithm. In most cases, walking and vehicles were correctly identified. However, the sensitivity of the cycling detection algorithm requires additional work. Walking trips with higher overall speeds tended to be incorrectly identified as cycling trips. This was determined through having prior knowledge of GPS traces that were incorrectly identified as cycling when they were actually walking trips. Transit trips are also not differentiated from private vehicle trips. For more detailed analysis, especially in relation to analysis of transit usage in the CTC, differentiating the two modes would be highly beneficial.

The data were also run through an automated stop detection algorithm which were used to identify destinations participants traveled to and from and could be used to assess the efficiency of the transit network. While this algorithm is largely able to identify stops with obvious stop trajectories (as discussed in Chapter 2 and 3), it also fails to identify very brief deviations in travel (such as a drive-thru or drop-off), and often dissolves two distinct walking trips into one due to the similarity in trajectories. The optimal variables for cluster identification and merging may also not have been fully considered. There are likewise failures in detection due to inaccurate or absent GPS data. In some cases, GPS signal was lost, and therefore trips appeared fragmented. Many of these issues were mitigated through manual analysis of the GPS data. In a sample size such as the one for this study, manual analysis is a viable method of data validation. However, in larger sample sizes, improved automation is ideal. It would therefore be beneficial for additional refinement of the stop detection algorithm. Improved differentiation of discrete walking trips and detection of minor deviations within the algorithm may be incorporated into the algorithm through additional conditions within the algorithm, or improved identification of optimal clustering and merging variable values. Improved GPS signal would also provide better data for stop detection and analysis, however, this would require improved smart-phone geolocation capabilities.

5.2.2 Demographic Appraisal

Those that participated in this study tended to be educated, young adults with varying income levels and dwelling types. This respondent demographic can be mostly attributed to the recruitment process. Preliminary recruitment occurred through contact with TravelWise. Member employers of TravelWise include D2L, Vidyard, and OpenText, all of which are tech companies with educated (as a requirement), young employees. For example, the average age of D2L employees is 36 (Eluta.ca, 2017). Most other participants in this study were university students, a demographic that is easily reached through online recruitment. The nature of this study and the recruitment process has provided a mixed sample of participants, while still unintentionally missing some demographic groups. Those over the age of 60 are completely absent from the sample respondents. This may have occurred for several reasons. One, this age range tends to be comprised of retirees, and given that much of the recruitment occurred through employers, retired people would not be directly contacted. Two, as discussed in Chapter 2, smart-phone and smart device ownership and usage reduces within increased age cohorts. It is a high possibility that those that heard of the study in older age groups did not own a smart device to use for the study. It is therefore recommended that future studies be provided additional means to either contact excluded demographic groups or provide smart devices for those that do not own one of their own. This will allow for greater representation of more vulnerable or absent demographics. As for the impact this exclusion has on the study itself, the full extent is not fully known. Given the small sample size of participants, it is more likely that more demographics would be excluded in general. However, Downtown is home to many social services, and representation from demographics that utilize these social services would be key in assessing travel in the area as well.

5.2.3 Transit Indicators Appraisal

Transit ridership is quite high in the study area. Given that the Downtown is part of the CTC, and numerous routes directly connect to the area, it is to be expected that transit usage is higher in the core than outlying areas. With the launch of ION light rail in 2018, bus routes will be shifted to connect with light rail. This will involve phasing out Charles Street Terminal, where many of the transfers will occur on-street instead of at a central hub.

As the current GRT bus network operates in a largely hub-and-spoke style system, many existing connections by bus between the study area and outlying directions are relatively direct and competitive already as the Downtown serves as a major hub for the network. With the introduction of light rail, the hub-and-spoke model is replaced with a grid-like system, where the radial network connecting every end of the city to Downtown Kitchener is modified or even split. A transfer may be introduced where there was not one before, but the intent of GRT's New Directions is to provide a more direct trip overall. This system does not prevent competitive travel, but schedule adherence and transfer locations will play a major role in the directness and efficiency of the new transit network. Additional transit performance indicators may also be relevant in future analyses, including other efficiency metrics focused more on operational or technical parameters.

5.2.4 Mode Share Indicator Appraisal

Mode share within the study area has not been comprehensively examined due to constraints on data availability. Transit mode share cannot be detected through the WatTrack app but cycling and walking can be. Cycling represents a small portion of the overall travel in the study area from respondents, which is to be expected due to the time of year the study occurred, and the existing low modal share of cycling within the Region of Waterloo. Walking is highly represented in the study results, as is consistent with most core areas of cities. Further data collection related to cycling is warranted to analyze what measures can be taken to increase cycling in Downtown Kitchener and the Region as a whole.

5.2.5 Walkability Indicator Appraisal

Downtown Kitchener is a highly walkable area, and this is also represented in the GPS data. This study also took place during a period with a great deal of construction, creating inconsistencies in the pedestrian network. Mostly, the pedestrian network is ideal for encouraging walking in Downtown Kitchener. Some additional analysis may be warranted to compare the quality of sidewalks and pedestrian connections in relation to width, slope, and landscaping to the paths chosen. It is likely that the higher quality sidewalk segments will be the more traversed paths. As will be discussed in the following section, additional analyses of the connectivity of the walking network are also relevant to the ION LRT.

5.2.6 Cycling Network Connectivity Indicator Appraisal

The overall connectivity of the cycling network in Downtown Kitchener is lacking, and also does not provide a high amount of separated bike infrastructure. The major corridors that would provide the most direct travel path are typically sharrows with no separated cycling infrastructure. Where bike lanes exist, they are disconnected from other bike lanes and are only present for several blocks at a time. This network therefore does not lend itself to encouraging cycling. Further analyses to understand the active transportation network to a greater degree would include analyzing the level of winter maintenance of bike lanes and trails in comparison to routes travelled, and the proportion of cyclists that bike on sidewalks, especially in areas where sharrows are provided. These analyses would demonstrate the effect weather and snow influence cycling, and the usefulness of sharrows as cycling infrastructure, respectively. These additional analyses are also supported by the observation made by Ducruet & Rodrigue (2017) regarding topological connectivity indices: "Several critiques have been made towards such indexes as they do not always take into account the real length, quality, and weight of the links; networks of equal size may exhibit contrasted topological forms. However, they remain useful for describing the changing structure of a given network." This statement supports topological connectivity analyses, while also indicating the absence of additional network characteristics beyond simple connectivity.

For this study, only the connectivity of the cycling network was analyzed. However, the connectivity of the entire active transportation network, including the connectivity of the pedestrian network, are relevant indicators to be considered in future. For example, Osama & Sayed (2017) concluded that a well-connected pedestrian network was a safer network. Such conclusions in the context of Downtown Kitchener would be relevant to the overall walkability and accessibility of the study area and around the CTC.

5.2.7 Policy Appraisal

The CBS and the PARTS Central Plan provide a good policy framework for ensuring the Downtown Core is transit-supportive and pedestrian-oriented. However, there are still some missing specific recommendations that should be addressed. The area's streetscaping master plan has not been completed and its creation would benefit streets such as Charles Street, Victoria Street, Frederick Street, and Duke Street which all serve as major transit corridors and pedestrian transfer zones. The provision of high-quality landscaping, street furniture and public art along these four streets would provide a high-level of pedestrian comfort and convenience. Lastly, the areas of improvement for wider sidewalks or the provision of sidewalks at specific locations have been recommended, but not implemented. An implementation timeline would provide a more concrete schedule for construction of these improvements.

5.3 Implications for the Region of Waterloo

In summary, the central conclusions of this study in relation to the Region of Waterloo include:

- Transit usage and walkability/pedestrian activity are already quite high in the area.
- While cycling does occur in the study area, improvements are needed to the connectivity and availability of cycling infrastructure to increase cycling. Separated cycling facilities would be more beneficial than on-street facilities.
- Current and future connections to the study area are relatively competitive, and will be improved with the launch of ION. The most marked improvements will be the Ottawa Street corridor with the introduction of the 205 iXpress, the southwest edges of Kitchener, and Conestoga College.
- While the study area is already a highly transit-supportive and pedestrian-friendly environment, the previously mentioned improvements to crossings, sidewalks, and connectivity should be undertaken to provide a further enhanced environment for pedestrians and transit-users.

5.4 Concluding Thoughts

The findings of this study have determined that passive, automated data collection can be used to determine a number of travel indicators. Data related to the diversity of travel and travel services are essential to the effective and efficient allocation of infrastructure funding and resources. The study area provides a case study of an area that has modal options, a mix of land uses and sociodemographics, and high walkability. All of these factors lend themselves to the travel patterns of individuals in the context of Downtown Kitchener that are consistent with transit-supportive design. It serves as a good example of transit-supportive designs that other light rail station areas in the Region may emulate.

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archText=Waterloo&SearchType=Begins&SearchPR=01&B1=All&GeoLevel=PR&GeoCode=3530&TABID=1

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Appendix A. Study Survey Questions

Home Location:
1) Provide as much information as you are comfortable providing for the following:

Street Number	Street Name	Closest Intersection
Postal Code (first 3 digits)	Postal Code (last three digits)	

2) Prefer not to disclose

Work Location:
1) Provide as much information as you are comfortable providing for the following:

Employer	Street Number	Street Name
Closest Intersection	Postal Code (first 3 digits)	Postal Code (last three digits)

2) Prefer not to disclose

Gender:
1) Male 2) Female 3) Other 4) Prefer not to disclose

Age:
1) 18-29
2) 30-39
3) 40-49
4) 50-59
5) 60-64
6) 65+
7) Prefer not to disclose

Highest level of completed education:

1) No certificate, degree or diploma
2) High school diploma or equivalent
3) Post-secondary education
4) Graduate education
5) Other
6) Prefer not to disclose

Employment type:

1) Part-time
2) Full-time
3) Seasonal/Freelance
4) Student
5) Retired
6) Not employed
7) Prefer not to disclose

Occupation type:

1) Construction/Manufacturing and related
2) Sales and Services and related
3) Agriculture, forestry, fishing and related
4) Health/Education and related
5) Computers and Technology
6) Government
7) Other
8) Student
9) Retired
10) Not employed
11) Prefer not to disclose

Annual personal salary (before tax):

1) Under $40,000
2) $40,000-$59,999
3) $60,000-$79,999
4) $80,000-$99,999
5) $100,000+
6) Prefer not to disclose

Total household income (before tax):

1) Under $40,000
2) $40,000-$59,999
3) $60,000-$79,999
4) $80,000-$99,999
5) $100,000+
6) Prefer not to disclose

Type of Dwelling:

1) Single-detached house
2) Semi-detached house/duplex
3) Townhouse
4) Apartment
5) Condominium

6) Other
7) Prefer not to disclose

Number of people in household:

1) 1
2) 2
3) 3
4) 4
5) 5
6) 6+
7) Prefer not to disclose

Number of people in household under 18 years of age:

1) 0
2) 1
3) 2
4) 3
5) 4+
6) Prefer not to disclose

Do you have a driver's license?

1) Yes
2) No
3) Prefer not to disclose

How many people in your household have a driver's license?

1) 1
2) 2
3) 3
4) 4
5) 5
6) 6+
7) Prefer not to disclose

Number of vehicles available for personal use:

1) 0
2) 1
3) 2
4) 3+
5) Prefer not to disclose

How often do you typically travel to the Central Transit Corridor in a given week? (See BASELINE MONITORING REPORT 2015 page xii for exact boundary http://www.regionofwaterloo.ca/en/regionalGovernment/resources/PW/Monitoring_Change_in_the_CTC_Baseline_Report.pdf)

1) Multiple times daily
2) Daily
3) Several times a week
4) Weekly
5) Several times a month
6) Monthly
7) Less than once a month
8) Never
9) Prefer not to disclose

How do you typically travel to the Central Transit Corridor in a given week?

1) Personal vehicle
2) Carpool
3) Taxi/Uber
4) Bicycle
5) Transit
6) Walk
7) Other
8) Prefer not to disclose

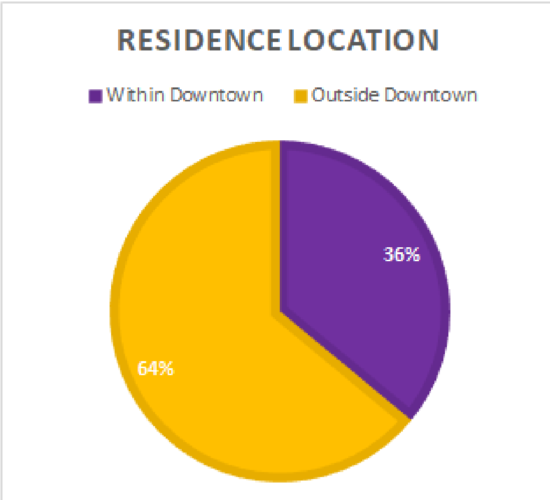
What are the majority of your trips to the Central Transit Corridor intended for? (Select up to 3)

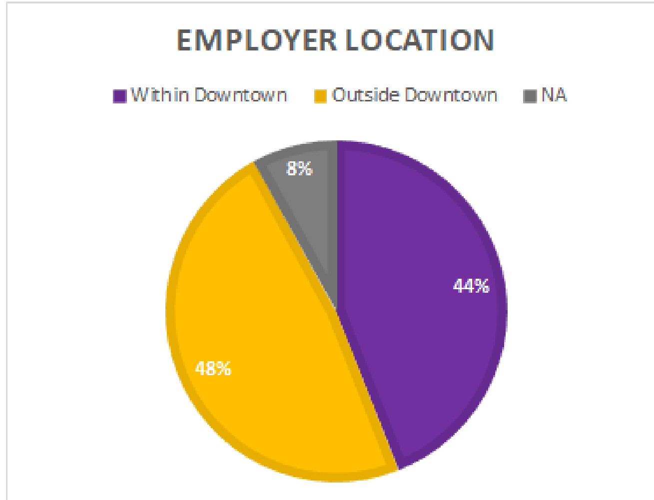
1) I live there
2) Work
3) Shopping
4) School
5) Visiting others
6) Volunteering
7) Other
8) Prefer not to disclose

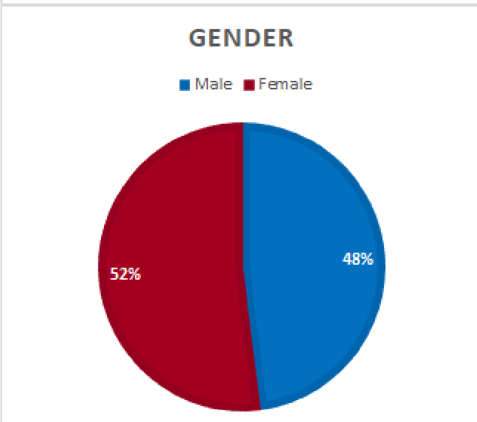
How many activities do you typically complete in one visit to the Central Transit Corridor?

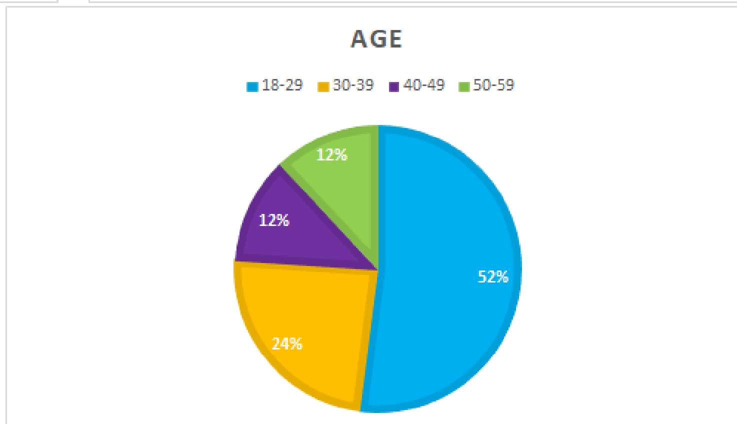
1) 0
2) 1
3) 2
4) 3
5) 4
6) 5+
7) Prefer not to disclose

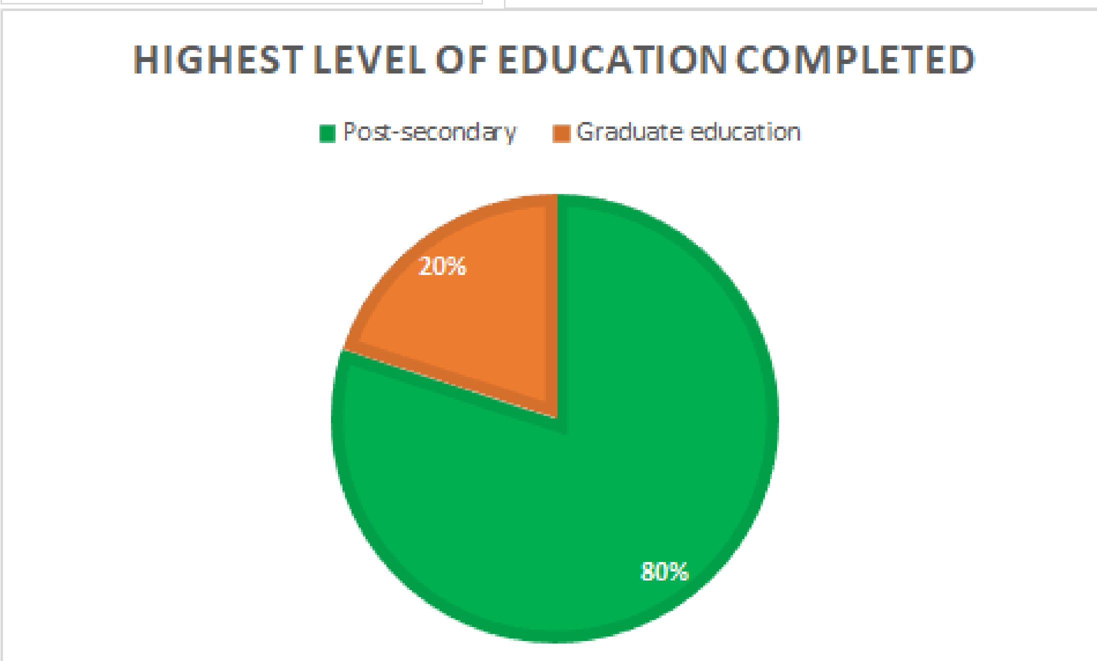
Appendix B. Results of Study Survey Questions

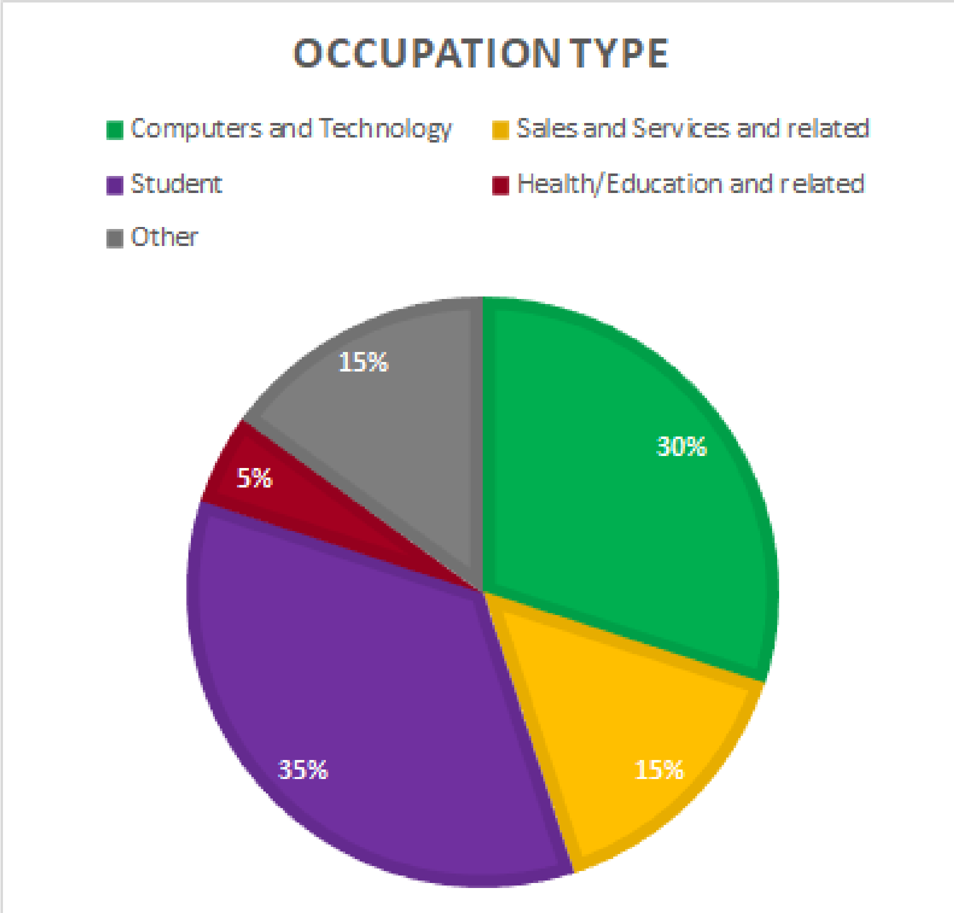


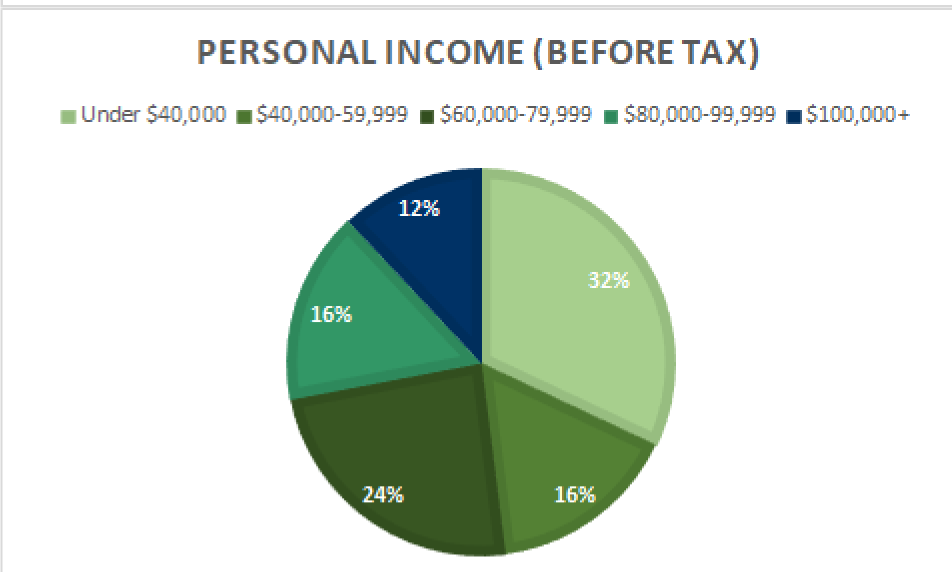


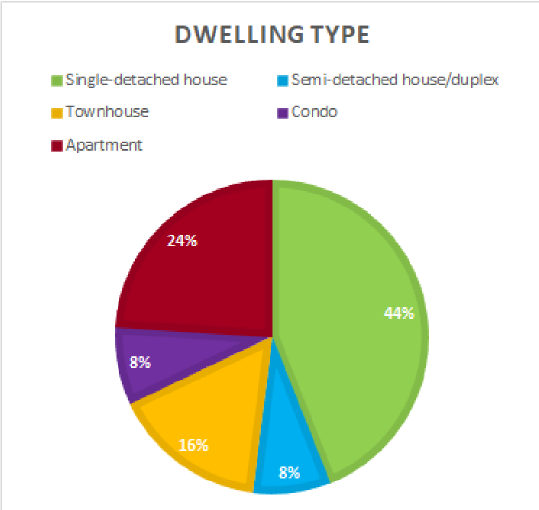


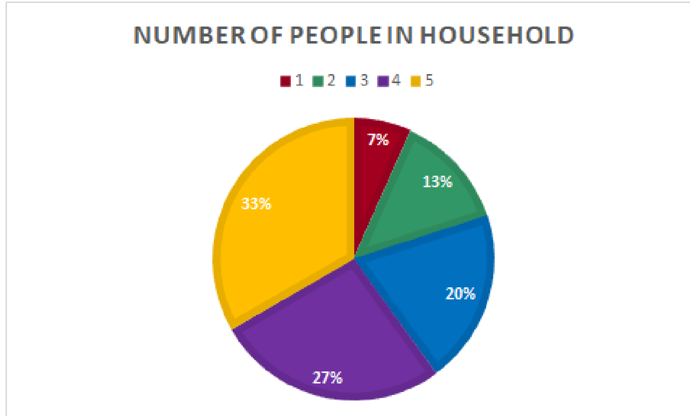


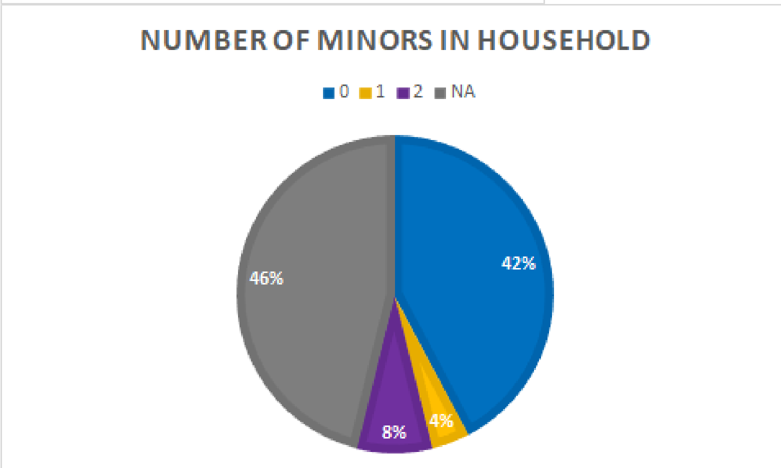


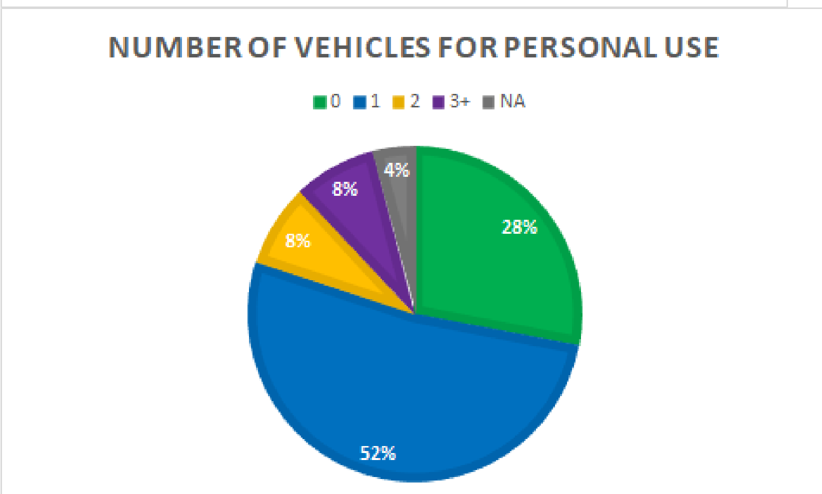

OCCUPATION TYPE
Computers and Technology
Sales and Services and related
Student
Health/Education and related
Other
15%
30%
5%
35%
15%

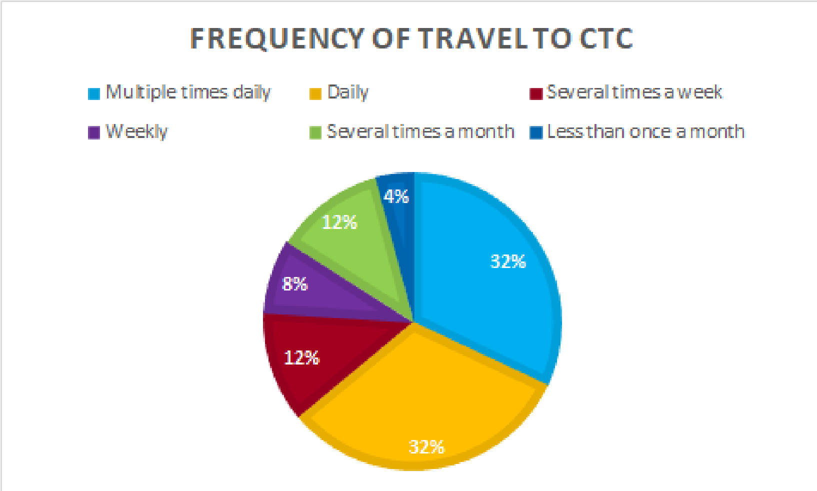

PERSONAL INCOME (BEFORE TAX)
Under $40,000
$40,000-59,999
$60,000-79,999
$80,000-99,999
$100,000+
12%
32%
16%
24%
16%

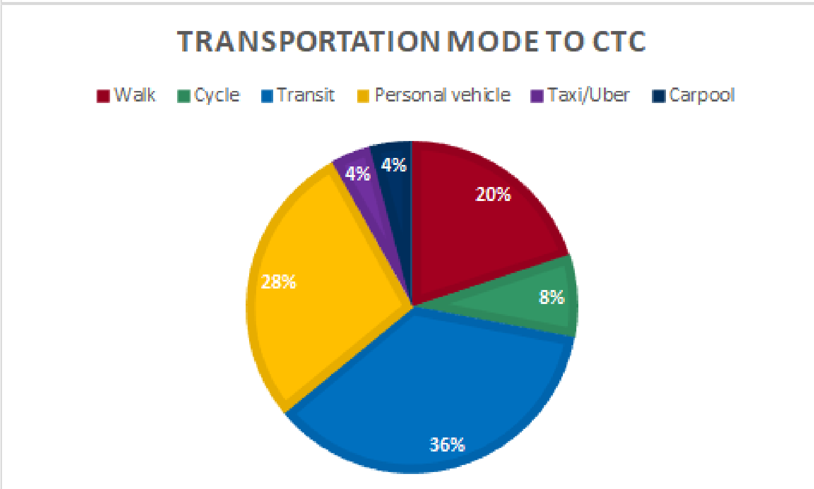

DWELLING TYPE
Single-detached house
Semi-detached house/duplex
Townhouse
Condo
Apartment
44%
8%
16%
8%
24%

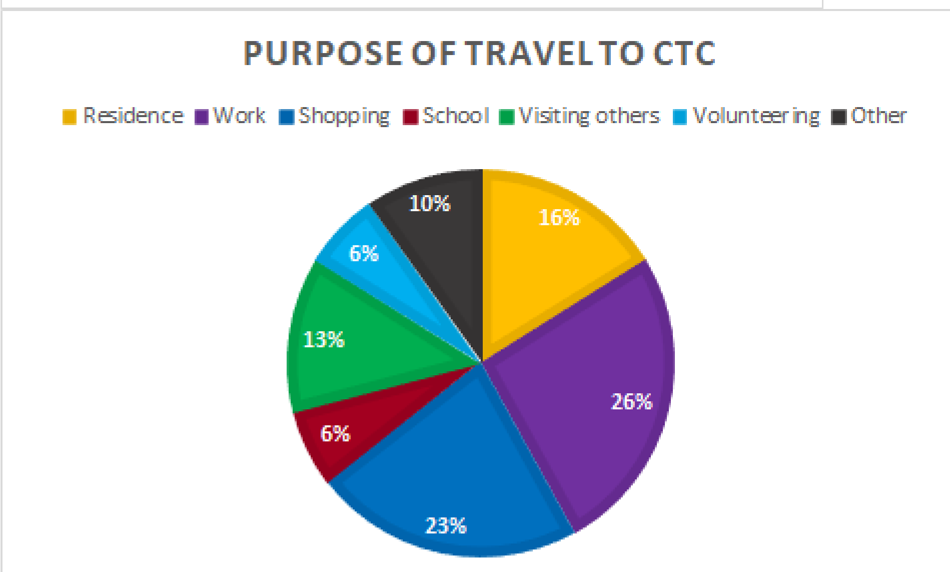

NUMBER OF PEOPLE IN HOUSEHOLD
1 2 3 4 5
7%
13%
20%
27%
33%

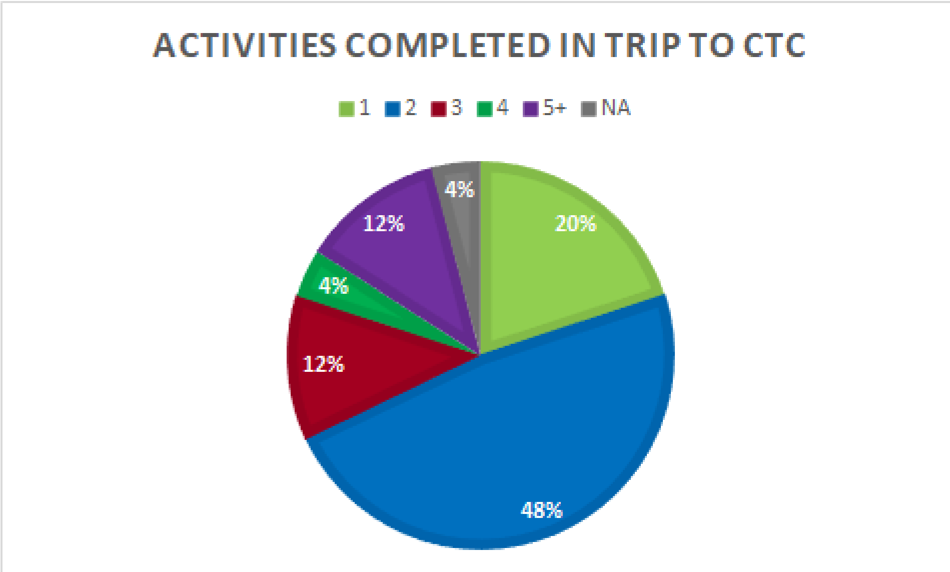

NUMBER OF MINORS IN HOUSEHOLD
0 1 2 NA
42%
4%
8%
46%


NUMBER OF VEHICLES FOR PERSONAL USE
0 1 2 3+ NA
28%
52%
8%
8%
4%


FREQUENCY OF TRAVEL TO CTC
Multiple times daily
Daily
Several times a week
Weekly
Several times a month
Less than once a month
32%
32%
12%
8%
12%
4%


TRANSPORTATION MODE TO CTC
Walk
Cycle
Transit
Personal vehicle
Taxi/Uber
Carpool
20%
8%
36%
28%
4%
4%


PURPOSE OF TRAVEL TO CTC
Residence
Work
Shopping
School
Visiting others
Volunteering
Other
16%
26%
23%
6%
13%
6%
10%


ACTIVITIES COMPLETED IN TRIP TO CTC
1
2
3
4
5+
NA
20%
48%
12%
4%
12%
4%

Appendix C. Python code for cluster identification

Input:
CSV of cell phone track (cellphonetrack.csv) with individuals (personID), unique point IDs (pointID), latitude, and longitude
Output: CSV (cellphonetrack.csv) with unique cluster IDs (clusterID) for individuals and points

Notes:
Q represents a set number value that can be changed based on context
G represent Q plus 1
K represents a set percentage value that can be changed based on context
W represents a set number value for merging that can be changed based on context

```
import csv
Databyperson = {}
with open ('GPSfilled.csv') as csvfile:
    for row in GPSwriter:
        personID = row[0]
        pointID = row[1]
        latitude = row[2]
        longitude = row[3]
        if personID not in DataByPerson:
            DataByPerson[personID] = []
        DataByPerson[personID].append('pointiD':int(pointID), 'latitude': float(latitude), 'longitude': float(longitude))

# Converts coordinates to radians and calculates distance between two points
from math import sin, cos, sqrt, atan2, radians

def calculateddistance(firstpoint, secondpoint):
    earthradiuskm = 6373.0
    latitude1 = radians(firspoint['latitude'])
    latitude2 = radians(firstpoint['latitude'])
    longitude1 = radians(firstpoint['longitude'])
    longitude2 = radians(secondpoint['longitude'])

    deltalat = latitude2 - latitude 1
    deltalong = longitude 2 - longitude 1

    a = sin(deltalat / 2)**2 + cos(latitude1) * cos(latitude2) * sin(deltalong / 2)**2
    c = 2 * atan2(sqrt(a), sqrt(1-a))

    return earthradiuskm * c * 1000

with open(cellphonetrack.csv)
    GPSwriter = csv.writer(csvfile)
    # Method of calculating distance between points and categorizing them into clusters
    clusterID = 0
    for personID in DataByPerson.iterkeys():
        data = DataByPerson[personID]
        for i in range (0, len(data)-Q):
            EuclideanDistance = calculateddistance(data[i], data[i+Q])
            ActualDistance = 0
            for j in range (i, i + Q)
                ActualDistance += calculateddistance(data[j], data[j+1])
            if ActualDistance == 0 or EuclideanDistance/ActualDistance < K:
                for j in range (i, i + G):
                    if 'clusterID' in data[i]:
                        data[j]['clusterID'] = data[i]['clusterID']
                    else:
                        data[j]['clusterID'] = clusterID
            else:
                clusterID += 1
```

```
# Method of identifying adjacent clusters and merging them if they meet the merge criteria
data[0]['clusterID'] = clusterID
DataByCluster = {}
for point in data:
    if 'clusterID' not in point:
        continue
    if point['clusterID'] not in DataByCluster:
        DataByCluster[point['clusterID']] = []
    DataByCluster[point['clusterID']].append(point)
clusterkeys = DataByCluster.keys()
clusterkeys.sort()
clusters = []
for key in clusterkeys:
    clusters.append(DataByCluster[key])
for i in range(len(clusters)-1):
    cluster = clusters[i]
    othercluster = cluster[i+1]
    for point1 in cluster:
        for point2 in othercluster:
            if calculateddistance(point1, point2) <= W
                IsSameCluster = True
    if IsSameCluster:
        for point in othercluster:
            point['clusterID'] = cluster[0]['clusterID']
for i in range (0, len(data)):
    if 'clusterID' in data[i]:
        GPSwriter.writerow([personID, data[i]['pointID'], data[i]['latitude'], data[i]['longitude'], data[i]['clusterID']])
```

Appendix D. Mode Detection Process

The mode detection process was developed by Dr. Akram Nour and refined by Amir Zarinbal from the University of Waterloo. The speed and GPS coordinates were used to identify the most likely mode for each user, and a second possible mode for each user, with a level of confidence. A numerical value was assigned for each mode type. See below for which numerical value represents each mode.

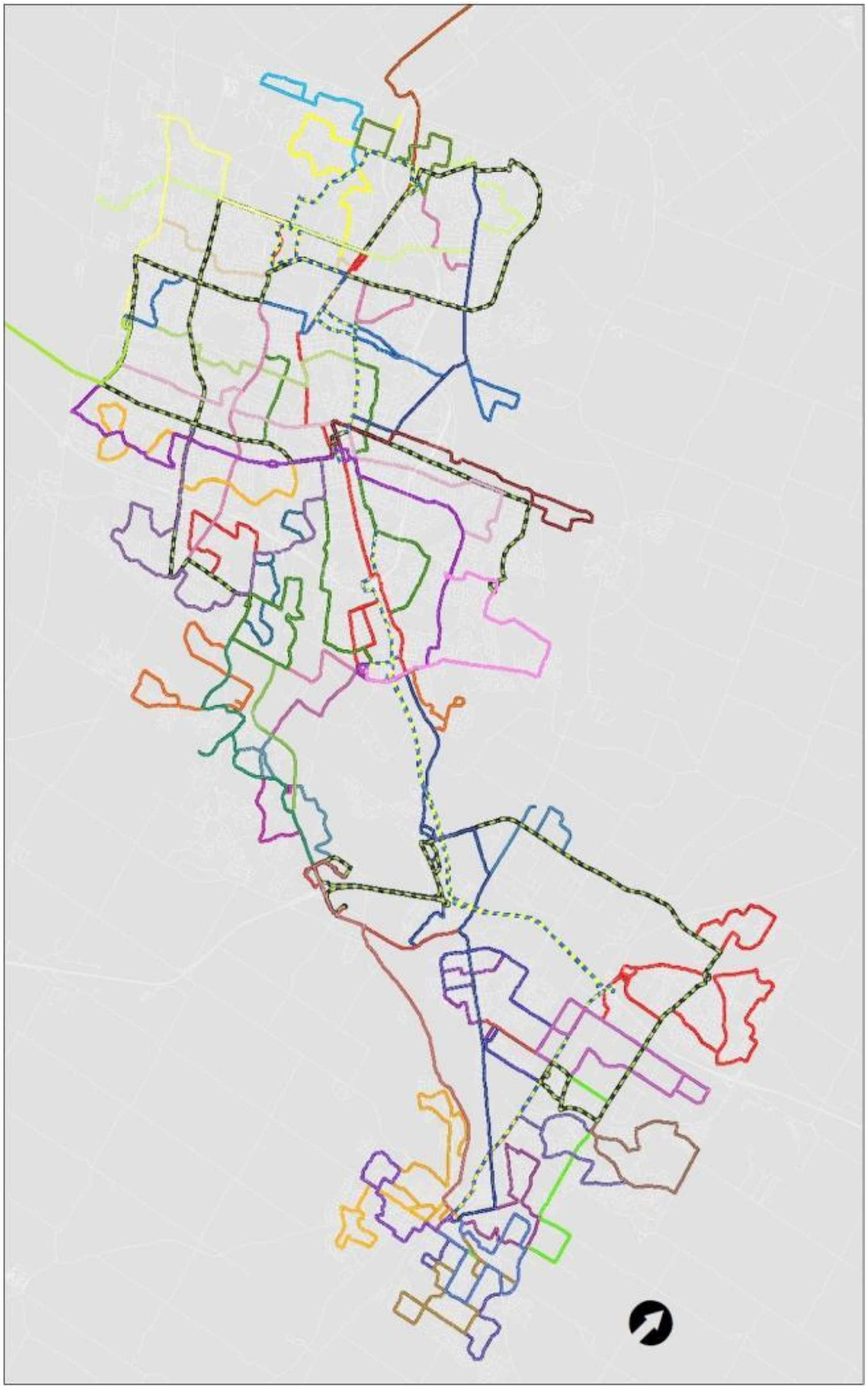
Android OS

0 IN_VEHICLE The device is in a vehicle, such as a car.
1 ON_BICYCLE The device is on a bicycle.
2 ON_FOOT The device is on a user who is walking or running.
8 RUNNING The device is on a user who is running.
3 STILL The device is still (not moving).
5 TILTING The device angle relative to gravity changed significantly.
4 UNKNOWN Unable to detect the current activity.
7 WALKING The device is on a user who is walking.

3 stationary
7 walking
8 running
0 automotive
1 cycling
4 unknown
If the mode is 0 and confidence interval is -1, it means the value that the OS is returning is not valid

Initial mode identification for cyclists, upon manual inspection of known walking trips, found that there was an overrepresentation of cyclists identified as the most likely mode. Therefore, only those identified as having cycling as their second possible mode as well, or no other possible mode detected, were included as detected cyclists.

Appendix E. Route Configurations as of February 2017 – GPS from GRT Open Data, map created by Andrea Mikkila



Appendix F. Stop Activity in Downtown Kitchener – raw data provided by GRT, aggregated by Andrea Mikkila

Stop	Ins	Outs	Total Activity
Benton / Church (2713)	14.4	11.6	26.0
Benton / Courtland (2714)	3.4	0.7	4.2
Charles / Water (5018)	52.1	15.7	71.0
Charles Terminal (2545)	337.8	145.2	496.6
Charles Terminal (2546)	282.6	194.0	503.4
Charles Terminal (2547)	451.0	268.6	747.4
Charles Terminal (2548)	833.3	474.8	1403.1
Charles Terminal (2549)	548.1	589.6	1247.2
Charles Terminal (2550)	662.4	469.8	1201.2
Charles Terminal (2551)	630.6	400.9	1072.3
Charles Terminal (2552)	179.0	248.2	466.7
Charles Terminal (2553)	268.4	278.5	585.2
Charles Terminal (2554)	549.3	394.9	1006.2
Charles Terminal (2555)	418.5	311.5	729.9
Charles Terminal (2556)	266.5	157.9	424.4
Charles Terminal (2557)	312.6	313.7	626.3
Charles Terminal (2558)	528.6	302.9	831.5
Charles Terminal (2559)	475.5	505.8	981.2
Charles Terminal (2560)	436.6	248.7	685.2
Charles Terminal (2708)	0.0	130.8	130.8
Charles Terminal (2709)	351.8	495.3	847.1
Charles Terminal (2710)	308.5	256.3	564.8
Charles Terminal (2711)	391.9	201.5	593.4
Courtland / Benton (2753)	3.1	15.0	22.8
Frederick / Irvin (1001)	15.1	10.8	25.9
Frederick / Irvin (1086)	7.9	10.6	18.4

Stop	Ins	Outs	Total Activity
Frederick / King (1000)	53.8	20.6	79.0
Frederick / King (1088)	21.3	96.3	136.5
Frederick / Lancaster (1085)	13.8	15.3	29.1
Frederick / Otto (1002)	17.0	11.1	28.1
Frederick / Weber (3575)	47.0	28.6	84.0
Joseph / Water (5011)	6.9	60.5	67.3
King / Benton (2561)	104.2	44.3	158.1
King / Cedar (1887)	62.0	59.6	114.1
King / Cedar (2564)	80.8	96.1	175.2
King / College (1891)	33.2	6.7	39.9
King / Francis (1892)	16.9	5.2	22.1
King / Frederick (1888)	44.9	107.7	172.0
King / Gaukel (2458)	18.0	131.8	175.0
King / Ontario (1890)	14.1	144.6	191.7
King / Queen (1889)	33.5	71.8	118.3
King / Queen (2562)	85.0	19.9	109.0
King / Scott (3730)	64.2	74.1	143.7
King / Victoria (1901)	5.7	39.1	53.8
King / Water (2457)	26.9	108.6	162.2
Queen / Ahrens (2320)	18.4	25.2	47.0
Queen / Ahrens (2358)	18.6	31.2	55.8
Queen / Courtland (2707)	17.8	68.7	105.0
Queen / St. George (3068)	33.4	10.1	46.2
Victoria / Bramm (3111)	52.1	28.8	84.3
Victoria / Henry (3112)	12.9	10.2	23.1
Victoria / Joseph (3110)	263.4	72.9	356.0
Victoria / Joseph (3227)	38.2	148.6	236.1

Stop	Ins	Outs	Total Activity
Victoria / Michael (3225)	61.8	66.8	146.6
Victoria / Park (3224)	3.7	8.7	12.3
Victoria / Weber (1930)	2.7	3.4	6.1
Victoria / Weber (2461)	3.5	23.8	27.2
Victoria / Weber (5038)	14.2	7.2	21.4
Water / Francis (5016)	19.6	25.7	45.2
Water / Joseph (5000)	21.4	12.0	33.3
Water / King (5005)	58.4	80.0	138.4
Water / King (5006)	85.7	77.9	163.6
Water / Weber (5015)	16.8	26.1	42.9
Weber / Cedar (2653)	5.6	9.6	16.5
Weber / Cedar (2843)	8.1	7.3	16.2
Weber / Frederick (2842)	2.6	15.2	18.6
Weber / Kitchener Rail Station (3580)	285.2	61.8	365.0
Weber / Ontario (2502)	2.5	5.7	8.2
Weber / Queen (2319)	90.2	56.1	164.8
Weber / Queen (2503)	25.6	44.0	69.6
Weber / Scott (2359)	14.5	5.0	20.4
Weber / Scott (2408)	14.0	46.2	74.1
Weber / Victoria (2500)	91.9	229.7	392.1
Weber / Young (2459)	28.3	29.6	57.8
Weber / Young (2501)	25.5	45.0	70.4

Appendix G. *Examples of streetscaping issues in Downtown Kitchener*

All images retrieved from Google Streetview

Young Street east of King – sidewalk in severe disrepair

Halls Lane – no pedestrian infrastructure

Charles Street at Francis – 3/4 corners of intersection are parking lots

Charles Street Terminal at Gaukel Street – differentiation of pedestrian realm and bus lanes unclear