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SUSTAINABLE REGIONAL TRANSPORTATION STUDY

FINAL REPORT

CLIENT: The University of Waterloo

DATE: April 21, 2022

CLASS: PLAN 405

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ASPHALT

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Mr. Mat Thijssen
Director of Sustainability
University of Waterloo Sustainability Office
200 University Avenue West
Waterloo, ON, N2L 3G1

April 21, 2022

Dear Mr. Thijssen,

Re: Sustainable Regional Transportation Study
Final Report

On behalf of our team at Asphalt Transportation Planning Solutions Ltd. we are pleased to submit the following report as the conclusion to our Sustainable Regional Transportation Study.

We would like to extend our thanks for the opportunity to work on this report with you while also extending thanks to Professor Clarence Woudsma as our Mentor. Should any questions arise regarding our materials, please do not hesitate to contact the undersigned via telephone at 519-123-4567 x890 or via email at cyunh@asphaltsolutions.ca. Our team looks forward to working with you.

Sincerely,

Christine Hyunh
Asphalt Transportation Planning Solutions Ltd., Project Manager

EXECUTIVE SUMMARY

With severe weather conditions, poor air quality, and increased pressure on socio-economic systems, the impacts of climate change can be felt on a global scale. In efforts to minimize the effects of climate change, the University of Waterloo is determined to achieve net-zero emissions by the year 2050.

The purpose of the Sustainable Regional Transportation report is to advance the goal of Action Item 41 of the University of Waterloo's Shift Neutral climate change action plan. Specifically, the following report seeks to address transportation mode choices among University of Waterloo employees and the best practices required to shift transportation behaviours towards sustainable mode options. In order to achieve this, Asphalt Transportation Planning Solutions Ltd. ("Asphalt" or "ATPS") will begin by providing necessary insight on the regional and university context. This will be followed by a literature review on transportation mode choice and influences thereto, as well as a comparative university review. The second part of this report will assess the factors that determine mode choice for University of Waterloo employees through a spatial analysis conducted in four phases (i.e., data processing, catchment area analysis, mode travel time analysis, data synthesis). Finally, a series of recommendations will be provided through an evaluation table supported by the collected data.

The report establishes that a significant proportion of University of Waterloo employees who drive to work could feasibly be commuting to work via more sustainable means such as walking, biking, or taking transit. Thus, travel demand strategies play an important role in shifting employee mode choices to more sustainable options that work to reduce greenhouse gas (GHG) emissions. These strategies include, but are not limited to, incentivized programs, parking lot management and services, and finally, transportation infrastructure improvements. Overall, further research and actions are required for the University of Waterloo to create a healthy, prosperous, and sustainable community via sustainable transportation mode choices.

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1.0 INTRODUCTION

The impacts of climate change can be seen at a global scale through the increased prevalence of severe weather conditions, declining air quality, and rapidly increasing pressure on human socioeconomic systems. To address these negative impacts at the local scale, the University of Waterloo and the Region of Waterloo (ROW) have committed to working together to reduce regional greenhouse gas emissions by 80% before the year 2050 (ClimateActionWR, 2022).

To assist the University of Waterloo ("the University" or "UW") in achieving this goal, Asphalt Transportation Planning Solutions Ltd. ("Asphalt" or "ATPS") has undertaken the following Sustainable Regional Transportation Study as solicited by the University's Sustainability Office ("Sustainability Office"). The Sustainability Office requested that the scope of the study include a review of previous works, a geospatial analysis of access to sustainable transportation options, research into the non-infrastructural barriers to taking sustainable transportation, and research into best practices from other comparative Universities.

To achieve this goal, ATPS has completed a cohesive study of options for sustainable transportation uptake at the University of Waterloo by completing both a literature review and statistical analyses. The literature portion of this report reviews the background for this report in addition to current literature on the topic of sustainable transportation uptake. To provide examples of where sustainable transportation uptake has been successful, the team has prepared a review of universities comparable to the University of Waterloo in both physical size, population size, and climate. This portion of the report informed the direction of the subsequent analysis which analysis utilized data provided by the University of Waterloo on employee locations via postal codes. This data was used to complete spatial analyses, catchment area analyses, and overall mode split analyses. The findings of these analyses were used to inform the recommendations of this report.

2.0 BACKGROUND & CONTEXT

The University of Waterloo continues to be one of the largest employers in Waterloo Region with over 42,000 full & part time students and 8,657 active employees (University of Waterloo, n.d.). As such a large employer and in being Canada's most innovative university, the University of Waterloo's actions in sustainability are not only beneficial to the greater population but have the potential to be very influential.

In 2017, the University of Waterloo released their first Environmental Sustainability Strategy (hereinafter "ESS Report") intended to be in force and effect from 2017 to 2025 (University of Waterloo, 2017). This report discusses the need to "develop a long-term Climate and Energy Action Plan to achieve carbon neutrality by 2050 […]"; the University identified that reaching this objective requires a review of the University's commuter related emissions (University of Waterloo, 2017).

When working towards achieving this goal, the University's Sustainability Office worked with SustainMobility to conduct an analysis on opportunities and constraints for increasing sustainable transportation uptake when it comes to the University's employees (Cuttleriwala et al, 2017). The goals of this report were threefold: (1) determine if there was a relationship between demography and the use of sustainable transportation in any specified geographic area within Waterloo Region; (2) determine if the availability of various infrastructural components influenced various mode choices; and (3) determine if there were gaps in sustainable transportation use regarding employee locations proximal to the University (Cuttleriwala et al, 2017). Through the completion of their analysis, SustainMobility determined that the University had an opportunity to enhance employee uptake of sustainable transportation when it came to demographics, infrastructure, and geography (Cuttleriwala et al, 2017). This report concluded with three recommendations:

1) The TravelWise survey should be redesigned to capture additional variables detailing transportation uptake;

2) Any transportation demand strategy completed by the University of Waterloo should be sectioned to reflect the commutes of employees in specific geographies; and
3) To use the SustainMobility report as a baseline to compare opportunities for sustainable transportation uptake following the launch of the ION Stage 1 Light Rail Transit System (Cuttleriwala et al, 2017).

The intention of this report is to branch from the findings and recommendations of the 2017 SustainMobility Report and complete a follow-up analysis of the opportunities for the uptake of sustainable transportation with respect to University of Waterloo Employees.

2.1 Regional Context

Since the release of the 2017 SustainMobility report, many factors have influenced the use of public transportation in the Region of Waterloo. As the use of public transportation to access the University of Waterloo is central to the analysis herein, this section will provide a brief overview of two regional factors which have significantly affected regional transportation for this report since the 2017 SustainMobility report: Public Health & Public Transportation.

2.1.1 Public Health

In March 2020, much of Canada shut down due to the Coronavirus pandemic ("COVID-19") with many provinces and municipalities declaring states of emergency (World Health Organization, 2020). In efforts to control the virus, many workplaces were directed by the Province of Ontario to shift to an online format where employees worked from home and/or alternate office locations (World Health Organization, 2020). Between 2020 and 2021, Statistics Canada found that between 30.6% and 41.4% of the Canadian employment force was consistently working from home. Statistics Canada also found that with many employees projected to continue working from home in a post-pandemic environment, transit ridership could drop by nearly 52% across Canada (Statistics Canada, 2021).

Though the Statistics Canada data has been helpful in determining national trends, no studies analyzing the effect of COVID-19 on the Region of Waterloo's transit system have been completed; this type of study is outside the scope of this report. As such, this difference in context between the 2017 SustainMobility report and this report should be acknowledged when comparing any results, findings, or recommendations.

Should the impact of COVID-19 on the regional transit system be studied in the future, this study should be undertaken a third time to determine how transit ridership will trend in the Region post-pandemic.

2.1.2 Public Transportation

The Region of Waterloo's public transit system, Grand River Transit ("GRT"), includes conventional bus routes, express bus routes, MobilityPLUS busses for those with disabilities, and a newly established ION Light Rail Transit System ("ION LRT" or "LRT") (Region of Waterloo, 2022).

The Region of Waterloo completed Stage 1 of the ION LRT in 2019 which established nineteen stations between the Conestoga Mall in Waterloo and the Fairway Mall in Kitchener (Region of Waterloo, 2013). The addition of the Light Rail Transit System to the existing public transportation network addressed the regions increasing ridership which has more than doubled since 2000 to nearly 22 million trips annually and is projected to continue growing (Region of Waterloo, 2012a). The Region is in the process of extending the ION LRT to Downtown Cambridge/Galt through the Stage 2 ION LRT project. This expansion would add eight additional stations along eighteen kilometres of track between the Fairway Mall in Kitchener and the intersection of Bruce Street and Ainslie Street in Downtown Cambridge/Galt (Region of Waterloo, 2012b).

The 2017 SustainMobility report accounted for the Region's public transit options before the release of the Stage 1 ION LRT in 2019. This report provides for the additional connections and opportunities for the uptake of sustainable transportation that the ION LRT has provided since the release of Stage 1.

It is recommended that this report be reassessed once Stage 2 of the ION LRT has been established to determine if there are new opportunities to incentivize sustainable transportation uptake for employees in South Kitchener and Cambridge.

2.2 University Context

When completing our analysis, ATPS Ltd. found three main areas within the University context level which impacted employee travel to campus. The first being the employees locations and if they are working remotely or commuting into the main campus. Secondly, our team identified that the concentration of employees' places of work within various buildings on campus would impact mode choice. Finally—and perhaps most importantly—mode choice is significantly impacted by the options for accessing main campus through each mode (ie: sidewalk connections for walking or frequency of bus stops if taking transit). This section will further explore each theme.

2.2.1 Employees

The University of Waterloo operates with employees across the country inclusive of full-time faculty, co-op students, food services staff, administration, and all others employed by the University (University of Waterloo, n.d.). Of these employees, the majority work within the Province of Ontario with 5,995 working from the Region of Waterloo, which is the scoped geographical context for this report.

The heatmaps included as Figure 2.1 and Figure 2.2 show the concentration of the University's employees in various postal code geographies. Figure 2.1 illustrates the Province of Ontario and shows that UW employees are generally concentrated around two nodes: the Greater Toronto and Hamilton Area ("GTHA") and around the Region of Waterloo. When looking at the Region of Waterloo as a whole, Figure 2.2 shows that employees are spread over the municipalities of Waterloo, Kitchener, Cambridge, North Dumfries, Wilmot, Wellesley, and Woolwich with the highest concentration being within the central and northern portions of the City of Waterloo.

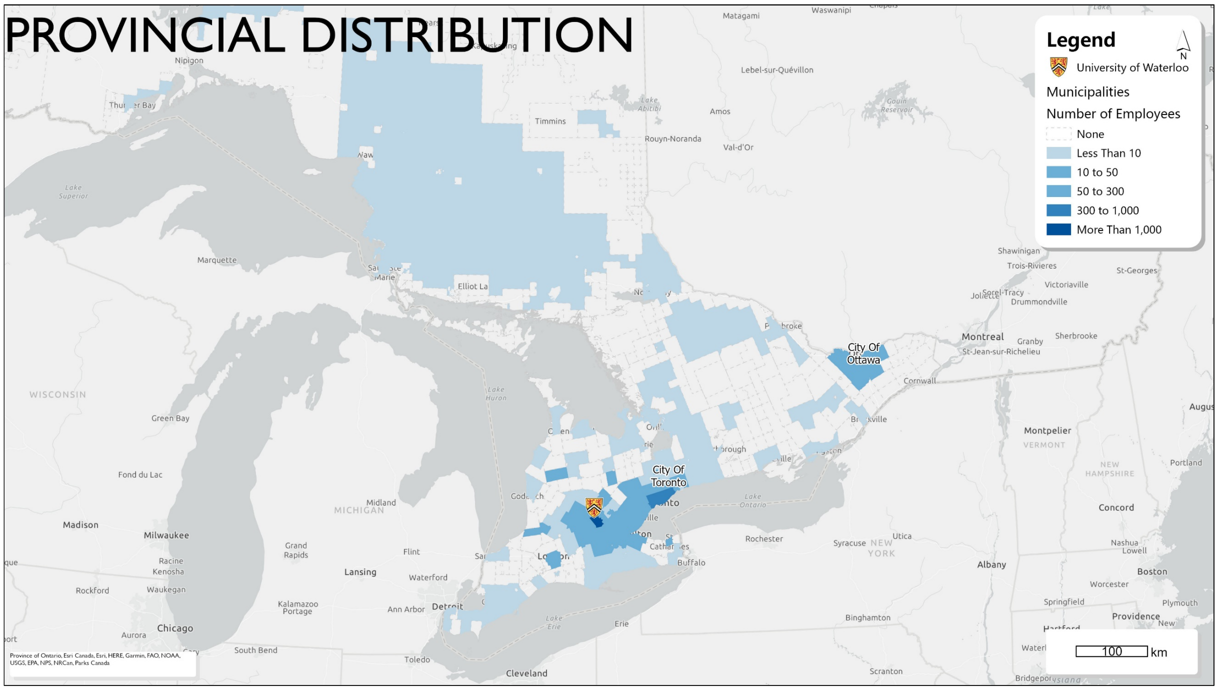


Figure 2.1*: Heatmap of Ontario showing locations of University Employees.*

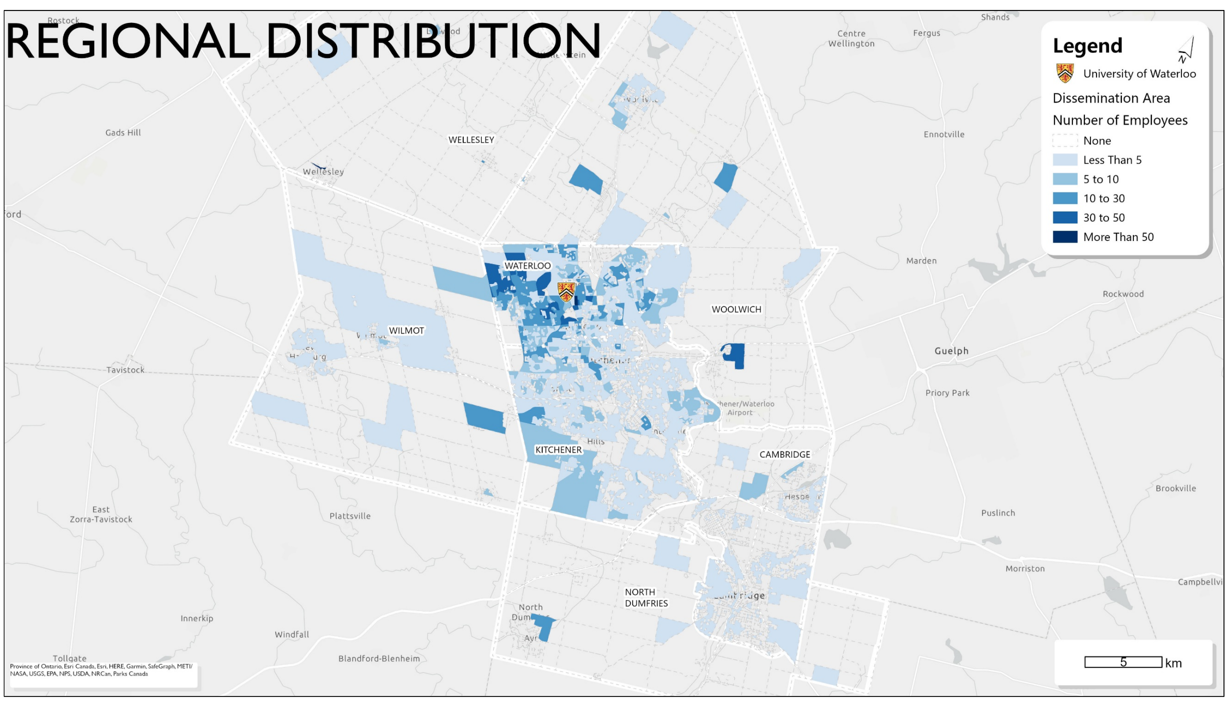


Figure 2.2*: Heatmap of the Region of Waterloo showing locations of University of Waterloo Employees within the Region.*

2.2.2 Places of Work

The University of Waterloo's main campus is located at 200 University Avenue West in Waterloo, Ontario ("Main Campus"). This campus is over 1,000 acres in size and includes over 100 buildings (University of Waterloo, n.d.). Figure 2.3 is a heatmap showing concentration of employee places of work at the Main Campus inclusive of the buildings within Ring Road, East Campus, Dormitories, and the Technology Park; this map shows that the majority of employees work in the buildings within Ring Road.

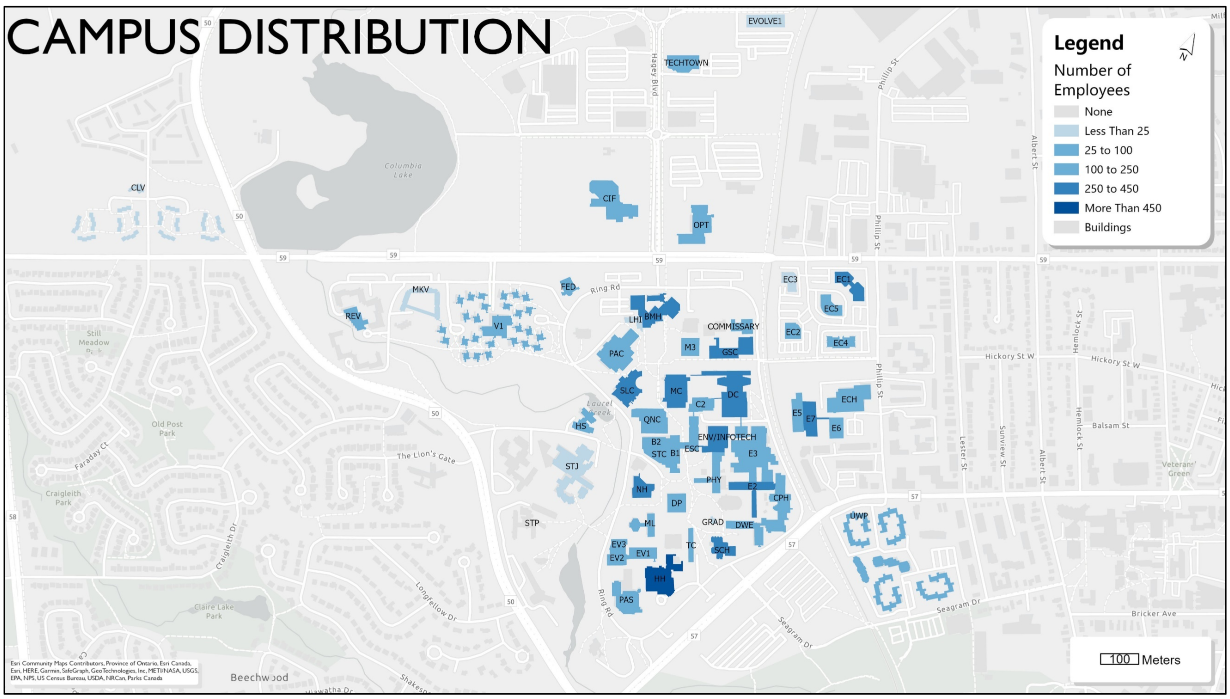


Figure 2.3: *Heatmap of the University of Waterloo's Main Campus showing employee places of work.*

2.2.3 Access to Main Campus

The various transportation networks surrounding the University of Waterloo provide many mode options for accessing campus inclusive of taking transit, walking/active transportation, and driving a personal vehicle.

Pedestrian access to the University's Campus occurs in four main gateways: at the intersection of University Avenue & Ring Road, the crosswalk by Carl A. Pollock Hall, the crosswalk by William Tutte Way, and finally the intersections of Hagey Boulevard, Ring Road, & Columbia Street West; these gateways are depicted by Figure 2.4. Further, this figure also shows the sidewalks which provide ample connections to all access points, north to the technology district, east through to the east campus buildings, south to University Avenue & C-lot parking, and west to Westmount Road & the subdivision across.

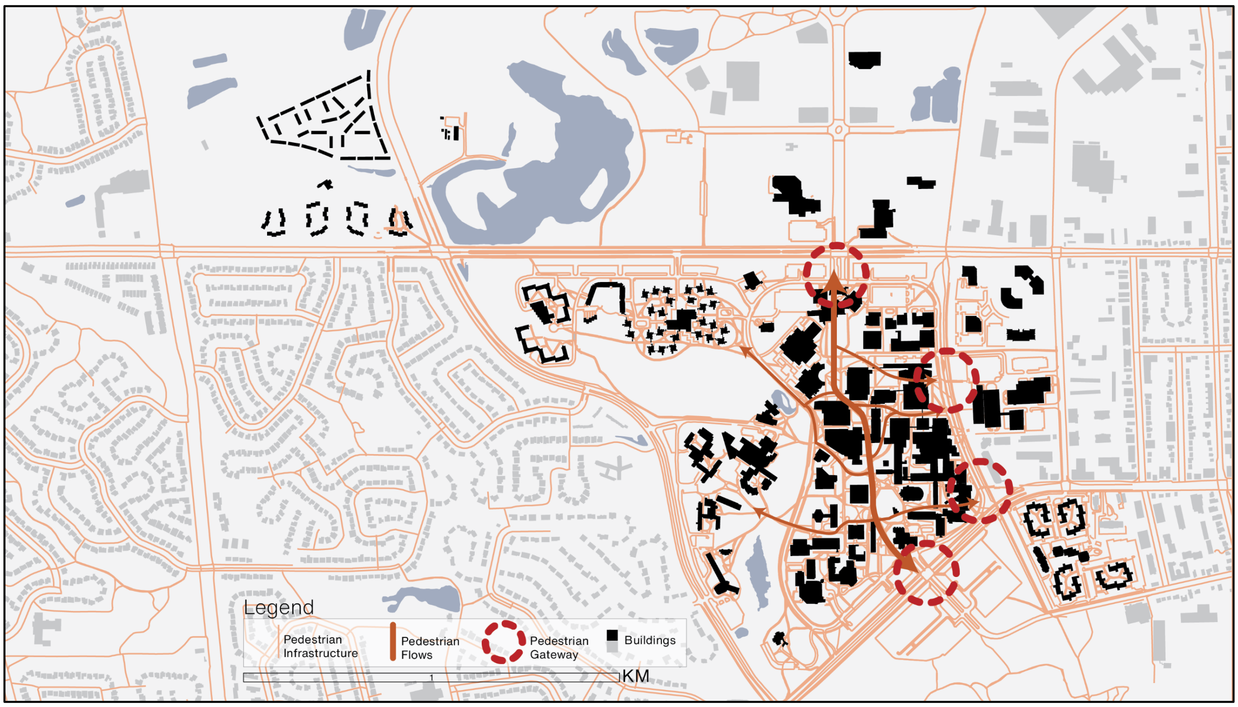


Figure 2.4: *Map of the University of Waterloo's Main Campus showing pedestrian access gateways and pedestrian paths throughout campus.*

The transit network around campus is shown by Figure 2.5. Transit accessibility is divided into two main categories: light rail transit and busses. The light rail transit runs parallel to the east portion of Ring Road with a stop between the new bus terminal and the Engineering 7 building. Busses provide connections through the main campus and are generally well dispersed along Ring Road. In particular, the iExpress bus routes provide strong coverage along the east half of campus as shown by Figure 2.6.

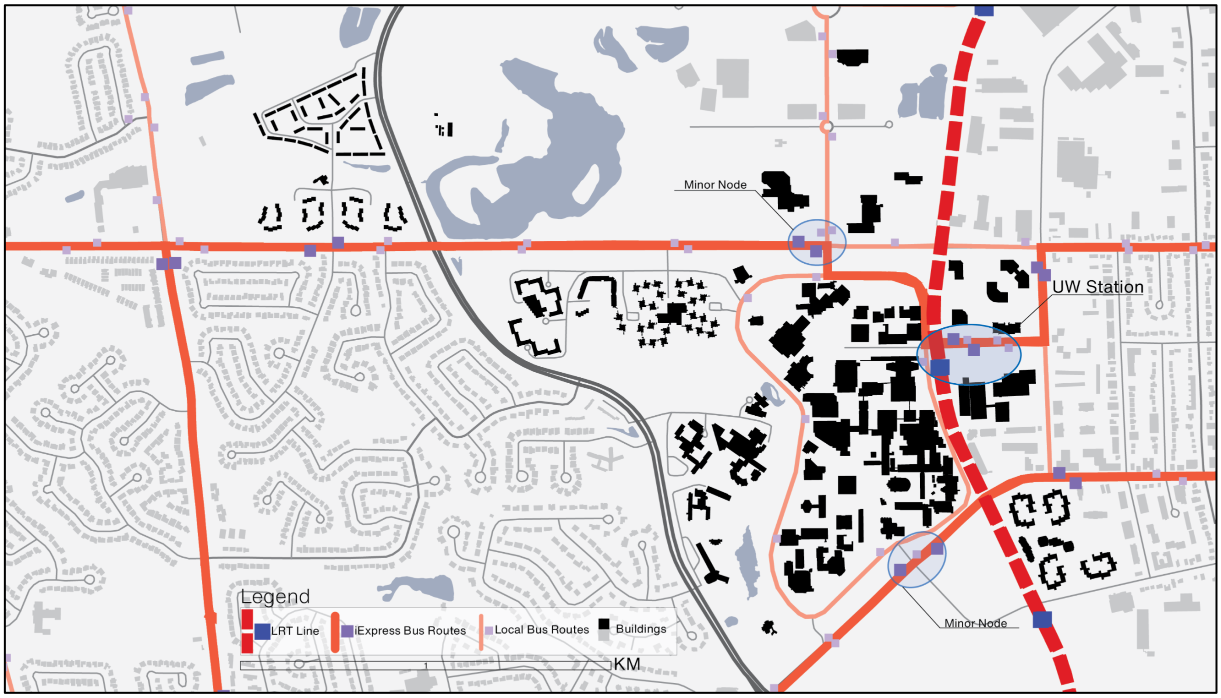


Figure 2.5: Map of the University of Waterloo's Campus showing transit connections.

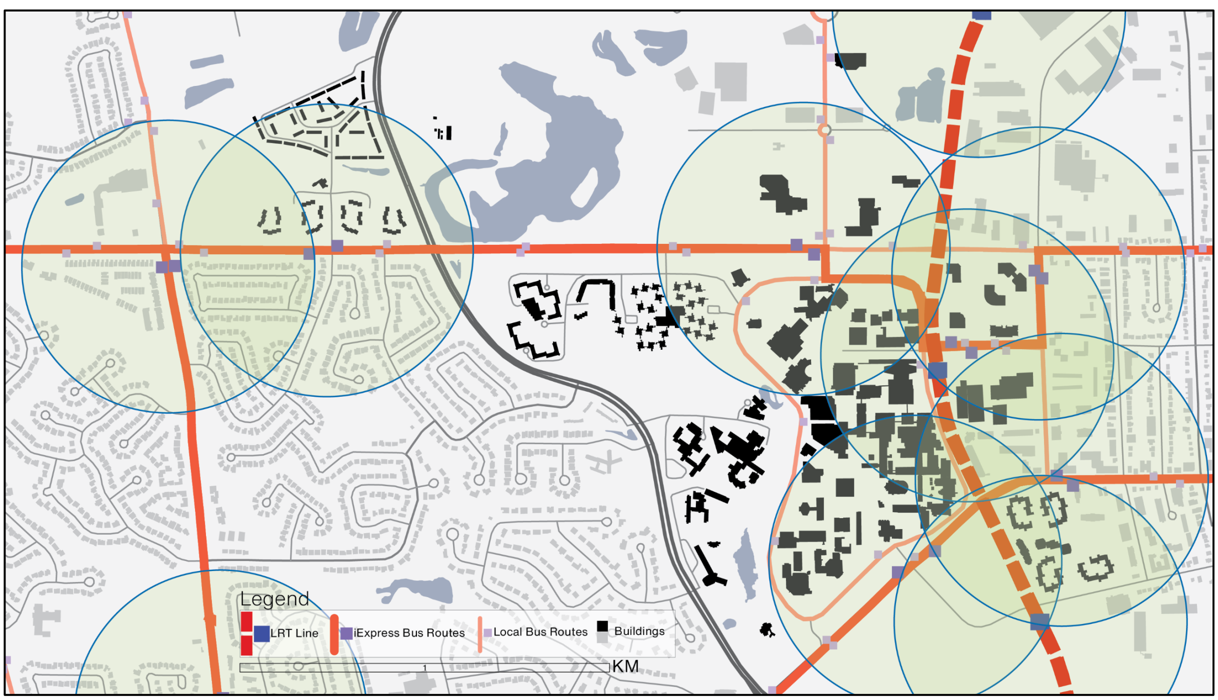


Figure 2.6: Map of the University of Waterloo's Main Campus showing transit accessibility within 400m (5-minute walking distance) from i-Express bus stations.

3.0 LITERATURE REVIEW

ATPS Ltd. intends to establish data-driven best practices and strategies to assist the University in promoting shifts in employee transportation behaviours by incentivizing low-carbon commuting (University of Waterloo, 2020). Our team will look to non-infrastructural and infrastructural barriers to address these sustainable transportation choices and create better options. Working together with the University, ATPS Ltd. will recommend solutions that will benefit all University employees and the broader community.

3.1 Travel Mode Choice & Utility Theory

As urbanization generates a rapid increase in travel demands, the quality of life within urban areas faces both socio-economic and environmental challenges (Jia et al., 2018). Among the most severe of these challenges, the impacts of climate change can be seen through the significant contribution that vehicular use has had on the rise of greenhouse gas emissions in urban areas (Jia et al., 2018). To reduce these emissions, municipalities, planners, and all other related disciplines & professionals encourage the use of public transportation systems and other environmentally friendly transportation options. As such, travel mode choice plays a critical role when determining the strategies needed to implement these transportation options and create sustainable mobile communities.

Travel mode choice is considered one of the most vital decisions in the transportation planning process as it heavily impacts policy decisions and actions (Sekhar, 2014). By understanding the connections between mode choice and its influencing factors, policymakers, planners, and employers can help alleviate certain transportation conditions (i.e., car congestion, traffic disruption), as well as adapt achievable solutions (Sekhar, 2014).

Utility-based theories are popular when deciding between travel mode choices (De Vos et al., 2016). These theories are often applied through discrete choice modelling to determine the different mode choices available (De Vos et al., 2016). To assess this, utility theory determines which travel mode choice has the highest utility ranking based on factors such as cost, location, time, and identity among others (De Vos et al., 2016). For instance, utility theory finds that location is a major influence for car dependency. In sprawled suburban neighbourhoods, car dependency is likely to be higher when compared to inner city mixed-use residences where cycling and transit are preferred. (De Vos et al., 2016). As such, individuals will make assumptions based on these factors and form alternative options that best fit their needs and maximize their utility (Saini, 2019). Travel mode choices are also subjected to patterns of behaviours and attitudes. If a particular mode choice generates an overall positive experience, it is probable that a commuter will make the same mode choice for their next trip (De Vos et al., 2016). For example, people are more likely to use cars because they may feel it is more convenient, safer, and requires less effort than public transit. Therefore, it is important that all factors influencing mode choice are evaluated when looking at incentivizing low-carbon commuting. This ensures all direct and indirect influences on mode choices have been accounted for. Within this literature review, the following influences will be discussed: identity, safety, employment, weather and urban design and planning.

3.2 Influences on Travel Mode Choice

3.2.1 Identity and Mode Choice

A significant determinant that utility theory uses to assess travel mode choice stems from a commuter's identity. From a sociological role theory perspective, identity is defined as the internalization of social roles that ultimately determines one's own set of norms and expectations (Murtagh, Gatersleben, & Uzzell, 2012). In everyday life, people will navigate their communities and municipalities by managing multiple identities within themselves. These identities will take on a hierarchy within a person's life, ranging from their most prominent identity to their least prominent (Murtagh, Gatersleben, & Uzzell, 2012). Some examples of significant identities a person may have include gender, parental & marital status, religion, race, and class among others. Personal identity can influence an individual's understandings of climate change as well as the actions they may or may not take to lessen their contributions thereto. Those whose identity is personally connected to a place or connected to nature itself have a more emotional connection to their environments, therefore positively effecting an individuals' climate-friendly behavior in different domains (Vesely et. al, 2021). In contrast, when a larger social identity that an individual is connected towards has no correlation to climate issues, there are fewer positive associations towards climate-friendly behavior (Vesely et. al, 2021). Identity is further exasperated in group settings, specifically in households with varying identities. For instance, commuters with families and children will be directly impacted by the travel needs of each member, especially when considering factors such as travelling to school to drop off children before travelling to work (McMillan, 2005).

Despite the rules society will place on each identity, the way people internalize their identities and roles will be interpreted subjectively (Murtagh, Gatersleben, & Uzzell, 2012). However, findings support that multiple identities are related to travel behaviour and habit patterns across varying different journey types (Murtagh, Gatersleben, & Uzzell, 2012). Overall, identity must be considered when establishing travel mode choices and strategies for commuters. By doing so, municipalities, employers, and transit companies, can begin to understand the barriers that individual identities may have when making mode choices and the demographics by which programs & services are used.

3.2.2 Safety and Mode Choice

Personal security and safety is another important determinant in utility theory for commuters deciding between travel modes. As mentioned under *3.1 Travel Mode Choice & Utility Theory*, private car use is often chosen by commuters due to its convenience and practical functionality though psychological factors such as a desire for privacy and safety act as another contributor to travel behaviour and choice (Murtagh, Gatersleben, & Uzzell, 2012).

The quality of an individual's urban environment, coupled with area crime rates and perceptions of crime, play a substantial role in either encouraging or discouraging certain mode choices (Appleyard & Ferrell, 2017). Findings show that when an individual's sense of safety is at risk, their fear of crime becomes associated with their urban context (Appleyard & Ferrell, 2017). Specifically, for downtown areas, feelings of insecurity based on crowded and unpredictable urban environments may deter people from local transit systems independent from the actual safety of the transit system itself; these insecurities ultimately lead people to avoid transit altogether (Appleyard & Ferrell, 2017).

It is important to note that personal security & safety can also be combined with the discussion on identity when it comes to mode choices. For example, research has found that those identifying as women are less likely to walk when neighbourhood crime rates increase (Appleyard & Ferrell, 2017). This can be further exasperated through urban design and planning. Spaces that are deemed to be poorly designed will often have (but are not limited to) poor lighting, lack of adequate signage, empty lots/ vacant areas, as well as lack of public stops and restrooms (Navarrete-Hernandez, Vetro , Concha, 2021). Therefore, municipalities must consider improved crime prevention strategies through urban design and planning and better enforcement along transit corridors to increase sustainable transit mode choices.

3.2.3 Employment and Mode Choice

Employment is another determinant of utility theory for transportation mode choice and behaviour amongst commuters. This often mean assessing a commuter's access to a place of work as well as the nature of that work. The location of transportation-based infrastructure influences the economic development and growth of urban areas (Thakuriah, 2011). Transportation investments, specifically major transportation developments (i.e., ION Light Rail Transit), directly affect labour market catchment areas, and as such effects the demand for labour, goods, and services (Metrolinx, 2012). More job opportunities are generated from transit investment and planning. Thus, it is essential to consider how easily employees can reach their employment destinations. Job accessibility can be determined by the commuting distance and cost between one's home and workplace (Xiao, Wei, & Wan, 2021). Higher commuting distances and costs are seen as barriers to both an employee and employer. For example, the temporal and financial requirements for long commutes can burden employees. At the same time, employers can be burdened by the decrease in employee productivity due to long or uncomfortable commutes. (Xiao, Wei, & Wan, 2021).

To encourage sustainable transportation networks amongst employees, places of employment can establish Travel Demand Management ("TDM") strategies. TDM strategies act as efficient tools that employers can use to reduce car trips through a wide variety of options (Ko & Kim, 2017). This may include flexible work schedules, shuttle services, financial incentives/ disincentives, and other options (Ko & Kim, 2017). Currently, the University of Waterloo uses some TDM strategies to increase sustainable commuting trips and reduce fossil fuel consumption across campus, in partnership with TravelWise and the Region of Waterloo (University of Waterloo, n.d.) Strategies such as bike loan programs and bike cages to increase safety are promoted to increase walking and cycling across campus. A CarSharing program is also available for employees that wish to use public transit or bikes to get to work but may still need a rental car to go to meetings near campus (University of Waterloo, n.d.). Findings show that the presence of rideshares, transit, and non-motorized services have significant positive effects on a commuter's choice of using a personal vehicle (Zhou, 2008). It is important, however, that employers coordinate with other government agencies to reach sustainable goals in any given city, therefore widening the scope of available strategies and initiatives. Land use design, placement of amenities, and land use policies to allow mixed-use of employment, business, and residential have strong ties to sustainable transit traffic flows (Zhou, 2008).

3.2.4 Climate, Weather, and Mode Choice

With the climate change crisis rising as a critical concern felt by the world, weather conditions have emerged as a vital issue when addressing infrastructure, travel behaviour, and urban planning practices (Böcker, Dijst, & Faber 2016). In 2022, experts at the University of Waterloo weather station reported that January had been the coldest winter the region had seen in over a decade (Turcotte, 2022). This first month alone was approximately 3.4 degrees colder than the 30-year January average of - 6.5C (Turcotte, 2022). These conditions are on-trend to become worse as local and global climate change trends indicate increasing extreme weather events (Turcotte, 2022)

Therefore, climate and weather another important determinant in utility theory when assessing mode choice.

Firstly, extreme weather conditions affect transportation infrastructure. Transportation infrastructure was designed to accommodate typical weather patterns based on trends found in local climate conditions, future climate and temperature trends, and precipitation levels (Transportation Research Board, 2008). However, the effects of climate change have caused weather patterns to become more unpredictable. These events can lead to various problems such as traffic and weather-related delays, roadway & rail line flooding, and damage to supporting structures (Transportation Research Board, 2008). As a result, such events strain both infrastructures and the economy due to the cost of repairing and implementing transportation planning and construction tactics (Transportation Research Board, 2008).

Furthermore, weather conditions link to travel behaviors and attitudes. Studies have shown possible connections to mood fluctuations based on seasonality, where summer presents the best moods and winter presents the worst moods, sometimes referred to as winter/ seasonal depression (Böcker, Dijst, & Faber 2016) (Oyane et al., 2007). Extreme cold, heat, and precipitation conditions—often exasperated by climate change—have also shown to cause aggressive discomfort, separate from any season. Such conditions, alongside travel behaviour, results in emotional responses of irritation, tiredness, and fear due to the discomfort associated with the threat of clouds, blowing wind, and getting wet (Böcker, Dijst, & Faber 2016). These emotions can affect travel experience across a variety of different transportation modes. For example, pedestrians and cyclists are prone to weather exposure and temperature-sensitive travel environments which can negatively impact their entire travel experience and result in fewer trips under those modes (Böcker, Dijst, & Faber 2016).

Overall, it would be beneficial for decision-makers to explore the complexities associated with climate, weather, and behavior to create strategies that could alleviate moods even in bad weather conditions.

3.2.5 Urban Planning, Design and Mode Choice

Urban design and transportation planning provide the necessary development tools to address growing urban issues. Through each, both private and public sectors can meet sustainable development goals that help promote healthy living in the built environment. This includes promoting active transportation through walking, cycling or public transit use (Boulange, 2017). This is done by utilizing important design and development elements such as bright and vibrant street aesthetics, accessible signage and wayfinding, lighting and seating infrastructure, and finally safe and reliable roadway and transit infrastructure (Blitz & Lanzendorf, 2020). When established, benefits are seen through reduced environmental impacts, improved public health and overall positive community welfare (Boarnet, Greenwald, & McMillan, 2008). On the contrary, poor urban design and planning can cause issues for the built environment as well as pedestrians within that environment. For example, when roadway and railway infrastructures are primarily oriented around the private vehicle, it can cause severance between pedestrian and cyclist networks, thus reducing overall local accessibility (Eldijk & Gil, 2020). Another design barrier for commuters includes segregating neighbourhoods from core urban areas, reducing overall job access. As such, limitations are created in the implementation of sustainable cities and communities.

3.3 Exploring Different Travel Mode Choices – Waterloo Case Studies

Within this review, a variety of influences were assessed through both non-infrastructural and infrastructural lenses. Non-infrastructure influences were found to be guided by the physiological behaviours of an individual and the impacts that has on a person's social and personal identity. Infrastructure influences include other components such as utility, functionality, and demand (Jia et al., 2018). Each influence plays a role in determining travel mode choice. Travel modes in urban communities can be categorized into four groups: private vehicles, public transportation, non-motorized vehicles (i.e., bicycles, skates, scooters), and walking. By considering mode choice case studies in Waterloo, further insight is provided on potential mode options that could be used by commuters and be implemented in future recommendations. These mode choices include, but are not limited to, the light rail transit (LRT) system, an exploration of e-scooters, and bicycle integration.

3.3.1 Light Rail Transit (LRT) system – Study by Cheung (2021)

The most transformational mode choice offered to residents in the Region of Waterloo is the light rail transit (LRT) system. The LRT system is an important transit development in the Region as it provides an alternative travel mode for commuters while also attracting new property as a major transit station development (Cheung, 2021). From a sustainable development perspective, the objective of the LRT system is to reduce overall traffic congestion and air pollution, improve transit ridership, and improve the built environment through sustainable land use and urban growth patterns (Cheung, 2021). Although ridership data is limited due to the pandemic, initial findings show that LRT ridership has risen since July 2019 and has attracted more public transit trips (Cheung, 2021). Overall, the LRT is an important mode choice for commuters and shows potential in improving active transportation use amongst residents.

3.3.2 Exploring the E-scooter – Study by Waterloo School of Planning (2019)

When considering the development of sustainable and smart cities, transportation planners must consider the ‘first and last mile problem’. Within public transportation terminology, ‘first and last mile’ refer to the spatial accessibility between public transportation stations and an individual’s original destination (Kåresdotter, 2022). Findings show that when there is a lack of connectivity between these two points, private car use is increased to combat this distance that may or may not be walkable. To address this concern, the City of Waterloo launched Canada’s first e-scooter pilot (School of Planning, 2019). E-scooters, otherwise known as electric scooters, emerged as a new urban mode choice in response to the last mile problem. Phase one of Waterloo’s E-scooter pilot restricted scooters to private streets and multi-use trails along the Laurel Trail and within David Johnson R & T Park (School of Planning, 2019). However, phase two of this project extended onto the University of Waterloo’s main campus, during which the Stage.1 of the Region of Waterloo’s ION LRT system also opened (School of Planning, 2019). The pilot project assessed that e-scooters have the potential opportunity to influence travel behavior, however, future studies need to be established for e-scooters to truly be considered a mode choice for commuters. As such, it is recommended that a comprehensive study on e-scooters that considers time and safety is done, alongside an increase in rider surveying.

3.3.3 Bicycle Integration – Study by Lin (2021)

Apart from the innovative mode solution of e-scooters, walking and cycling are typically used when considering first and last-mile options (Lin, 2021). Cycling is preferred and is often chosen as the more desirable mode choice for healthy living when compared to cars as it allows for faster travel time and larger spatial coverage. Cycling can also promote more active recreation amongst individuals, positive mental well-being, and reduce road congestion and pollution issues that come with motorized vehicles (Lin, 2021). Advantages are further increased when transportation planners consider integrating cycling infrastructure alongside transit infrastructure. For the Region of Waterloo, this means combining bicycle and LRT systems to reduce greenhouse gas emissions and advance sustainable living measures (Lin, 2021). Thus, it is essential that appropriate programming and policies, bike lanes, and bike rakes are established.

4.0 COMPARATIVE UNIVERSITY REVIEW

According to Sustainability Tracking, Assessment & Rating System ("STARS"), the University of Waterloo is considered a silver rated academic institution (STARS, 2021). In the pursuit of sustainability, innovation, and excellence, the UW Sustainability – Transportation Demand Management Planning Study strives to increase the percentage of employees utilizing sustainable transportation as their primary mode of transportation in their daily commute. This comparative university review highlights exemplary international, national, and provincial examples that have the potential to be successful at the University of Waterloo. Specifically, various incentives and strategies, alongside frameworks and guidelines were analyzed.

4.1 Frameworks & Guidelines

4.1.1 Vermont Clean Cities Coalition – The Sustainable Transportation Toolkit

The Vermont Clean Cities Coalition created the *Sustainable Campus Transportation Toolkit*, which is a framework created to recommend best practices for implementing and supporting sustainable transportation on college and university campuses in Vermont. According to the framework, sustainable transportation is a crucial component to improving social, economic, and environmental awareness in post-secondary institutions (Vermont Clean Cities Coalition, 2016). Sustainable transportation instills positive habits and knowledge in students, alongside aiding in mitigating and adapting to climate change (Vermont Clean Cities Coalition, 2016). Notably, this framework proposes priority parking for carpools and vanpools.

4.1.2 Urban Transport Group – The Scandinavian Way to Better Public Transport

Meanwhile, the Urban Transport Group commissioned the *Scandinavian Way to Better Public Transport*, analyzing the impact and performance of various modes of transportation utilized throughout Scandinavia (Urban Transport Group, 2017). Overall, research demonstrated an aptitude towards higher active transportation use –

especially cycling – in comparison to the United Kingdom ("UK") (Urban Transport Group, 2017). This was partially due to the culture around active transportation as well as the policies in place involving transportation and private vehicle ownership (Urban Transport Group, 2017).

4.2 Universities

4.2.1 Tufts University – Middlesex County, Massachusetts, U.S.A.

Tufts University is a private post-secondary academic institution located in suburban Middlesex County, Massachusetts, U.S.A (Tufts University, 2015). The campus is approximately 150 acres, with a reported 10,000 students and 4,000 employees (STARS, 2019). According to their 2015 TDM Report, Tufts University outlined nine transportation goals to improve the institutions existing parking and transportation program, including: planning for future growth; increasing campus sustainability; improving connectivity between campuses; cost effectiveness; maintaining campus competitiveness; improving transit accessibility; reducing parking demand; promoting bicycle use; and creating a pedestrian friendly campus (Tufts University, 2015). Moreover, Tufts University provided numerous strategies – organized by catalytic strategies, priority strategies, and secondary strategies – to succeed in fulfilling their transportation goals. Particularly, Tufts University has implemented:

- 50% discounted public transportation passes for employees;
- $20/month bicycle reimbursement benefit; and
- $50/month gas reimbursement for carpooling/vanpooling.

(Tufts University, 2015)

All of the above incentives are conducive to the University of Waterloo's objective of increasing the utilization of sustainable transportation amongst employees.

4.2.2 University of British Columbia – Vancouver, British Columbia, Canada

The University of British Columbia ("UBC") is a public post-secondary academic institution located in metropolitan Vancouver, British Columbia, Canada. According to STARS, UBC was considered a gold rated academic institution (STARS, 2015). The campus is approximately 993 acres with a reported 43,509 students and 13,387 employees (STARS, 2015). According to their 2014 TDM Report, UBC outlined several transportation strategies to improve the campus' sustainable transportation infrastructure, including guiding land development through planning; housing and urban design policies; regulating campus streets and parking; building and maintain campus roads, sidewalks & public spaces; and educating and empowering the campus community to make sustainable transportation choices (University of British Columbia, 2014). Specifically, but not restricted to:

- Improving cycling infrastructure on campus to increase connectivity to the surrounding cycling network; and
- Partnering with the local transit authority to influence surrounding transit stations and routes.

(University of British Columbia, 2014)

Furthermore, UBC has demonstrated the effectiveness of their previous TDM strategies by reducing single-passenger vehicle commutes by 15% and increasing transit usage by 37% from 1997 to 2012 (University of British Columbia, 2014). Ultimately, implementing these strategies could benefit the University of Waterloo in increasing the utilization of sustainable transportation amongst employees.

4.2.3 Ryerson University – Toronto, Ontario, Canada

Ryerson University is a public post-secondary academic institution located in Toronto, Ontario, Canada. According to STARS, Ryerson University is considered a silver rated academic institution (STARS, 2020). The campus is approximately 68.59 acres with a reported 46,452 students and 6,788 employees (STARS, 2020). According to STARS, 90% of Ryerson University utilize sustainable modes of transportation as their primary commute choice (STARS, 2020). This is attributed to established sustainable transportation infrastructure and systems including, cycling lanes, buses, streetcars, subways, and connectivity of complete streets in the City of Toronto itself. Notably, the Toronto Transit Commission ("TTC") is the primary public transit system in Toronto. Currently, a 12-month TTC PRESTO pass costs $143.00/month and allows unlimited trips (TTC, n.d.). Meanwhile, employee on-campus parking via parking permit costs $206/month (Ryerson University, n.d.), combined with condo parking when off-campus which ranges from $50-$200/month (la Fleur, 2020).

Ultimately, located in the current fastest developing region in Canada, the University of Waterloo has the potential for its surrounding infrastructure to similarly support sustainable transportation modes for its employees.

4.2.4 University of Vermont – Burlington, Vermont, United States

The University of Vermont is a public post-secondary academic institution located in Burlington, Vermont, United States. According to STARS, The University of Vermont is considered a gold rated academic institution (STARS, 2020). The campus is approximately 4,314 acres with a reported 15,968 students and 4,186 employees (STARS, 2020). According to the *University of Vermont Active Transportation Plan*, the University of Vermont outlined multiple strategies to improve sustainable transportation on campus, including:

- The utilization of merchandise incentives;
- A ticket diversion incentive;
- Reducing vehicle parking; and
- Holding educational workshops on cycling safety and parking.

(University of Vermont, 2017)

All of these above incentives and programs are anticipated to be applicable with the University of Waterloo's landscape and transportation objectives.

4.2.5 University of Colorado Boulder – Boulder, Colorado, United States

The University of Colorado Boulder is a public secondary academic institution located in Boulder, Colorado, United States. According to STARS, The University of Colorado Boulder is considered a gold rated academic institution (STARS, 2021). The campus is approximately 604 acres with a reported 35,528 students and 9,961 employees (STARS, 2021).

In the *University of Colorado Boulder Transportation Master Plan*, various strategies are outlined to improve on campus transportation. Of these strategies the University of Waterloo could benefit from integrating separated paths for walking and cycling as UW currently has no inner campus cycling paths and navigating a bicycling through crowded pedestrian areas can be hazardous and intimidating (University of Colorado Boulder, 2020).

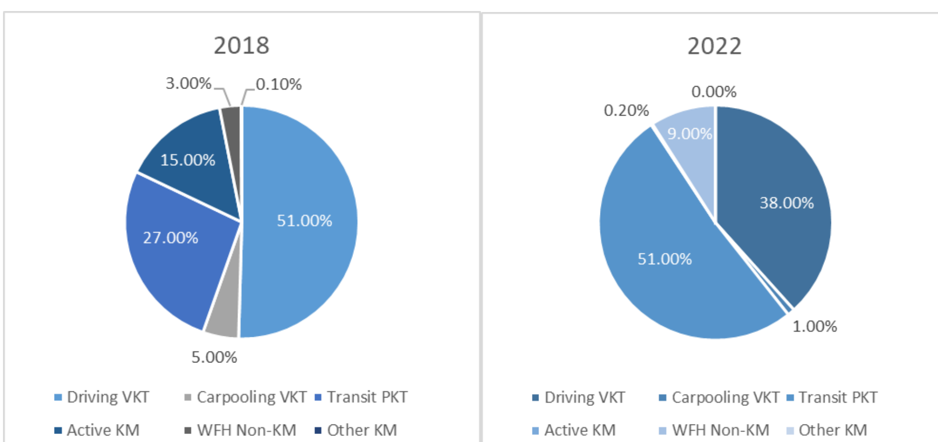
4.3 Findings

Ultimately, various case studies were where effective incentives and strategies were recommended. Feasibility within the University of Waterloo context will be decided based on similarities in physical geography and demographics as well as financial constraints. These recommendations will be discussed further in the recommendations section of the report.

5.0 SPATIAL ANALYSIS

The analysis and findings contained in this report are in response to the RFP issued by the uWaterloo Sustainability Office. This RFP directed ATPS Ltd. to review past work on commuting mode choice at the University of Waterloo, particularly the 2017 SustainMobility report. Elements of this past research have been acknowledged and replicated to reflect the present context in order to build off of and refine the analysis presented in the 2017 report.

The second component of the scope of work is a GIS analysis of commuting mode choice access for employees. Accordingly, the analysis presented in this report provides a mode choice model for 4 commuting options (walking, biking, driving, and transit) based on proximity, travel time and accessibility to appropriate infrastructure. Furthermore, specific cost factors are understood to be vital in determining mode choice. These factors are accounted for and implemented into the understanding of the mode choice model. Since no up to date modal split statistics are available, previous reports will be used as a baseline for comparison. This includes comparisons to the 2018 & 2020 TravelWise Commuter Survey as seen below in [Figures 5.1 & 5.2\, as well as the 2017 Sustain Mobility Report.



Figures 5.1 & 5.2: (left) 2018 TravelWise Commuter Survey results (right) TravelWise Commuter Survey results. Survey responders include all ages above 20, as well as faculty, staff, undergrad students, and graduate students.

The RFP further directed ATPS Ltd. to examine the non-infrastructural barriers to sustainable transportation options. Accordingly, this research was conducted primarily through literature review and a preference for research in the Waterloo context. Through this, the report identifies the major non-infrastructural barriers that are likely affecting mode choice for UW employees. With both spatial and literature-based analyses in mind, later sections of this report identify potential incentive programs that are in place at other similar institutions and highlights programs that are most applicable for the UW context.

5.1 Methodology

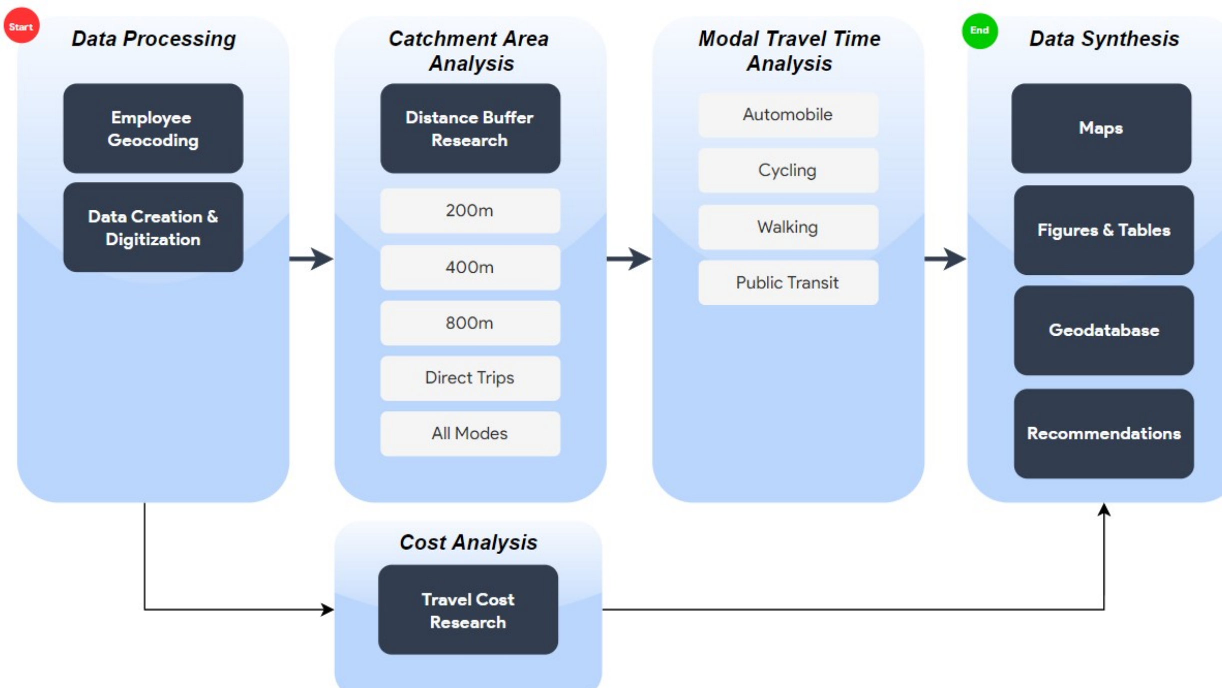


Figure 5.3: Overall workflow of spatial analysis as well as their variations, conducted in four phases.

The spatial analysis portion of the project consists of four discrete phases as shown above in Figure 5.3. In the pre-analysis phase, a series of data processing workflows are conducted mainly relating to the geocoding of raw employee data, as well as the creation of auxiliary data. The intermediate stages of analysis include two streamlined processes that assess service area and travel times as part of a catchment area analysis and modal travel time analysis, respectively. Lastly, the results from the analysis are then synthesized as part of a post-analysis phase which includes the creation of maps, figures, tables, and a simplified geodatabase containing all key models. Also, a travel cost analysis based on peer-reviewed research was conducted separately, since no spatial analytics are required for this type of assessment. Based on the results of the analysis, as well as the key findings of our literature review, recommendations are constructed.

5.1.1 Data Processing

Before conducting the analysis, preliminary data processing was required. Processing and analysis of data was completed using a combination of Microsoft Excel and ArcGIS Desktop suite products. Only two datasets required a significant level of processing: employee postal code locations and transit routes. Additionally, custom data was created and digitized to support later analysis, including datasets pertaining to UW Centrelines, UW Parking Lots, and UW Buildings.

Employee Geocoding

Employee postal code data was provided as a table, with no spatial reference, and included two attributes: 6-digit postal code of residence and UW Building place of work. These two attributes were recognized as trip beginnings and trip ends, respectively. Geographic boundaries at the 6-digit postal code level are not publicly available, thus the data was geocoded using the enhanced postal points (“EPP”) dataset, derived from the UW Geospatial Centre. Potential pitfalls when using EPP include the fact that they are centroid points rather than exact geographic boundaries, as well as their geography being limited to only the ROW. Since there are no 6-digit postal code boundaries available outside the ROW Forward Sortation Areas (“FSA”), which consist of geographic boundaries at the 3-digit level, were used to geocode the remaining employees. The raw data consists of a table containing the postal codes and building of employment of a total of 8,657 Employees. Of these employees, only 8,454 possessed valid postal codes; the remaining 203 employees consisted of postal codes that were unrecognizable, mostly due to origins existing outside of Canada.

While the ROW's open data portal provides up-to-date transit route data, it does not provide scheduling or frequency data. Thus, in-order to properly assess travel times, General Transit Feed Specification ("GTFS") data was used. GTFS is an open-sourced transit feed that records historical trips, stops, and routes on a per-month basis. Since the data originates in text file format, several steps were required to obtain transit routing data. This expressly involved python scripting, which was used to convert the data to the correct format as shown below in Figure 5.4.

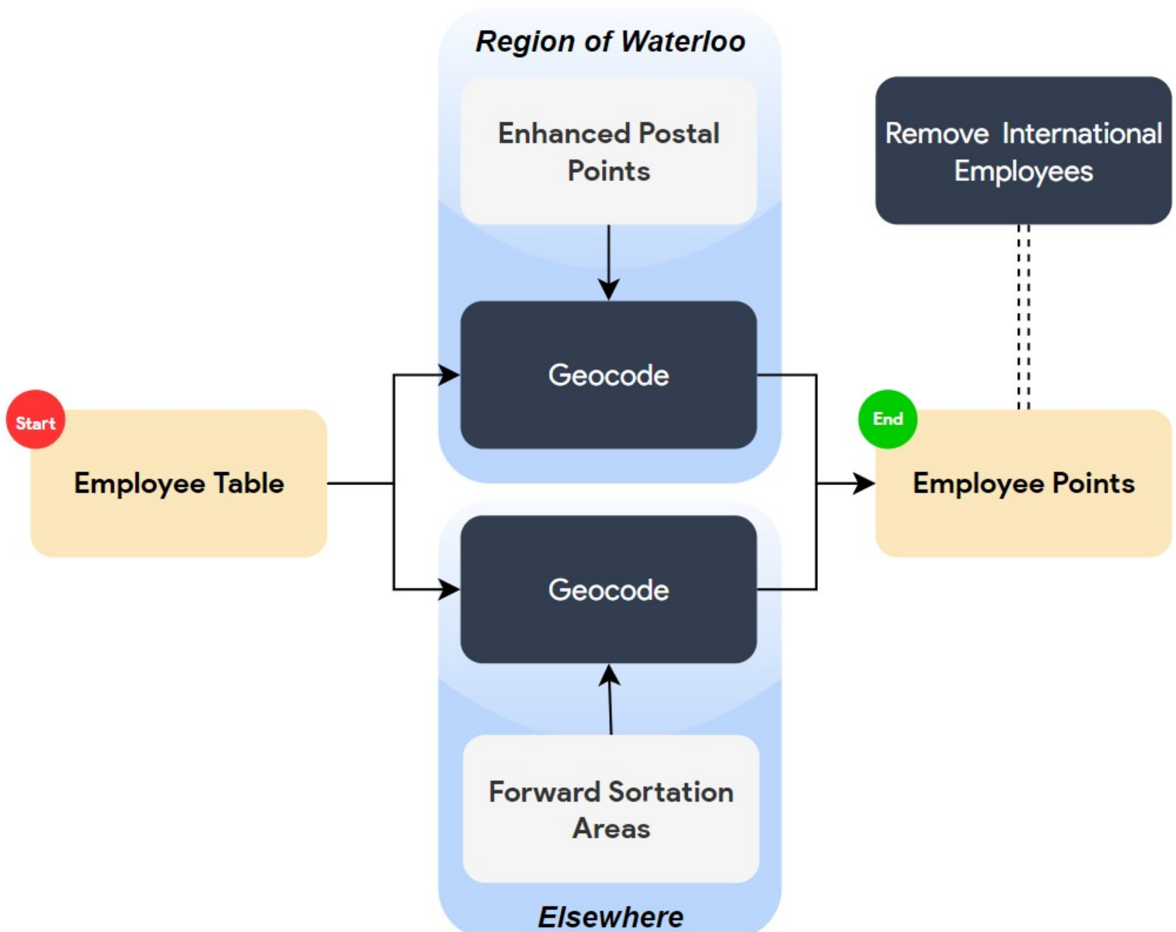


Figure 5.4: Workflow of employee tabular data conversion. Geocoding reference data was obtained directly from the uWaterloo Geospatial centre.

Data Creation & Digitization

For the purposes of enhancing the spatial analysis, several auxiliary datasets were created. The UW Campus Centrelines dataset contains the centrelines of pathways found throughout the main campus since the UW's proprietary sidewalk dataset contains path outlines which are not useful for analysis. Lines were simply digitized using an ESRI Basemap and were then merged to the existing road network dataset to be used in later analysis. The UW Campus Reserved Parking dataset is a simple point feature class that contains the X, Y, coordinates of parking lots reserved for UW faculty & staff. Points were digitized using approximate locations from the UW's campus map. Lastly, the UW Campus Buildings dataset contains standard building footprints obtained from the City of Waterloo's open data portal, however additional fields containing the full and abbreviated names of UW buildings were added. The simplified workflow of these processes is shown below in Figure 5.5.

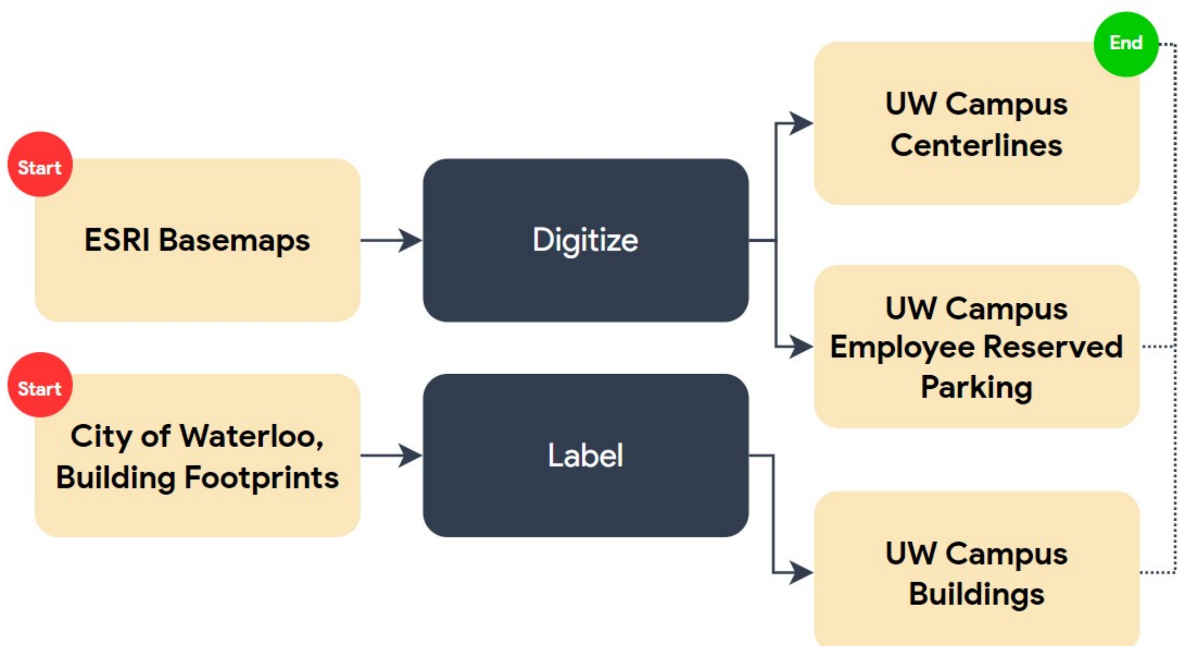


Figure 5.5: Workflow of data creation and data processing.

5.1.2 Sustainable Transit Catchment Analysis

Several sustainable transit catchment analyses were conducted at various levels for various scenarios. This analysis is intended to extend the 2017 SustainMobility Report, which involved a similar analysis for the given year. Using more up-to-date employee data, the analysis was reproduced in order to compare potential increases in sustainable transit ridership.

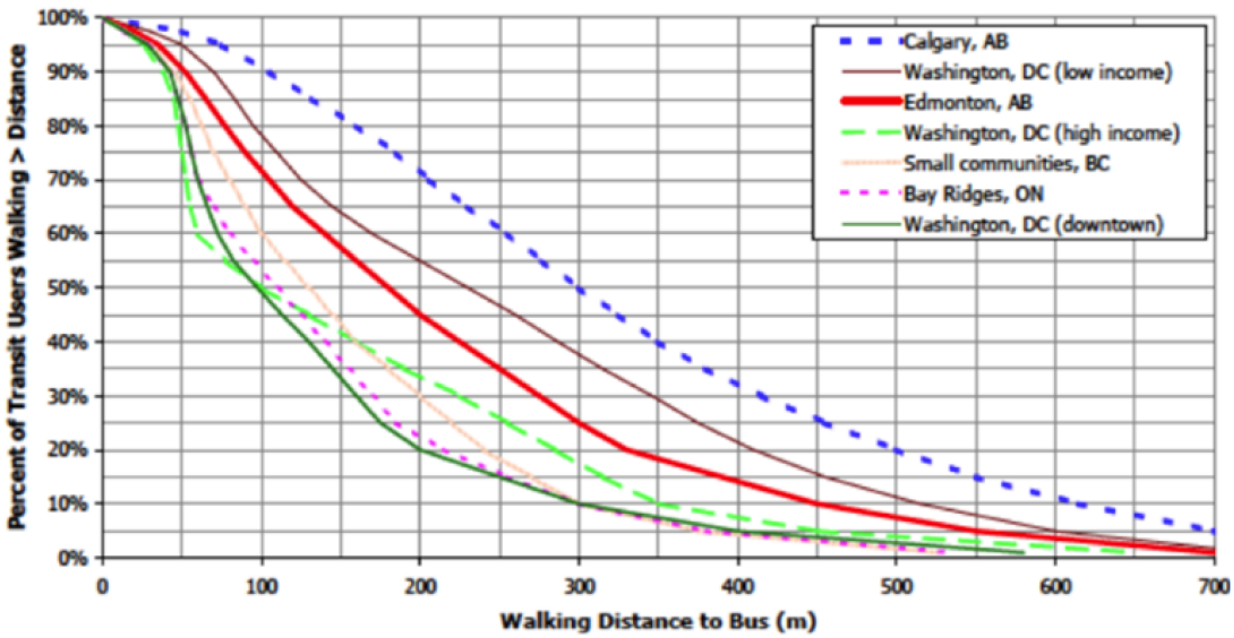


Figure 5.6: Tendency for users to take transit based on walking distances to a transit station across various metropolitan areas. (Source: TCQSM Chapter 3, Appendix A, p. 3-93.)

Research indicates--among a myriad of other factors--that transit is more attractive when the walking distance is relatively short. The most common industry standard for transit considered "accessible" is within 400 metres of a stop. Further to this, higher-order transit like the ION LRT can attract trips from further away, due to higher reliability, shorter headways, and quicker travel times (Walker, 2011). As such, ideal buffer sizes, which are also in line with the 2017 SustainMobility Report, are shown below in Table 5.1.

Infrastructure	Buffer Distance (m)
GRT Stop	400
Xpress Stop	600
ION Stop	800
Cycling Lanes	600
Sidewalks	200

Table 5.1: Table depicting ideal buffer distances for public transit infrastructure within the ROW. Cycling lanes and sidewalks are also included for later analysis.

The first set of catchment analyses included transit walksheds at various levels. Based on literature and research, it was found that the ideal walking distance to bus stops is approximately 400m, and decent walking distance to bus stops is approximately 800m. Thus, walkshed analyses were conducted using these distances as buffers, as well as an additional 200m analysis for the sake of assessing the most ideal scenario. For each distance, a buffer was created around GRT transit and ION stops. Using a spatial join, join counts were recorded to obtain the number of employees within each respective buffer distance. Figure 5.7 shows a simplified flow chart depicting this workflow.

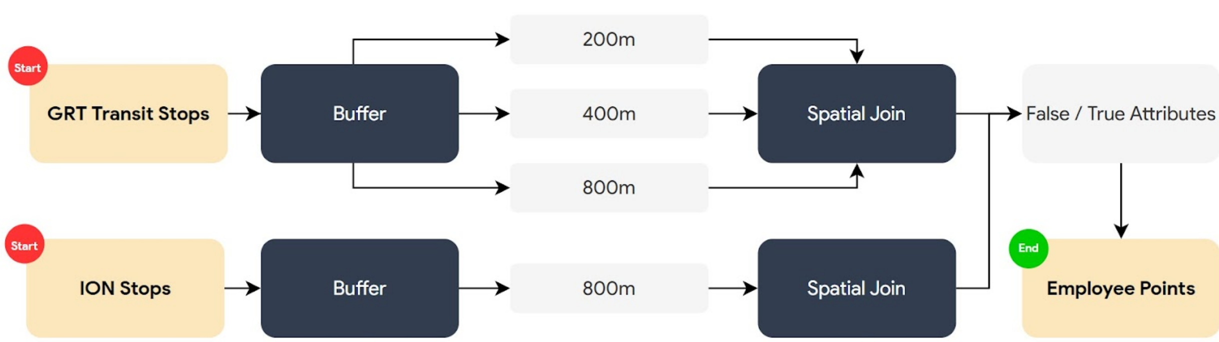


Figure 5.7: A simplified flow chart of the catchment analysis process.

A specialized catchment analysis was also conducted for "ideal circumstances", referring to transit routes that have direct connection to the UW campus. This catchment analysis also involved a 400m buffer around both direct GRT routes, as well as all ION routes. Direct routes were derived from a spatial query, which was set to include all routes that spatially intersect the university.

5.1.3 Modal Travel Time Analysis

To approximate the modal split of UW employees within the region, a travel time analysis was conducted to identify ideal travel behaviours for each individual employee. The network analyst toolset in ArcGIS Pro allows for this exact analysis through the Origin Destination Matrix Solver tool. Workflows involved in computing these travel times are shown below in [Figure 5.8]:

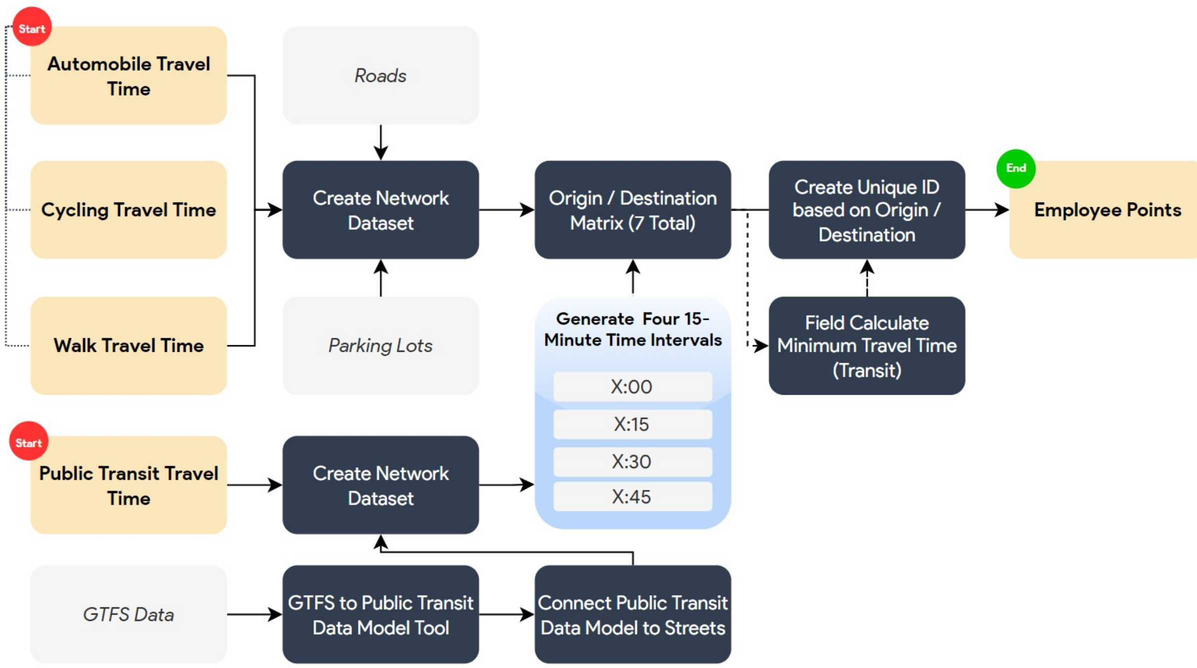


Figure 5.8: Workflow of travel time analysis. Conducted in two stages: automobile, cycling, and walking conducted similarly, while public transit was analyzed separately.

First, four methods of transportation are identified, including travel via personal automobile, public transit, bicycle, and walking. For each mode, using roads and auxiliary source data, a network dataset is created. Each network dataset is customized to realistically reflect travel behaviour for each mode. For example, for travel via personal automobile, an origin is set to the postal code of the employee and a destination is set to the employee building of employment. For this particular mode, an employee would theoretically start the trip in their vehicle, and then exit the vehicle at the nearest staff & faculty reserved parking lot relative to their building of employment, and then complete the trip on foot; the model would account for all modes involved in this trip and add their travel times up to represent a single "Automobile Travel Time". This is a similar case with travel via public transit where the initial walk to the bus stop, and the final walk from the bus stop to the building of employment are considered in the model.

Network datasets involving automobile, cycling, and walking travel modes are generated relatively similarly with each involving solely a road source layer as well as designated travel speeds for each mode per road segment. From this, an origin / destination matrix is generated which contains every possible route combination between each UW employee postal code and each building of employment. With a total of 172,840 possible trips for all employees cumulatively, the travel times of a specific trip can be assigned to an employee based on a unique ID generated from their origin and destination. Completing this join provides travel times for automobile, cycling, and walking.

For travel via public transit, a different workflow is required due to the nature of the network; the network dataset for public transit not only involves roads, but the public transit routes as well. In order to obtain these transit routes, which includes real-time scheduling, GTFS data is processed using a series of Esri Public Transit tools. Since GTFS data originates in tabular form, the data is first imported into a database with spatial references and specific attributes using the "Convert GTFS to Public Transit Data Model" tool. Next, connectivity is created between roads, which are used for walking paths in this particular network, and transit routes using the "Connect Public Transit Data Model to Streets" tool. Once connectivity is established, the model can accurately account for both walk times and transfers in the model and from here the network dataset can be created. For this specific network, the Public Transit evaluator is used, which is a custom Esri impedance that reads GTFS schedules to obtain trip times for a specific route. Since a specific input time is required to commence the trip, four-input times with 15-minute intervals starting 7:00 AM on a weekday, were chosen. This was specifically done due to the fact that the model considers time spent waiting at the bus stop which is ultimately dependent on when you leave your home. Thus, four origin / destination matrices were computed containing a total of 691,360 unique trips across all input times. The minimum travel time was identified across all four of the time intervals, which most accurately depicts travel time via public transit. These results were then joined to the employee dataset, completing the analysis.

5.2 Cost Analysis

One major determinant of mode choice is the cost of the potential options (De Vos et al., 2016). Generally, it is clearly understood that walking and biking are the cheapest options from this purely financial perspective, while private vehicle ownership is the most expensive with transit somewhere in between (Ratehub, 2020). Many accurately perceive transit to be a cheaper alternative to the private vehicle but may be hesitant to commit fully to not owning a car. Indeed, in Ontario, it is in some cases over 6 times as expensive to own a vehicle than to take transit as shown in Figure 5.9 below.

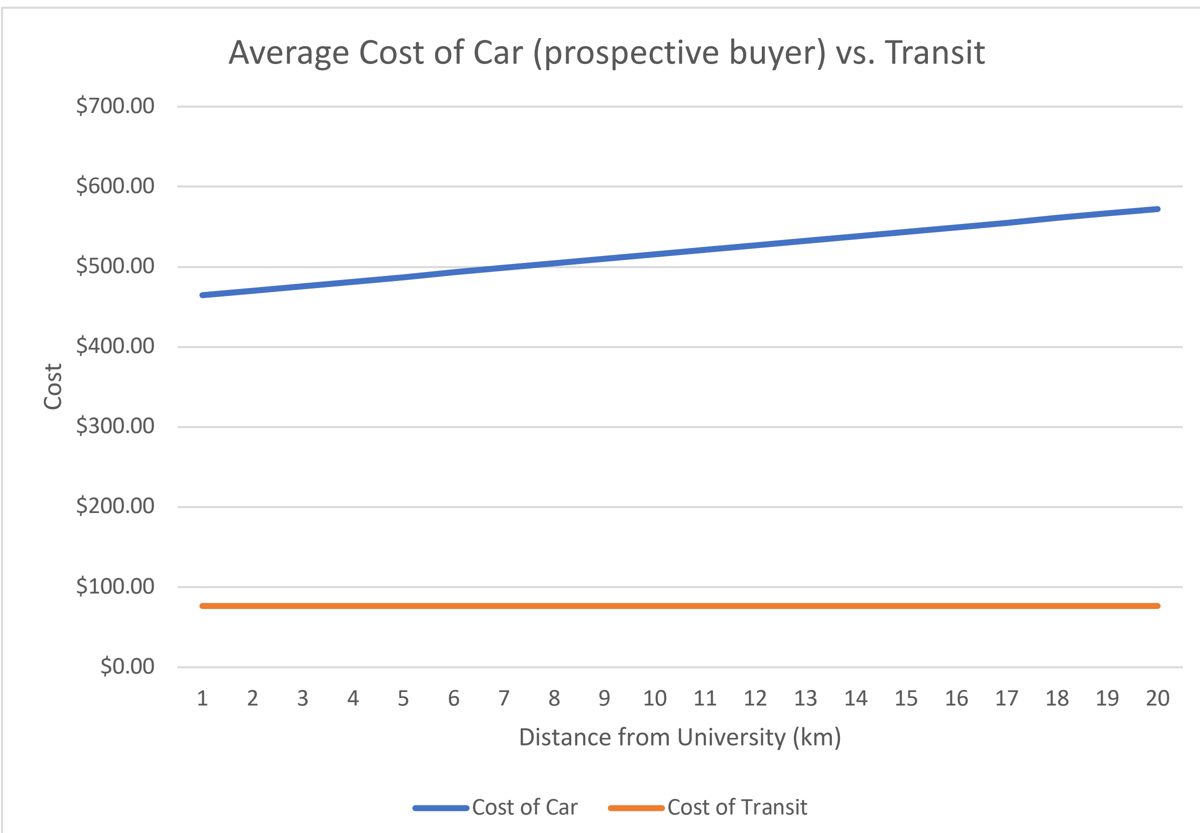


Figure 5.9: Summary graph of costs comparing a potential buyer of a private vehicle and a public transit user based on distance from the University. Data adapted from Ratehub (2020) & University of Waterloo (n.d.). Cost of gasoline assumed to be $1.59/L.

However, for the substantial population of employees who likely already own a vehicle for other purposes, the cost advantage is not as clear cut as depicted by [Figure 5.10]. For private vehicle commuters who already own a vehicle, it is assumed that the only additional cost of commuting is the fuel for the trips, and the cost of a University parking pass ($42.94). As such, for commuters living within a 6-kilometre distance from their destination, driving is cheaper. For distances beyond 6 kilometres, the flat rate of the transit pass is more appealing.

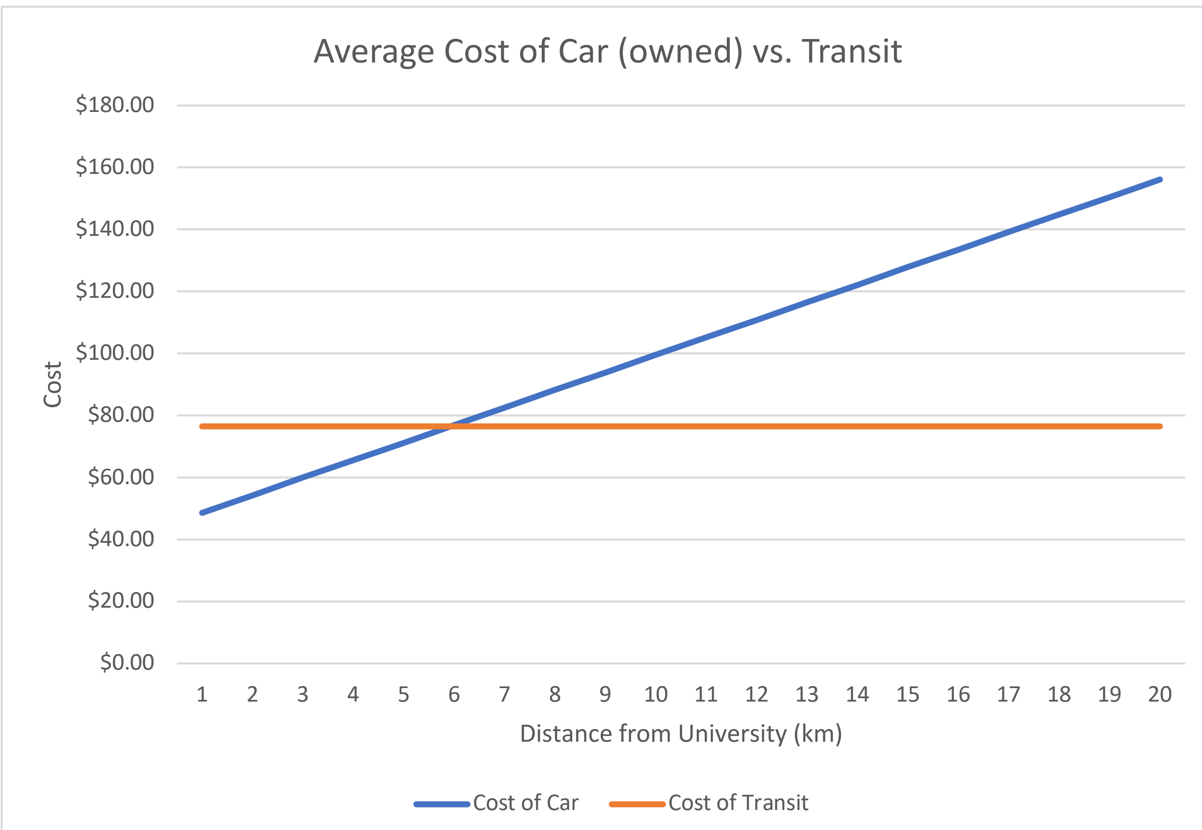


Figure 5.10: Summary graph of costs comparing an existing owner of a car and a public transit user based on distance from the University. Data adapted from Ratehub (2020) & University of Waterloo (n.d.). Cost of gasoline assumed to be $1.59/L.

5.3 Results & Discussion

5.3.1 Catchment Analysis

As mentioned previously, the results from the catchment analysis are intended to replicate the 2017 Sustain Mobility Report and are depicted in five variations. The first three are simplified and include a service area analysis of transit stops based on a 200-meter, 400-meter, and 800-meter buffer. Each of these simple variations includes the ION system, with 800-meter buffers to account for the increased acceptable walking distance for LRT. The fourth variation includes a direct transit map, depicting service areas with a 400-meter buffer for trips going to the UW Campus with no transfers. Lastly, a sustainable transit service map for all modes is depicted, which shows the number of employees with various levels of access considering all modes.

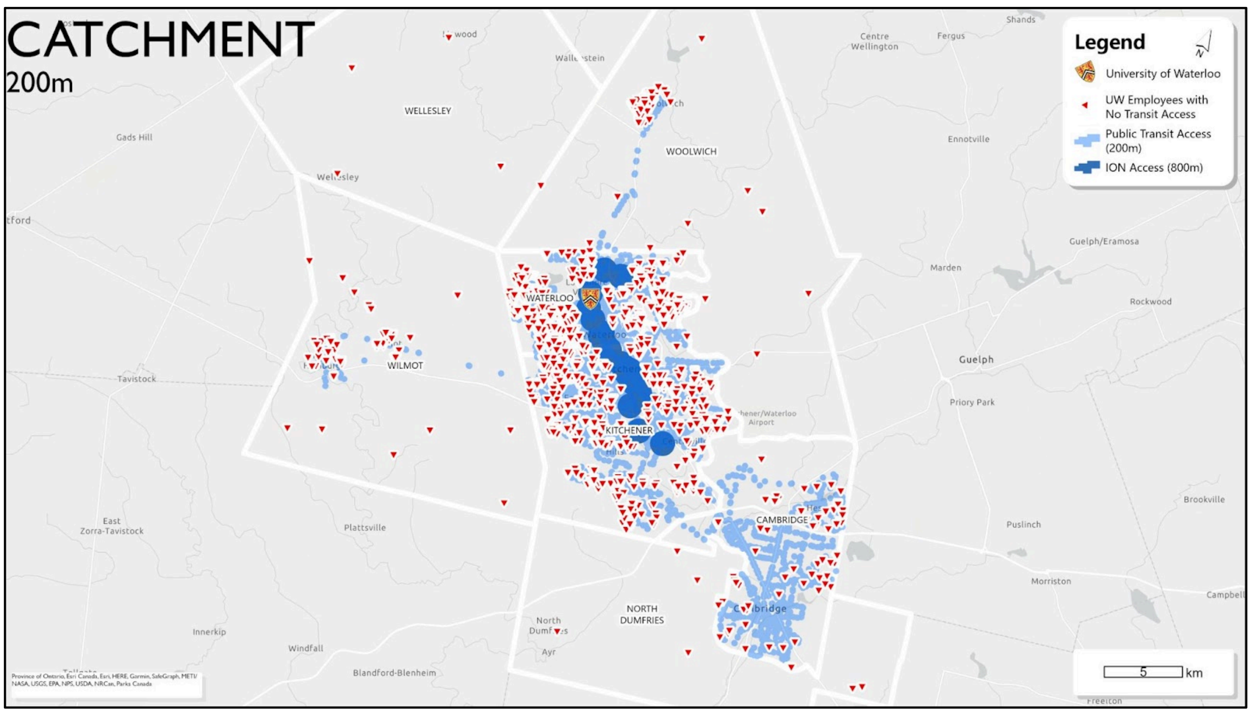


Figure 5.11: Catchment Area Analysis map depicting service area for GRT/ION with a 200-meter buffer around transit stops. 62% of Employees are covered.

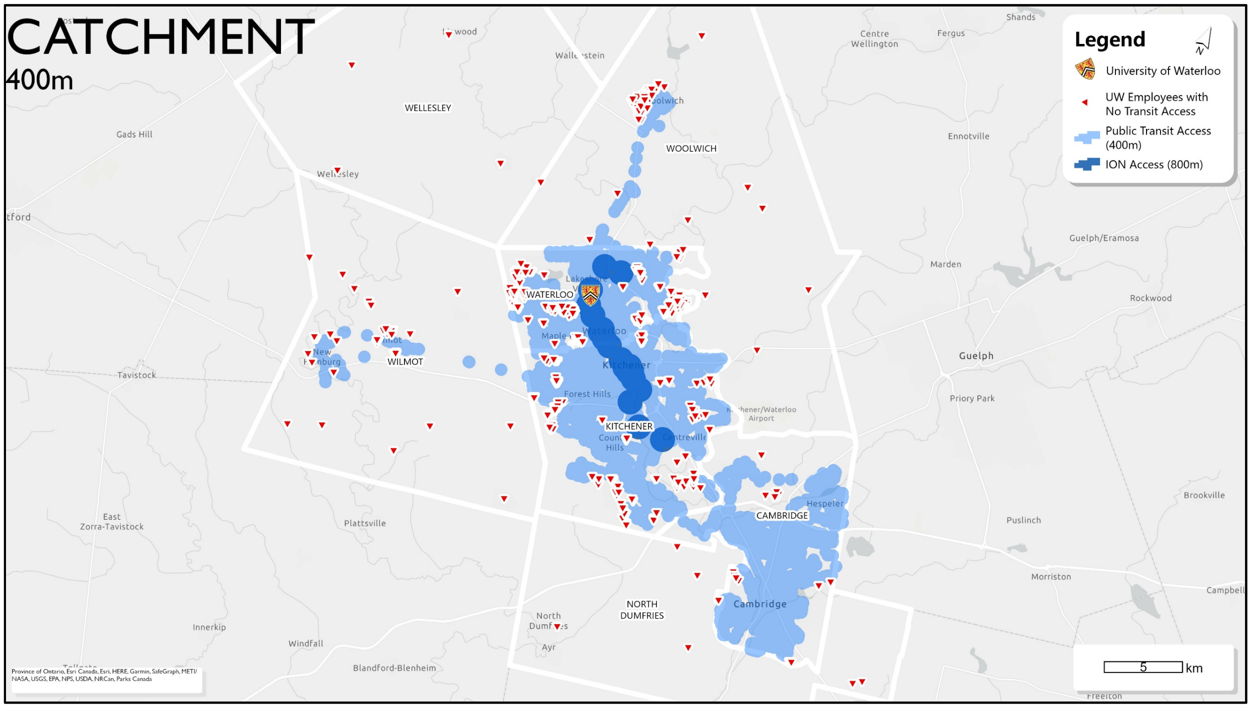


Figure 5.12: Catchment Area Analysis map depicting service area for GRT/ION with a 400-meter buffer around transit stops. 86% of Employees are covered.

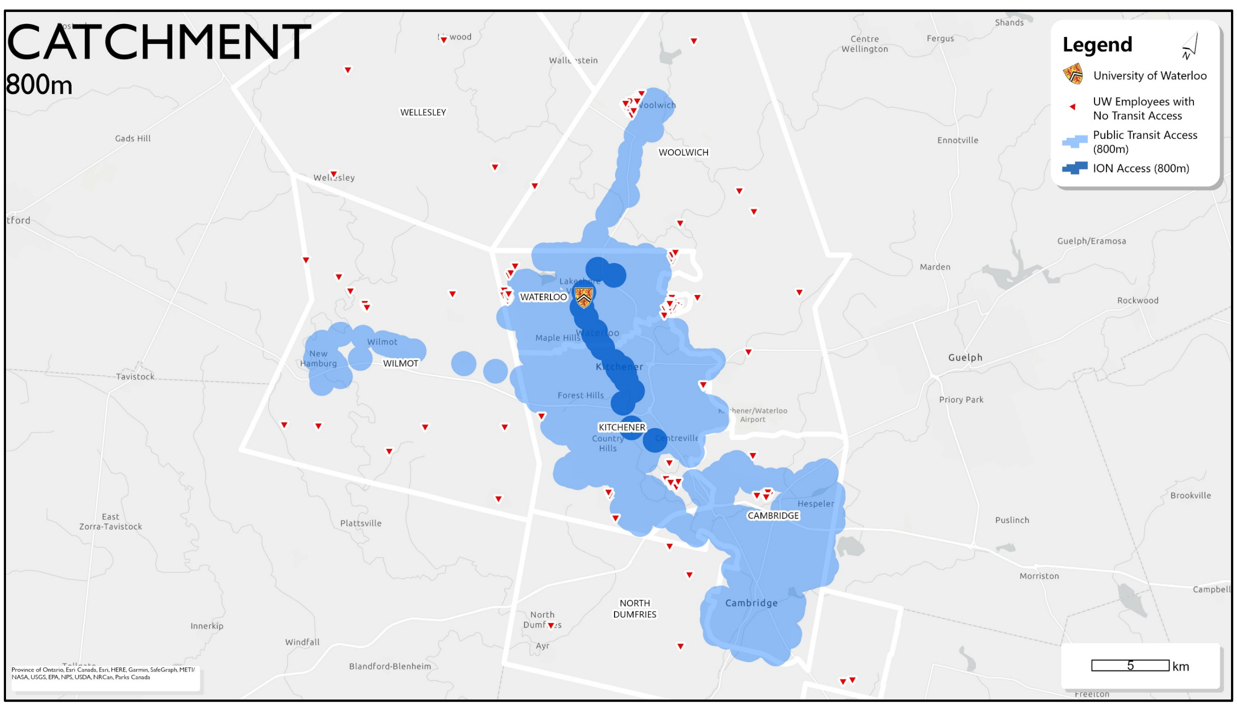


Figure 5.13: Catchment Area Analysis map depicting service area for GRT/ION with a 800 meter buffer around transit stops. 94% of Employees are covered.

Figures 5.11, 5.12, and 5.13 depict catchment area analyses with 200-, 400-, and 800-meter transit stop buffers, respectively. As expected, service coverage significantly decreases as the buffer decreases. With 200m buffers, out of 5,995 employees within the ROW, 3,717 employees have access to a GRT/ION transit stop. At the 400m level, 5,156 have access. Lastly, when 800m buffers are applied, 5,635 employees can access a transit stop within the ROW. As previously discussed, access to transit considering a 400m buffer seems to be ideal and is used as the basis for more complex catchment area analyses found below in Figures 5.14 and 5.15.

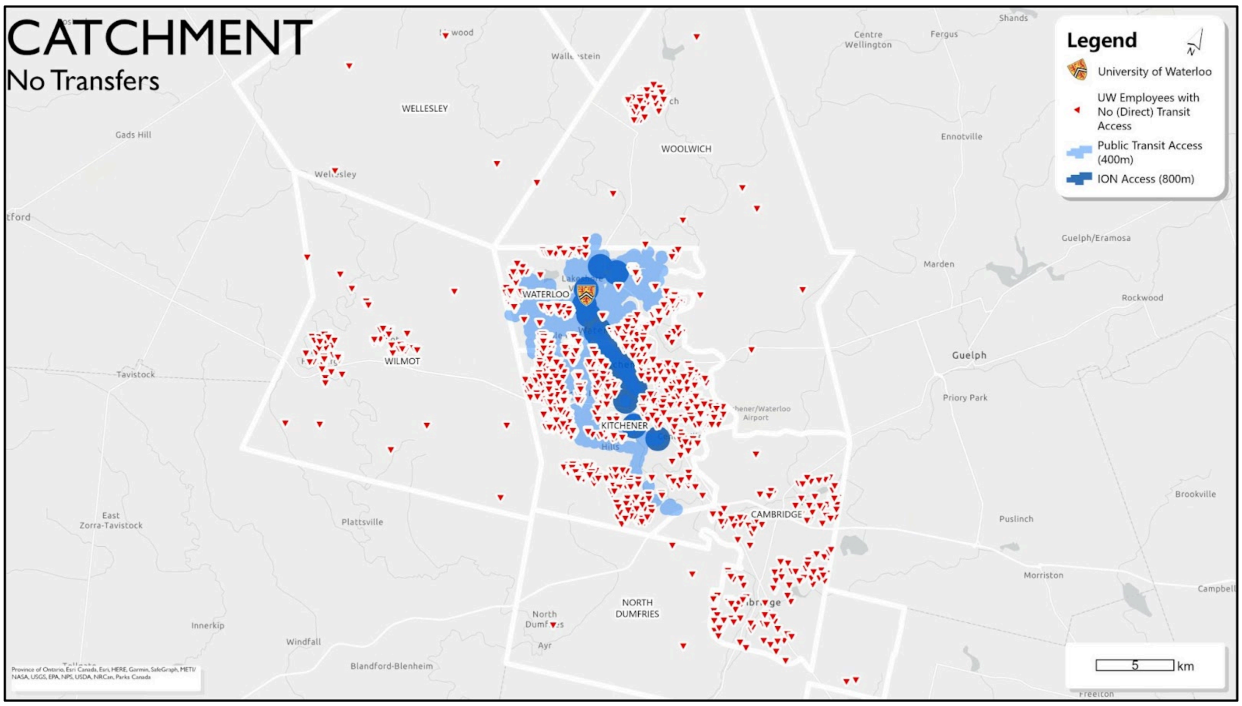


Figure 5.14: Catchment Area Analysis map depicting service area for GRT/ION with a 400-meter buffer around transit stops, direct routes with no transfers. 53% of Employees are covered.

Undoubtedly, routes that have direct access to the University are ideal in terms of time and convenience; transit users are more inclined to take transit if they are near said routes. Figure 5.14 above depicts this scenario, in which 53% of employees are within 400m of a transit route that travels directly to the main campus.

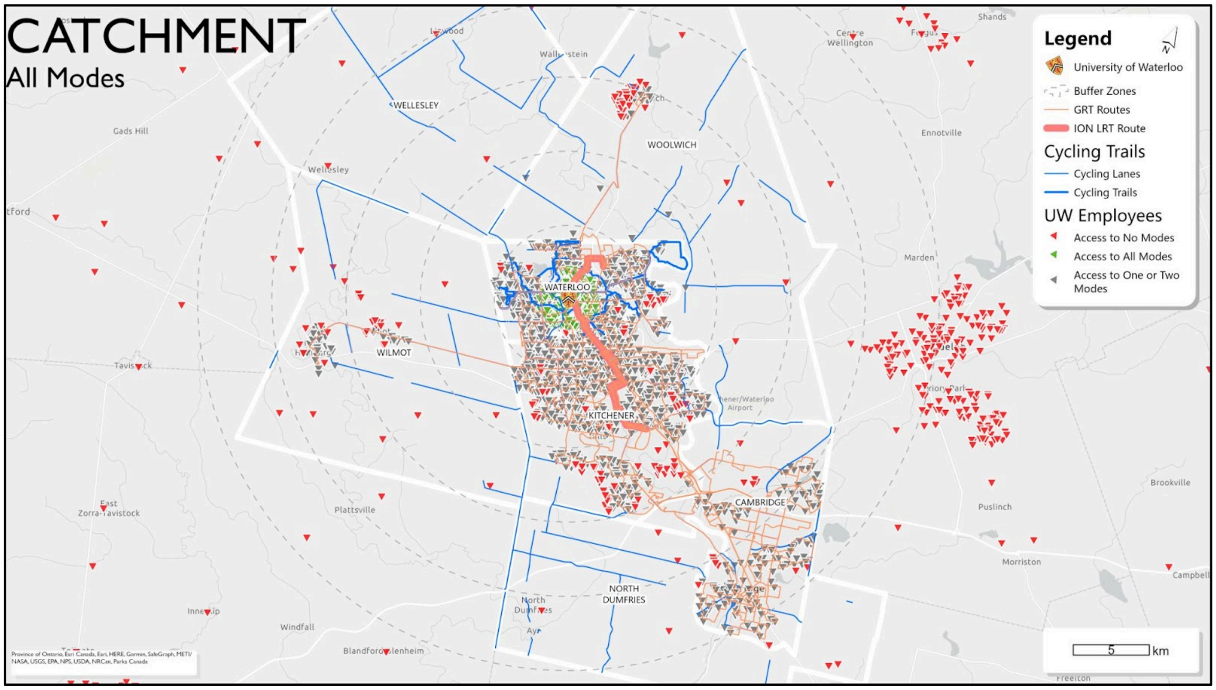


Figure 5.15: Catchment Area Analysis map depicting service area for GRT/ION, Cycling infrastructure, and Sidewalks at various buffer levels.

Distance	Total Employees (% Total within 25km)		Employees with Transit Access (% Total within 25km)		Employees Without Transit Access (% Total within 25km) (Expected to Drive)		Potential Increase (2022)	Employees Expected to Drive (2017)	Employees that Drive (2017)	Potential Increase (2017)	Potential Change
>2km	1311	21%	1242	94.7%	69	5.3%	17.7%	7.0%	23.0%	16.0%	1.7%
2-5km	2545	42%	2334	91.7%	211	8.3%	40.7%	13.7%	49.0%	35.3%	5.4%
5-10km	1245	20%	1016	81.6%	229	18.4%	46.6%	28.8%	65.0%	36.2%	10.4%
10-15km	517	8%	303	58.6%	214	41.4%	45.6%	43.0%	87.0%	44.0%	1.6%
15-20km	217	4%	95	43.8%	122	56.2%	18.8%	36.0%	75.0%	39.0%	-20.2%
20-25km	271	4%	145	53.5%	126	46.5%	38.5%	74.0%	85.0%	11.0%	27.5%
All	**6106**		**5135**		**971**						

Table 5.2: Tabular summary of sustainable transit catchment area analysis depicting the potential increase between those who should drive and those who are not.

The 2017 SustainMobility Report is complimented by Figure 5.15 and Table 5.2 above. At various distance ranges from the UW Main Campus, the report assesses the potential increase between those who are within range of transit services and those who are not within range. Figure 5.15 considers a variety of different buffer levels for each mode of transport, based on 'ideal' distances. GRT stops use a 400m buffer, ION stops use an 800m buffer, cycling lanes are buffered outward by 600m, and sidewalks are buffered by 200m. While these distances are grounded by literature, they are inherited directly from the 2017 report. As expected, areas close to the University--specifically within 2km--feature the greatest number of employees who have access to all modes of transportation, including walking, cycling, and transit. Beyond this distance, when walking becomes a physical burden, sustainable modes are restricted solely to cycling and transit. As distance increases from the University, the availability of cycling infrastructure decreases, resulting in a larger number of employees without access to any modes beyond the 15km mark.

Results from the current analysis and the 2017 report are directly compared in Table 5.2, which shows an overall increase in potential for all employees within 15km of the University, and a decrease in potential for employees beyond the 15km zone. While the processes between the current analysis and the 2017 report are effectively identical, the input data is different which may contribute to unreliable differences in potential change. Nonetheless, the results seem to still fall in line with reality. For example, the potential increase for areas closer to the University can be attributed to the introduction of the ION LRT, which was introduced after the initial 2017 report; increasing the number of transit stops also increases the number of people who 'should' be taking transit, effectively increasing potential increase. At longer distances however, where the ION has not yet been implemented this narrative ceases to exist.

While the catchment area analysis is useful in determining overall service area of various modes within the ROW, its chief objective is to resurface and compare to findings in the 2017 report. Evidently, linear distances from the University do not depict or reflect modality in any shape or form. For this reason, a travel time analysis was conducted which assess travel times for each employee based on their origins and destinations, for each specific mode.

5.3.2 Travel Time Analysis

Figures 5.16 through 5.19 depict the resulting origin / destination cost matrix for each travel mode. Each line represents a unique trip that connects an origin directly to a destination. Although these lines are completely linear, the travel times reflect the accumulated costs along the network. For the automobile, trips are clearly shorter, with virtually no trips extending beyond the 45-minute travel time mark. Short trips are well dispersed throughout the City of Waterloo and the City of Kitchener, and generally are centered around the main arterials. For transit, there is a very small number of short trips centered around the university and the LRT line, while longer trips extend towards the periphery. The cycling cost matrix, in Figure 5.17 below, shows that it is ideally the ideal method of sustainable transit, with a significant amount of short trips surrounding major transit corridors, and less long trips compared to transit. While this is true, the viability of cycling decreases with distance since it may become too much of a physical burden beyond a certain travel time. Walking distances are standard and straight forward; a very small number of short trips surround the university.

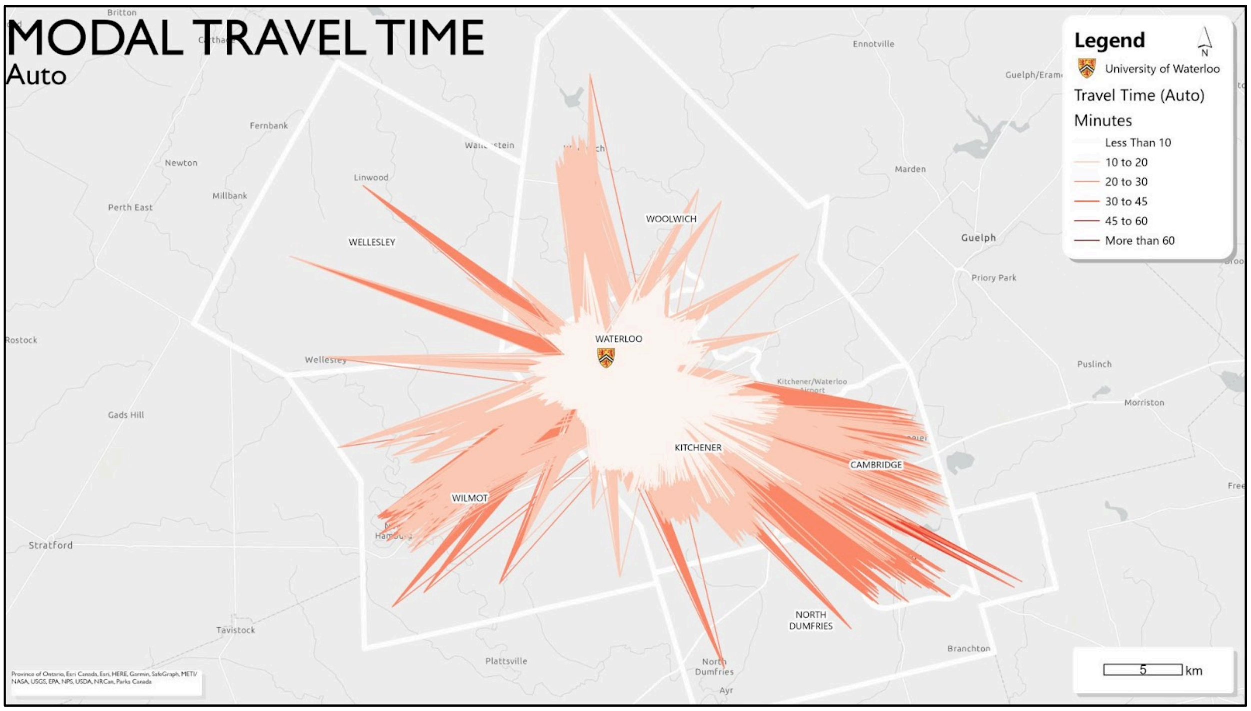


Figure 5.16: Modal travel time analysis for the automobile. Lines are derived from the OD Matrix tool and represent trip connectivity between origins and destinations.

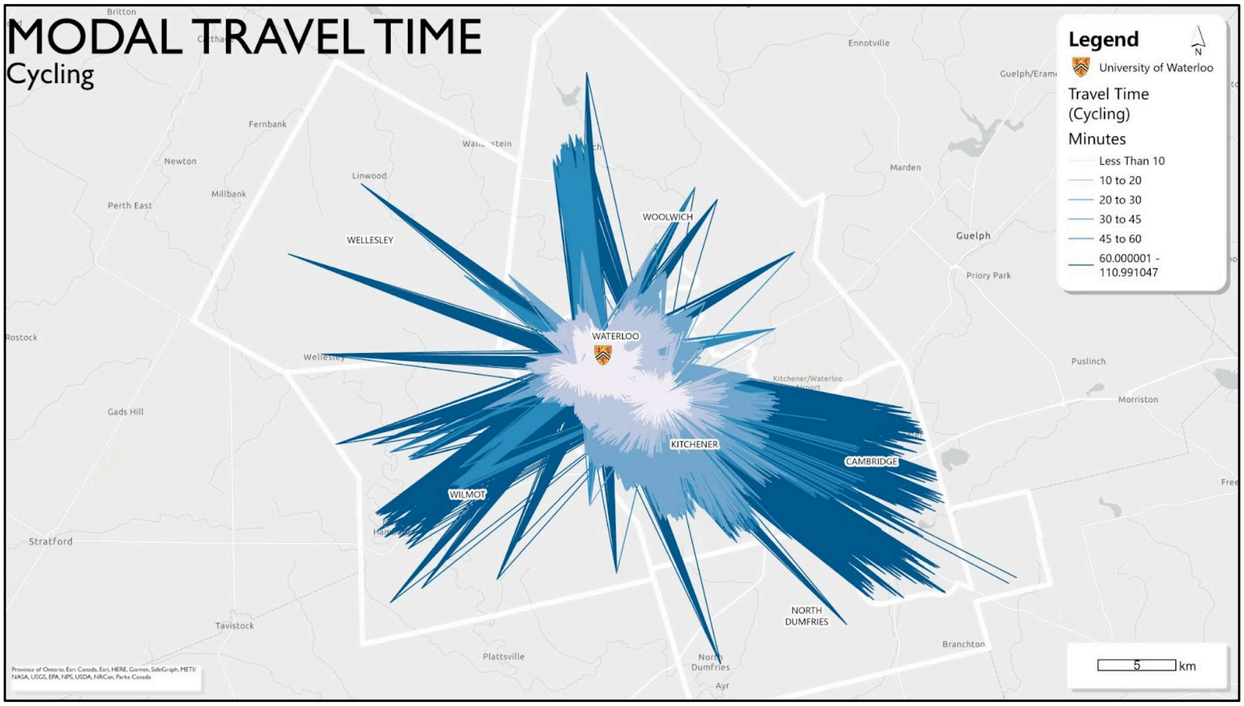


Figure 5.17: Modal travel time analysis for the cycling. Lines are derived from the OD Matrix tool and represent trip connectivity between origins and destinations.

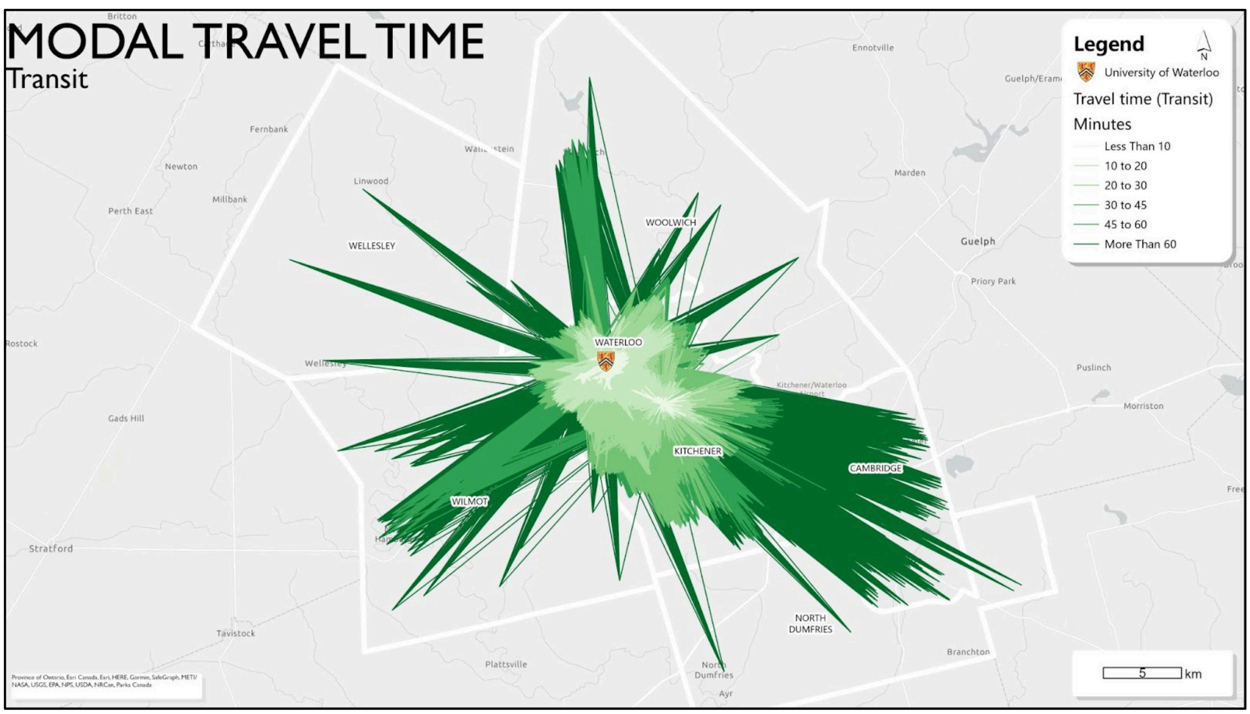


Figure 5.18: Modal travel time analysis for transit. Lines are derived from the OD Matrix tool and represent trip connectivity between origins and destinations

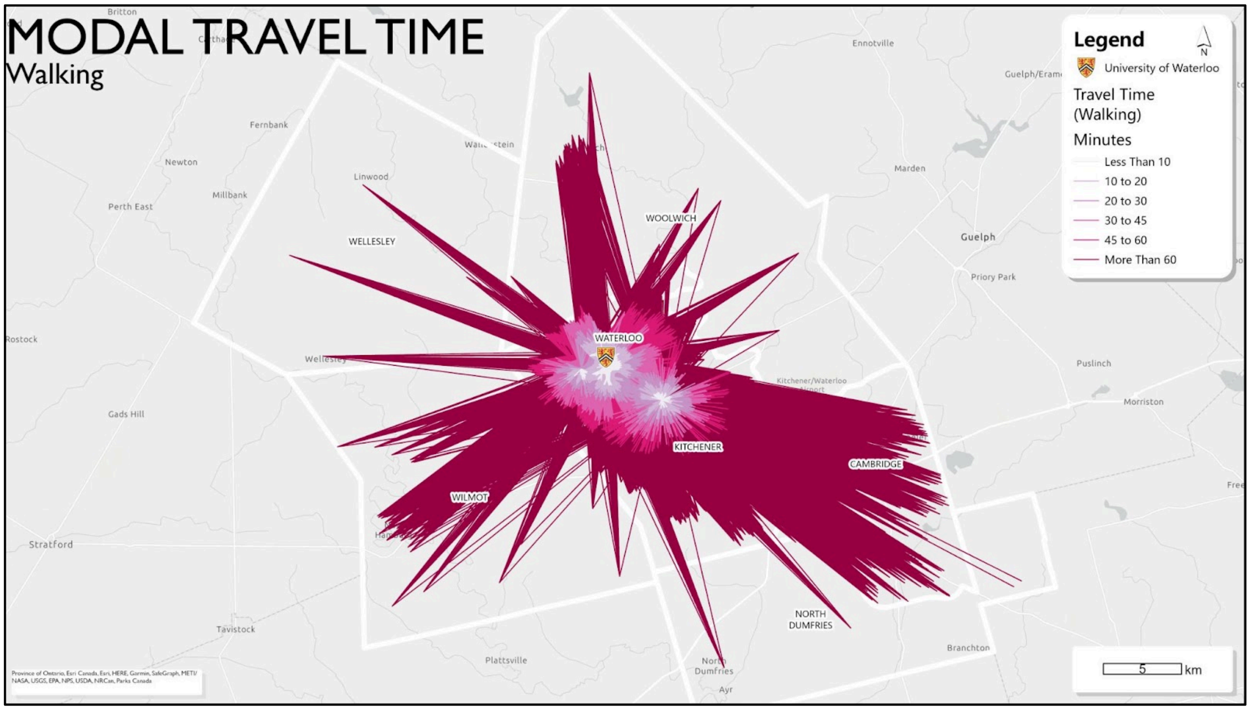


Figure 5.19: Modal travel time analysis for walking. Lines are derived from the OD Matrix tool and represent trip connectivity between origins and destinations.

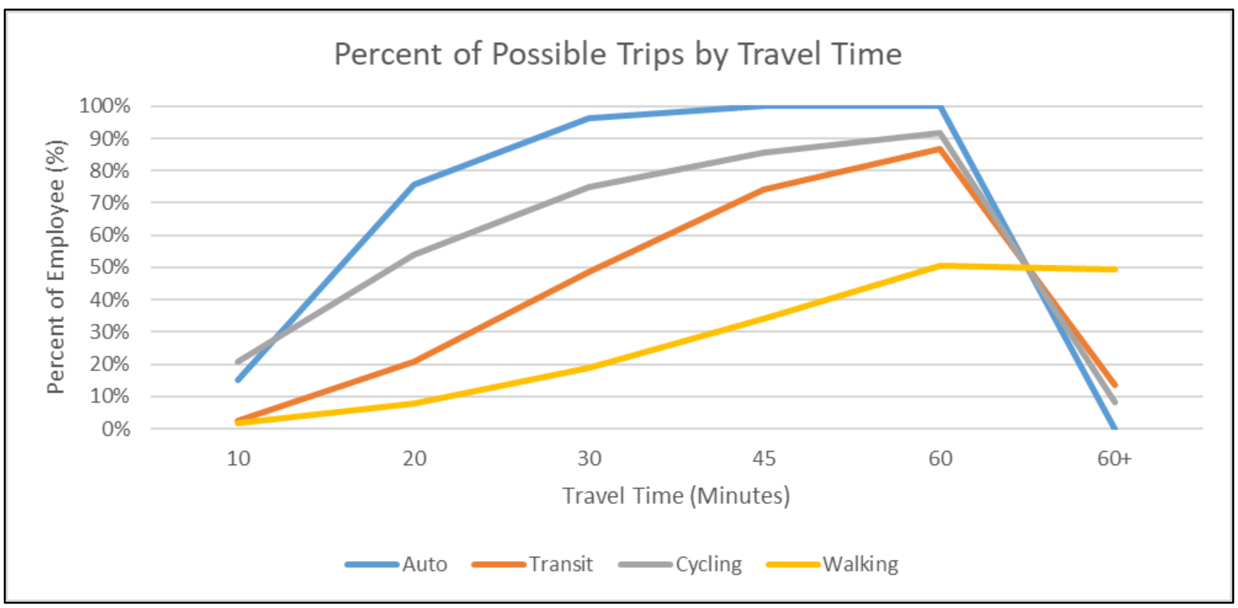


Figure 5.20: Linear graph representing the percent of employees who can reach their destination using various modes of transportation.

Mode	Number of Employees by Travel Time Travel Time (Minutes)					
	10	20	30	45	60	60+
Auto	880	4438	5652	5875	5876	0
Transit	143	1215	2858	4356	5089	787
Cycling	1223	3177	4402	5024	5396	480
Walking	95	469	1115	1999	2975	2901

Table 5.3: Tables representing the number of employees who can reach their destination using various modes of transportation.

Mode	Percent of Employees by Travel Time Travel Time (Minutes)					
	10	20	30	45	60	60+
Auto	15%	76%	96%	100%	100%	0%
Transit	2%	21%	49%	74%	87%	13%
Cycling	21%	54%	75%	86%	92%	8%
Walking	2%	8%	19%	34%	51%	49%

Table 5.4: Tables representing the percent of employees who can reach their destination using various modes of transportation.

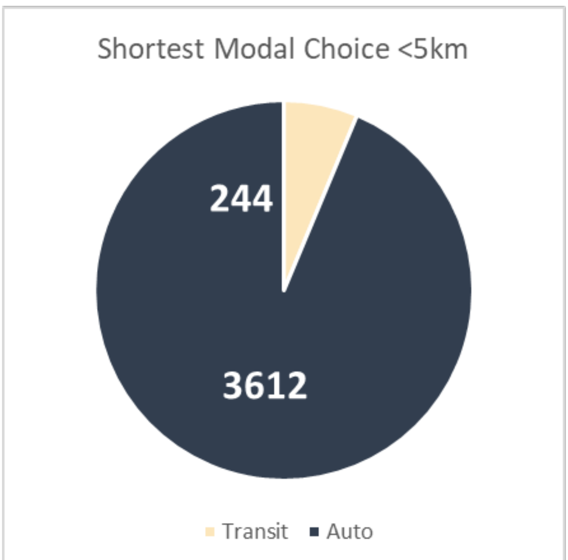
Figure 5.20 and Tables 5.3 & 5.4 depict travel time statistics for each mode. For all trips less than 10-minutes in length, cycling proves to be the ideal transportation method, being able to service 21% of UW employees. For all travel times beyond 10 minutes, Figure 5.20 shows that automobiles can serve the largest proportions of UW employees and exclusively has the potential to serve all UW employees within a 60-minute travel time. Across all modes of sustainable transit, cycling persists in being the most accommodating for UW employees, however beyond the 30-minute mark, the reality of cycling becomes difficult. From here, public transit becomes the dominant sustainable transit mode.

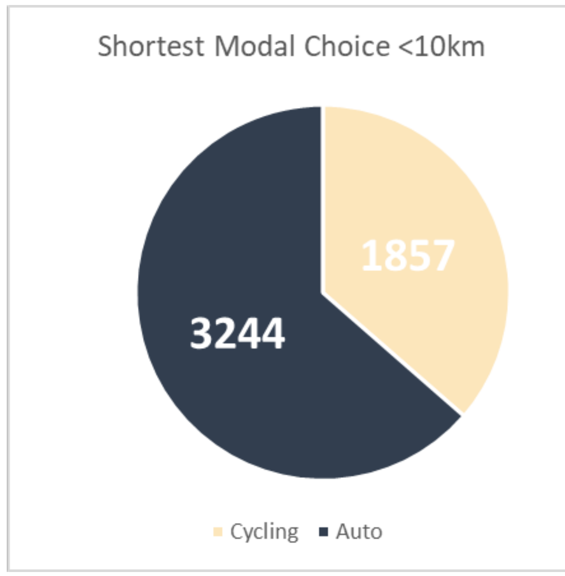
Mode	Number of Shortest Routes by Distance Interval Distance Range					
	<2 km	**2 to 5 km**	**5 to 10 km**	**10 to 15 km**	**15 to 20 km**	**20 to 25 km**
Transit	211 (16%)	33 (1%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Auto	1100 (84%)	[illegible]512 (99%)	[illegible]245 (100%)	517 (100%)	217 (100%)	271 (100%)

Table 5.5: Direct travel time comparison between transit and automobile. Transit ceases to be an ideal mode of transportation in terms of time after the 5km mark.

Number of Shortest Routes by Distance Interval						
Mode	Distance Range					
	<2 km	**2 to 5 km**	**5 to 10 km**	**10 to 15 km**	**15 to 20 km**	**20 to 25 km**
Cycling	1116 (85%)	718 (28%)	23 (2%)	0 (0%)	0 (0%)	0 (0%)
Auto	195 (15%)	1827 (72%)	1222 (98%)	517 (100%)	217 (100%)	271 (100%)

Table 5.6: Direct travel time comparison between transit and automobile. Cycling ceases to be an ideal mode of transportation in terms of time after the 10km mark.





Figures 5.21 & 5.22: a graphic representation of the data presented in Tables 5.5 & 5.6 above regarding shortest commute routes organized by distance intervals.

Figures 5.21 and 5.22 depict direct comparisons between the automobile and transit. While the automobile should theoretically be shorter in travel times for all distances, when considering the time it takes to park and the time it takes to travel from a reserved parking lot to the building of employment, there are certain cases where public transit becomes ideal. This is especially noticeable at the 0 to 2 km and 2 to 5 km travel intervals, where over 200 employees should ideally be taking public transit. When comparing cycling results become even more significant, with approximately 1,850 employees who would benefit in terms of time savings if they were to use cycling rather than a personal vehicle. In this case, the model assumes that cyclists are travelling directly to the building of employment. While not all UW buildings possess adjacent bike racks, this direct comparison highlights the potential of cycling as a whole.

5.3.3 Geodatabases

In an attempt to fuel future research, the analysis models and raw data is provided in the form of several geodatabases. A summary of provided data can be seen below in Table 5.7.

Dataset	Geodatabase	Description
Catchment_Buffers	UWSustainabilityData.gdb	Various distance buffers from the UW main campus.
Distribution_Campus	UWSustainabilityData.gdb	Employee count by building.
Distribution_Provincial	UWSustainabilityData.gdb	Employee count by municipality.
Distribution_Region_Das	UWSustainabilityData.gdb	Employee count by dissemination area within the Region of Waterloo.
OD_Matrix_Auto	UWSustainabilityData.gdb	OD Matrix line output represent travel times for auto.
OD_Matrix_Cycling	UWSustainabilityData.gdb	OD Matrix line output represent travel times for cycling.
OD_Matrix_Transit	UWSustainabilityData.gdb	OD Matrix line output represent travel times for transit.
OD_Matrix_Walking	UWSustainabilityData.gdb	OD Matrix line output represent travel times for walking.
UW_Buildings	UWSustainabilityData.gdb	Building footprints dataset labeled with UW building names.
UW_EmployeeParking	UWSustainabilityData.gdb	Self-authored employee parking lots in UW main campus.
UW_Employees	**UWSustainabilityData.gdb**	**Master data set containing various analysis results on a per employee basis.**
UW_MainCampus	UWSustainabilityData.gdb	UW Main campus center point.
AutoNetwork_ND	network.gdb	Custom network dataset built to assess travel times for auto.
CycleNetwork_ND	network.gdb	Custom network dataset built to assess travel times for cycling.
TransitNetwork_ND	network.gdb	Custom network dataset built to assess travel times for transit.
WalkingNetwork_ND	network.gdb	Custom network dataset built to assess travel times for walking.

Table 5.7: Data dictionary of final data deliverables. Highlighted in yellow is the master dataset which consists of employee point data with many fields pertaining to distances and times derived from previously mentioned analyses.

Two geodatabases are provided, one pertaining to input and resultant data from both the catchment area analysis and the modal travel times analysis, and one consisting of custom-built network analyst data. Custom built datasets are also included, specifically UW reserved parking lots, UW path centrelines which are joined to each network dataset, as well as UW building footprints which are properly labeled to match employee buildings of employment.

6.0 DISCUSSION & RECOMMENDATIONS

This report has identified the factors which determine mode choice for University of Waterloo employees. The catchment analysis of this report has established that a significant proportion of UW employees who drive to work, likely could feasibly be commuting to work via more sustainable means such as walking, biking, or taking transit.

In accordance with the University of Waterloo Sustainability Office Transportation Demand Management Planning Study RFP, Asphalt Transportation Planning Solutions Ltd. has identified recommendations which will assist the University in shifting the mode share to more sustainable options and reduce greenhouse gas emissions.

It is noted that much of the significant infrastructural improvements that would profoundly alter the mode share are outside of the purview of the UW Sustainability Office's mandate and powers. Accordingly, this section considers recommendations that the UW Sustainability Office can implement primarily via on-campus infrastructure improvements and employee benefits and incentives.

6.1 Interpreting Results

These recommended interventions are based on precedent of other similar institutions, interventions unique to the uWaterloo context, and emerging municipal strategies & best practices. Additionally, several recommendations directly relate to the main findings of the spatial analysis. The interventions are weighted in a Harvey Ball decision matrix, ranging from worse to better [Figure 6.1]. For example, a high cost, low impact, or difficult implementation would all score towards the "worse" end of the spectrum, while a higher impact, lower cost, or easy implementation would score towards the "better" end. Where possible, evidence from academic research is used to determine ratings, but some judgment and estimation is necessary in certain cases. Accordingly, this evaluation provides no summary rating of preferred interventions or tally of scores because it is not intended as an empirical measure of an intervention's effectiveness. Some decision-makers will inherently value some criteria higher than others and thus each reader should evaluate the evaluation matrix holistically.

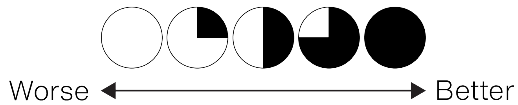


Figure 6.1: A graphic representation of the Harvey Ball evaluation scale used in evaluating the proposed intervention options.

The following categories are used to evaluate the overall effectiveness and viability of the interventions:

Impact

Impact measures the overall effectiveness that the proposed intervention has on favourably shifting mode choice towards sustainable options. This includes reducing private vehicle trips, increasing transit use, and increasing active transportation use.

Capital Cost

Capital Cost is the estimated initial investment that would be required to implement each intervention. Ideally, the cost would be low in comparison to the other factors.

Operational Cost

Operational Cost is the ongoing cost of the intervention, including labour, maintenance, or any other costs that are incurred over time.

Ease of Implementation

This category reflects the non-financial costs that may be present when implementing an intervention. Some may incur no financial cost but require significant effort or time investment with respect to marketing, enforcement, or other supportive functions.

Employee Satisfaction

Employee satisfaction is an important consideration. Ideally, interventions would improve all employee’s satisfaction while meeting the other objectives, but inevitably some employees will be unhappy with the result. The ideal intervention would both improve some employees' satisfaction, while successfully mitigating the dissatisfaction of the employees who do not benefit.

Equitability

This category reflects the equity that is provided to employees through the intervention. Private automobile commuting is generally inequitable, as cost can be a barrier to some. Options which are progressive with respect to income, where individuals bear the cost they impose, and where everybody is treated equally are considered more equitable.

6.2 Summary Evaluation Table

Intervention	Impact	Capital Cost	Operational Cost	Ease of Implementation	Employee Satisfaction	Equity
Bicycle Parking Improvements	◑	◑	◕	◑	◕	◕
Dynamic Ridesharing Program	◔	◕	◕	◑	◑	◕
Employee Shuttle	●	○	◔	◔	◕	●
Information and Encouragement Programs	◑	◕	●	◕	◑	◑
Parking Cost Increase	◕	●	●	◕	◔	◑
Parking Management Strategies	◕	◕	●	◑	◔	◔
Pedestrian and Bicycle Infrastructure	◑	○	◔	◔	◕	●
Remote and Hybrid Work Arrangements	◕	●	●	◕	●	●
Safety and Security Measures	◔	◑	◑	◑	◕	●
Transit Subsidy	●	○	○	◔	◕	●

Figure 6.2: Recommendation evaluation matrix organized alphabetically.

6.3 Improved Bicycle Parking

Sufficient bike parking and associated facilities are key when promoting cycling as an active and/or alternative transportation option. Bike spaces should be a mix of Class II (short-term spaces) and Class I (long-term spaces) (CycleSafe, 2022). Litman et al (2000) recommend 1 bike space per 5 university students and 1 bike space per 10 university employees. Associated facilities can include bike repair areas and showers or wash stations. Bike repair stations, such as Kitchener's (2018) 'fixit" stations, include allen keys, tire irons, wrenches, screwdrivers, and bike pumps for cycle users to maintain their bikes. With respect to shower facilities, the City of Vancouver (2003) recommends 1 water closet, wash basin, and/or shower per 30 bike spaces to encourage cycling.

Table 6.1: Decision Matrix for Improved Bicycle Parking Intervention Option.

Impact	*Capital Cost*	*Operational Cost*	*Easy to Implement*	*Employee Satisfaction*	*Equitability*
◑	◑	◕	◑	◕	◕

The impact would be high for those who have the option to cycle to work. As the results show from the analysis, specifically Figure 5.22, there is a significant number of employees who would benefit in terms of time-savings if they were to cycle instead of using a personal vehicle. This emphasizes the need to ensure that all employee destination possess sufficient cycling infrastructure. No capital costs would come from implementing Class II spaces as the university already has many. Costs for Class I spaces would be moderate to meet the rate of 10% of employees (Victoria Transport Policy Institute, 2015). Operational costs would come from maintenance and repairs to facilities; these would not likely recur on monthly, quarterly, annually, etc. Implementation would be rather easy as the University already has a large supply of bike racks; these Class II racks would need to be relocated. More Class I racks may need to be purchased. For those employees who do bike, an increase to the number of bike parking spaces would be quite appealing. However, as research shows only 1 space is needed for every 10 employees, this would only address a fraction of the employee population (Litman et al, 2000). With respect to equity, not everyone has the option to bike due to location, bike availability, and/or physical ability.

A few successful examples of improved bicycle parking can be seen below:

Bay Area Rapid Transit Route, Oakland, California

By adding on site bike parking, secure bike lockers, and repair facilities along the Bay Area Rapid Transit Route in Oakland, California, bicycle trips to and from increased by 69% (Cervero, Caldwell, & Cuellar, 2013).

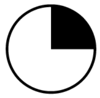
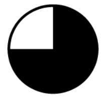
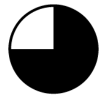
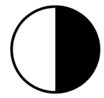
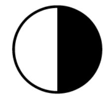
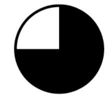
City of Utrecht, Netherlands

Bike parking was integrated into the design of a new station area in the City of Utrecht. The bike parking was located in paid parking facilities monitored 24 hours by staff. After implementation, survey of bikers stated that 50% use the parking more than three days per week and 70% stated they previously parked bikes in public spaces to prevent vandalism (Van der Spek & Scheltema, 2015).

6.4 Dynamic Ridesharing Programs

Encouraging and supporting employee carpooling and ridesharing can be an effective strategy to reduce GHG emissions, particularly among employees living in locations captive to automobiles. The University may utilize a program that matches commuters located near each other with similar schedules so that they can arrange carpooling. The University can create priority parking zones which are free and/or in prime locations in each parking lot to further incentivize and advertise the initiative. Depending on demand for the service, this can be done by hand, where each employee interested in the program submits a survey and is hand-matched with another person or group by an administrator. It can also be done by automated program that takes each commuters' origin, destination, schedule, and special needs into consideration to find an appropriate carpooling partner or group (VTPI, 2022).

Table 6.2: Decision Matrix for Dynamic Ridesharing Intervention Option.

Impact	*Capital Cost*	*Operational Cost*	*Easy to Implement*	*Employee Satisfaction*	*Equitability*
					

The potential impact of a dynamic ridesharing program is moderate. It does little to improve active transportation, even potentially reducing the distance commuters walk (VTPI, 2022). The employee location analysis reveals that many employees who likely drive live in very close proximity. Bringing awareness to this could greatly increase levels of carpooling, potentially increasing the attractiveness of this mode compared to transit or active transportation.

While the financial cost for the university would be low, some implementation efforts would be required including initiating the required marketing for the initiative and redesignation of priority parking spaces. Initializing the matching software or survey would also be a somewhat time-intensive endeavour.

This option is strong with respect to equity, particularly when targeting employees without access to transit or where active transportation is not viable.

Rideshareonline.com

This website is an example of a website service that helps matchmake carpoolers using workplace, commuter location, and shift schedule information. They also provide recommendations for employers such as marketing the website to employees and providing priority parking for carpoolers.

Vanpool Marketing Plan

This study outlines several best practices that can assist ridesharing programs including allowing for a greater employee flexibility, using targeted marketing to promote incentive, and providing a renting option for groups of two to five that do not have a suitable vehicle (York & Fabricatore, 2003).

6.5 Employee Shuttle

Employee shuttle solutions usually involve an in-house organization-operated shuttle which takes custom or predetermined routes to pick up employees at the beginning and end of the workday. A 'demand-response' shuttle approach could involve employees registering for pick up the day before. The shuttle could then custom craft a route to pick up all the employees who registered. A predetermined model would involve targeting areas where many employees live and providing a regular shuttle service to these locations. It is recommended to target auto-captive employees first with a shuttle service (VTPI, 2022).

Table 6.3: Decision Matrix for Employee Shuttle Intervention Option.

Impact	*Capital Cost*	*Operational Cost*	*Easy to Implement*	*Employee Satisfaction*	*Equitability*
●	○	◔	◔	◕	●

It is expected that this can have a significant impact in mode shift. Where services such as this exist, demand typically averages 2 to 3 annual trips per capita. Shuttles often support pedestrian-oriented connections and reduce driving effectively (Law et al., 2009).

The primary cost of shuttle services is the acquisition of vehicles and ongoing operation of the shuttles including driver wages, which can be significant. Shuttle vehicles are usually heavily subsidized or entirely financed by the institution (Spielberg & Pratt, 2004).

Implementation of a shuttle bus could be a significant undertaking. It involves extensive planning, investment, and survey/marketing to employees for the highest chance of success. If successful, this can heavily contribute to employee satisfaction, providing an equitable and convenient way to reach work.

Drawbacks to this intervention include that many employees have non-conventional work hours. It is unclear if shift overlap is strong enough at times to support the prerequisite demand for this approach to succeed.

Microsoft CTR and Connector Bus System

Pre-determined shuttle routes to residential areas with large employee populations. Dedicated commute website that allows employees to register for shuttle access (Seattle Times, 2018).

The Google Bus

Google's Seattle office operates a demand-responsive shuttle which custom crafts routes daily to pick up employees as needed (Chan, 2017).

Tufts Inter-Campus Shuttle

Primarily inter-campus shuttle to take people to and from satellite campuses and some other predetermined locations (Tufts University, 2015).

6.6 Information & Encouragement Programs

Transportation marketing works to determine consumer needs and preferences when it comes to their transit, transportation, and transport needs (Victoria Transport Policy Institute, 2019). Besides gathering information to inform further decisions, this can include providing Multi-Modal Access Guide for transportation options on campus, identifying & overcoming barriers, promoting a change in modal split, and encouraging transit use among others.

Table 6.4: Decision Matrix for Information & Encouragement Intervention Option.

Impact	*Capital Cost*	*Operational Cost*	*Easy to Implement*	*Employee Satisfaction*	*Equitability*
◑	◕	●	◕	◑	◑

These programs increase walking, cycling, and work-from-home opportunities by increasing awareness. Capital and operational costs would be high as the funding for staff / materials / research / etc. to get the programs running would be high. Funding would be required to maintain program staff, materials, events, etc. and would require significant and ongoing coordination to implement. Employees would be provided new options for their commute that could potentially save them time and money. Generally, this option benefits all groups equally though uptake may differ based on socioeconomic variables.

A few examples of information and encouragement programs for the uptake of sustainable transportation include education on the U-Pass system and the UBC TransLink Tomorrow program as explained below:

Education on U-Passes

Previous studies showed a ridership increase of 50-150% over a ten-year period after a U-Pass--which allows unlimited transit access--was introduced. After running a campaign and survey to gauge student interest, Memorial University in Newfoundland found that 62% of students would be willing to pay a per semester fee for access to a U-Pass (Campbell, 2020).

UBC TransLink Tomorrow Program

This program links the need to move around (commuting, errands, etc.) to increased congestion, noise, and pollution while marketing the need to be responsible for the future, together. This program acts as an open call for innovation to garner public opinions and ideas on the future of transportation within their city. The marketing uses video (YouTube) to engage the audience before providing access to policy options, strategic frameworks, and discussion on the New Mobility Lab which engages stakeholders, university students, and researchers in the process.

6.7 Increase Parking Costs

The automobile currently stands as a very attractive mode of transportation. This is expressly depicted by the time travel analysis conducted above, where the automobile continues to dominate travel times regardless of distance from the University. As [Table 5.4], almost all employees within the ROW can reach their destination in under 30 minutes. While travel time is undoubtedly a primary driver of automobile reliance, there are other factors that play a role, including parking costs. To incentivize driving, the university can increase the price of parking by a determined amount. There is significant research on best practices. Charging per day rather than per month is effective in overcoming the sunk cost fallacy with mode choice and encouraging alternate modes at least some of the time. The price of parking should be set to exceed transit costs and potentially paired with transit subsidies. Rates can be variable to account for those living in more rural locations who are underserved by transit to account for equity concerns.

Table 6.5: Decision Matrix for Increased Parking Cost Intervention Option.

Impact	*Capital Cost*	*Operational Cost*	*Easy to Implement*	*Employee Satisfaction*	*Equitability*
◕	●	●	◕	◔	◑

Increasing parking cost can be an extremely effective measure for disincentivizing driving and reducing emissions. Frank, et al. (2011) found that increasing parking fees from $0.28 to $1.19 per hour reduced Vehicle Miles Traveled by 11.5% and GHG emissions by 9.9%. Switching from a monthly parking pass model to a daily parking fee model is also highly effective at reducing GHG emissions (Gutman, 2017).

This intervention is extremely beneficial to the university with respect to cost. Naturally, increasing the cost of parking would generate additional revenue for the university. Ideally, this increased revenue would be contributed to other transportation initiatives outlined in this report that provide incentives for modes alternative to driving.

This would likely result in employee dissatisfaction, being a punitive measure. Nevertheless, this can be mitigated by providing alternative mode options to employees and still providing subsidized parking rates to employees that are demonstrably automobile-captive.

Discussion of parking pricing implementation and management best practices

Pratt (1999), Rye and Ison (2005), Shoup (2006) and Litman (2006a & b): Prices should be well-publicized and predictable; Payment should be convenient; Prices structured to maintain 85-90% occupancy rates; and Parking rates should be consistent across campus.

Parking Management Study

Study of various universities found a 10$ increase in parking charges reduces driving by 1-3%. Charging cost-recovery prices typically reduces drive alone commuting by 10-30% (Shaw, 1997).

Tufts University

Tufts University, as well as many other universities, in principle and/or in practice, generally recognize the importance of making parking more expensive than transit pass. Further, Tufts charges parking per day, incentivizing employees to use alternate modes on some days (Tufts University, 2015).

6.8 Parking Management

Parking management refers to a set of strategies involving all aspects of parking including pricing but primarily the supply and accessibility. The primary strategy highlighted here for the UW context is an overall reduction in the number of parking spaces, in tandem with the other recommendation of increasing parking cost. This could be performed on a temporary or seasonal basis, for example sectioning off areas of parking lots for other purposes. It could also be done on a more permanent basis by demolishing parts of or whole parking lots for other purposes. The intended result of the strategy would also directly impact travel times as depicted by the modal travel time analysis, as the model accounts for the time it takes to walk from the nearest parking lot to an employee's destination building. As depicted by [Tables 5.5 & 5.6], there is a decent number of cases that effectively surpass the automobile in terms of time at shorter distances. If done correctly, parking management would increase the amount of walking time from lot to building, which effectively increases the cases where alternative modes would save more time. That being said, in order for parking management to be effective, it must be coordinated with parking pricing and allocation of parking passes.

Table 6.6: Decision Matrix for Parking Management Intervention Option.

Impact	*Capital Cost*	*Operational Cost*	*Easy to Implement*	*Employee Satisfaction*	*Equitability*
◕	◕	●	◑	◔	◔

Parking management strategies used effectively can significantly influence mode shift towards more sustainable modes. More strategies and expected driving reductions are outlined by the Victoria Transport Policy Institute, many ranging from 5-30% depending on the extent a strategy is implemented (VTPI, 2022).
The cost of implementing these strategies is also highly variable, but generally results in a net benefit for the university in the form of increasing available real estate.

Reducing parking and similar strategies will likely result in some level of employee dissatisfaction. It is recommended that if parking passes must be revoked, it is based on level of car-dependence an employee is subject to, thus avoiding negative effects towards automobile-captive individuals.

European Parking Management Study

This study examined European cities which performed a variety of parking management strategies. In Paris, a 9% reduction in parking along with other transit improvements has led to a 13% decrease in driving (Kodransky and Hermann, 2011).

Parking Management Strategies for Universities

This survey of campuses identified that most are converting parking lots to buildings, with the general trend of reducing overall parking. Very few universities are increasing the quantity of parking. A variety of strategies are available for mitigating spillover parking impacts further detailed in this report (Isler, Hoel, and Fontaine, 2005).

6.9 Pedestrian & Bicycle Infrastructural Improvements

Pedestrian and bicycle transportation not only refers to walking and cycling but also pedestrian-powered transportation methods including skateboarding, rollerblading, scootering, wheelchairs, etc. Improving the infrastructure facilitating these activities includes, *inter alia*, improving sidewalk / crosswalk / path / bike lane condition, improving the pedestrian realm through street furniture & design elements to improve public experience, and implementing traffic calming measures to enhance pedestrian and cyclist safety (Victoria Transport Policy Institute, 2018b). Improving these elements improve the pedestrian / cyclist experience and create a more welcoming and accessible environment.

Table 6.7: Decision Matrix for Pedestrian & Bicycle Improvements Intervention Option.

Impact	*Capital Cost*	*Operational Cost*	*Easy to Implement*	*Employee Satisfaction*	*Equitability*
◑	○	◔	◔	◕	●

Improving infrastructure would aid in shifting to alternative travel modes which would reduce total traffic and assist in balancing peak period traffic. Capital costs are high as new bike lanes average $10,000-$50,000 per mile, new curb ramps average $1,500 each, new speed bumps average $2,000 each, and new raised pedestrian intersections average over $70,000 each. Operational costs would also be relatively high as snow removal would be required during late fall, winter, and early spring months. Facilities would need to be swept and kept clear of litter / foliage. Costs would likely recur predictably each quarter. Implementation would not necessarily be simple as existing infrastructure (roads, pathways, bike lanes) would need to be altered to accommodate the retrofits and upgrades. Employee satisfaction would be high as facilities would provide more options and increase accessibility however construction would likely be perceived as nuisance. Improving infrastructure increases mobility and accessibility in addition to providing options to all regardless of socioeconomic status (ie: can't afford car, facilities to walk / skateboard / roller skate are available), Two strong examples of improving pedestrian and bicycle infrastructure can be found below:

Tufts University

Implemented a Campus Bike Plan which included bike-share opportunities, repair stations, discounts for choosing active transportation over motorized, and security programs through campus police (Tufts University, 2022).

Best Practices

Adult walking and alternative transportation preferences are influenced by the number of obstacles, how direct / accessible the route is, the maintenance level of the route, the safety of the route, and the route options available Craig et al (2002).

6.10 Remote & Hybrid Work Options

Remote and Hybrid Work Arrangements refers to an effort to, instead of targeting modal shift to reduce greenhouse emissions, instead aim to reduce the overall number of trips to campus. The COVID-19 pandemic has greatly assisted in establishing the infrastructure to support work-from-home, and the university should consider giving employees flexibility to continue to do so if possible. The University of Waterloo already has a policy which allows a maximum of 2 days per week of WFH. As a result, the university has gained experience about the efficacy of this practice and should consider extending it beyond the pandemic indefinitely.

Table 6.8: Decision Matrix for Remote & Hybrid Work Intervention Option.

Impact	*Capital Cost*	*Operational Cost*	*Easy to Implement*	*Employee Satisfaction*	*Equitability*
●	○	◔	◑	◕	●

The impact of a remote or hybrid work policy is highly variable depending on the extent which it is implemented. The impact is easily understood as eliminating trips proportionate to the number of employees who work remotely. However, the mode of the trip which is eliminated may not be certain.

Much of the capital and operational expenditures that are required to support remote work have already been carried out by the university in response to the COVID-19 pandemic. Accordingly, continued support for this work option is expected to have low cost and high degree of ease of implementation.

Opportunity to work remotely as needed is generally seen as a positive employee benefit. Increasing remote work can provide equity, particularly if targeted towards those with further commutes and those underserved by transit. However, employees whose work requires in-person presence are excluded. A few examples can be found below:

Tufts University
University-wide telecommuting and tele-lecturing policy particularly for employees with longer commutes (Tufts University, 2015).

University of Luxembourg Remote Work Case Study
This study found teleworking and flexible work time are effective tools for reducing staff travel and GHG emissions without negatively affecting productivity in a research environment (Sprumont et al., 2014).

6.11 Security Improvements

The aim of improving campus security is to encourage walking, cycling, and transit use through a reinforced public security system. The principles of Crime Prevention Through Environmental Design ("CPTED") address landscape and building design to enhance personal safety. These principles include natural surveillance, access control, territorial reinforcement, and space management (Penrith City, 2014). Natural surveillance might include maintaining vegetation and ensuring adequate lighting to maintain sight lines. Access control might include providing clear entrances and exists for pedestrians. Territorial reinforcement might include implementing fences to indicate where vehicles are not permitted. Space management might include rapidly addressing vandalism or graffiti in a public space (Penrith City, 2014).

Table 6.9: Decision Matrix for the Security Improvement Intervention.

Impact	Capital Cost	Operational Cost	Easy to Implement	Employee Satisfaction	Equitability
●	○	◔	◔	◕	●

CPTED designs reduce local traffic by making it safer to walk, cycle, and take transit which makes these modes more attractive to users and creates a large impact. Capital costs would come from the retrofitting of campus spaces with CPTED principles and would be moderately high. Operational costs would come from two places: the upkeep of security programs and the costs associated with remedying graffiti or vandalism. These costs are expected to be moderately high as well. Retrofitting the University's campus with CPTED principles would be straight-forward. Alternative security-based programs such as increased presence would also be relatively simple due to implement due to the existing security system on campus. As the goal of this intervention is to make spaces safer for users—such as employees—this would most likely result in high employee satisfaction. This design would benefit all law-abiding groups equally and improve basic transportation options for all. The potential downside is that not all individuals are responsible for the costs they impose, if an area is vandalized it is most likely that program implementer (ie: the University of Waterloo) would be responsible for the cost of repairs (Victoria Transport Policy Institute, 2018a). Some examples of successful CPTED implementation can be found below:

uWaterloo Emergency Ride Home Program

As a reminder, UW employees who walk, cycle, carpool, or take transit to work are eligible for reimbursement up to $75 in taxi or rideshare fees for an unforeseen emergency (e.g., personal or family member illness).

Best Practices

Thomas (1992) stresses the importance of locating highly used spaces along a well-traveled main road to enforce the 'territoriality' aspect of CPTED. For the University, this includes: transit stops located along Ring Road (already implemented); dedicated bike paths along Ring Road; and main sidewalks along Ring Road (already implemented). Additionally, Patterson (2016) indicates that spaces that are not landscaped or go without garbage collection/ regular maintenance leave a "poor and sometimes, uncared for impression"; this would fall under the 'space management' theme aspect of CPTED. For the University, this could look like: Increased soft-scaping at public transit stops around campus; Re-colouring / painting bus stops to remove the "institutional feel" of concrete / metals and establish them as bright, welcoming spaces; and Clearing garbage from bus stops regularly and maintaining the cleanliness of bus stops on campus.

6.12 Transit Subsidies

The university currently provides a 15% subsidy to a monthly GRT transit pass (GRT, 2022). This could be increased to a higher level such as 50% or 100% to incentivize transit. This is one of the most direct measures to increase transit ridership, as it directly rebalances the cost assessment that employees undertake in determining a mode choice. Many other universities in North America already have significant or complete transit subsidies (Brown, Hess, & Schoup, 2003). Best practices to consider include marketing the subsidies to users to ensure awareness (VTPI, 2022). Soft incentives can be used to encourage initial mode adoption of transit.

Table 6.10: Decision Matrix for Transit Subsidy Intervention Option.

Impact	*Capital Cost*	*Operational Cost*	*Easy to Implement*	*Employee Satisfaction*	*Equitability*
●	○	○	◔	◕	●

A partial or full transit subsidy can significantly increase transit ridership, with some studies identifying up to a 400% ridership increase among some university populations

(Brown, Hess, & Schoup, 2003). Another study indicates that transit price elasticity is -0.6 to -0.9, meaning a 1% decrease in transit cost, increases ridership of 0.6 to 0.9% over the long term, though it is unlikely this level of elasticity would continue to a 100% cost reduction (Pratt, 1999)

The cost of a transit subsidy would be significant. However, the university would likely be able to leverage the existing GRT agreement. Studies indicate the average cost of this arrangement to the institution is an average of approximately $0.57 per trip taken (Brown, Hess, & Schoup, 2003).

Generally, a subsidized or free transit pass is seen as a positive and attractive benefit for employees and is very equitable, providing access to all employees which can access transit.

Tufts University

Provides a 50% transit pass discount (Tufts University, 2015).

U-Pass analysis

This research provides an analysis of U-Pass programs across the US, finding that the average cost per eligible person per year was $32 and the rides per eligible person was 52, for an average cost per ride of $0.57. They further found that U-Pass programs improve local transit service and reduce operational cost per rider (Brown, Hess, and Shoup, 2003).

6.13 Summary of Proposed Interventions

This section has presented 10 recommended actions that the University can undertake to achieve the desired mode shift. These recommendations are supported by evidence including peer-reviewed research and case studies of implementation, particularly in a university setting and reflect current TDM best practices with a focus on sustainability. It is recommended that an appropriate mix of interventions are applied to achieve the greatest effect, rather than just one or two. Ultimately, University decision-makers have greater knowledge of available University resources and access to employee data, and accordingly should decide which interventions are most appropriate, with the aid of this research.

7.0 CONCLUSION

In acknowledging and addressing the global climate change crisis, UW Sustainability consistently strives to promote sustainable living amongst the UW community. This includes, implementing climate change mitigation and adaption strategies through on campus initiatives. With the knowledge of transportation being a significant contributor to the release of GHG emissions, understanding the reasoning behind single occupancy vehicles persisting as the primary mode choice for UW employees is imperative.

Supporting UW Sustainability in achieving net zero emissions by 2050, alongside Action Item 41 of the University of Waterloo's Shift Neutral climate change plan, ATPS Ltd. conducted this *Sustainable Regional Transportation Demand Study*. This included a stringent research and analysis process ultimately recommending various sustainable transportation best practices to increase the utilization of sustainable transportation modes amongst UW employees; notably, strategies revolving around sustainable transportation incentives, policy changes, as well as parking management were recommended. Furthermore, it was discovered through the literature review and statistical analysis that cost, time, and distance were significant intersectional factors that heavily impacted employee travel mode choice. Meanwhile, the discussion and recommendations highlighted several notable strategies with excellent potential to improve sustainable transportation amongst UW employees.

Ultimately, further research and actions are required to gauge a more accurate representation and applicability in the UW context.

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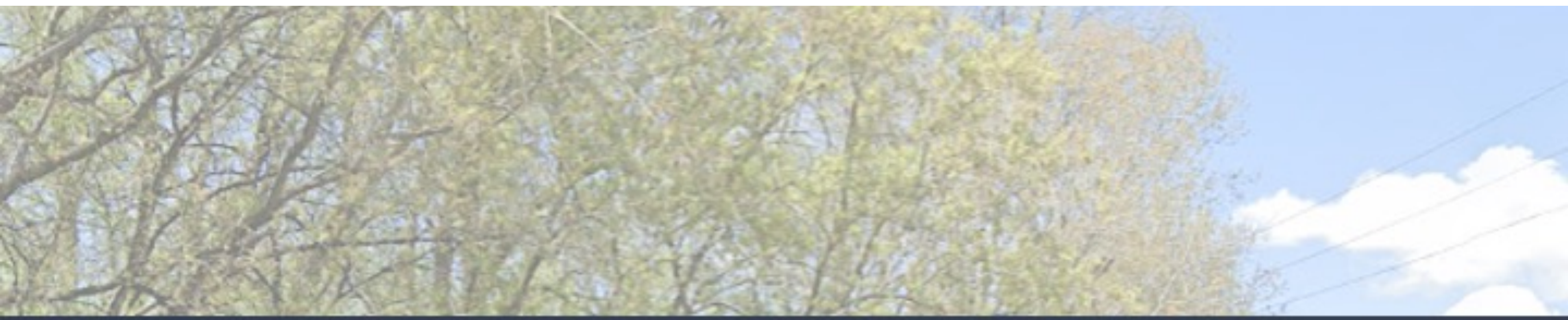

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