Increasing Winter Bikeability in Toronto
Through Improved Bicycle Network Design

By

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Cycling, a sustainable mode of transportation, is often discredited as a four-season option as it is perceived as being dependent on weather conditions. This research presents the concept of winter cycling and its impact on, and how it is impacted by, bicycle network design. Winter bikeability criteria were synthesized from the literature and applied to four case study cities known for their bikeability and year-round maintenance of cycling infrastructure, including Montréal (Canada), Minneapolis (USA), Copenhagen (Denmark), and Oulu (Finland). Through analysis of the applied criteria, a set of best practices from each city was created based on safety, ease of use, and improved bikeability. The best practices were supported by current literature and active transportation guidelines. The best practices were then applied to Toronto (Canada) as design recommendations to improve the City’s bicycle network design. The results provide direction for planning of bicycle networks in cities with winter climates.
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Table of Contents

Acknowledgements ................................................................. iii
List of Tables ........................................................................ vii
List of Figures ......................................................................... viii

Chapter 1 – Introduction ......................................................... 1
Goal and Objectives ................................................................. 3
Research Questions ................................................................. 3
Relevance to Landscape Architecture ...................................... 3
Thesis Outline ......................................................................... 4

Chapter 2 - Contextual Background ........................................ 6
Advent of the Bicycle ............................................................... 6
Introduction of the Automobile ................................................. 7
Cycling for Health and the Environment .................................. 9
Renaissance of the Bicycle ....................................................... 12
History of Cycling in Toronto ................................................ 14
Conclusion ............................................................................... 16

Chapter 3 – Research Design .................................................. 17
Methodology ........................................................................... 17
Literature Review ..................................................................... 19
Case Studies ............................................................................ 19
Site Selection ........................................................................... 21

Chapter 4 – Literature Review ................................................. 25
Bikeability ............................................................................... 25
Winter Cycling ......................................................................... 34
Winter Bikability Criteria .......................................................... 41
Bicycle Facilities ..................................................................... 42
Bicycle Infrastructure .............................................................. 42
Traffic Calming & Safety ......................................................... 43
Street Connectivity & Bicycle Route Density ......................... 44
Bicycle Route Separation ......................................................... 44
Route Safety ........................................................................... 45
Maintenance ............................................................................ 46
LIST OF TABLES

Table 4.1 – Bikeability Criteria and Environmental Audit Summary.......................... 33
Table 4.2 – Winter Bikeability Criteria........................................................................ 41
Table 5.1 – Summary of Best Practices from Montréal, Minneapolis, Copenhagen, and
Oulu.......................................................................................................................... 95
Table 6.1 – Summary of Design Recommendations for Toronto............................... 106
LIST OF FIGURES

Figure 1.1 – Thesis Structure.............................................................. 5
Figure 3.1 – Methodology Flowchart.................................................. 18
Figure 3.2 – Case Study Cities’ Köppen-Geiger Climate Classification........ 22
Figure 4.1 – Winters et al. Bikeability Map.......................................... 29
Figure 5.1 – 1897 Bicycle Map of Montréal........................................ 49
Figure 5.2 – Montréal Bicycle Rack Pole............................................. 52
Figure 5.3 – Bi-directional Protected Bicycle Lane with Snow Storage in Montréal… 54
Figure 5.4 – Physically Separated Bicycle Lanes.................................... 57
Figure 5.5 – Intersection of a Bicycle Lane and a Street.......................... 58
Figure 5.6 – Advanced Stop Line for Cyclists....................................... 59
Figure 5.7 – Bicycle Box at an Intersection.......................................... 59
Figure 5.8 – A Road Diet to Accommodate Bicycle Lanes....................... 60
Figure 5.9 – Minneapolis Bicycle Station along the Midtown Greenway........ 65
Figure 5.10 – The Midtown Greenway................................................ 68
Figure 5.11 – Types of On-Street Vertical Protection from Traffic............... 70
Figure 5.12 – Cycle Track Routed behind a Transit Stop.......................... 71
Figure 5.13 – Treatment of a Right-Turn Lane with Through Bicycle Traffic... 71
Figure 5.14 – Ramp on Staircase in Copenhagen.................................... 75
Figure 5.15 – Danish Best Practices for Cycling Infrastructure.................. 77
Figure 5.16 – Right Turning Lane on a Cycle Track in Copenhagen............ 78
Figure 5.17 – The Well-Lit Inderhavnsbro (Inner Harbour Bridge) in Copenhagen... 80
Figure 5.18 – Copenhagen's Winter Maintained Cycle Tracks…………………………………… 81
Figure 5.19 – Protected Pedestrian and Bicycle Path in Oulu with Snow Storage Allocation……………………………………………………………………………………………………………………… 85
Figure 5.20 – A Bicycle and Pedestrian Underpass beneath a Busy Intersection……………… 86
Figure 5.21 – Protected Pedestrian and Bicycle Path Lit at Night…………………………… 87
Figure 6.1 – Bicycle Corral in Toronto…………………………………………………………………… 98
CHAPTER 1 – INTRODUCTION

North American cities are currently facing two major challenges. Greenhouse Gas (GHG) emissions have increased enormously since the pre-industrial era, in part due to the consumption of fossil fuels by motorized vehicles (Amiri & Sadeghpour, 2015). Cities are now faced with the question of how to discourage vehicle use and promote sustainable transportation alternatives, such as cycling. Studies have shown that encouraging cycling as a non-automobile alternative can effectively reduce GHG emissions, as long as sufficient infrastructure and facilities exist (Amiri & Sadeghpour, 2015).

The other major challenge facing many cities is the problem of chronic illness and obesity. Many North Americans are not getting enough recommended daily exercise. Health-enhancing physical activity (HEPA) has been defined as “the accumulation of 30 minutes or more of moderate-intensity exercise on most, or preferably all days of the week” (Oja, Vuori, & Paronen, 1998, p. 1). One of the best and easiest ways to incorporate exercise into daily routines is by actively commuting to and from work. Active transportation can include any human-powered form of transport including walking, cycling, rollerblading, skateboarding, non-mechanized wheelchairing, and in the winter months, snowshoeing or skiing (Government of Canada, 2009). The two most common modes of active transportation are walking and cycling. However, in terms of replacing automobile travel with a ‘green mode,’ cycling is faster and more efficient, and nearly as accessible and economical as walking, making it the optimal choice for distances greater than one kilometer (Winters, Brauer, Setton, & Teschke, 2013). Increasing active forms of transportation has the dual benefit of increasing citizens’ physical activity and improving health, and reducing GHG emissions by reducing the number of vehicles on the road. Many cities are now looking toward cycling as a viable sustainable mode of transportation (Gatersleben & Haddad...
2010). However, many North American cities do not see cycling as a four-season option, and have concerns over the ridership and usage of facilities during the long winter season (Amiri & Sadeghpour, 2015).

Toronto, like most Canadian cities, is accustomed to winter weather. Climate normals from 1981-2010 show that Toronto sees an average snowfall of 51.4 days per year, with at least one centimetre of snow on the ground for an average of 65 days (Environment Canada, 2016). Average winter temperatures are between 5°C and -5°C, with average winter lows between 0°C and -10°C (Environment Canada, 2016). Many Torontonians would consider winter cycling an impossibility for those 65 days a year. However, quite the opposite is true. In fact, many winter cities, such as Umea, Sweden and Oulu, Finland continue to see high bicycle mode shares (the percentage of travellers using cycling as a mode of transportation) throughout the winter. Umea keeps a ridership of 24 percent, even though it gets 130 days of snow per year (Jaffe, 2016).

Perhaps surprising to most, it is not the cold that deters the majority of people from cycling. The two biggest factors determining winter cycling rates are “the strength of a city’s bike network, ideally made up of protected bike lanes,” and “maintenance of this network during cold and snowy months” (Jaffe, 2016, para. 5). A study by Amiri and Sadeghpour in 2015 showed that cyclists who continue to cycle through the winter are rarely deterred by temperature and 71 percent of the participants surveyed would be comfortable cycling in temperatures as low as -20°C. In a study conducted by Pucher, Buehler, and Seinen (2011), a comprehensive look at cycling mode shares for commuting to work was done for the 50 U.S. states and the 13 provinces and territories of Canada. Incredibly, the highest cycling percentages in both the US and Canada were found in the Yukon (2.6 percent) and the Northwest Territories (2.1 percent), “two of the northernmost and coldest parts of Canada” (Pucher et al., 2011, p. 452).
GOAL AND OBJECTIVES

The goal of this research is to explore the concept of winter bikeability and how it can be increased in Toronto, Canada, with improved bicycle network design. The following objectives will be met in order to achieve this goal:

- Conduct a literature review to explore bikeability of cities and winter cycling.
- Develop a set of criteria based on the literature to assess the winter bikeability of cities.
- Apply the winter bikeability criteria to cities recognized for their high rates of winter cycling.
- Evaluate the results and develop a list of best practices for winter bikeability.
- Use best practices to suggest changes and provide design recommendations for Toronto, Canada.

RESEARCH QUESTIONS

To conduct research on winter bikeability, the following questions needed to be addressed:

- What elements (infrastructure, facilities, etc.) contribute to a successful bicycle network?
- How are those elements affected by winter conditions?
- Which of these elements are suitable for Toronto?

RELEVANCE TO LANDSCAPE ARCHITECTURE

Many cities are improving streetscapes to be more inclusive of active transportation. To achieve this, ‘complete streets’ frameworks are being adopted, where streets, are designed to be safe for all users, such as people who walk, bicycle, take transit or drive, and people of varying ages and levels of ability. [Complete streets] also consider other uses like sidewalk cafés, street furniture, street trees, utilities, and stormwater management. (City of Toronto, 2016a, para. 3)
The best time to implement bicycle facilities and infrastructure is in the design phase, so landscape architects can play a large role in helping cities design their complete streets frameworks and active transportation guidelines. However, most cities have pre-established plans for land use, with buildings and transportation infrastructure already in place. Because of this, much of the cycling infrastructure needs to be built on roads that, in some cases, already accommodate their maximum levels of vehicular and pedestrian traffic. It is an important design challenge to create a safe environment for cyclists and pedestrians while still accommodating vehicle use. Landscape architects will have a key role in developing designs that support active, liveable cities.

THESIS OUTLINE

Having introduced the background of this thesis, the following chapters focus on meeting the stated goal and objectives (see Figure 1.1). Chapter 2 provides a contextual background to bikeability. This chapter explores the history of cycling in Toronto, how the automobile influences cycling, health and environmental implications, and provides insight into the recent renaissance of cycling around the world. Chapter 3 outlines the research design, discussing the methods and data collection used in this study. Chapter 4 includes a review of the literature involving bikeability and winter cycling in order to create a set of winter bikeability criteria. Chapter 5 introduces the four case study cities, through which an analysis of their bicycle networks created a list of best practices. Chapter 6 takes the best practices found in the previous chapter and determines their applicability to Toronto, in order to create design recommendations. Chapter 7 discusses limitations and overall conclusions.
<table>
<thead>
<tr>
<th>Introduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chapter 1 - Introduction</td>
</tr>
<tr>
<td>Data Collection</td>
</tr>
<tr>
<td>Chapter 4 - Literature Review</td>
</tr>
<tr>
<td>Analysis and Application</td>
</tr>
<tr>
<td>Chapter 6 - Design Recommendations for Toronto</td>
</tr>
<tr>
<td>Discussion</td>
</tr>
<tr>
<td>Chapter 7 - Discussion and Conclusion</td>
</tr>
</tbody>
</table>

**Figure 1.1 - Thesis Structure**
CHAPTER 2 - CONTEXTUAL BACKGROUND

ADVENT OF THE BICYCLE

North Americans first had a taste of the speed and freedom afforded by the bicycle in the 1860s with its earliest iteration, the velocipede (Norcliffe, 2001). The velocipede was quickly replaced by a lighter, faster and slightly more comfortable bike, the ordinary bicycle, also known as the highwheeler (Norcliffe, 2001). Although the highwheeler gained popularity, it was considered quite dangerous and was known to frequently throw its rider over the handlebars (Norcliffe, 2001). Because of the level of danger, and the fashions of the day, it was usually only men who braved the streets on their highwheelers, battling for space on the roads with pedestrians, streetcars, horses and carriages (Norcliffe, 2001). It was not until the invention of the safety bicycle, in the late 1880s, that the bicycle boom truly began in earnest in North America (Norcliffe). The bicycles we have today are closest to the original safety bicycles, with only slight improvements to materials and design. Cycling even impacted the women’s fashion industry. By the 1890s, women’s fashions were changing and hemlines were inching up above the ankles, enabling them to ride the newer, safer, and more comfortable bicycles (Norcliffe, 2001).

The bicycle had its heyday at the end of the 19th century and many North American cities formed cycling groups and advocated for better roads with the Good Roads movement (Norcliffe, 2001). The popularity and demand for the bicycle required new production techniques, and bicycles became one of the first mass-produced products around the world (Norcliffe, 2001). In many ways, the bicycle paved the way for the automobile; due to mass production, the cost of the bicycle was halved from $100 to $50 in the 1890s making it a more affordable mode of transport for the masses and introducing the concept of flexible travel (Heitmann, 2009). People on bicycles now had the option to go where they wanted, when they wanted (Heitmann, 2009). Bicyclists also
gained the legislative rights to use public roads as early as 1879 in Massachusetts (Heitmann, 2009). By the 1910s and 1920s in North America, the once prolific bicycle became all but extinct.

INTRODUCTION OF THE AUTOMOBILE

After the introduction of the automobile in the early 1900s, it has steadily cemented its place as the number one transportation mode on the continent. In Canada, according to the 2011 National Household Survey (NHS), 79.6 percent of Canadians commuted to work in a personal vehicle as a driver or passenger (Statistics Canada, 2016a). In the United States, between 2008-2012, 86.2 percent of people commuted to work by personal vehicle (McKenzie, 2014). The remaining population commuted by either public transit, walking, or cycling (Statistics Canada, 2016a). The bicycle mode share for commuters in Canada and the US is low, with only 1.3 percent and 0.6 percent of the population cycling to work, respectively (Statistics Canada, 2016a; McKenzie, 2014). However, several Canadian cities had bicycle commuting mode shares higher than the national average, such as Ottawa - Gatineau (Ontario side) at 2.4 percent, Kelowna, B.C. at 2.6 percent, and Victoria, B.C. at 5.9 percent (Statistics Canada, 2015).

In contrast, the Danish city Copenhagen, world renowned for being bicycle-friendly, had a cycling commuting mode share of 35 percent in 2011 (Carstensen, Olafsson, Bech, Poulsen, & Zhao, 2015). Copenhagen has long been popular with cyclists but even it could not escape the automobile boom (Carstensen et al., 2015). During and after WWII, there were a number of restrictions on the import of vehicles and rationing of oil, fuel, and rubber in Denmark (Carstensen et al., 2015). Only when restrictions were lifted in the 1950s did the automobile become more widely available, and traffic levels exploded during that decade and the next (Carstensen et al., 2015). In the late 1960s, cycling levels dropped from an impressive 40 percent to 19 percent - still high by North American standards - and the car share doubled from 24 percent to 46 percent
In the 1970s, with more cars on the roads, and travelling at faster speeds, Copenhagen saw the highest number of fatal accidents involving cyclists in its history (Carstensen et al., 2015). Uneasy with this, the Danish Cyclists’ Federation, citizens, planners, and grassroots activists began to push back against plans to increase motorways within central Copenhagen and instead demanded better cycling infrastructure (Carstensen et al., 2015). Since the 1970s, the City of Copenhagen has taken a very progressive approach to planning by restricting car use, adding traffic calming measures, pedestrianizing streets and, of course, increasing its bicycle infrastructure (Carstensen et al., 2015).

North America has had more hurdles to face than Copenhagen and many other Northern European cities did when it comes to increasing cycling. While Copenhagen was able to keep its cycling levels high during the first half of the twentieth century, due largely to WWI and WWII, cycling all but died out in North America by the end of the nineteenth century (Carstensen et al., 2015; Norcliffe, 2001). The automobile changed the urban design of cities as residents now had the ability to travel further, and get there faster (Handy, Boarnet, Ewing, & Killingsworth, 2002). Cities began to expand outward, densities were lowered, land use became less mixed, and streets and block sizes became larger (Handy et al., 2002). Post-war North American suburbs were comprised mainly of “commercial strips, plazas, malls, employment districts, and neighbourhood units,” often connected to the downtown core by expressways and major arterial roads (Relph, 2013, para. 16).

The same land use and urban design that works well for the automobile makes walking, cycling, and other forms of active transportation very difficult, if not nearly impossible (Handy et al., 2002). In Northern Europe, land use planning is done regionally and is usually more restrictive of the lower-density, auto-centric sprawl typified by North American cities (Pucher, Dill, &
Handy, 2010). Higher density, mixed-use development is encouraged, which results in shorter trip
distances between destinations, easily achieved by bike (Pucher et al., 2010). Many Northern
European cities also employ several disincentives to car use such as limited parking, lower speed
limits, comprehensive traffic calming and car-free zones (Pucher et al., 2010). Few North
American cities are using these car-restrictive policies, which arguably are as important as
supporting and implementing bicycle-friendly policies (Pucher et al., 2010). The cost of vehicles
is also far less expensive in North America, with lower taxation rates and lower gasoline prices
(Buehler, 2014).

CYCLING FOR HEALTH AND THE ENVIRONMENT

Twenty-first century North America is no longer the same as it was half a century ago. Cities are now dealing with the implications of road congestion, air pollution, increases in chronic illness and obesity, and climate change due to increasing greenhouse gas emissions (Tolley, 1990; Pucher and Buehler, 2012). Many citizens are not satisfied with the status quo and are looking for more sustainable transportation alternatives, including ‘green modes’ like walking and cycling (Tolley, 1990). Walking is the most natural form of transportation for human beings:

Humans on foot are thermodynamically more efficient than any motorised vehicle and most animals, yet humans on bicycles surpass them, able as they are to go three to four times faster and yet use five times less energy in the process. Equipped with a bicycle, man is more efficient than all machines and all animals too. (Tolley, 1990, p. 13)

More and more evidence is showing that getting a moderate amount of regular physical activity, such as walking or cycling, has a significant beneficial impact on public health (Frank & Engelke, 2001; Pucher et al., 2010; Oja, Vuori, & Paronen, 1998; City of Toronto, 2014a). One of the easiest ways of incorporating regular physical activity into hectic lifestyles is by changing a daily work commute from automobile to a form of active transportation like walking or cycling
(Government of Canada, 2009; Oja et al., 1998). Many shorter distance commutes have the potential to be transferred to cycling trips provided the routes are perceived to be available, in good condition, and safe (Oja et al., 1998).

Several studies have been done on the effects of cycling on health in both clinical studies and population-based evidence. Clinical studies found that cycling improves “fitness, cardiovascular risk factor levels and postprandial blood sugar uptake” (Pucher and Buehler, 2012, p.33). Population-based studies show an inverse relationship between active commuting and body mass index, lipid levels, blood pressure, chronic disease (in cyclists aged fifty to seventy years), diabetes incidence, obesity rates and some types of cancer (Pucher and Buehler, 2012; City of Toronto, 2014a). Cycling also has associated psychosocial health benefits. Increased rates of cycling have been shown to have a range of mental health benefits from “preventing and treating anxiety and depression to improving cognitive functioning and increasing subjective well-being” (Pucher and Buehler, 2012, p.37).

Cycling has known social health benefits – streetscapes that support pedestrians and cyclists and discourage car use create greater community attachment and liveability and can improve social interactions (Pucher and Buehler, 2012). Roads that are designed to support heavy traffic have been linked with “community disruption, noise pollution, social isolation, urban sprawl, restrictions on children’s independent mobility and opportunities for outdoor play and social interactions” (Pucher and Buehler, 2012, p.40). Studies have also shown that higher density, permeable urban environments that support pedestrians and cyclists are linked with lower levels of crime through increased activity on the street and ‘natural surveillance’ (Pucher and Buehler, 2012). Cycling is also known to help with social inclusion. Bicycles are reasonably affordable and
are a convenient and accessible form of personal mobility, making them a far more socially equitable form of transportation than cars (Pucher and Buehler, 2012).

Cycling has several environmental impacts when used as an alternative transportation mode to decrease automobile traffic. Motor vehicles are one of the greatest contributors to air and noise pollution in most cities and is most harmful in dense urban centres (Pucher and Buehler, 2012). Cycling has the greatest potential to reduce air and noise pollution in these dense urban centres as trip distances are likely to be shorter (Pucher and Buehler, 2012). Motor vehicles are also associated with rising levels of greenhouse gas emissions that contribute to climate change (Pucher and Buehler, 2012; Tolley, 1990). Climate change is resulting in sea-level rise, degraded air quality, and extreme weather events (Pucher and Buehler, 2012). Cycling is a zero-emission mode of transportation, and converting trips (especially short distances) from motor vehicle to bicycle can lower emissions in the passenger transportation sector (Pucher and Buehler, 2012).

A segment of the non-cycling population would consider cycling as an option for health or environmental reasons but are worried about their personal safety (Pucher et al., 2010). However, studies have shown that the health benefits gained from cycling far exceed the health risks from traffic incidents (Pucher et al., 2010). The saying ‘safety in numbers’ is particularly relevant when it comes to cycling since when cycling levels increase, injury rates fall, in part due to cyclists’ increased presence and visibility on the roads (Pucher et al., 2010). However, safety is a significant and realistic concern. In 2009 in the United States, 33,808 deaths occurred on U.S. roadways across all modes (CDC, 2015). Of those deaths, 630 were bicyclists (CDC, 2015). Encouragingly, from the period of 1975-2012 the rates of cyclist mortality per year have decreased by 44 percent, with the most significant decline in mortality found among children aged 15 or less (CDC, 2015). The decrease in cyclist mortality corresponds with an increase in cycling over the past decade (CDC,
2015). There are several steps that can be taken to improve cyclist safety, including: “improved
cycling infrastructure networks (particularly separated bike lanes), traffic calming measures (speed
bumps), legal interventions (lower speed limits, greater enforcement of traffic laws), and programs
and education to encourage safe cyclist and motorist behaviour” (CDC, 2015, p.840).

RENAISSANCE OF THE BICYCLE

As cycling meccas like Copenhagen and Amsterdam demonstrate, cycling is rapidly
becoming the go-to mode of transportation in many cities. In cities where ‘rush hour’ tends to last
all day and gridlock is commonplace, an alternative to the car needs to be found (Adamo, 2014).
Cyclists have long been associated with vastly different stigmas – some view cycling as a last
resort, when one is unable to afford a personal vehicle or public transportation (Flanagan,
Lachapelle, and El-Geneidy, 2016). On the opposite end, cycling has also been adopted as a
recreational pastime for the affluent (Flanagan et al., 2016). Increasingly, cycling is being adopted
by environmentally- and socially-conscious millennials (Flanagan et al., 2016). Many millennials
are opting out of owning vehicles for additional reasons like rising costs, maintenance and lack of
parking (Adamo, 2014).

Studies have also shown the economic benefits of cycling compared to driving. The
benefits can be difficult to quantify and monetize, but some cost-benefit analyses have been
conducted (Pucher and Buehler, 2012). A study in Toronto showed that cycling levels (in 2012)
resulted in savings to direct health care costs of $110-$160 million due to reduced chronic disease
(City of Toronto, 2012). In 2012, at the time of publication, if Toronto “were to increase its
commuting mode share to 12 percent for walking and 6 percent for cycling, this could prevent
about 100 additional deaths from chronic diseases each year, yielding additional annual benefits
of $100 to $400 million” (City of Toronto, 2012, para. 5). Illness related to physical inactivity in
the UK directly costs the National Health Service £1.08 billion per year, in 2007 prices (Davis, 2010). Indirect costs run upward of £8.2 billion per year, in 2002 prices (Davis, 2010).

Traditionally, most transportation investments are evaluated through a cost-benefit analysis over the lifetime of the project (Davis, 2010). The benefits were historically mostly related to a reduction in travel time (Davis, 2010). However, recent cost-benefit analyses are considering additional benefits to the economy, the environment, society and distribution patterns (Davis, 2010). In the past, anything greater than a 2:1 benefit to cost ratio was considered ‘high’ value for money by the UK Department for Transport (Davis, 2010). A study done by the UK Department of Health assessed both peer reviewed and grey literature from around the world to determine the economic benefits of walking and cycling interventions (Davis, 2010). Globally, the median benefits from investment were found to be 13:1 (19:1 in the UK), resulting in significant health benefits and ‘very high’ value for money (Davis, 2010).

Cycling has been proven to have local economic benefits as well (Rajé and Saffrey, 2016). Studies show that cyclists visit local shops more regularly and spend more on average than drivers and most other modes of transportation (Rajé and Saffrey, 2016; TEDx Talks, 2016). Increasing bike parking also has economic benefits – “Per square metre, cycle parking delivers five times higher retail spend than the same area of car parking” (Rajé and Saffrey, 2016, p.3). It has been shown that compact urban environments that support walking and cycling can have a retail density (spend per square metre) that is 2.5 times higher than the average urban centre (Rajé and Saffrey, 2016).

Cycling is having a renaissance in the United States and Canada (Pucher et al., 2011). In the United States, transportation data was collected through National Personal Transportation Surveys (NPTS) of 1977–1995 and the National Household Travel Surveys (NHTS) of 2001 and
The surveys showed that the “total number of bike trips in the USA more than tripled between 1977 and 2009, while the bicycle share of total trips almost doubled, rising from 0.6 percent to 1.0 percent” (Pucher et al., 2011, p.452). Another metric from the US Census Bureau measures daily trips to work (Pucher et al., 2011). The survey displayed a slight fall in the bicycle share of work commuters, from 0.5 percent to 0.4 percent during the period 1980-2000, but the US Census Bureau’s American Community Survey (ACS) “reports almost twice as many daily bicycle commuters in 2009 as in 2000 and an increase in bicycle mode share to 0.6 percent” (Pucher et al., 2011, p.452). The only measurement of cycling in Canada is done through the Canadian Census and only measures trips to work (Pucher et al., 2011). Canadian Census data, only collected from 1996-2006, shows a 42 percent increase in the number of daily bicycle commuters during that period (Pucher et al., 2011). The overall bicycle share of work commuters steadily grew from 1.1 percent to 1.3 percent from 1996-2006, over double the bicycle mode share for work commuters in the USA (0.6 percent) (Pucher et al., 2011).

HISTORY OF CYCLING IN TORONTO

Cycling has a long history in Toronto. The bicycle boom of the late 1800s prompted Toronto cyclists to lobby for better road conditions (City of Toronto, 2001). By 1896, plans were approved to build three-foot-wide (0.91 metre) bicycle lanes on Spadina Avenue, Harbord Street and Winchester Street (City of Toronto, 2001). The subsequent automobile boom of the early 1900s hit Toronto the same way it did other cities in North America and the bicycle quickly lost popularity, as well as its place on the road (City of Toronto, 2001). Little attention was paid to the bicycle in Toronto until the second bicycle boom of the 1970s (City of Toronto, 2001). In 1975, the former City of Toronto developed the Toronto City Cycling Committee, comprised of volunteers, citizen activists and City Counsellors (City of Toronto, 2001). The Toronto City
Cycling Committee promoted cycling and safety initiatives, including establishing new bicycle routes, and were instrumental in the development of Toronto’s first bicycle lane installed on Poplar Plains Road (City of Toronto, 2001).

The 1980s saw the development of many of Toronto’s trail systems. The City of Toronto constructed the Martin Goodman Trail along the waterfront while Metropolitan Toronto began to construct the river valley trails (City of Toronto, 2001). The City of Toronto also developed the iconic post and ring bicycle stand and thousands of old catch basin grates were replaced with more bicycle-friendly ones (City of Toronto, 2001).

The City of Toronto began a study in 1991 to determine the best streets in the city for the development of on-street cycling infrastructure (City of Toronto, 2001). The 1990s also saw amendment of a zoning by-law that would require developers to provide secure bicycle parking in all new buildings (City of Toronto, 2001). At the same time, most Toronto Transit Commission (TTC) and GO Transit stations were installed with bicycle parking (City of Toronto, 2001). In 1995, Toronto was named the number one bicycling city in North America by Bicycling Magazine (City of Toronto, 2001). Shortly after this, the previous City of Toronto was amalgamated to create the new City of Toronto, which changed the city dramatically (City of Toronto, 2001). The new City of Toronto expanded to cover 240 square kilometres, and planning for bicycle infrastructure now involved a much larger city (City of Toronto, 2001).

In 2001, the City developed the Toronto Bike Plan in an effort to build upon past initiatives and re-establish the new City of Toronto as a bicycle-friendly city and a top cycling city in North America (City of Toronto, 2001).
CONCLUSION

A study done by Oja et al. (1998) found that non-walkers or cyclists were most often deterred from actively commuting because of lack of time (50 percent), lack of interest (54 percent), and bad weather conditions (61 percent). Most North Americans would agree that the winter months are not typically viewed as having ideal cycling conditions. However, Oulu, Finland, which receives 160-175 days of snow coverage per year, manages to keep a winter ridership of about seven percent (over five times Canada’s national year-round average) (Swanson, 2016; Perälä, 2015). Umea, Sweden, which receives on average 130 days of snow coverage per year, maintains a winter ridership of a staggering 24 percent (roughly 18.5 times Canada’s national year-round average) (Jaffe, 2016). Based upon data of the benefits of cycling and on the findings of winter bike ridership in Canada, the northern United States, and Northern Europe, further investigation is warranted to explore how to adapt urban streets to allow for the expansion of winter biking.
CHAPTER 3 – RESEARCH DESIGN

METHODOLOGY

The research for this thesis is mostly qualitative in nature as it seeks to explore the concept of winter bikeability. Unlike more traditional quantitative research, the research question or problem in a qualitative study is not stated as an if-then hypothesis derived from theory; rather, it is founded in observations, dilemmas or questions from the real-world (Marshall and Rossman, 1989). As with most qualitative research, the research topic, significance of the research or context, and related literature review form the conceptual framework of the study (Marshall and Rossman, 1989).

Although there is plenty of research on walkability, there is less on bikeability, and even less with a focus on winter, or four-season, bikeability. The method used in this thesis was a cross-case study approach which demonstrated what factors encourage and promote cycling in winter cities. The case studies also demonstrated challenges or limitations that each city faced.

The reasoning behind the selection of each case study city is illustrated at the end of the chapter. Each of the case study cities differ from one another in terms of their climate, size, cycling mode shares, and winter bicycle network maintenance; however, each has developed best practices that work for their own respective networks. A review of the literature and travel to each of the cities was done to determine the best practices. As Toronto cannot be directly compared to any of the case study cities in terms of the factors listed above, it was necessary to determine the best practices from a range of cities in order to find applicability for Toronto. Figure 3.1 below displays the methodology involved in this thesis.
FIGURE 3.1 - METHODOLOGY FLOWCHART

1. Introduction
2. Literature Review
3. Bikeability Criteria
4. Winter Cycling
5. Generate Bikeability Criteria for Determining Winter Bikeability
6. Winter Bikeability Criteria Applied to the Case Study Cities
   - Montreal, Canada
   - Minneapolis, USA
   - Copenhagen, Denmark
   - Oulu, Finland
7. Data Collection and Analysis Based on Winter Bikeability Criteria
8. Best Practices Based on Analysis Results
9. Design Recommendations for Toronto
10. Discussion and Conclusion
LITERATURE REVIEW

A literature review was conducted to further explore the concepts of bikeability and winter cycling. Although cycling is increasingly being discussed due to its benefits to health and the environment, there is little academic research done on what factors contribute to bikeability in cities. What research has been done often provides metrics for walkability and bikeability simultaneously, although the criteria for each can differ significantly. Pucher, Komanoff, and Schimek (1999) summarized eight main factors that affect cycling rates in North America including: (1) public attitude and cultural differences, (2) public image, (3) city size and density, (4) cost of car use and public transport, (5) income, (6) climate, (7) danger, and (8) cycling infrastructure. Every one of these factors has an enormous impact on cycling levels, and an entire thesis could be written on each factor. To narrow the scope, this research focuses mainly on the last three factors – climate, danger, and cycling infrastructure - and their relationship to design. There is even less in the academic literature on winter, or four season, cycling. This study attempts to explore the gaps in previous research that the literature review identified. Due to the limited academic literature, the literature review also examined other sources including public documents and online references.

CASE STUDIES

The case study method is frequently used in qualitative research. Marshall and Rossman (1989) write that there can be several purposes to case study research, including “chronicling events, to render, depict, or characterize, to instruct, and to try out, prove, or test (p.44).” The preparation of a case study can be broken down into six steps, as defined by Lundberg (1993). The first step involves gaining familiarity with the case study subject (Lundberg, 1993). For this thesis, the subject of each case study is the winter bikeability of the four cities. Familiarity of the subject
was gained by both real-world experience and a review of relevant literature. To understand the success of these bicycle-friendly cities, it was first necessary to understand what led to success of bicycle networks. Through a review of the literature, winter bikeability criteria were created - a list of factors leading to the success of a winter bicycle network - which could be applied to each case study city. Travel to each of the case study cities in January and February of 2017 allowed first-hand experience of each city’s winter bikeability. Tours of the bicycle networks were taken in each of the cities, and information from local cyclists greatly enhanced understanding of each city’s facilities and infrastructure.

The second step involves recognizing the symptoms, or problems of the situation (Lundberg, 1993). The problem, and the reason for this research, is the common perception in North America that cycling is not a feasible four-season option.

The third step in a case study is identifying the goal (Lundberg, 1993). The goal of the case studies was to determine the best practices for each of the winter bikeability criteria used in each city. The goal of the case studies is also to determine what contributes positively to winter bikeability, and what elements can be applied to Toronto.

The fourth step in the case study process is analysis, through the systematic application of appropriate ideas, models and theories to the facts of the situation (Lundberg, 1993). For this thesis, the analysis component involved the systematic application of the winter bikeability criteria to each city, and determining, based on literature and a form of street ethnography, the best practices used in each city. Marshall and Rossman (1989) describe street ethnography as a cultural description focussed on a particular site such as an alleyway, a street, or a park. In these case studies, the site involves the entire bicycle network.
The final two steps of the case study process include diagnosis and action planning (Lundberg, 1993). Diagnosis involves seeking discrepancies between the goal and facts (Lundberg, 1993). Action planning involves determining what would correct or improve the discrepancies listed above (Lundberg, 1993). In other words, for each case study city, it must be asked which implementations for each criterion are actually effective at enhancing winter bikeability and which implementations could use improvement.

SITE SELECTION

Each of the selected cities experience varying degrees of winter weather. According to the Köppen-Geiger climate classification, Toronto, Montréal, Minneapolis and Oulu all fall under the Boreal classification, while Copenhagen falls under warm temperate classification (Rubel and Kottek, 2010). These climate classifications are based on temperature and precipitation observations from the period 1951-2000 (Figure 3.2) (Rubel and Kottek, 2010). Rubel and Kottek also present a Köppen-Geiger climate classification map for the extended period of 2003-2100 based on “global trends in observed climate and projected climate change scenarios” (Rubel and Kottek, 2010, p. 135). According to projected climate data, Toronto will shift into the warm temperate classification for the period of 2003-2100, while Montreal, Minneapolis and Oulu will remain in the Boreal classification (Rubel and Kottek, 2010). Site selection criteria apart from climate are listed below.

Toronto is selected for design critique and recommendations as it is known for having an active bicycle culture, although it is not internationally known as one of the world’s great cycling cities. Toronto has already implemented several pilot and permanent cycle infrastructure projects, which are being met with success in both acceptance and usership (Torontoist, 2016). With promising cycling and ‘complete streets’ policies and plans in the works, Toronto has a lot of
Figure 3.2 – Case Study: Cities’ Köppen–Geiger Climate Classification

Source: Rubel and Kottek (2010)
potential to improve its cycling infrastructure and facilities, and become a world class cycling destination.

Minneapolis and Montréal were both chosen for their global reputation as bike-friendly cities. Both cities appear on the 2015 Copenhagenize Index – a comprehensive ranking of metropolitan cities around the world with populations greater than 600,000 people to determine the most bicycle-friendly cities. In 2015, Minneapolis ranked 18th best in the world, and Montréal ranked 20th best (Copenhagenize Design Company, 2016). Both cities also experience moderate to severe winters and still maintain relatively high levels of cyclists throughout the winter.

Minneapolis is an example of how an auto-centric American city can become bicycle-friendly with the implementation of bicycle-friendly policies, infrastructure and maintenance practices. It is also an example that demonstrates if you spend money on infrastructure, people will use it. Minneapolis is one of four population centres in the U.S. that received $25 million in federal funding over four years as a pilot project to try and increase cycling rates (Friedman, 2010). As a result, the cycling rates in the city jumped from 1.9 percent in 2000 to 4.1 percent in 2008-2012 (McKenzie, 2014). Additionally, the Winter Cycling Congress, which is hosted by the Winter Cycling Federation, was held in Minneapolis in 2016, bringing greater awareness of the positive benefits of cycling.

Montréal is ranked among the best cycling cities in Canada while also experiencing cold, snowy winters. Montréal also has one of the oldest bicycle networks in the country, and one of the highest percentages of protected bicycle lanes. The February 2017 Winter Cycling Congress was held in Montréal.

Copenhagen, Denmark, has steadily risen to prominence as a cycling mecca since the 1970s. It is ranked the number one bicycle-friendly city in the world on the 2015 Copenhagenize Index.
Index. Copenhagen pioneered the ‘Copenhagen style’ cycle track, a raised bicycle lane between
the street and sidewalk. The city has been inspiration for many other cities around the world for
best cycling practices. Copenhagen is dedicated to prioritizing and maintaining its bicycle and
pedestrian networks and strives to be a liveable city. After a snowfall in Copenhagen, city policy
mandates that cycling infrastructure be cleared before any other roads, with the exception of the
four largest roads which are plowed at the same time (Lindholm, n.d.). Although Copenhagen
winters are mild and the overall climate is more temperate than Toronto, significant lessons can
be learned and adapted from this top cycling destination.

Oulu, Finland may not be internationally recognized for its overall bikeability; however, it
appears in the literature numerous times in relation to winter bikeability. Oulu experiences almost
one third of the year as ‘snow days’ (days where it snows or has snow on the ground) and yet
maintains high cycling mode shares year-round (Jaffe, 2016). Oulu is also the founding city of the
Winter Cycling Federation, an international group that promotes winter cycling, and held the first
Winter Cycling Congress in 2013. Northern Europe, particularly Scandinavia, continuously
dominates worldwide in terms of cycling culture, infrastructure, policies, programs, and
maintenance.

Before the case study cities could be analyzed, a greater understanding of the concepts of
bikeability and winter cycling was needed. Chapter 4 discusses the various literature that was used
to create bikeability criteria and better understand winter cycling. The two topics were combined
to generate a new list of winter bikeability criteria.
CHAPTER 4 – LITERATURE REVIEW

BIKEABILITY

The term bikeability can be found frequently in the literature; often it will be used in relation to some sort of measure such as a bikeability index. Although the term bikeability appears often, it is rarely defined. A paper by Lowry, Callister, Gresham and Moore (2012) provides a valuable distinction between three similar terms: bicycle suitability, bikeability, and bicycle friendliness. Lowry et al. (2012) define bicycle suitability as “an assessment of the perceived comfort and safety of a linear section of bikeway (the term bikeway includes shared-use paths and any roadway where bicycle travel is permitted)” (p. 3). Bikeability, according to Lowry et al. (2012), is “an assessment of an entire bikeway-network in terms of the ability and perceived comfort and convenience to access important destinations” (p. 3). The final term, bicycle friendliness, is more all-encompassing, being defined as “an assessment of a community for various aspects of bicycle travel, including bikeability, laws and policies to promote safety, education efforts to encourage bicycling, and the general acceptance of bicycling throughout the community” (Lowry et al., 2012, p. 3).

While a city may have bikeways that are suitable, if those bikeways lack connection to one another and to suitable destinations, the overall network is not very bikeable (Lowry et al., 2012). Likewise, if a city has high bikeability, but the cycling culture is not supported by citizens or policy makers, it will lack a feeling of bicycle friendliness (Lowry et al., 2012). While bicycle friendliness is essential for cycling to become an accepted and encouraged form of transportation, it cannot be improved by modifying cycling infrastructure alone. It involves a more complex process of shifting cultural beliefs and norms from auto-centricity toward active forms of transportation.
through policy, advocacy, and education. Since this thesis focuses more on streetscape design, only criteria that relate to bicycle suitability and bikeability are explored.

Several groups have created lists of criteria that define bicycle suitability, bikeability, or bicycle friendliness. Copenhagenize, a Danish design firm that specializes in helping cities become more bicycle-friendly, produces a bi-annual index of the top bicycle-friendly cities in the world, as mentioned in Chapter 3 (Copenhagenize Design Company, 2016). Copenhagenize publishes the top 20 cities, who earn their spot after being evaluated in 13 different categories (Copenhagenize Design Company, 2016). These categories include:

(1) Advocacy;

(2) Bicycle Culture;

(3) Bicycle Facilities;

(4) Bicycle Infrastructure;

(5) Bike Share Programme;

(6) Gender Split;

(7) Modal Share for Bicycles;

(8) Modal Share Increase Since 2006;

(9) Perception of Safety;

(10) Politics;

(11) Social Acceptance;

(12) Urban Planning; and
(13) Traffic Calming. (Copenhagenize Design Company, 2016)

Each category is ranked from zero to four points for each city, with the potential to receive a maximum additional 12 bonus points for extraordinary efforts or results (Copenhagenize Design Company, 2016). The rankings are based on similar systems used by both Monocle's Liveable Cities Index and the Economist (Copenhagenize Design Company, 2016).

Of these categories, the majority relate to measures of bicycle friendliness. However, Category 3 (Bicycle Facilities), Category 4 (Bicycle Infrastructure), Category 5 (Bike Share Program), and Category 13 (Traffic Calming), can all be used as measures of bikeability. Bicycle facilities refers to such factors as “readily accessible bike racks, ramps on stairs, space allocated on trains and buses and well-designed wayfinding” (Copenhagenize Design Company, 2016, para. 7). Bicycle infrastructure deals with the overall rating of the bicycle network, including paths, on-street lanes, and protected bicycle lanes (Copenhagenize Design Company, 2016). Traffic calming looks at “what efforts have been made to lower speed limits - for example 30 km/h zones - and generally calm traffic in order to provide greater safety to pedestrians and cyclists” (Copenhagenize Design Company, 2016, para. 17).

A study was completed by Winters et al. (2013) to create a bikeability index based on the results of an opinion survey (in Metro Vancouver), travel behaviour studies and focus groups. The resulting bikeability index included five factors shown to consistently influence cycling:

(1) Bicycle facility availability;

(2) Bicycle facility quality;

(3) Street connectivity;
(4) Topography, and

(5) Land use. (Winters et al., 2013, p. 867)

From these factors, Winters et al. created a set of criteria that were mappable using GIS data. These included:

(1) Bicycle route density;

(2) Bicycle route separation;

(3) Connectivity of bicycle-friendly streets;

(4) Topography; and

(5) Destination density. (Winters et al., 2013, p. 872-873)

Winters et al. (2013) went on to create a city map of Metro Vancouver based on the compiled GIS data for each of the criteria, with colour coding to indicate the level of bikeability (Figure 4.1). Areas of the city with a lot of overlap from the five mapped criteria are considered highly bikeable, while areas of the city with little or no overlap lack bikeability and indicate areas in need of improvement.

Another term used frequently in the literature that relates to bikeability is environmental audit. An environmental audit can be defined as “a systematic observational assessment of factors in the physical and social environment (e.g., recreational facilities and sidewalks) that hinder or facilitate physical activity” (Hoehner, Ivy, Ramirez, Handy, & Brownson, 2007, p. 534). Therefore, many studies have been conducted to create environmental audit tools that use a series of factors to evaluate an environment. Often these factors are the same as ones used to determine
bikeability. Included in this literature review are some studies that have created an environmental audit tool that relates to cycling.

In an article written by Hoedl, Titze, and Oja (2010) a set of criteria was developed to determine bikeability and walkability of a route or neighbourhood. Due to increasing evidence that the built environment has an impact on levels of physical activity, Hoedl et al. (2010) created a Bikeability and Walkability Evaluation Table (BiWET). The BiWET is designed to be used as an audit tool to get a quick understanding of the environmental attributes along a route or in a neighbourhood (Hoedl et al., 2010). The BiWET was based primarily on other environmental audit
tools such as those developed by Pikora, Bull, Jamrozik, Knuiman, Giles-Corti, and Donovan (2002) and by Hoehner et al. (2007). The BiWET is based on four categories:

(1) Traffic safety (combination of speed limitations and traffic lanes);

(2) Attractiveness of the surroundings (billboards or walls, greenstrip [green space with width<10 m], trees, green space, public greenspace [sports playing field or park], open space [non-green]);

(3) Land use (residential or business area, lower or higher than three stories, special [attractive/historic/cultural] buildings); and

(4) Walking and cycling infrastructure (cycle lanes, sidewalks). (Hoedl et al., 2010, p. 457)

While the tool itself is used for the purposes of determining characteristics of the route environment, the criteria are still applicable as overall measures of bikeability.

As mentioned above, Pikora et al. (2002) also developed an environmental audit tool based on input from experts in a variety of fields and a literature review. The tool they developed is a Systematic Pedestrian and Cycling Environmental Scan, or SPACES (Pikora et al., 2002). SPACES is evaluated based on several factors related to the pedestrian and cyclist experience (Pikora et al., 2002). These include:

(1) The Walking or Cycling Surface (path type, surface type, path maintenance, path continuity, direct route, width of path/lane, gradient);

(2) Streets (width of street, vehicle parking, curb type (mountable);

(3) Traffic (volume, speed, traffic control devices);
(4) Permeability (street design, intersection distance, intersection design, other points of access);

(5) Safety – personal (lighting, surveillance, path/lane obstruction);

(6) Safety – traffic (crossings, crossing aids, verge width, driveway crossovers, lanes marked, path/lane continuity);

(7) Aesthetics – streetscape (trees, garden maintenance, maintenance, cleanliness, pollution, parks);

(8) Aesthetics – views (sights, architecture);

(9) Destination Facilities (parks, shops, services, local facilities, vehicle parking, public transport, bicycle parking); and

(10) Subjective Assessment (attractiveness for walking, difficulty for walking, attractiveness for cycling, difficulty for cycling). (Pikora et al., 2002, p. 190-193)

Because this is a tool designed for both walkability and bikeability, some of the factors will have a greater influence on walking and may not be as important for cycling. For example, a view of architecture may be the determining factor in a pedestrian’s choice of route, while a cyclist may choose a route with a greater feeling of safety rather than aesthetics.

Hoehner et al. (2007) created an environmental audit tool named the Active Neighbourhood Checklist, or just “the Checklist.” The Checklist was created to act as a more refined version of other environmental audits existing at the time (Hoehner et al., 2007). The Checklist (p.535) identifies five different sections including:
(1) Land Use Characteristics (predominant land use, land use mix, specific residential and non-residential land uses, parking, and recreational facilities);

(2) Sidewalks (sidewalk presence, buffers, continuity, width, curb cuts, misalignments, obstructions);

(3) Shoulders and Bicycle Lanes (presence, width, continuity, designated bicycle signs, obstructions);

(4) Street Characteristics (transit stops, number of lanes, crossing aids, traffic-calming devices, speed limit, and cul-de-sacs); and

(5) Quality of the Environment for Pedestrians (building setback, pedestrian amenities, litter or broken glass, shade trees, slope).

Similar to the tool developed by Pikora et al. (2002), the Checklist contains a mixture of criteria for both cycling and walking, and certain factors are more relevant than others.

Finally, a comprehensive review of transportation, urban design and planning literatures was done by Saelens, Sallis, and Frank (2003) to develop correlates between the environment and walking and cycling rates. Saelens et al. (2003) determined that people walk or cycle for two purposes – as a form of transport, or for recreation or exercise. Saelens et al. (2003) then created a list of neighbourhood environment factors and individual factors that could influence one’s decision to walk or cycle. The neighbourhood environment factors are listed below:

(1) Density, connectivity, and land use mixture;

(2) Safety (e.g., traffic, crime, animals);

(3) Bicycle/walking trails, sidewalks, bicycle lanes;
(4) Parks, community recreation centres, other physical activity facilities;

(5) Neighbourhood aesthetics and topography. (Saelens et al., 2003, p.88)

The individual factors that may influence one to walk or cycle include car ownership, income, age and gender (Saelens et al., 2003).

Below (Table 4.1) is a summary of the different literature on bikeability and environmental audits.

**TABLE 4.1 - BIKEABILITY CRITERIA AND ENVIRONMENTAL AUDIT SUMMARY**

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Copenhagenize Index (2016)</th>
<th>Bikeability Index (Winters et al., 2013)</th>
<th>BIWET (Hoedl et al., 2010)</th>
<th>SPACES (Pikora et al., 2002)</th>
<th>The Checklist (Hoehner et al., 2007)</th>
<th>Environmental Correlates (Saelens et al., 2003)</th>
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<tbody>
<tr>
<td>Bicycle Facilities (ex. Parking)</td>
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<td>Bicycle Infrastructure</td>
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<td>Traffic Calming/Safety</td>
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<td>Street Connectivity</td>
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<td>Topography</td>
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<td>Bicycle Route Density</td>
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<td>Bicycle Route Separation</td>
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<td>Destination Density/Land Use</td>
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<td>Attractiveness of Surroundings</td>
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<td>Street Safety (ex. Lighting)</td>
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<td>Maintenance</td>
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<td>Attractiveness/Difficulty of route</td>
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<tr>
<td>Car Ownership, Income, Age, and Gender</td>
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</table>
WINTER CYCLING

Although literature on cycling is steadily increasing due to renewed interest in its health benefits and potential for sustainable transportation, little focus is put on cycling in cold climates. Cycling in cold and snowy conditions adds additional considerations to a commute, including shorter daylight hours, reduced visibility, unmaintained or poorly maintained lanes and paths, and safety.

Amiri and Sadeghpour (2015) conducted a study that focused on “establishing a baseline for the characteristics of cyclists and cycling behavior in a typical North American city with cold weather” (p.397), in order to provide guidance to cities regarding investments and planning for cycling infrastructure and facilities. Amiri and Sadeghpour (2015) determined that there are two main factors involved in increasing cycling levels: improved cycling infrastructure and improved safety. Amiri and Sadeghpour (2015) distilled the literature to develop eleven variables that they identified as the most influential with respect to cycling characteristics and demand. The variables included “age, gender, frequency of cycling (winter and year-round), safety concerns, temperature, comfort, trip purpose, trip distance, trip duration, use of intermodal transportation, and concerns with regards to infrastructure deficiencies” (Amiri & Sadeghpour, 2015, p.398). The data was collected through an intercept survey along a newly constructed bicycle lane near downtown Calgary, Canada in March of 2012 (Amiri & Sadeghpour, 2015). The results of the survey showed that cycling was used overwhelmingly 96 percent of the time as a form of commuting to work (Amiri & Sadeghpour, 2015). This is contrary to the general perception that cycling is done mainly for recreation (Amiri & Sadeghpour, 2015). The survey also found that the majority of cyclists (71 percent) did not mind cycling in temperatures up to or below -20°C (Amiri & Sadeghpour, 2015). The main safety concern of winter cyclists was icy road conditions and the primary choice for
improving the facilities was better snow and gravel removal (Amiri & Sadeghpour, 2015). Based on the results of the survey, men were 5.5 times more likely to cycle in the winter than women (Amiri & Sadeghpour, 2015).

Fisher (2014) produced a document for Plan Canada entitled *Cycling Though Winter* after attending the international Winter Cycling Congress held in Winnipeg in 2014. Fisher (2014) makes the distinction that winter conditions vary based on fluctuating temperature, daylight and precipitation. Winters can be classified as mild, moderate, or severe, and the different classifications will affect planning, design and maintenance approaches to cycling infrastructure in different cities (Fisher, 2014). Fisher (2014) classifies Copenhagen as having mild winters, Toronto and Minneapolis as having moderate winters, while Montréal and Oulu have severe winters.

Cyclists who continue to cycle through the winter (roughly one quarter of the existing cycling population) have been found to be dedicated and confident (Fisher, 2014). Fisher (2014) notes that winter cyclists are primarily commuters or people cycling for some utilitarian purpose. The main deterrent to cyclists in the winter was found to be a lack of road surface maintenance, and not temperature or weather (Fisher, 2014). Surveys showed that cyclists prefer to be separated or protected from traffic on dedicated lanes but, if they lack proper maintenance through the winter, cyclists will change their routes to major arterial and collector roads that are plowed regularly (Fisher, 2014). Fisher (2014) notes that “establishing prioritized routes that are predictable and comfortable leads to higher rates of winter cycling” (p. 39).

Fisher (2014) suggests a conceptual framework cities can use to prepare for a winter cycling network and maintenance strategy. The framework provides details on planning and
prioritizing, design and procedures, promotion, monitoring and evaluation, and challenges and issues (Fisher, 2014).

Planning and prioritizing for winter cycling involves the improved safety and maintenance of infrastructure and “prioritizing bicycle facilities and routes within a snow removal by-law or specific winter maintenance plan” (Fisher, 2014, p.39). Fisher (2014) provides some guidance for determining priority cycling routes. First, a city should analyze cycling origin and destination patterns and identify high use on-street and off-street infrastructure (Fisher, 2014). Next, consider how the routes will be maintained and any operational procedures required (Fisher, 2014). Finally, the existing road priority snow removal routes should be compared with the proposed winter cycling priority snow removal routes to create a priority network (Fisher, 2014).

Any future cycling infrastructure should be designed to accommodate snow storage and removal (Fisher, 2014). For example, Copenhagen, Denmark ensures 0.5m of space between cycle tracks and sidewalks for snow storage (Fisher, 2014). Cities should coordinate between all departments involved such as roads, parks, active transportation, planning, and public works (Fisher, 2014). Different types of infrastructure will require different maintenance vehicles such as snowplows, pick-up truck plows, or broom snow sweepers (Fisher, 2014). Cities can evaluate whether to maintain routes in-house or contract the service out (Fisher, 2014).

Promotion of the priority winter cycling network is essential (Fisher, 2014). Communication with cyclists and road users can be done through the city website, promoting the winter cycling routes and publishing a winter cycling map (Fisher, 2014). Winter cycling can be normalized through positive promotion and displaying the city’s efforts to improve winter cycling conditions (Fisher, 2014).
Little information is known about winter cycling behaviour since the majority of transportation surveys are conducted in early spring at the beginning of the typical cycling season (Fisher, 2014). To evaluate the quality of the cycling network in the winter, surveys, censuses, and bicycle counts should be done year-round (Fisher, 2014). Bicycle infrastructure investments should be monitored as well as operation and maintenance crews (Fisher, 2014).

Snow clearance is one of the biggest challenges cities have to face when it comes to maintaining a winter bicycle network (Fisher, 2014). Lack of snow clearance on cycling routes pushes cyclists onto busier, but better maintained collector and arterial roads (Fisher, 2014). Bicycle boulevards – low volume, traffic calmed streets that prioritize cyclists – are a good alternative, provided they receive priority snow clearance (Fisher, 2014). Bicycle lanes are challenging because they require a “second pass’ to remove snow, which is expensive (Fisher, 2014). On-street markings, like painted bicycle-lanes, disappear in a snow event, emphasizing the importance of street-level signage in the winter (Fisher, 2014).

A Swedish study by Bergström and Magnusson (2003) examined attitudes toward winter cycling and particularly the winter maintenance of bicycle lanes. The study clearly found that car trips increased in the winter (by 27 percent) while cycling trips decreased (by 47 percent) (Bergström and Magnusson, 2003).

Bergström and Magnusson (2003) conducted two surveys in two Swedish cities to examine the potential to increase winter cycling through improved maintenance of cycling infrastructure. A disproportionately low number of women took part in the two surveys (17 percent and 22 percent, respectively). Respondents were sorted into four categories: winter cyclists (cycled at least twice a week to work in winter), summer cyclists (cycled at least twice a week to work in summer), infrequent cyclists (cycles less than twice a week to work, no matter the season) and never cyclists.
(cyclists who never cycle to work) (Bergström and Magnusson, 2003). Winter cyclists listed exercise as their primary reason for continuing year-round, along with cost and the environment (Bergström and Magnusson, 2003). Summer cyclists listed temperature, precipitation, and road conditions as their main deterrents, with travel time and exercise also being important (Bergström and Magnusson, 2003). Nothing can be done to change temperature and precipitation but improvements in road conditions could convince some summer cyclists to continue cycling through the winter (Bergström and Magnusson, 2003). Non-cyclists listed time constraints as the biggest obstacle and were unlikely to consider any incentive promoting winter cycling (Bergström and Magnusson, 2003). In any category, employees were unlikely to cycle to work if the distance was longer than 10 kilometers (Bergström and Magnusson, 2003).

Due to the low number of female respondents, Bergström and Magnusson (2003) note that it is questionable to compare the travel behaviour of men and women; however, several factors appeared more important to women in both surveys. Women listed road conditions, precipitation, temperature, darkness, and the additional need to do errands as important factors to their commute (Bergström and Magnusson, 2003).

Bergström and Magnusson (2003) asked respondents to specify how they wished maintenance of the winter cycle routes could be improved. The top desire was more frequent snow clearance and de-icing, and the desire for snow to be cleared earlier in the morning (Bergström and Magnusson, 2003). Other desires included the prevention of frozen tracks that create an uneven surface, and the importance of clearing continuous path networks, not leaving sections uncleared (Bergström and Magnusson, 2003).

Nankervis (1999) conducted a study of the effects of short-term weather conditions and long-term seasonal variations on bicycle commuting. The study was conducted in Melbourne,
Australia, and while the focus of the study is not on winter weather, elements of the data collected are applicable. Nankervis (1999) notes several factors relating to cyclists including having to carry bulky goods, the need to arrive at a destination well-groomed, age, health, gender, and culture. Each of these can be affected by wind, temperature, precipitation, and sudden changes in weather conditions (Nankervis, 1999).

Nankervis (1999) found that wind, temperature and precipitation can change ridership numbers on a daily basis, but that riders are particularly sensitive to extremes in temperature. Nankervis (1999) notes that the perception of the effect of weather conditions is also a strong psychological deterrent. There are several factors that can be used to encourage cycling, according to Nankervis (1999), including better facilities for cyclists at the workplace, and flexible arrival or departure times to accommodate unpredicted weather.

An article written by Jaffe (2016) describes some key lessons to be learned from Northern European cities. The most important factors found to influence winter cycling rates include “the strength of a city’s bike network (ideally made up of protected bike lanes) and how well it maintains this network during the cold and snowy months (ideally as a top priority)” (Jaffe, 2016, para. 5).

Different cities prioritize winter maintenance in different ways. Linköping, Sweden, provides year-round maintenance to 60 miles of prioritized bicycle routes (Jaffe, 2016). The routes get plowed after one centimetre of snow accumulation. This is exceptional, especially since any more than three centimetres can discourage cycling (Jaffe, 2016). Copenhagen, Denmark, salts all bicycle lanes before a snow event and then prioritizes snow clearance on all routes (Jaffe, 2016). In Copenhagen, cycle routes get cleared of snow even before the general roadways for car traffic do (Jaffe, 2016). In Oulu, Finland, the snow fall rates can sometimes be too great to clear regularly.
(Jaffe, 2016). Instead, the city packs the snow down and adds a layer of gravel to give traction so that even cyclists without studded tires can ride in relative comfort (Jaffe, 2016). The article notes that any cycling infrastructure built in a city should be installed with the intention of year-round maintenance (Jaffe, 2016).

Swanson (2016) writes about the difference between Winnipeg and Oulu, Finland. Both cities feature similar box stores and strip malls, and suburbs filled with single family homes (Swanson, 2016). They also have similar daytime winter temperatures and snow cover; however, Oulu has kilometers of connected bicycle paths in all directions and thousands of people riding bicycles in the snow (Swanson, 2016).

Swanson (2016) notes that much of our perception of winter cycling is based on myth. A frequent mindset is that it is too cold to cycle in the winter, even though extremes in temperature are uncommon; however, it is often forgotten that the act of cycling keeps you quite warm (Swanson, 2016). Another common mindset is that it is too dangerous to cycle in the winter (Swanson, 2016). The greatest risk factor to cycling at any time of year is the speed of the surrounding traffic, and in the winter traffic speeds tend to drop (Swanson, 2016). Finally, Swanson (2016) argues that our senses have been dulled to the beauty of a winter day. Cycling in the winter allows one to appreciate the smooth, clean lines and quiet that follows a snowfall (Swanson, 2016).

Swanson (2016) describes several other actions Oulu takes that enhances the winter cycling experience. Oulu has bicycle underpasses at most road intersections which relieves stress and saves time (Swanson, 2016). When it snows, equipment is sent out to plow, remove, pack or texturize (with various gritty materials) every path in the network (Swanson, 2016).
WINTER BIKABILITY CRITERIA

Based on review of previous studies and literature on bikeability and winter cycling, a set of criteria was developed related specifically to winter bikeability. Since the criteria will be used to make recommendations for bicycle network design, only those criteria found in Table 4.1 that can be modified in a given bicycle network are used. From the original criteria, a city’s topography, destination density/land use, attractiveness of surrounding buildings, and car ownership, income, age, and gender were deemed unable to be modified through a bicycle network alone and were therefore eliminated. Although these criteria are eliminated for their applicability to bicycle network design, they are still very important to increasing overall bikeability. The remaining criteria are listed in Table 4.2 and described in detail below.

**TABLE 4.2 - WINTER BIKEABILITY CRITERIA**

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Winter Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bicycle Facilities (including parking, ramps on stairs, etc.)</td>
<td>Covered parking or bicycle shelters. Secure bicycle parking. Bicycle ramps on stairs, etc.</td>
</tr>
<tr>
<td>Bicycle Infrastructure</td>
<td>Bicycle lanes and paths have allocated space for snow storage, and are designed to accommodate snow clearing vehicles.</td>
</tr>
<tr>
<td>Traffic Calming &amp; Safety</td>
<td>Traffic calming measures on priority cycling routes. Safety features like bicycle underpasses or overpasses to avoid traffic.</td>
</tr>
<tr>
<td>Street Connectivity &amp; Bicycle Route Density</td>
<td>Bicycle network is highly connected both on streets and on paths. Is the entire network maintained year-round?</td>
</tr>
<tr>
<td>Bicycle Route Separation</td>
<td>Separated bicycle lanes provide additional safety from cars. Other path routes useable throughout winter?</td>
</tr>
<tr>
<td>Route Safety (including lighting and signage)</td>
<td>Most winter cities experience short daylight hours. Is the bicycle network well lit? Additional street signage at eye level to alert cyclists and vehicles of the bicycle network.</td>
</tr>
<tr>
<td>Maintenance</td>
<td>Degree of maintenance of the bicycle network. Consider timing and frequency of snow clearance.</td>
</tr>
<tr>
<td>Attractiveness &amp; Degree of Difficulty of Route</td>
<td>Is the route appealing to use in the winter? Is it easy to use and navigate?</td>
</tr>
</tbody>
</table>
BICYCLE FACILITIES

The terms bicycle facilities and bicycle infrastructure are often used interchangeably in the literature. For the purpose of this study, the term ‘bicycle facilities’ refers to various items dedicated to cyclists within the bicycle network. A major component of bicycle facilities is bicycle parking. Some factors to consider when designing and installing bicycle parking include location, visibility and security, weather protection, type of facility, and clearance (Ontario, 2013). Other bicycle facilities could include end-of-trip facilities such as shower and change rooms and bicycle rooms with repair stations (Ontario, 2013). Bicycle facilities may include rest stops such as lookouts or restaurants, which could be found along rural or urban routes (Ontario, 2013). Finally, facilities could include ramps (or slides) on stairs, footrests or hand-holds at stoplights, allocated space for bicycles on public transit, and city bike share programs. City bike share programs that are available through the winter should be maintained of snow and ice to ensure accessibility. For the winter, sheltered, secured, and even heated bicycle parking will have the greatest impact. For summer cyclists that switch to public transit in the winter months, including ample sheltered or secured parking at transit stations and allocating space for bicycles on public transit could extend the cycling season.

BICYCLE INFRASTRUCTURE

For the purpose of this study, the term ‘bicycle infrastructure’ refers to all types of bicycle paths creating the bicycle network, including on-road infrastructure and in-boulevard infrastructure. The Ontario Traffic Manual defines on-road infrastructure as shared roadway and bicycle routes with only signage, shared bicycle route with paved shoulder, conventional bicycle lane, separated bicycle lane (sometimes called protected bicycle lanes), raised cycle track, and bicycle priority streets (often referred to as bicycle boulevards) (Ontario, 2013). In-boulevard
infrastructure refers to active-transportation and multi-use paths, and any one- or two-way raised cycle track beyond the curb of a roadway (Ontario, 2013). All bicycle facilities and infrastructure should consider emergency and service vehicle access (Ontario, 2013). Of particular note in the winter is the allocation for snow storage included in the bicycle infrastructure design.

**Traffic Calming & Safety**

As noted previously, safety is one of the most cited concerns of cyclists in the winter. Proximity to fast moving traffic is one of the major stressors for any cyclist, so efforts to slow traffic down are instrumental toward creating a safer cycling environment. Traffic calming measures are defined as “the combination of mainly physical measures that reduce the negative effects of motor vehicle use, alter driver behaviour, and improve conditions for non-motorised street users” (Bunn et al., 2003, p.200). Traffic calming measures can include changes to the road layout, hierarchy, or environment, such as “road narrowing, road closures, creation of one-way streets, changes at junctions, mini-roundabouts, road surface treatment, or speed humps” (Bunn et al., 2003, p.200). Traffic calming measures may also include alterations to traffic lights or street signage, and traffic speed reductions (Bunn et al., 2003). The creation of home zones, derived from the ‘woonerf’ – or ‘living streets’ – movement in the Netherlands in the 1960s, can also be used as a traffic calming measure (Pucher et al., 2010). Home zones, or residential areas, have the potential to modify streets for use as play areas as well as active roadways, using physical elements like “benches, flowerbeds, trees, lamp posts, play structures, and pavement treatments” (p. S110), and enforcing speed limits of 10 mph (~16 km/h) (Pucher et al., 2010). Aside from traffic calming, cyclist safety can be enhanced through reduced conflict with traffic and separation from traffic. Separate bicycle traffic signals help reduce conflict with traffic at intersections. Bicycle traffic signals can help with right turning traffic by delaying through bicycle traffic at a light. Measures
such as installing separated bicycle lanes, raised cycle tracks, active-transportation and multi-use paths, and grade separated crossings such as pedestrian/cyclist only underpasses, bridges and overpasses all reduce conflict between vehicles and cyclists, thereby increasing cyclist safety.

STREET CONNECTIVITY & BICYCLE ROUTE DENSITY

Studies have proven the adage “if you build it, they will come,” as it relates to cycling infrastructure. Dill and Carr (2003) analyzed consistent data from the ‘Bureau of the Census 2000 Supplemental Survey’ reflecting a cross-section of 43 large U.S. cities (not solely college towns). Results showed that “higher levels of bicycle infrastructure are positively and significantly correlated with higher rates of bicycle commuting” (Dill and Carr, 2003, p.122). The greater the bicycle route density, and overall street connectivity, the greater the percentage of cycling as a mode share will be. Of particular importance in the winter is consistent access to this bicycle network. Many cities reduce the size or completely close sections of the network, severely restricting access and usability. Often parts of the bicycle network are closed or not maintained through the winter due to a decrease in ridership, however, it is partly a chicken and egg situation since a fractured bicycle network will result in fewer cyclists.

BICYCLE ROUTE SEPARATION

As noted above, bicycle route separation is a major contributing factor to both real and perceived cyclist safety. Installing separated bicycle lanes, or cycle tracks, is mentioned frequently in current literature as being safer and more appealing to a broad range of users (National Association of City Transportation Officials, 2014; Ontario, 2013; Dill and Carr, 2003; Fisher, 2014; Jaffe, 2016; Van Cleve, 2015). Separated bicycle lanes are “a portion of a roadway for preferential or exclusive use by cyclists which is delineated from the motor vehicle lanes by pavement markings or a physical barrier and signage” (Ontario, 2013, p.86). The degree of
physical separation is dependent on several factors including the available width of the right-of-way and vehicular speed, type, and volume (Ontario, 2013). Barriers between traffic can include flexible delineator posts (bollards), concrete curbs, planters, parking lanes, and raised medians (Ontario, 2013). Cycle tracks are separated from traffic by a change in grade. With safety being a significant concern of winter cyclists, as mentioned above, separated bicycle lanes provide the highest degree of safety while still remaining part of the regular street network. Protected bicycle lanes also provide the opportunity to include snow storage areas in the winter, either on the street side to provide an additional buffer from traffic, or on the curb side beside the sidewalk (Van Cleve, 2015). Protected bicycle lanes are typically preferred by commuters as they remain part of the regular street network, unlike active-transportation and multi-use paths which are also physically separated from traffic but are typically built in parks and greenbelts and geared toward recreational use (Dill and Carr, 2003). Active-transportation and multi-use paths also tend to have fewer points of access and tend to be less connected to the remaining bicycle network or major employment locations (Dill and Carr, 2003). It is important to note, however, that there is no one-size-fits-all solution to cycling infrastructure, and individual cities must consider which type of bicycle infrastructure will enhance the bicycle network to the greatest degree.

**ROUTE SAFETY**

Winter cities in the northern hemisphere deal with periods of shortened daylight hours. For many commuters, this often means leaving for work in the dark and returning home in the dark. For this reason, adequate lighting of the entire bicycle network is especially important in the winter. A study by Bergström and Magnusson (2003) indicated that women felt darkness was of greater significance to feeling safe than men did. Municipalities frequently use paint at the street level to delineate bicycle infrastructure on the roadway. The problem with this in the winter is that
bicycle lanes virtually disappear after a snow event. Snowfall combined with low priority (or total lack of) maintenance results in severe restrictions to the overall bicycle network. Thus, additional signage at eye level indicating bicycle routes is of particular importance in the winter.

**MAINTENANCE**

Maintenance could be argued as the single greatest factor determining winter cycling rates. Maintenance of the entire bicycle network should be prioritized throughout the winter. Consistency in the design of the bicycle network could make maintaining it easier, reducing the need for several types of maintenance equipment. It is beneficial to create consistency in infrastructure type and path width throughout the bicycle network.

**ATTRACTIVENESS & DEGREE OF DIFFICULTY OF ROUTE**

Finally, traditional streetscape environments are low in visual stimuli and complexity so that motorists, with limited ability to process detail when driving at high speeds, are better able to concentrate (Frank & Engelke, 2001). The opposite is true for slower-moving pedestrians and cyclists. The streetscape (or bicycle network) environment plays a far greater role in the desire or choice to walk or cycle. The attractiveness of a route depends on the richness of the pedestrian or cyclist experience including maintaining visual and sensory attention (Frank & Engelke, 2001). At the street level, aesthetic factors that contribute to the appeal of a route is dependent on the design of “buildings, including the size and orientation of windows, the location of the door relative to the street, decoration, and ornamentation; landscaping, particularly trees and the shade they provide; and the availability of public amenities such as benches and lighting” (Handy et al., 2002, p.66). Extra care could be taken to enhance winter streetscapes. Winter planters are aesthetically pleasing and can create separation between traffic and a bicycle lane and festive decorative lighting is cheerful and contributes to a greater feeling of safety.
To conclude, the literature reviewed in this chapter created a greater understanding of bikeability and winter cycling. The bikeability criteria generated from the six key articles summarized in Table 4.1 were reconfigured to consider winter cycling. The resulting eight winter bikeability criteria synthesized in this chapter are applied in the following chapter to each of the case study cities.
CHAPTER 5 – CASE STUDIES

This chapter details a brief history of each case study followed by the application of the eight winter bikeability criteria. The result is a series of best practices identified in Montréal, Minneapolis, Copenhagen and Oulu.

CASE STUDY 1: MONTRÉAL, CANADA

OVERVIEW

Montréal is Canada’s second largest city, with the census metropolitan population numbering over four million in 2016 (Statistics Canada, 2016b). Montréal was officially incorporated as a city in 1832 (35 years before Canada’s confederation) but had a long and rich history before that (Linteau, 2015). The island of Montréal and surrounding area was long inhabited by the St. Lawrence Iroquois before one of the villages was visited by Jacques Cartier in 1535 (Linteau, 2015). By 1642, Montréal was an established colony, warring with the Iroquois for dominance in the fur trade (Linteau, 2015). It wasn’t until 1701, after the signing of the treaty, La Grande Paix, that permanent peace was reached between the French settlers and the aboriginal groups in the area (Linteau, 2015).

Montréal quickly became the heart of the fur trade, but the city grew slowly throughout the 1700s (Linteau, 2015). Only after the invasion of the British in 1760, the development of the surrounding hinterland and Upper Canada, and an influx of British immigrants in the early 1800s did the population and urban development of Montréal begin to increase (Linteau, 2015). Major railway development and the expansion of the St. Lawrence seaway in the middle of the nineteenth century created an industrial boom and turned Montréal into a major urban centre (Linteau, 2015).
Rural French Canadians looking for work and immigrants from around the world flooded the city, increasing Montréal’s population nearly 12 times between 1850 and 1914 (Linteau, 2015).

Montréal’s unique island location and proximity to the river influenced its urban development. Rows of farmland, or côtes, were drawn perpendicularly to the river shores (Marsan, 1981). After the shores were settled, another côte was created behind the first, connected by roads called montées (Marsan, 1981). The côtes, later called rangs or ranges, continued back from the shores, creating the orthogonal grid and social organization of the city (Marsan, 1981). These original côtes proved useful for the development of roads, pipes, and rail, as well as the development of buildings, division of land, and regulation of traffic, and still create the basic framework of streets in Montréal today (Marsan, 1981).

By the late 1800s, bicycling was increasing momentum in Canada and Montréal became the first Canadian city to form a cycling club in 1878 (Humber, 2006; Norcliffe, 2001). Bicycle
paths were formed in Montréal as early as 1874, and the first map of cycling routes in the city was published in 1897 (Figure 5.1) (Heffez, 2010; Nadeau, 2017). Cycling has had a stronger culture in Montréal compared to most other Canadian cities (Nadeau, 2017). While Montréal experienced the same decline in cycling popularity at the beginning of the 20th century as other North American cities, it saw a renewal of interest in the interwar years (Nadeau, 2017). The oil crisis of the 1970s also created a bicycle boom, which spurred a flurry of adults to purchase bicycles again (Vélo Québec, 2017a). Unlike many other cities, the bicycle boom of the 70s was not a temporary fad, but continued to be promoted in the city.

Québec as a province is supportive of cycling and Vélo Québec, a non-profit organization founded in 1967, is its leading advocate (Vélo Québec, 2017a; Vélo Québec, 2017b). Vélo Québec has its headquarters in Montréal and provides a variety of services such as training, community events, cycling excursions, and a number of cycle-related publications (Vélo Québec, 2017b). Vélo Québec’s consistent support of cycling for all purposes has encouraged a growing cycling culture in Montréal and the province as a whole. Since 1995, Vélo Québec has been gathering cycling data on the province and publishes a detailed report every five years analyzing “cyclists’ habits, the economic, health and ecological benefits of cycling, and the prevalence and use of bicycle-friendly facilities” (Vélo Québec, n.d.a, p.2). There were 4.2 million cyclists in Québec as of 2015, a number that has grown by 600,000 since 1995 (Vélo Québec, n.d.a). This is largely due to a dedicated effort by the province to support cycling; since 1995, the Government of Québec in collaboration with Vélo Québec, invested $88.5 million over ten years to create the Route verte, over 4,000 kilometres of bikeways linking all parts of Québec (Route Verte, n.d.a). From 2015 to 2020, Québec plans to invest an additional $27.5 million toward the development and maintenance of the now 5,000 kilometres making up the Route verte (Vélo Québec, n.d.a).
Montréal has been listed as one of the most bicycle-friendly cities in the world (Copenhagenize Design Company, 2016; Vélo Québec, n.d.a). The City has seen a growth in its cycling mode shares. The Island of Montréal had a mode share in 2013 of 2.5 percent, with the central neighbourhoods having a mode share of 4.0 percent and Plateau Mont-Royal District seeing mode shares as high as 10.8 percent (Vélo Québec, n.d.a). The percentage of women cyclists grew from 1.2 percent to 1.8 percent between 2008 and 2013. On any given day, 116,000 trips are made by bicycle in Montréal, a 57 percent increase from 2008 to 2013 (Vélo Québec, n.d.a). In support of multi-modal sustainable trips, 82 percent of rapid transit stations in Montréal are located within 400 metres of a bicycle path (Vijayakumar and Burda, 2015). For the 2016-2017 period, the City of Montréal invested $15 million into cycling projects and added 57.6 kilometres to the bicycle network (Ville de Montréal, n.d.a). This included 63 development projects and 9 upgrade projects (Ville de Montréal, n.d.a). Montréal hosted the annual Winter Cycling Congress in February of 2017 (attended by the author).

Montréal is located at a latitude of 45° (Environment Canada, 2016). Data from 1981 to 2010 show that Montréal receives snow fall on average 78.4 days per year in the amount of 0.2 centimetres to 25 centimetres (Environment Canada, 2016). Montréal has snow at a depth of at least one centimetre for an average of 104.1 days per year (Environment Canada, 2016). The average temperature in December is -5.4°C, -9.7°C in January, and -7.7°C in February (Environment Canada, 2016).

WINTER BIKEABILITY CRITERIA

The first winter bikeability criterion looked at for Montréal was bicycle facilities. In the Master Plan for Montréal, created in 2002, the City added a provision stating that “borough by-laws must include provisions regarding parking requirements for bicycles upon the construction,
extension or change of use of a building” (Ville de Montréal, n.d.b, para. 3). This provision was added to ensure bicycle parking would be available in areas with concentrated urban activities (Ville de Montréal, n.d.b). Some private employers and institutions, such as Concordia University, provide secure indoor bicycle parking and shower and change facilities. Vélo Québec also provides a practical how-to guide that citizens can use to determine the best bicycle parking options for their space based on required capacity and location (Vélo Québec, n.d.b). In Montréal, existing parking space markers were retrofitted in 2007 with a steel ring in order to accommodate bicycle locks (Figure 5.2) (Provencher Roy, n.d.). These designated Stationnement de Montréal bicycle rack-poles can be found on most city sidewalks. Additional bicycle parking is usually provided by businesses or employers in the area. Montréal has employed the technique called ‘the green wave’, which synchronizes traffic lights to a typical bicycle commuter pace of 20 kilometers per hour on one of its more heavily used routes, Boyer Street. Bicycles are allowed, with some restrictions, on
Société de transport de Montréal (STM), Montréal’s public transit system. Bicycle racks are
available on eight bus lines, but will only transport bicycles from April 15 to November 15 (Société
de transport de Montréal, 2017). Bicycle parking is available at all métro stations, and a secured
bicycle shelter is currently being piloted at Lionel-Groulx station (Société de transport de
Montréal, 2017). STM has also installed bicycle slides, a track running down a ramp along the
edge of the stairs, at some stations (Société de transport de Montréal, 2017). Currently, only 10 of
68 métro stations have elevators, with plans for that number to increase to 31 by 2022 (Corriveau,
2016). Montréal has the largest bike share system in Canada (Vijayakumar, and Burda, 2015). A
total of 6,200 BIXI bicycles are available at 540 stations across Montréal, Longueuil and
Westmount, accounting for over four million trips in 2011, up from one million trips in 2009
(BIXI, 2017b; Vijayakumar, and Burda, 2015). Unfortunately, BIXI is not available year-round in
Montréal. The BIXI bicycles are available only from April 15 to November 15 of each year, which
limits winter cycling for that user group in the city (BIXI, 2017a).

Montréal uses an assortment of different bicycle infrastructure types, but many of the older
bicycle lanes installed in the 1980s are protected bi-directional, on-street lanes. Although bi-
directional bicycle lanes on streets with bi-directional vehicular traffic is not considered best
practice (uni-directional lanes on either side of the road is best), Montréal was ahead of the curve
on installing its network of protected bicycle lanes. Montréal also uses cycle tracks, conventional
bicycle lanes, contra-flow lanes (on one-way streets), bicycle boulevards and has numerous active-
transportation and multi-use paths. These separated bicycle lanes provide space to store snow,
which provides additional separation from traffic as shown in Figure 5.3.

The City of Montréal has made concentrated efforts to calm traffic, installing speed humps,
curb extensions (chicanes) on over 130 kilometres of streets between 2010 and 2015 (Vélo Québec,
n.d.a). Montréal is divided into 19 boroughs, each having its own mayor who manages local streets and public spaces (Bruntlett, 2014). Montréal’s Master Plan states that each borough is responsible for traffic calming measures which could also include “installing appropriate signage, reducing road widths and widening sidewalks, landscaping roads or sidewalks, modifying road surfaces, eliminating certain one-way streets, and modifying the direction of traffic on certain streets in order to break up continuous traffic flow” (Ville de Montréal, n.d.c, para. 11).

In 2015, the city had 748 kilometres in its cycling network – 181 kilometres of shared streets, 214 kilometres of bicycle lanes, 82 kilometres of cycle tracks, and 271 kilometres of off-street bicycle paths (Vélo Québec, n.d.a). The city plans to expand this network to 1,280 kilometres in the future (Vélo Québec, n.d.a). With the 353 kilometres of combined on-street and off-street routes, Montréal boasts the oldest and largest protected bicycle network in North America (Bruntlett, 2014). The on-street bicycle lanes are often separated from traffic with green bollards,
planters or medians, or parked cars. The protected bicycle lanes result in space for snow storage, either on the street or on the curb side. The City has plans to invest another $15 million in 2017 through 52 development projects and 20 upgrade projects (Gadoury, 2017).

Montréal provides signage at eye level to help cyclists with wayfinding and navigation. There is also a website called Ride the City Montréal which helps cyclists find a ‘safer’ route to their destination, using “the nearest greenway, bike lane, or street segment that users have suggested” (Riga, 2011, para. 4). Ride the City Montréal also shows users where the nearest bicycle shops and bicycle rentals can be found (Riga, 2011). Routes within the on-street network are well lit day and night, year-round.

Montréal has work to do in keeping its bicycle network maintained year-round. Of the 748 kilometres in Montréal’s bicycle network, only 260 kilometres were maintained throughout the winter as of 2014 (D’Alimonte, 2014). That number was increased to 432 kilometres in 2016 (Gomez and Rodrigue, 2017). Appendix A shows the four-season network as of 2016-2017 (Ville de Montréal, n.d.a). However, the City is dedicated to maintaining this winter bicycle network and is testing out new maintenance machinery and techniques in order to provide the best winter cycling experience. Currently some boroughs are testing out brush sweepers on bicycle lanes instead of plows, and using liquid brine as opposed to rock salt. This technique has displayed high quality results, provided the snowfall was not too dense or heavy. In 2014, 7.1 percent of Montréal’s cyclists continued to cycle through the winter, and by 2015 the number of winter cyclists had increased to 11.3 percent (Gomez and Rodrigue, 2017).

Montréal’s impressive network of protected bicycle lanes is a big draw for cyclists in the city. The protected bicycle lanes enhance the feeling of safety even when riding on busy streets.
Many of the bicycle lanes are lined with decorative planters or planted medians which adds to the aesthetic value of the route.

**BEST PRACTICES & FURTHER ACTIONS**

Montréal excels in North America in its proactive installation of a protected bicycle network. Best practice in the industry is increasingly showing that protected bicycle lanes are the safest and most comfortable form of bicycle infrastructure for the greatest number of riders. Vélo Québec publishes a technical guide for the development or maintenance of routes and facilities used for the purpose of active transportation, including cycling. The guide was created through research conducted by Vélo Québec and input from professionals in urban planning, transportation planning, engineering, economics, architecture and safety analysis. The guide does not present a formal set of design standards, but instead offers design solutions based on formulas which have been successful in North America and Europe (Vélo Québec, 2010).

The Vélo Québec guide dedicates an entire chapter to the development of both on-street and off-street infrastructure. On-street infrastructure is broken down into shared roadways, paved shoulders and bicycle lanes, and physically separated lanes. The guide provides useful details on many aspects of design, including minimum path widths, typical infrastructure designs, drainage and grading, and intersection design. For example, a single bicycle lane should be at least 1.5 metres in width, as this is how much space a cyclist in motion occupies (Vélo Québec, 2010). Figure 5.4 displays an example from the guide of two types of separated bicycle lanes in both plan view and section view (Vélo Québec, 2010). Figure 5.5 displays one treatment for the intersection of a bicycle lane and a street when using on-street lanes. Ideally this treatment would be used only on slower moving local roads, and protected bicycle lanes used instead where possible. Figure 5.6 displays an advanced stop line for cyclists at an intersection which allows for greater visibility of
cyclists. Figure 5.7 illustrates a bicycle box, another intersection treatment that provides even greater visibility of cyclists and gives them an advanced start through the intersection. Finally, Figure 5.8 illustrates a road diet, or a reorganization of travel lanes, to accommodate bicycle lanes in each direction. A new edition of the guide is in the works with a section dedicated to physically separated bicycle lanes.
Figure 5.5 - Intersection of a Bike Lane and a Street
Source: Vélo Québec (2010, p.100), Used with Permission
**Figure 5.6 - Advanced Stop Line for Cyclists**
Source: Vélo Québec (2010, p. 100), Used with Permission

**Figure 5.7 - Bicycle Box at an Intersection**
Source: Vélo Québec (2010, p. 100), Used with Permission
The development of Montréal’s bicycle facilities has been impressive, with the addition of the ‘green wave’ on some routes and the bicycle-friendly additions to most of the métro stations. Montréal has one of the largest bicycle networks in Canada, and continues to add to it each year. City-wide traffic calming policies help cyclists feel safe on the on-street network. Montréal is ahead of most Canadian cities in terms of the winter maintenance of its bicycle network, and is dedicated to trying new techniques to create the best user experience. Actions that would further improve the network include expanding winter maintenance, making the bike share program available year-round and expanding bicycle access on public transit.

Figure 5.8 - A Road Diet to Accommodate Bicycle Lanes
Source: Vélo Québec (2010, p.110), Used with Permission
CASE STUDY 2: MINNEAPOLIS, USA

OVERVIEW

Minneapolis is the largest city in the state of Minnesota with an estimated population of 410,939 as of 2015 (United States History, n.d.; Pioneer Press, 2016). Minneapolis combined with St. Paul, Minnesota’s capital, make the Twin Cities - a metropolitan area of just over 3.5 million residents (Pioneer Press, 2016). The Twin Cities is the United States’ sixteenth largest (and coldest) metropolitan area (Pioneer Press, 2016; Van Cleve, 2015). The City of Minneapolis straddles the Mississippi River and is surrounded by bodies of water, garnering the nickname the ‘City of Lakes.’

The area, long occupied by Native Americans, was first settled by the French in the 1680s (United States History, n.d.). The land passed between Spanish and French occupation before being sold to the United States in the early 1800s. Minneapolis became incorporated as a city in 1867 and in its early years supported a flourishing lumber industry (United States History, n.d.). Once the timber was exhausted, Minneapolis industry turned largely toward milling flour (United States History, n.d.).

Minneapolis was a pedestrian oriented city up to the 1890s, with workers settling in homes nearby their jobs (Adams, 2013). Electric streetcar lines were built in the 1890s and radiated out from the city centre (Adams, 2013). The streetcars opened the possibility for residential development of nearby farmland and by the 1950s, seven residential sectors formed around the main lines (Adams, 2013). Private vehicles were easily incorporated into the outlying residential areas but competed with streetcar traffic and the pedestrian oriented streets in the downtown core (Adams, 2013). The installation of interstate highways facilitated further sprawl to outlying areas and divided the inner city’s neighbourhoods (Adams, 2013).
Minneapolis’s pedestrian-friendly origins also supported cyclists, and many of the first paved streets were also the first bicycle routes (City of Minneapolis, n.d.). Minneapolis has one of the best and most highly developed park systems in the United States thanks to the establishment of the Minneapolis Board of Park Commissioners in 1883 (City of Minneapolis, n.d.). With the cycling craze of the late 1800s, Minneapolis built several recreational cycling paths, mostly near the lakes and rivers in the area (City of Minneapolis, n.d.). The established trail system in Minneapolis today is thanks to the dedicated park and trail investments made for over one hundred years, often with the help of federal funding (City of Minneapolis, n.d.).

Fuel shortages in the 1970s and increased environmental awareness created a new surge of people interested in cycling as a form of transportation (City of Minneapolis, n.d.). The already well established trail system was expanded, but the City understood that these trails primarily served recreational cyclists (City of Minneapolis, n.d.). In order to better serve commuters and utilitarian cyclists, the City of Minneapolis began to add a network of bicycle signs near the University of Minnesota campus (City of Minneapolis, n.d.).

Federal sources of funding have helped Minneapolis become the bicycle-friendly city it is today. The first was the passing of the Intermodal Surface Transportation Equity Act (ISTEA) in 1991 (Pucher et al., 1999; Smith, 2014). ISTEA urged states and metropolitan planning organizations to include walking and bicycling in their transportation plans (Pucher et al., 1999). ISTEA also required that states designate bicycling coordinators, and dedicated federal transportation funds for enhancements to non-traditional transportation projects, specifically including bicycling facilities (Pucher et al., 1999). In 1998, federal transportation legislation replaced ISTEA with the Transportation Equity Act for the Twenty-First Century (TEA21) (Pucher et al., 1999). TEA21 enhanced most of the bicycle provision from ISTEA, adding an
additional 50 percent of funding for bicycle enhancement projects, and required that highway design standards be developed with regard to cycling (Pucher et al., 1999).

Then, in 2008, Minneapolis became one of four sites in the United States chosen for the Non-Motorized Transportation Pilot Program (NMTPP) (Smith, 2014). Each city in the NMTPP received $25 million in federal funding as part of a four-year study to determine if funding cycling projects increases cycling rates (Smith, 2014). The pilot project proved fruitful as the average number of bicyclists in each pilot city increased by 49 percent (U.S. Department of Transportation, 2014). In 2010, approximately 16 million miles (25.8 million kilometres) were walked or bicycled in the pilot cities that would have otherwise been driven (U.S. Department of Transportation, 2014). These non-motorized trips in 2010 reduced the economic cost of mortality by approximately $6.9 million (U.S. Department of Transportation, 2014). Despite, or perhaps because of, the increases in cycling and walking rates in each city, pedestrian and cyclist fatalities held steady or decreased across the board (U.S. Department of Transportation, 2014).

In 2015, Minneapolis was rated the eighteenth best bicycling city on the planet by the Copenhagenize Index, and Bicycling Magazine ranked Minneapolis as the sixth best cycling city in the United States in 2016 (Copenhagenize Design Company, 2016; Dille, 2016). Minneapolis increased its cycling commuting rates from 1.9 percent in 2000 to 4.1 percent in 2008-2012 (McKenzie, 2014). Women represented 28-32 percent of cyclists across the Twin Cities in 2013, a number that has remained roughly the same since 2008 (U.S. Department of Transportation, 2013). Roughly one fifth of Minneapolitans continue to bicycle through the winter (Van Cleve, 2015). While absolute numbers of cyclists in the Twin Cities are lower in the winter, winter cycling rates are increasing at a greater pace than summer cyclists during the same time period (U.S.
The Twin Cities were host to the Winter Cycling Congress in February of 2016.

Minneapolis is located at a latitude of 44° (Minnesota Department of Natural Resources, 2017). From 1981 to 2010, the Twin Cities experienced an average of 138 centimetres of snow per year (Minnesota Department of Natural Resources, 2017). The Twin Cities saw an average of 116.5 days per year with precipitation over 0.025 centimetres (Minnesota Department of Natural Resources, 2017). Days with snowfall greater than 2.54 centimetres averaged 16 per year (Minnesota Department of Natural Resources, 2017). The average daily temperature in December was -6.8°C, -9.1°C in January, and -6.2°C in February (Minnesota Department of Natural Resources, 2017).

**Winter Bikeability Criteria**

In 2011, City Council adopted the Minneapolis Bicycle Master Plan. The purpose of the plan was to “establish goals, objectives, and benchmarks that improve safety and mobility for bicyclists and increase the number of trips taken by bicycle” (City of Minneapolis, 2016a, para. 1). The Bicycle Facility Manual is a companion document to the master plan and provides detailed guidelines for bicycle facilities and infrastructure in Minneapolis. Currently Minneapolis measures its bicycle parking under three classifications. Class I bicycle parking are bicycle lockers, which are fully enclosed and protected from the elements (City of Minneapolis, 2016a). There are only a handful of bicycle lockers in Minneapolis, all of which are in high density locations. The second classification, Class II bicycle parking are bicycle racks which lock both the front and back tires (City of Minneapolis, 2016a). Class III bicycle parking is the most common and economical type, which are standard bicycle racks designed for short term parking (City of Minneapolis, 2016a). Bicycle shelters are listed as a possible parking solution. The Bicycle Facility Manual also provides
guidelines on choosing the appropriate style of bicycle parking when installing new facilities (City of Minneapolis, 2016a). Minneapolis has a number of bicycle repair stations in the city, equipped with air pumps and various screwdrivers and wrenches which are available to the public (City of Minneapolis, 2016a). The City of Minneapolis requires that all new developments exceeding 500,000 square feet must include shower and locker facilities, and recommends including these facilities in all institutions as general best practice (City of Minneapolis, 2016a). Minneapolis has one bicycle station which is a full service indoor bicycle storage facility with showers, change rooms, a store, rentals and repairs (Figure 5.9) (City of Minneapolis, 2016a). The bicycle station is located off the Midtown Greenway, a major cyclist and pedestrian only path in the city (City of Minneapolis, 2016a).
Minneapolis, 2016a). All of the Metro Transit buses in Minneapolis (and most of the suburban express buses) are equipped with bicycle racks (City of Minneapolis, 2016a). Each car in the Light Rail system in Minneapolis has reserved space for bicycles as well (City of Minneapolis, 2016a). The Twin Cities’ bike share program, Nice Ride, has 1800 bicycles at over 200 locations in Minneapolis and St. Paul (Nice Ride Minnesota, 2017). Unfortunately, like Montréal, all the bicycles are available only from April to November and are removed for the winter season (Nice Ride Minnesota, 2017).

Minneapolis has a unique and extensive network of off-street paths as well as on-street infrastructure. The on-street network is made up of bicycle boulevards, on-street bicycle lanes, shared lanes, and protected bicycle lanes (City of Minneapolis, 2016a). Off-street paths include multi-use and separated trails, unpaved trails, and mountain biking trails (City of Minneapolis, 2016a). The city is encircled by the Grand Rounds Scenic Byway, a ring road network of vehicle, pedestrian, and cycling paths (Smith, 2014). In the past decade, Minneapolis has been converting old railway lines into bicycle paths to connect different points of the circle, increasing the overall path network (Smith, 2014). Paths like the Midtown Greenway and the Cedar Lake trail exist on former rail lines (Smith, 2014). In addition to continually adding cycling infrastructure to the regular street grid, Minneapolis is also creating a separated bicycle freeway system (Smith, 2014). Off-street paths have plenty of room for snow storage while snow from on-street infrastructure is mostly plowed to the sidewalk or removed. Problems tend to occur when parked cars push snow from the windrow onto plowed bicycle lanes, making formerly clear bicycle lanes difficult to traverse.

Traffic calming measures in Minneapolis include curb bump outs, traffic diverters, traffic circles, speed humps, no left-turn signs, pre-emptive walk signals and opposing one-way streets.
(Imboden, 2012). It appears that these traffic calming measures are only installed when requested or necessary and that Minneapolis does not have a city-wide traffic calming plan. In Minneapolis, the installation of speed bumps is only eligible on certain local streets that are not designated as “through streets” (City of Minneapolis, 2013). The local streets must also meet the criteria of a set of guidelines, such as traffic volume must exceed 300 vehicles per day and 75 percent of property owners must agree to the speed humps (City of Minneapolis, 2013). Minneapolis has several examples of pedestrian and cyclist underpasses, overpasses and bridges and recognizes the importance of grade separated crossings in removing physical barriers that would discourage cycling (City of Minneapolis, 2016a). Physical barriers could include “major highways or freeways, rivers, railroad corridors, and steep hills” (City of Minneapolis, 2016a, p. 24).

With the funding provided by the Non-Motorized Transportation Pilot Program, Minneapolis added 75 miles (120.7 kilometres) of bicycle lanes and trails between 2008 and 2012 (Smith, 2014). As of 2015, Minneapolis has 129 miles (207.6 kilometres) of on-street bikeways and 97 miles (156 kilometres) of off-street bikeways (City of Minneapolis, 2016b). Appendix B shows the bicycle network per Minneapolis’s Bicycle Master Plan.

In 2015, Minneapolis added an updated section the Bicycle Master Plan focused solely on protected bikeways (City of Minneapolis, 2016a). Protected bikeways include off-street trails, pedestrian and cyclist bridges, street side paths, and protected bicycle lanes (City of Minneapolis, 2016a). As of 2014, Minneapolis had 96 miles (154.5 kilometres) of protected bikeways, and plans to increase that to 174 miles (280 kilometres) long-term (City of Minneapolis, 2016a). Most of the protected bicycle lanes in Minneapolis are separated from traffic using flexible delineator posts. The City plans on adding an additional 30 miles (48.3 kilometres) of protected on-street bicycle lanes by 2020 (City of Minneapolis, 2016a). Apart from protected bicycle lanes as part of the on-
street network, Minneapolis is famous for its off-street path network. Perhaps most famous is the Midtown Greenway (Figure 5.10), a ten-kilometre long bicycle freeway running east-west through the city centre (Babin, 2016). Many commuters use the Midtown Greenway, as the sunken converted rail line runs unimpeded (cars remain at street level above) for 10 kilometres and is often the fastest way across town. Another well-used line is the trail alongside the LRT, which provides useful links between transit and bikeways.

The main hindrance of the extensive off-street path system in terms of the winter is its lack of lighting. Unless individual cyclists have powerful bicycle lights, the path system becomes unusable for average commuters when the daylight hours grow short. Minneapolis has plenty of signage for cyclists (and vehicles) at eye level, and falls under two categories: bicycle route signage
and guide signage (City of Minneapolis, 2016a). Bicycle route signage is typically found on streets without any cycling infrastructure and is used to “bridge bikeway gaps and to provide bicyclists with basic information about where to ride” (City of Minneapolis, 2016a, p.96). Guide signage is used primarily to provide cyclists with useful information along bicycle routes and is often found at decision points along the route (City of Minneapolis, 2016a). Minneapolis has several websites aimed at providing information to cyclists including bicycle maps, traffic volumes, detour information, elevations, and points of interest (City of Minneapolis, 2016a).

The Midtown Greenway along with other trails like the Luce Line Regional trail, North Cedar Lake, and Cedar Lake Regional trails are plowed all year long (Jaralambides, 2017). However, not all trails within the network are plowed through the winter. On-street infrastructure is typically plowed at the same time as the rest of the street. Bikeways are also sanded and salted as needed (City of Minneapolis, 2016a). With plows on the routes sometimes several times per day, Minneapolis remains committed to the winter maintenance regime of its bicycle network (Babin, 2016).

The network of separated bikeways, mostly off-street in Minneapolis, makes cycling a very easy and convenient way to get around the city. The off-street paths feel very safe to ride on and provide a respite from the sounds and smells of traffic.

**BEST PRACTICES & FURTHER ACTIONS**

Protected bikeways are considered to be best practice, especially in the winter, and Minneapolis is dedicated to improving its protected bikeway network, as seen by the addendum to their Bicycle Master Plan. Several guidelines have been published in the United States to provide bicycle network planners with design recommendations such as the Urban Bikeway Design Guide by the National Association of City Transportation Officials (2014). The Urban Bikeway Design
Guide provides design guidance and recommendations on all sorts of bicycle infrastructure including bicycle lanes, cycle tracks (protected bicycle lanes), bicycle boulevards, intersection design, signalling, and signage and markings (National Association of City Transportation Officials, 2014). The Urban Bikeway Design Guide provides an entire chapter dedicated to cycle tracks, which it has defined as “an exclusive bike facility that combines the user experience of a separated path with the on-street infrastructure of a conventional bike lane” (National Association of City Transportation Officials, 2014, p. 27). At the beginning of the chapter, the Urban Bikeway Design Guide provides a set of required features of cycle tracks in the United States as well as providing a set of recommended features to enhance cyclists’ experience and safety. Figure 5.11 displays different methods of vertical separation from traffic along a cycle track at the street level (National Association of City Transportation Officials, 2014). Most of the protected bicycle lanes (cycle tracks) in downtown Minneapolis use tubular markers, also called flexible delineator posts, as the main vertical separation. The Urban Bikeway Design Guide also provides best practice infrastructure recommendations (Figure 5.12), which demonstrate lowering the risk of conflict between pedestrians, cyclists and vehicles by routing the cycle track behind a transit stop (National Association of City Transportation Officials, 2014). Figure 5.13 demonstrates best practice
At transit stops, consider wrapping the cycle track behind the transit stop zone to reduce conflicts with transit vehicles and passengers.

**Figure 5.12 - Cycle Track Routed Behind a Transit Stop**
Source: National Association of City Transportation Officials (2014, p. 32)

**Figure 5.13 - Treatment of a Right-Turn Lane With Through Bicycle Traffic**
Source: National Association of City Transportation Officials (2014, p. 77)
guidelines for right turning lanes with through bicycle traffic (National Association of City Transportation Officials, 2014). Minneapolis’s bicycle network could be further improved by integrating other best practices from the Urban Bikeway Design Guide into their bicycle network in the future, such as more on-street protected bicycle lanes. The off-street network could use adequate lighting to feel safer on dark winter mornings and evenings. Like Montréal, the Minneapolis bicycle system would be improved, making its bike share system available year-round. Ideally, Minneapolis will continue to maintain its winter bicycle network to a high degree in the future, and increase the maintenance of its off-street paths.

CASE STUDY 3: COPENHAGEN, DENMARK

OVERVIEW

Copenhagen is the capital of Denmark and its largest city with a population of just under 600,000 in 2016 (Danishnet, 2016). The population of the area of Greater Copenhagen is closer to 1.3 million (Danishnet, 2016). The first written record of Copenhagen’s existence dates back to the year 1043 (Copenhagen, 2017). At the time, Copenhagen was a small fishing village and slowly grew to a prosperous town (Copenhagen, 2017). Copenhagen was made the capital of Denmark by the King in 1343 and remains the seat of the government and home to the Danish royal family (Copenhagen, 2017). Due to the location of Copenhagen, it was the centre of attack over the years from Norwegian, Swedish and German forces (Copenhagen, 2017). As the capital grew, its progress was set back by two major fires in 1728 and 1795 (Copenhagen, 2017). Much of the city was destroyed; however, this gave the town officials the opportunity to create a newer, grander town plan (Copenhagen, 2017).

Greater Copenhagen continued to grow throughout the 1800s, but the spreading municipalities were in danger of reaching capacity for their public transportation (Rahunen, n.d.).
The Danish Town Planning Institute created a plan for Greater Copenhagen in 1947 called ‘Egnsplan’ or Finger Plan (Thandi Norman, 2015; Urban Life Copenhagen, 2015). This now famous plan attempted to control the urban growth through the creation of urban ‘fingers’ (Rahunen, n.d.). These fingers consisted of concentrated urban development around railways and arterial roads radiating out from the city centre, with undeveloped green wedges remaining between them (Rahunen, n.d.). This plan is often referred to as the five-finger plan, as the layout of Greater Copenhagen looks like a hand, with the City of Copenhagen as the palm and the new urban developments as the fingers (Rahunen, n.d.). Copenhagen’s urban development strongly favours sustainable lifestyles and mobility choices. Since 1989, all new developments in Copenhagen must be within one kilometre of a railway station (Rahunen, n.d.).

Bicycle infrastructure was built in the inner central districts and areas of the northwestern ‘fingers’ from the late 1910s to the mid-1930s (Carstensen et al., 2015). The original cycle paths were often paved-over horse tracks, and were created due to a former lack of cyclist comfort on the roads (Carstensen et al., 2015). Despite the public transportation-friendly urban planning, Copenhagen saw increasing numbers of private vehicles in the post-war period and a dramatic decrease in cyclists (Carstensen et al., 2015). Although the number of private vehicles increased, the road network remained relatively consistent after having its greatest expansion during the 1920s to the 1940s (Carstensen et al., 2015). Even with the increase in vehicles, the bicycle network continued to grow in both the inner and outer districts, but cycling levels remained low compared to the peak cycling levels of the 1930s (Carstensen et al., 2015). Renewed interest in cycling infrastructure started in the late 1970s after cyclist fatalities due to vehicles reached their highest level in the history of Denmark (Carstensen et al., 2015). Support from residents, planners, and activists dissuaded the proposed introduction of more motorways and encouraged further
development of the bicycle network (Carstensen et al., 2015). Since the 1980s, Copenhagen has made concerted efforts to reorganize streets, redesign urban spaces, traffic calm roadways and improve cyclist infrastructure (Carstensen et al., 2015). Over the past ten years, Copenhagen invested 1 billion DKK (roughly 193.5 million Canadian dollars) into cycling infrastructure facilities and bicycle bridges (Colville-Andersen, 2016).

In 2015, Copenhagen was listed as the best cycling city in the world (Copenhagenize Design Company, 2016). As of 2016, 56 percent of citizens in Copenhagen use their bicycle daily to travel to work or school (Colville-Andersen, 2016). Citizens from the outer districts of Greater Copenhagen cycle into the city for work or school at an impressive mode share of 41 percent per day (Colville-Andersen, 2016).

Copenhagen is situated at a latitude of 55° (Maps of World, 2017). The average temperature in Copenhagen in December is 2.1°C, 0.6°C in January, and 0.5°C in February (Yr, 2017a). Copenhagen experiences an average of nine days with precipitation in December and January, and six days with precipitation in February (Yr, 2017a). Intermittent snowfall occurs mainly from December to March with rain as common as snow during these months (World Weather and Climate Information, 2016).

**WINTER BIKEABILITY CRITERIA**

Copenhagen is the birthplace of many innovative bicycle facilities. Copenhageners love cycling so much that bicycles outnumber citizens – there are 650,000 bicycles in the city and fewer than 600,000 residents (Cycling Embassy of Denmark, 2017). There are 48,000 bicycle racks in Copenhagen and citizens always want more (Cycling Embassy of Denmark, 2017). Often there are so many bicycles cluttering the sidewalks, pedestrians are forced onto the street. Better bicycle parking is planned for Copenhagen Central Station with the addition of 7,550 new spots in a new
parking facility (Colville-Andersen, 2015). Fisketorvet - Copenhagen Mall has a large indoor bicycle parking garage, with dedicated space for regular bicycles and cargo bicycles. The City of Copenhagen is struggling to keep up with the bicycle parking demand, but is aware of the problem and has published a ‘checklist for bicycle parking’ that should be considered before installing new bicycle parking (Colville-Andersen, 2011). The City of Copenhagen also prioritizes bicycle parking as a main area of development in its 2011-2025 Bicycle Strategy (City of Copenhagen, 2011). All of the train stations in Copenhagen have elevators that can be used to transport bicycles, and the staircases are also fitted with ramps to easily move bicycles up or down. Many sets of stairs in the city have ramps or bicycle ‘slides’ built into the design as shown in Figure 5.14. In Copenhagen, attention has been put into small details to enhance the cycling experience. Garbage receptacles can be found on some routes mounted and angled so that riders can dispose of their waste without even slowing down. At some stoplights, foot rests or hand rails are installed at the side of the road so that cyclists do not have to dismount. There are 289 bicycle shops in Copenhagen and 20 companies that design and build bicycles (Cycling Embassy of Denmark,
Bicycles are allowed on city buses for a fee, and each bus can only accommodate two bicycles (Visit Copenhagen, n.d.b). Bicycles are allowed on trains and the metro, with some restrictions during rush hours. Copenhagen’s public bike share program, Bycyklen, supplies bicycles at over 100 stations across the city and is available 24 hours a day, 365 days a year (Visit Copenhagen, n.d.a).

Copenhagen has a very uniform network of cycling infrastructure, and all of the infrastructure in the city falls within a few main categories of Danish best practice (Figure 5.15). Firstly, on roads with traffic speeds of 10-30 kilometres per hour, cyclists share the roadway with motorists (Colville-Andersen, 2013b). At traffic speeds of 40 kilometres per hour, painted lanes are used (Colville-Andersen, 2013b). Next is what Copenhagen is famous for, the ‘Copenhagen style’ cycle tracks - grade separated bicycle paths on both sides of the on-street network. Cycle tracks are used at traffic speeds of 50-60 kilometres per hour, which includes many of the streets in the city centre (Colville-Andersen, 2013b). At traffic speeds of 70-130 kilometres per hour, on-street bicycle lanes should be fully separated with a median (Colville-Andersen, 2013b). Any off-street infrastructure should always be bi-directional, and Danish best practice states that bicycle infrastructure should always be placed to the right of parked cars (Colville-Andersen, 2013b). Some of the cycle tracks in Copenhagen include a ‘conversation lane’ (Colville-Andersen, 2013a). These cycle tracks are divided by small paint markers on the route, allowing for two cyclists to be able to cycle side-by-side and hold a conversation, while faster cyclists can go in the passing lane on the left (Colville-Andersen, 2013a). Higher volume cycle track routes will often have a through lane and a right turning lane at an intersection to reduce conflict (Figure 5.16).
Copenhagen’s bicycle network is extensive and has a huge presence on the streetscape, yet the City is still dedicated to implementing traffic calming measures. Using techniques like reduced traffic speeds, and speed bumps for vehicles increases safety for cyclists (City of Copenhagen, 2011). Copenhagen also employs additional techniques to improve cyclist safety. When bicycle lanes go through intersections, they are often painted a bright solid colour or stenciled with bicycle
symbols to alert vehicles of their presence. When vehicles have a right turning lane, the transition zone between the through bicycle traffic and the right turning vehicles is often painted a bright colour as well (as previously demonstrated in Figure 5.13). Many intersections also have separate bicycle traffic signals or advanced bicycle stops (sometimes referred to as bike boxes) to increase bicycle safety. When vehicles are stopped at a stoplight further back from the bicycles there is greater visibility of the cyclists and helps drivers when making right turns. Copenhagen has some noteworthy examples of dedicated cyclist and pedestrian bridges. In the past decade, 13 bicycle bridges have been built to improve connectivity between previously isolated neighbourhoods and to create more connections for cyclists across the harbour (Riefkohl, 2016). Ten of those bridges are permanent, three are temporary, and four more bridges are planned for installation in the coming years (Riefkohl, 2016). New and high profile bridges include the Cykelslangen, (The
Bicycle Snake), the Inderhavnsbro (the Inner Harbour Bridge), and the Cirkelbroen (the Circle Bridge) (Riefkohl, 2016). Copenhagen also has underpasses to make traveling easier and quicker including the underpass beneath Dronning Louises Bro (a heavily used bridge) and the newly constructed and well-lit Østerbro tunnel (Riefkohl, 2016).

Copenhagen has 429 kilometres of bicycle paths within the municipality, and Copenhageners cycle 1.27 million kilometres daily (Cycling Embassy of Denmark, 2017). Copenhagen has a long history of building cycling infrastructure and continues to add to its network each year. The main efforts of the past decade have been to increase connectivity to Greater Copenhagen by creating regional bicycle super highways linking the outer districts with the inner city (Carstensen et al., 2015). The City of Copenhagen’s Bicycle Strategy 2011-2025 outlines its goal for increasing its bicycle mode share and making the city even more bicycle friendly (City of Copenhagen, 2011). By 2025, the City of Copenhagen plans to create the PLUSnet, a network of the most highly used bicycle routes, bicycle superhighways and chosen green routes (City of Copenhagen, 2011). The PLUSnet will receive the highest priority for quality of space, intersections and maintenance (City of Copenhagen, 2011). The goal for the PLUSnet is to have 80 percent of the network equipped with ‘conversation lanes,’ in other words having lanes three bicyclists wide in each direction and two bicyclists wide on bi-directional paths (City of Copenhagen, 2011). Appendix C shows Greater Copenhagen’s current bicycle network and Appendix D illustrates the central city’s bicycle network.

The first on-street protected bicycle lane was installed in Copenhagen in 1915, and since then the City has developed one of the most extensive protected bicycle networks in the world (Colville-Andersen, 2013b). Many of the cycle tracks are so heavily used, the city has had to widen them to a width of three to five metres. The City of Copenhagen plans to add even more cycle
tracks to the network by 2025 and to increase the cycle tracks up to intersections as standard practice (City of Copenhagen, 2011). The City of Copenhagen wants cyclists of all ages and abilities to feel safe and comfortable in the bicycle network, which is why it is devoted to creating the ‘conversation lanes’ and creating connections with the green and blue routes (bicycle paths separated from traffic through greenspaces and alongside water) (City of Copenhagen, 2011).

Much of the cycling network in Copenhagen is integrated with the street network, and as such it is well lit at all times (Figure 5.17). 76 percent of Copenhageners feel safe bicycling in traffic, and the goal is to have 90 percent of Copenhageners feel safe by 2025 (Cycling Embassy of Denmark, 2017; City of Copenhagen, 2011). Denmark has a system of bicycle signage to provide information to both vehicles and cyclists, with signs posted at eye level. Since the cycle tracks are so fully integrated into the street network, cyclists often have their own traffic signals which are timed differently from the vehicle traffic signals to improve the safe flow of traffic.

![Figure 5.17 - The Well-Lit Inderhavnbro (Inner Harbour Bridge) in Copenhagen](image)

**Figure 5.17 - The Well-Lit Inderhavnbro (Inner Harbour Bridge) in Copenhagen**

*Photo Credit: Author*
Since 75 percent of Copenhageners continue to cycle through the winter, the City views winter maintenance of the network as a top priority (Cycling Embassy of Denmark, 2017). When comparing a map of the city’s bicycle network and a map of the network that gets maintained through the winter, the two maps are exactly the same (Figure 5.18). The cycle tracks are often plowed before the streets are plowed. Since Copenhagen has such a uniform bicycle network with similar types of infrastructure, maintaining the network is much easier and requires fewer types of equipment. Funding for the maintenance of the bicycle network in Copenhagen was increased by 10 million DKK (roughly 1.94 million Canadian dollars) a year since 2011, including maintenance of bumps and potholes (City of Copenhagen, 2011). Funding for winter maintenance and snow clearance was increased 2 million DKK (roughly 389,000 Canadian dollars) a year since 2012 (City of Copenhagen, 2011).

Cycling in Copenhagen is one of the easiest and most comfortable cycling experiences on the planet. In 2011, 48 percent of cyclists said that the main reason they chose the bicycle for travel
is because it was the fastest and easiest way to get around the city (City of Copenhagen, 2011). Copenhageners benefit from a ‘green wave’ network of cycle tracks with traffic lights timed to turn green at a pace of 20 kilometres per hour (a typical bicycle commuting speed) to speed up commutes. There are several major construction projects going on in Copenhagen, including the construction of several new metro stations. Despite this disruption, the City of Copenhagen is ensuring there will be no main roads closed to bicycle and pedestrian traffic from 2011 to 2018 (City of Copenhagen, 2011). The City of Copenhagen also understands that cyclists experience their environment differently from vehicles. It recognizes that street trees, street furniture, and an overall vibrant street scene encourages citizens to cycle, but also that a successful bicycle network in itself contributes to that vibrant street scene (City of Copenhagen, 2011).

BEST PRACTICES & FURTHER ACTIONS

Danish bicycle network design is frequently referenced as industry best practice. Copenhagen pioneered the protected bicycle lane movement, and continues to increase its protected bicycle (cycle track) network each year. Copenhagen’s simplified types of bicycle infrastructure, as shown earlier in Figure 5.15, are a great way to create consistency within a bicycle network, which is better for wayfinding as well as maintenance. Cities from around the world frequently look to Copenhagen for the latest innovations in bicycle facilities and infrastructure. Any of the aspects from the criteria listed above have been tested and developed in Copenhagen for decades in order to become the best practice for each situation. Copenhagen is still developing and learning and is dedicated to providing a livable, bicycle-friendly city for its citizens. Although Copenhagen winters are mild, the City’s dedication to prioritizing the maintenance of its bicycle network is commendable. The overall best practice to take away from Copenhagen is its approach to integrating bicycle infrastructure into the streetscape design as an
essential part of the network, and not just as an afterthought or when space is available. Moving forward, Copenhagen needs to find a better solution for bicycle parking, and is already looking for solutions to create greater connectivity between the outer districts and the inner city.

CASE STUDY 4: OULU, FINLAND

OVERVIEW

Oulu is the largest city in Northern Finland with a 2015 population of just under 200,000 people (Oulu, n.d.). The City of Oulu was founded in 1605 and is the capital city of Oulu province and the capital of Northern Scandinavia (Oulu, n.d.). Oulu is situated at the mouth of the river Oulujoki, on the shore of the Gulf of Bothnia and was first settled as a Swedish military base (Finland was part of Sweden at the time) (Oulu, n.d.). In the 1650s, after its official establishment, a new town plan was created including the installation of a grid network (Oulu, n.d.). In the 1700s the most important exports from Oulu were tar, timber, salmon and butter (Oulu, n.d.). Several fires destroyed buildings in Oulu, including a fire in 1822 which razed most of the wooden buildings in the town (Oulu, n.d.). By 1886, the railway reached Oulu and the population began to steadily increase (Oulu, n.d.). Finland gained its independence in 1917 which caused the country to break out into civil war, resulting in destruction within the city (Oulu, n.d.). The amalgamation of the town of Oulujoki and the Pateniemi part of Haukiputaa into Oulu made it temporarily the largest city if Finland by area in 1965 at 369.8 square kilometres (Oulu, n.d.). In 2013, Oulu merged again with four surrounding municipalities to create a new municipality, the fifth largest in Finland (Oulu, n.d.). Oulu is home to many high-tech industries, including Nokia’s electronics department and one of Nokia’s product development centres (Oulu, n.d.).

The City of Oulu is considered the cycling capital of Finland and the winter cycling capital of the world (Perälä, 2015). In 1969, walking and cycling were included in the transport system
plan for the first time (Perälä, 2014). Starting in 1972, Oulu began to plan an extensive pedestrian and cyclist network separated from vehicles and covering the entire city (Perälä, 2014). The plan had separate allocated funding for bicycle and pedestrian projects (Perälä, 2014). The city centre began to be developed with pedestrian and cyclist infrastructure in 1981, and by 1987 it had created a pedestrian and cyclists only zone downtown called Rotuaari (Perälä, 2014). Rotuaari was extended in 1993 and again between 2011 and 2013, with sections of the street network installed with in-ground heating to melt snow and ice (Perälä, 2014). In 1998, the City of Oulu began to contract out the maintenance of the regional pedestrian and bicycle network (Perälä, 2014). A regional strategy was created for bicycle and pedestrian traffic in 2007, and in 2010 the City updated its pedestrian and bicycle development plan to include winter cycling (Perälä, 2014). Oulu’s bicycle network is due to dedicated city planners who fought for cycling infrastructure despite criticism (Perälä, 2014). Around 20 percent of citizens in Oulu choose cycling as their primary mode of transportation, and roughly 33 percent of those continue to cycle through the winter (Perälä, 2015). Almost 50 percent of 13 to 17 year-olds bicycle year-round (Van Cleve, 2015). Oulu is the birthplace of the Winter Cycling Federation, a global organization aimed at promoting and normalizing winter cycling (Winter Cycling Federation, 2015). Oulu also held the first Winter Cycling Congress in February of 2013, and conferences have been held in different winter cities around the world each year since, as indicated previously.

Oulu is located at a latitude of 65° (Pratte, 2011). The average daily temperature in Oulu in December is -7.5°C, -9.7°C in January, and -9.5°C in February (Yr, 2017b). Oulu experiences one hundred days of snowfall or more per year (Jaffé, 2016).
WINTER BIKEABILITY CRITERIA

New developments in Oulu prioritize cycling by placing bicycle parking near the front door and automobiles in parking lots away from building entrances (Pratte, 2011). Many of the high-tech industries in the area offer shower and change facilities and tend to support cycling in their corporate culture (Pratte, 2011). Bicycle racks can be found outside of most businesses and institutions in the city. The central train station in Oulu, which can be accessed via a pedestrian and bicycle underpass, is equipped with a staircase to the railway above that has ramps to help move bicycles or strollers.

Oulu’s bicycle network is one hundred percent separated from vehicle traffic and is mostly shared with pedestrians (Perälä, 2014). All the routes within the city are protected, either on-street or off-street (Figure 5.19) (Perälä, 2014). Most of the bicycle infrastructure in Oulu consists of off-street separated paths, but the city also has some of the ‘Copenhagen style’ raised cycle tracks
Bicycle paths parallel to roads in residential areas are separated with a green lane, which is used for snow storage in the winter (Perälä, 2014). Since most of the network is separated from traffic with a buffer zone, the entire network is designed to accommodate plenty of snow storage.

In 1972, the City of Oulu integrated citizen associations into the planning process for bicycle infrastructure (Pratte, 2011). Through this process, traffic calming measures became instituted across the city (Pratte, 2011). Oulu is dedicated to removing unnecessary conflict with traffic and installs underpasses to avoid busy intersections (Figure 5.20). Oulu has over 150 underpasses across the city dedicated to pedestrian and cyclist use (Perälä, 2014). Due to the nature of the separated bicycle network and use of underpasses at the busiest intersections, Oulu has created a very safe environment for cyclists.

Figure 5.20 - A bicycle and pedestrian underpass beneath a busy intersection
Photo credit: Author
Oulu has an extensive bicycle network with around 613 kilometres of bicycle routes (Perälä, 2015). That equals about 4.3 metres per inhabitant. Oulu adds an average of 17 kilometres to this network each year (Perälä, 2014). The minimum width of any path in the network is three metres, while main routes can be three and a half metres or wider (Perälä, 2014). Appendix E illustrates Oulu’s bicycle network map.

Despite the majority of Oulu’s bicycle paths being separated from the street, one hundred percent of the network has street lights (Figure 5.21) (Perälä, 2014). This is particularly important in Oulu, as the daylight hours during the winter can be as short as four hours (Pehkonen, 2009).

Figure 5.21 - Protected Pedestrian and Bicycle Path Lit at Night
Photo Credit: Author
Since the bicycle routes in Oulu are not plowed down to bare pavement in the winter, extra care had to be taken to ensure adequate signage of bicycle routes at eye level. The path systems have signage to show joint pedestrian and bicycle use, and are important for wayfinding, especially at decision points along the route.

Cyclists in Finland benefit from a federal transport policy which requires that urban areas maintain year-round active transportation networks, including cycling infrastructure (Pratte, 2011). The City of Oulu maintains 98 percent of its bicycle network throughout the winter and often the bicycle routes are cleared of snow before the streets are (Perälä, 2014; Perälä, 2015). The City is divided into nine maintenance areas, five of which are maintained by private contractors with four-year contracts (Perälä, 2015). The City divides maintenance of the bicycle network into three different classes. The first includes roughly 150 kilometres, or 15 percent of the network designated for ‘super’ maintenance, or 24 hour a day care (Macrae, 2017). Class 1 bicycle routes are cleared after three centimetres of snow and Class 2 routes are cleared after five centimetres of snow (Macrae, 2017). Class 1 bicycle routes are also treated before the peak hours of 7 a.m. and 4 p.m to ensure clear paths for commuters (Macrae, 2017; Perälä, 2014). In Oulu, no salt is used on the bicycle network or any of the streets apart from a few of the larger highways. Instead, the city does not plow bicycle routes down to bare pavement, but leaves a base of three centimetres of packed snow. Gravel or other aggregates are spread on top of the base layer of snow to provide additional traction. Oulu spends approximately 1.5 million euro (roughly 2.17 million Canadian dollars) on maintenance of its bicycle network per year (Perälä, 2014). Winter maintenance is essential in Oulu as snow can begin to fall in October and stay on the ground from November to late April or early May (Nordlund, 2008). The philosophy held in Oulu is: if you build any new bicycle infrastructure in the city, you should maintain it year-round.
Oulu benefits from an extensive off-street network that is highly connected to all areas of the city. The benefit of a bicycle path system separated from the street network is the peace and quiet of the network. Cycling through Oulu from November to April is a winter wonderland. Without the use of salt, and with packed snow as the base of the paths, the network is quiet and bright, even in the dark morning and evening hours due to the reflective qualities of the snow and the benefit of fully lit paths.

**BEST PRACTICES & FURTHER ACTIONS**

While Oulu’s climate and geographical position differ from Toronto and some maintenance practices would be infeasible, it still has a lot to offer in terms of bicycle network design. The completely separated network of bicycle paths is impressive due to its degree of connectivity throughout the city; every place in the city is accessible via bicycle. The uniform network design also helps Oulu maintain the network more easily. Oulu’s philosophy that any new infrastructure built should be maintained year-round is something other cities could adopt as best practice. The city’s dedication to winter maintenance should be commended, especially considering the amount of snow Oulu receives each year. The lighting of all off-street paths in Oulu is something that all cities should implement, especially for safety and usability during the winter. The use of underpasses to avoid conflict with traffic is ideal, and could be implemented in other cities provided they are well lit and well drained. Oulu’s commitment to growing its bicycle network is impressive considering its location and small population. Oulu has space throughout the entire network to store snow, without compromising path width in the winter.

Even with Oulu’s bicycle-friendly policies and infrastructure, cycling rates have been declining in the city due to urban sprawl and growth of the road network. Moving forward, Oulu could enhance bicycle parking options and facilities by including more sheltered parking.
Expanding bicycle infrastructure into the expanding areas of the city is essential to maintain connectivity with the overall network. Finally, increasing connections with public transit could help increase ridership throughout the winter.

SUMMARY OF BEST PRACTICES

BICYCLE FACILITIES

Each of the cases above demonstrated best practices for their own respective cities. Overall, best practices for bicycle facilities included ample bicycle parking, particularly in highly-used areas like urban centres, schools, institutions, and transit stations. The type of bicycle parking should be determined by anticipated usage, space available and funds available. Sheltered and secured bicycle parking is best in the winter, but may be expensive or impractical in areas with little space, low usage or where it would interrupt sight-lines. All bicycle parking should be cleared of snow throughout the winter. Additions to a bicycle network that enhance the user experience should be implemented when possible, such as bicycle stations and rest stops. Details like hand rails, mounted garbage receptacles, and foot rests add to the ease of a cyclist’s experience and may encourage greater levels of cycling. Many cities are making an effort to increase connections between cycling and transit. Ideally all transit stations should be equipped with elevators or bicycle ramps on staircases, and allow bicycles on public transit all year-long. Other staircases in cities on or near bicycle routes should be equipped with bicycle ramps to increase usability. Bike share programs should remain available year-round for greater bikeability.

BICYCLE INFRASTRUCTURE

Best practice for bicycle infrastructure is dependent on many individual factors and must be determined on a case by case basis. However, the Danish best practice for bicycle infrastructure design (as displayed in Figure 5.15) is a simple and convenient way of planning a network based
on traffic speeds, and adds cohesion to an entire bicycle network. Increasing separation between bicycles and automobile traffic is essential for both real and perceived cyclist safety, and the Danish best practice of separating cyclists at automobile traffic speeds greater than 50 kilometres per hour should be adopted universally. On-street bicycle infrastructure should be uni-directional on either side of the road. Bi-directional paths should be reserved for off-street infrastructure. Bicycle lanes should be given as much available space as possible, with a minimum width of 1.5 metres. A three metre wide lane permits multiple cyclists to ride side-by-side and allows for individual cyclists to ride at their own pace while faster cyclists have room to pass. Examples from the case studies show the necessity of including snow storage in the design of the bicycle infrastructure. Allocation for snow storage should be at least 0.5 metres wide.

**Traffic Calming & Safety**

All of the case study cities have implemented traffic calming measures to some degree. Traffic calming methods could include reduced traffic speeds, speeds bumps, curb extensions, road width reduction, changes to road hierarchy, and landscaping roads or sidewalks. Cities should prioritize cycling by making concerted efforts to traffic calm the entire on-street bicycle network, with emphasis on shared vehicle and cyclist routes without protected bicycle infrastructure. The reduction of conflict with cyclists and vehicles is important to improve safety and increase cycling rates. Grade-separated crossings are an effective way to avoid conflict with vehicles at busy intersections, and installing underpasses, overpasses and pedestrian and bicycle bridges can vastly improve cyclist safety. Grade-separated crossings must be well-lit and well-drained in order to be effective. When grade-separated crossings are not possible, extra care should be taken to improve cyclist safety at conflict points. When space is available, right turning vehicles should be given a turning late to the right of through bicycle traffic, with the transition zone clearly marked at both
the street and eye level. When space is not available, traffic stop lines should be further back from cyclists stop lines at an intersection to improve visibility of cyclists. Bicycle boxes (Figure 5.7) may also be used. Intersections should be clearly marked at the street and eye level to indicate bicycle crossings. When possible, cyclists should be routed to the right of transit stops.

**Street Connectivity & Bicycle Route Density**

All of the case study cities are dedicated to keeping at least a portion of their bicycle networks open and maintained throughout the winter. The greater the connectivity of the network year-round, the more people will continue to cycle throughout the winter. Each city continues to add to its bicycle network each year, and is dedicated to improving the connectivity of its network. Best practice from Copenhagen involves viewing cycling as a central aspect of the transportation network, and prioritizing bicycle infrastructure in its design, as opposed to installing it as an afterthought or only when space is available. Most of the case study cities have extensive bicycle master plans and plan to continue to invest in and support their bicycle networks into the future.

**Bicycle Route Separation**

Separated bicycle infrastructure is being implemented as best practice in more and more cities. These case study cities all have separated bicycle infrastructure as part of their networks and have plans to include more. There are varying degrees of protection, and different solutions will be more applicable for individual situations. Vertical separation can include flexible delineator posts or bollards, planters, curbs, medians (planted or otherwise), bioswales, and parked cars. Best practice shows that cyclists should be routed to the right side of parked cars as most vehicles are single occupant and the likelihood of being ‘doored’ is far less when kept to the right. The cycle track itself can also be separated vertically either to the sidewalk level or somewhere in-between the street and sidewalk. Considerations for vertical separation elements include access for
emergency and service vehicles and space for snow storage. Bollards and planters may need to be removeable and curbs, medians and cycle tracks should be mountable. Planters may also need to have hazard markers for winter plowing. Flexible delineator posts are a great option for pilot projects as they are relatively inexpensive and can be moved in order to change the design, however, they offer the lowest degree of safety. For winter maintenance, delineator posts mounted on a pre-cast curb will facilitate snow clearing. Off-street separated bicycle infrastructure provides the greatest degree of separation from traffic but may also lack connection to the rest of the bicycle network. Care should be taken to ensure off-street paths remain highly connected at many points along the route.

ROUTE SAFETY

As winter tends to mean shorter daylight hours for many cities, it is essential that the entire bicycle network be adequately lit, especially the off-street paths. Many of the case study cities also provided ample signage at eye level for better awareness and wayfinding for both cyclists and motorists. Signage is vital in the winter as street level painted markings disappear under snow cover. Bicycle traffic signals also improve safety, especially along highly used routes.

MAINTENANCE

Each of the case study cities provides varying levels of winter maintenance. Copenhagen and Oulu provide extremely high levels of bicycle network maintenance. Ideally, a city’s bicycle network, and any new infrastructure added to the network, should be fully maintained year-round. Dedicated funding should be allocated for winter maintenance, and cities can decide whether to maintain the network themselves, or contract the service out. Cities should ensure that path width and quality is maintained throughout the winter. Copenhagen and Montréal have been maintaining routes with a brush sweeper and applying liquid brine instead of rock salt, which has been
providing the highest quality results provided the snowfall was not too heavy. The advantage of a brush sweeper over a traditional plow is that the sweeper conforms to irregularities in the path surface, clearing the surface more consistently. Brush attachments can often be put on existing equipment. Brine is more effective than rock salt for cyclists; cyclists’ narrow tires and lower weight cannot crush rock salt and generate the heat needed to activate it like vehicles can. The disadvantages of brine are that it is more expensive, it is difficult to see where it has been applied, and it is not always effective in heavy precipitation. Consistency in the design of the network is key in creating an effective and efficient maintenance routine. Care should be taken that painted bicycle lanes on roads not become snow storage areas, and may require a second pass from plows. When bicycle lanes are placed in between traffic and parked cars, parked cars entering traffic drag snow from the windrow through the bicycle lane, resulting in poor conditions. For this reason, as well as others listed above, it is best practice to route cyclists to the right of parked cars. Some cities are even using in-ground heating of cycling infrastructure to melt snow and ice, guaranteeing bare pavement conditions.

**ATTRACTIVENESS & DEGREE OF DIFFICULTY OF ROUTE**

Finally, the aesthetic quality of a bicycle network is important to keep cyclists riding through the winter. Creating a vibrant street scene with street furniture, street trees, decorative planters, and decorative lighting can improve the sensory experience. Aspects that make cycling easier will also enhance ridership. The ‘green wave’ implemented in Copenhagen and Montréal is used mainly at rush hour or peak commuting times. Future steps could be taken to implement the ‘green wave’ when weather is poor as well, to help cyclists arrive at their destinations faster.

Applying the eight criteria that support winter bikeability resulted in identification of best practices in each of the case study cities, summarized in Table 5.1 below. Chapter 6 applies these
best practices to Toronto, Canada, and makes recommendations to improve winter bikeability in Toronto.

**Table 5.1 - Summary of Best Practices from Montréal, Minneapolis, Copenhagen, and Oulu**

<table>
<thead>
<tr>
<th>Winter Bikeability Criteria</th>
<th>Montréal, Canada</th>
<th>Minneapolis, USA</th>
<th>Copenhagen, Denmark</th>
<th>Oulu, Finland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bicycle Facilities</td>
<td>- New secure bicycle parking at some metro stations, regular bicycle parking at all stations - Bicycles allowed on public transit</td>
<td>- Offers bicycle lockers and bicycle racks across the city - Bicycle repair stations across the city - Bicycles allowed on public transit</td>
<td>- Sheltered and secured bicycle parking - Ramps on stairs - Public bike share program available year-round - Bicycles allowed on public transit</td>
<td>- Bicycle parking maintained of snow year-round - Ramps on some staircases</td>
</tr>
<tr>
<td>Bicycle Infrastructure</td>
<td>- Snow storage allocation on most on-street bicycle lanes</td>
<td>- Extensive off-street bicycle network - Snow storage allocation within infrastructure or snow removed</td>
<td>- Very uniform network of cycling infrastructure according to traffic speed (see Figure 5.15)</td>
<td>- Majority of network off-street with snow storage allocation - Minimum path width is 3 metres</td>
</tr>
<tr>
<td>Traffic Calming &amp; Safety</td>
<td>- Traffic calming on over 130 kilometres of streets between 2010 and 2015</td>
<td>- Several pedestrian and cyclist underpasses and overpasses - Traffic calming implemented on request</td>
<td>- Extensive traffic calming - Several pedestrian and cyclist underpasses and overpasses</td>
<td>- Traffic calming initiatives since 1972 - Over 150 underpasses across the city dedicated to pedestrian and cyclist use</td>
</tr>
<tr>
<td>Street Connectivity &amp; Bicycle Route Density</td>
<td>- In 2015, 748 kilometres in the bicycle network</td>
<td>- As of 2015, 363 kilometres in the bicycle network (207</td>
<td>- 429 kilometres of bicycle paths within the municipality</td>
<td>- 613 kilometres of bicycle routes in the network</td>
</tr>
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<td></td>
<td>Kilometres of on-street bikeways, 156 kilometres of off-street bikeways</td>
<td>- Construction of bicycle superhighways connecting Greater Copenhagen</td>
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</table>
| **Bicycle Route Separation**                                                                 | - As of 2015, 82 kilometres of cycle tracks  
- 271 kilometres of off-street bicycle paths | - As of 2014, 154.5 kilometres of protected bikeways  
- Well connected network of cycle tracks and separated lanes  
- As most of the network is off-street, the majority of the network is protected |
| **Route Safety**                                                                  | - Signage posted at eye-level as well as ground-level  
- Bicycle route signage and guide signage found on streets without any cycling infrastructure or at decision points along the route | - Most of network on-street and well-lit  
- Danish bicycle signage integrated into city network at eye-level  
- Entire bicycle network well lit, including all off-street paths  
- Signage used at eye level to indicate bicycle infrastructure and facilities |
| **Maintenance**                                                                 | - As of 2016, maintenance of 432 kilometres of a priority winter bicycle network | - Priority maintenance of bicycle routes  
- Entire bicycle network maintained year-round  
- Priority maintenance of bicycle routes  
- Most the bicycle network maintained year-round |
| **Attractiveness & Degree of Difficulty of Route**                                   | - The green wave used on a busy route to make commuting faster and easier  
- Decorative planters and planted medians used as dividers from traffic  
- Off-street network an attractive option for many cyclists | - The green wave used on priority routes to make commuting faster and easier  
- Bicycle often easiest and fastest way to get around the city  
- Off-street network quiet and peaceful  
- Well connected to any destination in the city makes travel by bicycle easy |
CHAPTER 6 – DESIGN RECOMMENDATIONS FOR TORONTO

Using criteria that support winter bikeability from Chapter 4 and the findings of best practices identified from the case studies in the previous chapter, the status of winter bikeability in Toronto, Canada is examined and recommendations for further improvement are provided.

APPLICATION OF BEST PRACTICES TO TORONTO, CANADA

Toronto is Canada’s largest city with the census metropolitan population numbering over 6.2 million in 2016 (Statistics Canada, 2016b). The City of Toronto is home to over 2.7 million people and is the capital of the province of Ontario (City of Toronto, 2017e; City of Toronto, 2017f). Toronto is located at a latitude of 45° (Environment Canada, 2016). Data from 1981 to 2010 show that Toronto receives snow fall on average 51.4 days per year in the amount of 0.2 centimetre to 25 centimetres (Environment Canada, 2016). The average temperature in December is -0.5°C, -3.7°C in January, and -2.6°C in February (Environment Canada, 2016).

Cycling as a commuting mode share rates are increasing in Toronto. In 1996, 0.8 percent of workers in Toronto cycled to work, while 1.7 percent cycled to work a decade later (Pucher et al., 2011). The bicycle mode share exceeds ten percent in some of Toronto’s central neighbourhoods (Pucher et al., 2011). Women made up roughly 36 percent of the cyclists in Toronto as of 2010 (Pucher et al., 2011). According to the City of Toronto Cyclists Survey in 2009, 66 percent of households in Toronto had bicycles in 2009, with an average of 2.2 bicycles per household (Ipsos Reid, 2010).

BICYCLE FACILITIES

Best practice from the case studies demonstrated that cities should provide ample bicycle parking, ideally with sheltered or secured options when possible. Toronto’s iconic post and ring
bicycle parking can be found across the city along the sidewalks. By 2016, Toronto had installed roughly 17,500 bicycle rings (City of Toronto, 2017b). Toronto also has bicycle parking in the form of bicycle corrals (Figure 6.1), bicycle lockers, and secure bicycle parking. Bicycle corrals are installed in the place of one on-street parking space and can park up to 14 bicycles (City of Toronto, 2017b). However, the bicycle corrals are seasonal, and are removed in the winter for snow clearance (City of Toronto, 2017b). Bicycle lockers can be found at many transit stations and institutions in the city, and Toronto currently has two secure indoor bicycle parking stations located at Union Station and Victoria Park Subway Station (City of Toronto, 2017b). Best practice also shows that greater accessibility for bicycles on public transit can help encourage greater...
cycling rates. Currently, bicycles are allowed on TTC vehicles at off-peak times, as well as on Toronto Island ferries. Roughly half of the TTC stations have elevators (35 out of 69) (Toronto Transit Commission, 2017b). Bicycle repair stops have also been installed at 29 TTC stations, equipped with wrenches, Allen keys, screw drivers and bicycle pumps (Toronto Transit Commission, 2017a). New ‘easy access fare gates’ have been installed at TTC stations to allow bicycles to enter the station more easily (Toronto Transit Commission, 2017a). In 2015, Toronto had 98 bicycle shops, which equals roughly four shops per 100,000 people (Vijayakumar and Burda, 2015). Toronto’s public bike share program, Bike Share Toronto, has 2,000 bicycles at 200 stations across the city (Krantzberg, 2017). Bike Share Toronto is operated 365 days a year, although the fleet is reduced to 75 percent in the winter (Krantzberg, 2017). The busier stations are cleared of snow first, and only in extreme weather events will the stations be temporarily shut down (Krantzberg, 2017). This is great for maintaining winter ridership levels, and follows best practice as seen from the case study cities. Toronto also has bicycle sensors at many traffic signals in the city. Over half of the existing traffic signals in the city are semi-actuated, meaning signals remain green on main streets until a vehicle is sensed at the cross street or a pedestrian presses the button to cross the street (City of Toronto, 2017a). These sensors cannot detect cyclists so, since 1995, the City of Toronto has adjusted the sensitivity of the detectors to be able to detect cyclists at all new semi-actuated intersections (City of Toronto, 2017a). This is depicted by three white dots on the pavement alerting cyclists to where the detectors are. The City is also trying new techniques like video detection of cyclists at intersections (City of Toronto, 2017a). Overall Toronto is following many of the best practices set out for bicycle facilities by the case study cities. Moving forward, I would recommend that Toronto continue to increase its sheltered bicycle parking options, as well as bicycle friendly extras like adding ramps on staircases.
BICYCLE INFRASTRUCTURE

Toronto’s bicycle network is made up of an assortment of different bicycle infrastructure types. The City uses bicycle lanes, protected bicycle lanes, cycle tracks, contra-flow lanes, bicycle boulevards, shared roads, and off-street paths. In Ontario, under the Highway Traffic Act, bicycles are considered vehicles on the road, just like a car or truck (Ministry of Transportation, 2016). Apart from controlled series highways like the 400-series highways, cyclists in Ontario have equal rights to the road as any other vehicle (Ministry of Transportation, 2016). This means that in Toronto, cyclists have equal rights to all of the roads; however, certain roads have been designated as shared bicycle routes, using traffic calming measures to increase cyclist safety and comfort. Best practice from the case study cities shows that allocation for snow storage is an important design feature of bicycle infrastructure. Moving forward, Toronto could make efforts to include space to store snow along the bicycle network.

TRAFFIC CALMING & SAFETY

The City of Toronto implements traffic calming measures in neighbourhoods across the city. A harmonized traffic calming policy was developed following the amalgamation of the former municipalities into the current City of Toronto. The City uses a variety of traffic calming measures, grouped into two main categories. The first are vertical deflections which include speed humps and raised intersections for two-way stop control (City of Toronto, 2016d). The second involves horizontal deflections such as chicanes (curb extensions), traffic islands, and traffic circles (City of Toronto, 2016d). Other traffic calming measures on roads other than local roads or collectors could involve posted speed limit reductions, police enforcement (where necessary), or obstructions like directional road closures, diverters, full closures, and raised medians through intersections (City of Toronto, 2016d). These options to calm traffic all lead to greater pedestrian
and cyclist safety, and follow best practices as shown by the case study cities. Toronto has a number of pedestrian and cyclist underpasses and bridges along its network as marked on the Cycling Network Plan in Appendix F. As of 2016, the City of Toronto approved a Cycling Network Ten Year Plan which details investments planned for the bicycle network between 2016-2025 (City of Toronto, 2017c). The Ten Year Plan has identified several potential areas for pedestrian and cyclist tunnel or bridge development along the network. This reflects the best practices being used in many of the case study cities.

**STREET CONNECTIVITY & BICYCLE ROUTE DENSITY**

As of 2015, Toronto had 856 kilometres of bicycle infrastructure both on- and off-street (Vijayakumar and Burda, 2015). Painted or protected bicycle lanes accounted for 230 kilometres of that network, while multi-use paths accounted for 297 kilometres (Vijayakumar and Burda, 2015). In 2015, 76 percent of rapid transit stations were within 400 metres of a bicycle path (Vijayakumar and Burda, 2015). By 2016, the bicycle network included 18.7 kilometres of cycle tracks, 216.8 kilometres of white bicycle lanes, 7.5 kilometres of yellow contra-flow bicycle lanes, 34.4 kilometres of signed routes with sharrow, and 302 kilometres of signed routes without pavement markings (City of Toronto, 2016b). Multi-use trails totalled 300 bi-directional kilometres, made up of rail trails, hydro corridors, boulevard trails and major parks trails (City of Toronto, 2016b). The Cycling Network Ten Year Plan has evaluated the current bicycle network and has created a map of the areas in the city that are within 500 metres of the network. All blank areas on the map indicate zones that could use further development of bicycle infrastructure in order to create the greatest possible connectivity of the network. The Cycling Network Ten Year Plan includes five different scenarios based on funding between $8-$25 million per year (City of Toronto, 2016c). The plan recommends Scenario 3 which proposes investments of $16 million per
year into the bicycle network (City of Toronto, 2016c). If the total amount of proposed bicycle infrastructure is built, Toronto could see an additional 280 kilometres of protected and non-protected bicycle lanes, 190 kilometres of shared routes, and 55 kilometres of sidewalk level boulevard trails (Spurr, 2016). Toronto is also developing Complete Streets Guidelines which involves considerations for bicycle infrastructure, and one of the objectives of the City of Toronto’s 2013-2018 Strategic Plan involves emphasizing active transportation options, including cycling. The City of Toronto’s bicycle network is provided in Appendix F. One of Toronto’s main challenges to increase overall ridership levels will be encouraging residents from the outer suburbs to cycle into the city instead of drive. Long term, this will mean developing greater connections between the suburbs and the inner city, potentially developing bicycle superhighways like Copenhagen is now doing.

**Bicycle Route Separation**

Toronto has been making huge strides since 2010, implementing many new separated (protected) bicycle infrastructure projects including the Richmond Street and Adelaide Street lanes, the Queen’s Quay multi-use path, the Sherbourne cycle tracks, and the Bloor Street pilot lanes. At the Winter Cycling Congress in Montréal this year, Toronto’s Sherbourne cycle tracks were brought up on numerous occasions as a great example of best practice cycling infrastructure. Continuing to move toward a protected bicycle network is one of the best ways to increase cycling rates in the city, and is especially great in the winter for making cyclists feel safer. Hopefully the maximum proposed 280 kilometres of bicycle lanes in the Cycling Network Ten Year Plan leans more heavily toward protected bicycle lanes, as well as further development of protected bicycle infrastructure in the future.
ROUTE SAFETY

Toronto’s on-street bicycle network is fully lit by street lights. The 2001 Toronto Bike Plan notes that the majority of the off-street paths are not lit, but recognized the importance of lighting to improve winter cycling conditions (City of Toronto, 2001). The 2014 Toronto Multi-Use Trail Design Guidelines also includes a section on lighting (City of Toronto, 2014b). The guidelines recommend lighting for all multi-use trails, “except where lighting would impact sensitive wildlife activities, invite trail users into dangerous situations, or where lighting would conflict with special requirements (in hydro corridors, for example)” (City of Toronto, 2014b, p.50). Some trails in the city are already lit like the Martin Goodman Trail waterfront promenade at Marilyn Bell Park (City of Toronto, 2014b, p.50). Hopefully Toronto continues to light its multi-use trails moving forward.

The City of Toronto uses a number of different types of on-street and eye level signage to help cyclists and vehicles. On-street signage includes sharrows, yellow painted lines delineating contra-flow lanes, bicycle actuated signal markings, and multi-use trail road crossings (The City of Toronto, 2017f). The City also has an entire strategy devoted to wayfinding in Toronto, which includes cycling. Signage could include decision signs, confirmation signs, turn signs, bicycle route markers, advance direction and off-network waymarkers (City of Toronto, 2015). The City already has signage at eye-level including bicycle route signage. Continuing to develop and implement this eye-level signage in Toronto will be essential for wayfinding in the winter, especially when a large proportion of the current infrastructure is denoted by painted markings at the street level.

MAINTENANCE

A survey of City of Toronto cyclists in 2009 showed that only 10 percent of cyclists continue to bicycle through the winter (Thorpe, 2015). The same report indicated that 29 percent
of respondents would consider cycling through the winter, provided the network was maintained and free from snow (Ipsos Reid, 2010). A Staff Report made in 2014 was adopted by the City of Toronto’s Public Works Committee to improve the winter maintenance of bicycle routes. In the winter of 2015/2016, the City of Toronto maintained a priority bicycle network for the first time in the downtown core which included all cycle tracks and contraflow lanes, and additional bicycle lanes with volumes exceeding 2,000 cyclists per day (Thorpe, 2015). Conditions along the priority network are to be maintained to bare pavement. This winter maintenance plan is a great start, and hopefully Toronto will continue to add to this priority network each year. Ideally, one hundred percent of the network will be maintained throughout the winter in the future. Snow should always be cleared before peak traffic times, such as seven a.m. and three p.m, and at any point during the day before three centimetres have accumulated. To ease maintenance of the routes, it will be useful for Toronto to keep its bicycle network as uniform in its design as possible. Creating consistency in bicycle route width and infrastructure type will help with this. A map of Toronto winter bicycle network can be found in Appendix G.

ATTRACTIVENESS & DEGREE OF DIFFICULTY OF ROUTE

Finally, Toronto’s core is where the highest cycling rates can be found, which is also the densest part of the city and has the most vibrant street scenes. Improving bicycle infrastructure and increasing aesthetically pleasing elements like street trees, street furniture, and decorative elements could help increase cycling rates in other parts of the city as well. Some of the protected bicycle lanes, such as those on Richmond Street, are separated from the street with planters. Some planters had winter displays this year, which serves to enliven a winter streetscape. Making bicycle travel easier from the outer suburbs into the inner city will be an important aspect of the bicycle network moving forward. In the future, Toronto should aim to incorporate the ‘green wave’ into its priority
cycling routes, with the potential to use the green wave on days with poor weather, a further incentive to keep cyclists riding through the winter.

SUMMARY OF DESIGN RECOMMENDATIONS

Based on the best practices found through the case study cities explored in the previous chapter, it appears Toronto is well on its way to increasing winter cycling rates. The development of the Cycle Network Ten Year Plan, the Complete Street Guidelines, and emphasis on active transportation options in the Strategic Plan 2013-2018 are all very encouraging and show Toronto’s commitment to increasing cycling rates. Looking forward, increasing winter cycling rates in Toronto would also be amplified by the addition of more sheltered bicycle parking. Toronto already has a fairly extensive bicycle network but, per capita, it lags behind other cities in Canada. The Cycle Network Ten Year Plan proposes some major investments into this network, and with the addition of more protected bicycle lanes, Toronto could see a real increase in winter cycling mode shares. Toronto should consider lighting more of its off-street trails, and keeping them maintained through the winter. As time goes on, hopefully we will see Toronto increase maintenance of its winter bicycle network. A summary of design recommendations for Toronto are listed in Table 6.1.

Overall, Toronto has been developing and implementing a number of bicycle-friendly policies and infrastructure. If it continues moving in this direction, Toronto could soon be on the level of other great cycling cities around the world. It is important to once again note that improving design-related elements of a bicycle network is only one aspect to increasing winter cycling rates. The social and cultural aspects that support and normalize cycling like bicycle friendly policies, advocacy groups, education, and unified political support are also extremely important to increasing cycling rates in Toronto. Lastly, all of these cycling initiatives are helpful,
but may not increase cycling rates to a high degree without also implementing disincentives for driving.

**Table 6.1-Summary of Design Recommendations for Toronto**

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Winter Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bicycle Facilities (including parking, ramps on stairs, etc.)</td>
<td>Toronto should consider adding more sheltered or secured bicycle parking. Continue to add elevators to all TTC stations and have fewer restrictions with bicycles on public transit at peak times. Add ramps on staircases.</td>
</tr>
<tr>
<td>Bicycle Infrastructure</td>
<td>Bicycle lanes and paths have allocated space for snow storage, and are designed to accommodate snow clearing vehicles.</td>
</tr>
<tr>
<td>Traffic Calming &amp; Safety</td>
<td>Continue to implement traffic calming measures on roads shared with bicycles and vehicles. Increase the amount of cyclist underpasses and overpasses to reduce conflict with vehicles.</td>
</tr>
<tr>
<td>Street Connectivity &amp; Bicycle Route Density</td>
<td>Continue to add connections between the outer suburbs and the inner city. Increase the connectivity of the entire network. Ensure more of the network in connected through the winter.</td>
</tr>
<tr>
<td>Bicycle Route Separation</td>
<td>New infrastructure added to the network should be protected whenever possible.</td>
</tr>
<tr>
<td>Route Safety (including lighting and signage)</td>
<td>Increase the amount of lit off-street paths wherever possible. Continue to make wayfinding easier, and post eye-level signage especially in areas where much of the signage is painted on the ground.</td>
</tr>
<tr>
<td>Maintenance</td>
<td>Continue to increase the priority winter maintained bicycle network. Continue maintaining the path to a high quality of snow clearance (such as bare pavement). Ensure paths are cleared before peak travel times such as seven a.m. and three p.m.</td>
</tr>
<tr>
<td>Attractiveness &amp; Degree of Difficulty of Route</td>
<td>Consider adding decorative elements to the network in the winter such as winter planters and festive lighting. Create vibrant complete streets that are aesthetically pleasing. Consider implementing the green wave on priority routes to make commuting easier and encourage citizens to cycle instead of drive.</td>
</tr>
</tbody>
</table>
CHAPTER 7 – DISCUSSION AND CONCLUSION

Winter cycling is becoming an increasingly popular area of interest, with cities expanding their cycling and active transportation networks. Although bicycling has been around for almost 150 years, many cities have only recently begun to explore how to integrate bicycle facilities and infrastructure into their urban landscapes. North America in particular is just beginning to create ‘complete streets’ and active transportation networks. Luckily there are some great examples around the world, demonstrating the successful integration of cyclists with streetscapes and greenspaces. This research provides some examples of best practices being used in five winter cities around the world, including Toronto.

LIMITATIONS

The four case-study cities offered different approaches to bicycle network design and maintenance. Some were more applicable to Toronto than others. Finding accurate and current climate data was difficult for some of the cities, including Toronto. Climate normals from Statistics Canada are from the period 1981-2010, which may not reflect Toronto’s changing climate. Oulu was studied because of its prominence in the winter cycling community; however, its climate and precipitation amounts are very different from what Toronto experiences and the maintenance techniques used in Oulu would not be possible in Toronto. Regional laws and policies may change what is possible to do in one city versus another.

Limited academic research in the field of winter cycling led to many of the sources of information throughout this thesis coming from non-academic references. Therefore, the validity and reliability of the data may be called into question. For example, statistics from cycling advocacy groups may be skewed in their favour. Also, the combination of walkability metrics with
bikeability in many of the indices may have skewed some of the criteria to be overly generalized and not bicycle specific.

Selecting the scale of the site for each case study city was challenging. I decided to study the entire bicycle network for each city in an effort to generate as many best practices as possible. Since the case study cities all vary from Toronto in different ways, studying an entire network seemed like the best solution to find applicable design recommendations. However, studying the scale of an entire bicycle network in the time frame available inevitably led to generalizations and possible oversights. Certain examples of key facilities or infrastructure may have been omitted.

Finally, this study reflects only a few of the aspects of the changes required to make cycling, and especially winter cycling, accepted and normalized. The development of a bicycle network is important in increasing ridership, but equally important is the social-cultural support from advocacy groups, education, proactive bicycle policies, and political backing. Another important action toward supporting cycling is actively making driving more difficult. Focussing on the design related aspect of a bicycle network was done in this thesis for the sake of limited time, and it may result in downplaying the importance of those social-cultural aspects.

FUTURE RESEARCH

Future academic research is needed to better understand what contributes to increased winter cycling rates. Greater data on cycling statistics is needed. Data should be gathered at multiple scales, such as municipality, region, and country. Canada collects cycling data in the Census, but only keeps track of cycling as a form of commuting to work. This omits all information about recreational cycling, and cycling rates of youth going to school. Often cities who do collect data only count ridership during the peak cycling months. Installing bicycle counters along key routes and gathering data throughout the winter season will be essential to creating accurate winter
statistics. User preference studies will also help to understand what contributes to cyclists continuing to cycle year-round, and what prevents fair-weather cyclists from cycling through the winter. Further studies on specific winter bicycle facilities and infrastructure is needed. Women tend to cycle less in the winter; further research could find out why this is.

Additional research into combining cycling with other forms of sustainable modes of transportation, including public transportation and other forms of active transportation, could be done. Cycling is an excellent mode of transportation for short distance trips, but it may prove challenging to convince those with longer commutes to cycle the full distance. Making sustainable intermodal choices easy and accessible is an area that warrants further research.

With climate change affecting many cities, looking at extremes in heat is also an area for possible future research. Cyclists experience the outdoor environment fully, as they are mostly unprotected from the elements. Heat provides its own unique challenges to cycling, and alternative solutions along a bicycle network may be necessary. Shelter and refuge are elements that need to be integrated into bicycle networks in both hot and cold environments and aspects of research for each extreme may be applicable to the other.

CONCLUSION

In 2014, 54 percent of the world’s population lived in urban areas (United Nations, 2014). By 2050, that number is expected to increase to 66 percent, meaning another 2.5 billion people will be added to global urban populations (United Nations, 2014). This will stress already maximized capacities on roadways, resulting in greater levels of congestion. The time to start planning for more sustainable transportation alternatives is now. Improving bicycle networks and creating disincentives for driving will help improve road congestion, reduce greenhouse gas emissions, improve the health of our populations and improve the economy. Bicycling offers a
sustainable means by which the problems resulting from urban densification can be mitigated. Cities examined through this research demonstrate that with more awareness and accurate data, Toronto has the potential to become bicycle-friendly year-round making the city more vibrant and sustainable.

Ultimately, when a citizen wakes up on a cold, dark, snowy winter morning they will make a choice about what mode of transportation to take. It is up to cities to make sustainable transportation choices the most appealing option. For winter cycling, this means prioritizing the maintenance of bicycle networks, and improving safety and ease of use. The best practices covered in this research are a jumping off point for improving the winter bikeability of a city, and the results can help provide direction for future planning of bicycle networks in cities with winter climates.
REFERENCES


BIXI. (2017b). We are BIXI Montréal. Retrieved from https://montreal.bixi.com/en/who-we-are


City of Toronto. (2017d). *Cycling snow routes*. Retrieved from http://www1.toronto.ca/wps/portal/contentonly?vgnextoid=de68ab4335211510VgnVCM10000071d60f89RCRD&vgnextchannel=1a63970aa08c1410VgnVCM10000071d60f89RCRD


Yr. (2017b). *Weather statistics for Oulu (Finland)*. Retrieved from https://www.yr.no/place/Finland/Oulu/Oulu/statistics.html

122
APPENDIX A – MONTRÉAL’S FOUR SEASON BICYCLE NETWORK MAP

SOURCE: VILLE DE MONTRÉAL (N.D.D)
APPENDIX B – MINNEAPOLIS’S BIKEWAY MASTER PLAN

SOURCE: CITY OF MINNEAPOLIS (2016b, p. 160)
APPENDIX C – GREATER COPENHAGEN’S BICYCLE NETWORK MAP

SOURCE: KØBENHAVNS KOMMUNE (2013)
APPENDIX F – TORONTO’S BICYCLE NETWORK MAP

SOURCE: CITY OF TORONTO (2017c)
APPENDIX G – TORONTO’S WINTER BICYCLE NETWORK MAP

SOURCE: CITY OF TORONTO (2017d)