METROLINX

THE ECONOMIC VALUE OF REGIONAL STRATEGIES TO IMPROVE TRANSPORTATION OUTCOMES:

CYCLING INTERVENTIONS
ECONOMIC AND FINANCIAL PERSPECTIVE

Background Paper to the
Draft 2041 Regional Transportation Plan

Prepared for Metrolinx
by CPCS and David Kriger Consultants Inc.
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METROLINX
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PREPARED BY

CPCS

IN ASSOCIATION WITH

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TRANSPORTATION POLICY AND RESEARCH

FINAL REPORT JANUARY 2017

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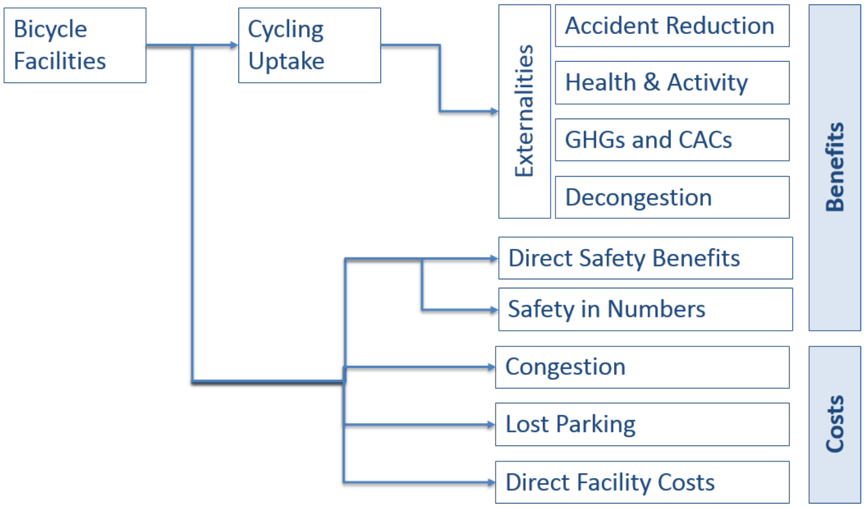
Acronyms

CAC	Criteria air contaminant
GHG	Greenhouse gas
GTHA	Greater Toronto and Hamilton Area
KM/km	Kilometres
MAIS	Maximum Abbreviated Injury Scale
MET	Metabolic equivalent
min	Minutes
MTO	Ministry of Transportation of Ontario
NHTSA	National Highway Traffic Safety Administration
NZ	New Zealand
O&M	Operations and maintenance
OECD	Organization for Economic Co-operation and Development
PKT	Passenger kilometres travelled (Sum of all person trips multiplied by their distance)
PD	Planning district
QALY	Quality-adjusted life year
ROW	Right-of-way
sqkm	Square kilometres
TTC	Toronto Transit Commission
TTS	Transportation Tomorrow Survey
USD	U.S. dollars
VKT	Vehicle kilometres travelled (Sum of all vehicle trips multiplied by their distance)

1.0 EXECUTIVE SUMMARY

This study examines the potential for a "high shift" in cycling in the GTHA, through the lens of a cost-benefit framework. Specifically, it examines the potential benefits and costs of a significant increase in bike lanes or cycle tracks, quantifying the external benefits, the direct benefits to cyclists, and costs such as increased traffic congestion, lost parking spaces, and costs of constructing, operating and maintaining the bike facilities (Figure ES 1).

Figure ES 1: Benefit and Cost Diagram for Factors used in Study



Benefit Cost Scenarios

We evaluate a generic "high shift" scenario assuming a 50% increase in cycling above current levels, and three scenarios involving varying levels of cycling investments. We also evaluate a scenario that assumes a 10% increase in cycling mode share to commuter rail stations.

Generic High Shift Scenario

Figure ES 2 shows the annual benefits for an assumed 50% increase in cycling from current levels. The net benefits add up to approximately $41 million per annum across the GTHA, largely in the form of health benefits. The 50% increase is taken to be approximately in line with the lower end of the shifts from Scenarios 1 and 2 below. Figure ES2 is purely indicative of the benefits. In reality, these benefits would not be expected to be attainable absent specific interventions (which would generally have offsetting cost implications); these are detailed in subsequent scenarios.

Figure ES 2: Net Benefits for a 50% Increase in Cycling Levels

	Central part of Toronto	**Rest of Toronto**	**GTHA outside Toronto**
% Increase in Biking	50%	50%	50%
Increase in Bike Trips	14,319,271	2,165,893	5,958,607
Increase in Bike PKT	44,557,564	8,179,873	16,839,614
External Benefits			
External Accident Benefits	$ 1,144,879	$ (144,651)	$ (168,938)

	Central part of Toronto	**Rest of Toronto**	**GTHA outside Toronto**
External Health Benefits	$ 17,840,934	$ 4,202,132	$ 9,852,303
Decongestion Benefits	$ 4,190,049	$ 1,037,546	$ 1,563,291
CAC Emission Benefits	$ 105,958	$ 27,907	$ 64,144
GHG Emission Benefits	$ 570,744	$ 146,520	$ 358,727
Total Benefits			
Total	$ 23,852,564	$ 5,269,453	$ 11,669,527

Source: CPCS Analysis

Cycling Investments Scenarios

Investment Scenario 1: 600 KM Increase in Bike Lanes

Scenario 1 assumes a 600-kilometre investment in bike lanes region-wide. Figure ES3 shows the annual benefits and costs of Scenario 1. Under Scenario 1, net benefits are positive in all geographic areas and total $40 m. per annum across the GTHA. Most of the benefit is in the form of health benefits.

Figure ES 3: Scenario 1: 600 KM Investment in Bike Lanes

	Central part of Toronto	**Rest of Toronto**	**GTHA outside Toronto**
KM Installed	200	200	200
Increase in Bike Trips	25,363,825	5,675,160	5,716,338
Increase in Bike PKT	78,929,169	19,536,981	17,324,669
% Increase in Biking (Trips and PKT)	89%	119%	51%
Internal Benefits			
Direct Benefits to Users	$ 10,542,660	$ 3,625,937	$ 2,254,110
External Benefits			
External Accident Benefits	$ 2,363,968	$ (189,810)	$ (79,459)
External Health Benefits	$ 31,603,392	$ 10,036,460	$ 10,136,093
Decongestion Benefits	$ 7,422,243	$ 2,478,096	$ 1,608,320
CAC Emission Benefits	$ 187,693	$ 66,653	$ 65,991
GHG Emission Benefits	$ 1,011,014	$ 349,952	$ 369,060
Costs			
Congestion due to Loss of Lane	$ 15,062,173	$ 6,718,850	$ 3,797,266
Loss of Parking Space	$ 12,558,308	$ 1,346,843	$ -
Construction and Maintenance	$ 1,591,406	$ 1,591,406	$ 1,591,406
Total Benefits and Costs			
Total Benefits	$ 53,130,970	$ 16,367,289	$ 14,354,115
Total Costs	$ 29,211,887	$ 9,657,099	$ 5,388,672
Total Net Benefits	$ 23,919,082	$ 6,710,190	$ 8,965,443
Benefit/Cost Ratio	1.8	1.7	2.7

Source: CPCS Analysis

Investment Scenario 2: 600 KM Increase in Cycle Tracks

Figure ES4 shows the annual benefits and costs of Scenario 2. This scenario is similar to Scenario 1 except reflecting investment in cycle tracks rather than bike lanes.

Annual net benefits in this scenario equal $66 million across the GTHA. Of note, combined scenarios with bike lanes and cycle tracks can be constructed by weighting Scenarios 1 and 2 as desired. However, the two scenarios are not considered additive because the total coverage of the bike facilities would exceed the maximum network density modelled in this study in the central part of Toronto.

Figure ES 4: Scenario 2: 600 KM Investment in Cycle Tracks

	Central part of Toronto	**Rest of Toronto**	**GTHA outside Toronto**
KM Installed	200	200	200
Increase in Bike Trips	40,328,482	9,023,504	9,088,977
Increase in Bike PKT	125,497,379	31,063,800	27,546,224
% Increase in Biking (Trips and PKT)	141%	190%	82%
Internal Benefits			
Direct Benefits to Users	$ 21,894,646	$ 7,862,829	$ 4,385,251
External Benefits			
External Accident Benefits	$ 4,135,257	$ 88,283	$ 201,950
External Health Benefits	$ 50,249,393	$ 15,957,971	$ 16,116,388
Decongestion Benefits	$ 11,801,367	$ 3,940,173	$ 2,557,229
CAC Emission Benefits	$ 298,432	$ 105,979	$ 104,926
GHG Emission Benefits	$ 1,607,512	$ 556,423	$ 586,806
Costs			
Congestion due to Loss of Lane	$ 17,720,203	$ 10,028,134	$ 5,667,561
Loss of Parking Space	$ 12,558,308	$ 1,346,843	$ -
Construction and Maintenance	$ 9,693,561	$ 9,693,561	$ 9,693,561
Total Benefits and Costs			
Total Benefits	$ 89,986,606	$ 28,511,658	$ 23,952,550
Total Costs	$ 39,972,073	$ 21,068,538	$ 15,361,123
Total Net Benefits	$ 50,014,534	$ 7,443,120	$ 8,591,427
Benefit/Cost Ratio	2.3	1.4	1.6

Source: CPCS Analysis

Investment Scenario 3: 200 KM Increase in Multiuse Paths

Scenario 3 assumes an investment in 200 kilometres of multiuse paths in the GTHA outside Toronto. The annual net benefits are $1.1 million and the benefit-cost ratio is 1.2. Although the net benefits of this alternative are smaller than for a similar implementation of bike lanes or cycle tracks, multiuse paths may be a superior alternative in certain settings, such as along busy traffic thoroughfares.

Figure ES 5: Scenario 3: 200 KM Investment in Multiuse Paths

	GTHA outside Toronto
KM Installed	200
Increase in Bike Trips	2,285,392
Increase in Bike PKT	6,926,404
% Increase in Biking (Trips and PKT)	21%
Internal Benefits	
Direct Benefits to Users	$ 696,247
External Benefits	
External Accident Benefits	$ 7,977
External Health Benefits	$ 4,052,411
Decongestion Benefits	$ 643,007
CAC Emission Benefits	$ 26,383
GHG Emission Benefits	$ 147,550
Costs	
Congestion due to Loss of Lane	$ -
Loss of Parking Space	$ -
Construction and Maintenance	$ 4,500,000
Total Benefits and Costs	
Total Benefits	$ 5,573,576
Total Costs	$ 4,500,000
Total Net Benefits	$ 1,073,576
Benefit/Cost Ratio	1.2

Source: CPCS Analysis

10% Mode Shift to Cycling for GO Station Access

This scenario assumes that 10% of GO Station access trips switch to bicycle, which is a high shift compared to the current 1% of access trips that are by bicycle. The annual benefits of a 10% mode shift are shown in Figure ES6. There are significant external benefits, especially in terms of health. The major benefit is in the form of parking cost savings for GO Transit. Currently, these parking spots, many of which are structured, are offered free of charge to GO commuters.

This analysis does not account for the costs nor internal benefits of interventions. These benefits and costs are highly dependent on the specific intervention applied (e.g. bike lanes, enhanced theft deterrence, etc.). However, what the analysis does suggest is that an annual investment of around $20 million would be economically beneficial if it could result in a 10% shift of access trips to cycling.

The exact net benefit would depend on the interventions required. For example, based on the assumptions used in this study, a bike lane requiring the loss of a lane of traffic could have significant costs, at $75,000 per annum per lane (i.e. around 13 km would cost $1 million in increased driver delay). These costs should be considered in evaluating the effectiveness of any specific intervention that would remove vehicle travel lanes.

Figure ES 6: 10% Mode Shift to Cycling for GO Station Access

	GTHA outside Toronto
Mode Shift to Cycling (Percentage Points)	10%
Increase in Bike Trips	2,437,875
Increase in Bike PKT	6,877,565
External Benefits	
External Accident Benefits	$ (128,835)
External Health Benefits	$ 4,324,619
Decongestion Benefits	$ 1,237,962
CAC Emission Benefits	$ 30,398
GHG Emission Benefits	$ 165,807
Agency Benefits	
Parking Cost Savings	$ 14,498,941
Total Benefits	$ 20,128,892

Source: CPCS Analysis

Conclusion

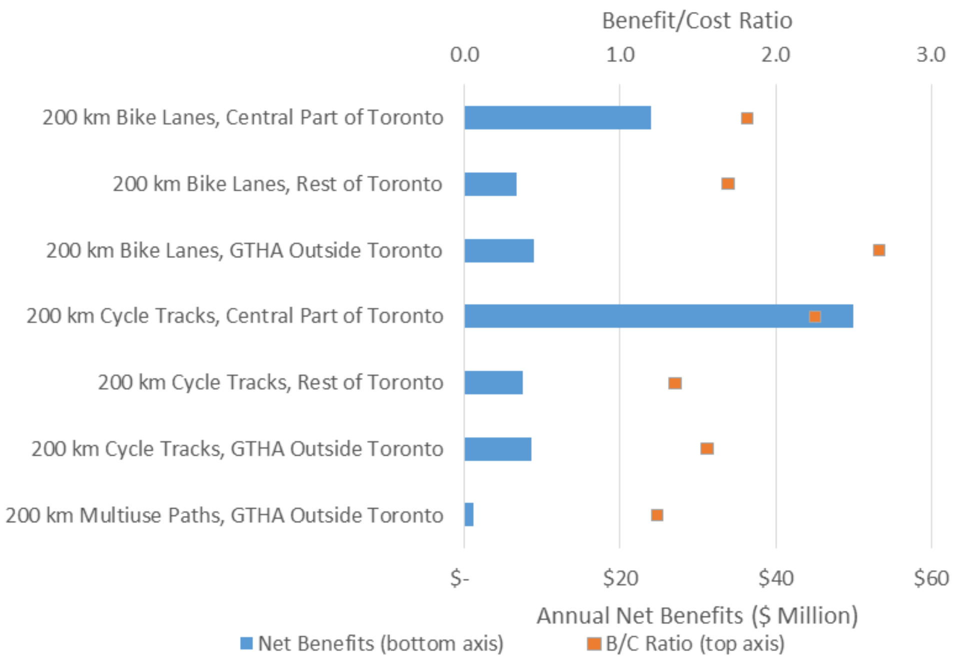
This study concludes that a large-scale investment in bicycle facilities in the Greater Toronto and Hamilton Area is, in general, economically justified. The benefits attainable from a "high shift" to cycling can be substantial, although it is unlikely that Toronto will ever reach extremely high levels of cycling mode share such as those in some European cities like Amsterdam or Copenhagen.

In general, the economic rationale is strongest for bike lanes and cycle tracks in the central part of Toronto. For these facilities the benefit/cost ratios are 1.8 and 2.3 (respectively), while net benefits range from $24 million to $50 million annually (for a 200-centreline-km implementation). This suggests a strong economic rationale for the implementation of a dense network of cycling facilities in the central part of Toronto.

For the rest of Toronto and the rest of the GTHA, benefit/cost ratios also exceed 1, suggesting bike facilities on average are economically justified. Compared to the central part of Toronto, the net benefits are smaller, mostly due to lower anticipated uptake. The benefit-cost outcome is also more sensitive to changes in input values. This suggests that bicycle facilities should be implemented strategically, starting with high-demand and/or low-cost settings. The fact that benefit-cost ratios are above 1 suggests that bike facilities are on balance economically worthwhile, even if a dense network may be less suitable than in the central part of Toronto.

Figure ES7 shows the net benefits and benefit/cost ratios of the various scenarios, broken down by geographic area. (For example, Scenario 1 consists of 600 km of bike lanes, of which 200 km are in each of the three geographic areas – this figure breaks out each area separately). Not shown are a general increase in cycling (non-intervention specific) and GO station access, as these were evaluated for their external benefits alone.

Figure ES 7: Summary of Net Benefits and Benefit/Cost Ratios



Source: CPCS analysis

It is important to note that the findings of this report are not meant to be applicable at the corridor level. In particular, the traffic delay resulting from removal of traffic lanes may be highly dependent on the particular road. Uptake may also be highly variable even within the broad geographic areas defined in this study, as it depends on an interplay of demand and supply factors (demand for cycling, availability of other good bike routes). Any corridor study should take these factors into account in a more granular fashion than is done in this study.

Moreover, it may be the case that a certain network, tested as a whole, is economically beneficial, but that individual components of it are not. In general, policy should be to install bike infrastructure first in those places where its net benefits are greatest, and to continue until such a point is reached where the marginal costs of the next-best project exceed its marginal costs.

As new bicycle facilities are introduced, the benefits and costs of these facilities should be assessed so as to guide and inform future investment on an ongoing basis.

2.0 INTRODUCTION

Background and Purpose

CPCS and DKCI have been retained by Metrolinx to investigate the potential economic value of significant changes in cycling outcomes in the Greater Toronto and Hamilton Area (GTHA) as well as the marginal impacts that discrete interventions/strategies would have in accomplishing these outcomes. This research will provide a better understanding of the likely magnitude of the overall potential benefits related to investments in cycling infrastructure in the GTHA. It will also contribute to the development of a more robust business case methodology used to evaluate potential investments in cycling infrastructure in the future.

A significant portion of motorized trips in the region are less than 5km in length. In other cities and in parts of the GTHA, there has been a significant growth in cycling as a main mode of transportation for trips less than 10km. However, currently cycling remains a relatively small component of overall mode share and cycling infrastructure is limited. New investments in cycling infrastructure are being made across the GTHA, predominantly at the municipal level.

As of 2011, there were approximately 75 km of dedicated cycling facilities in the central part of the City of Toronto (consisting of bike lanes, but not including shared or signed lanes, or multiuse paths). In years since bike lanes have been expanded in the City of Toronto (a smaller number have also been removed), and cycle tracks have been constructed on such roads as Sherbourne Street (2012) and Richmond/Adelaide Streets (2014), among others. Bicycle facilities also continue to be expanded in much of the rest of the GTHA outside of Toronto.

Given these new investments, this study seeks to describe the potential economic value of a feasible 'high shift scenario' towards cycling in the GTHA based on international precedents in comparison to the GTHA's trajectory as suggested by local baseline/trends information.

Objectives

This study examines the potential for this "high shift" in cycling in the GTHA through the lens of a cost-benefit framework. It examines the potential benefits and costs of a significant increase in cycling in the GTHA, harnessing the available academic literature, local data, and in several cases novel approaches to measuring benefits and costs.

This study specifically examines significant increases in cycle tracks, bike lanes or multiuse paths in the GTHA. However, we acknowledge that there are a variety of potential available investments in cycling infrastructure as well as other strategies that can increase the uptake of cycling infrastructure. Other types of policy investments and strategies including bike share infrastructure and education camps (Bike to Work, etc.) can increase awareness of cycling both among cyclists and non-cyclists more generally, although these investments are not evaluated in this study. The cost portion of this study does include a provision for bike parking, signage, studies, and major barrier crossings (such as highways) to accompany an expansion in bike facilities, in line with the levels in Toronto's recent Cycling Network Plan (scaled to the size of the investment).

The research follows the approaches prescribed in Metrolinx's Business Case Development Handbook. However, it differs from a 'standard' business case in that it does not propose a specific program or infrastructure. Hence the research focuses on the Economic and Financial cases. As described in the Metrolinx Handbook, these cases consider the economic impact and the financial implications of the initiative, respectively. Other components of a 'standard' business case accordingly are not considered.

Organization of this Report

The report is organized as follows:

- Introduction
- Approach
- Methodology and Factors
- Economic Case
- Financial Case
- Sensitivity Analysis
- Conclusions

Cycling Working Group

A special Working Group was convened in order to provide guidance to the analysis, review assumptions and methods, coordinate and provide data, and review the outputs and reports.

The Working Group comprised members of several representative local and regional organizations and offices:

- Metrolinx, Planning and Policy
- Metrolinx, Smart Commute
- City of Mississauga, Active Transportation
- City of Toronto, Cycling Infrastructure and Programs
- City of Toronto, Transportation Infrastructure Management
- York Region, Active and Sustainable Transportation
- McMaster University, Geography & Earth Sciences (PhD Researcher)

Two Working Group meetings were held. The first meeting (May 12, 2016) was to introduce the project and to discuss initial methodology, and the second meeting (November 7, 2016) was to review the final methodology, scenarios, and analysis. The consultants wish to express their appreciation to Metrolinx and to the members of the Working Group for their inputs, guidance and direction over the course of the study.

3.0 APPROACH

Much of this study's analysis makes use of Metrolinx's Tier 3 Draft Guidance[1] (also referred to in this report as Metrolinx Guidance) on business case development, in many cases supplementing and advancing this with factors derived from analysis of cycling and other literature.

The analysis also makes heavy use of the 2011 Transportation Tomorrow Survey (TTS)[2] for the purpose of understanding baseline commuting behaviour in the GTHA, in particular mode shares. The TTS is a quinquennial study of commuting patterns in the GTHA (and beyond) based on a 5% sample of the population. Although this data product has its shortcomings, most notably concerns about potential bias arising from weighting trips differentially on the basis of respondent age,[3] we find it to be the best, most comprehensive source of commuting behaviour data in the GTHA.

To the extent possible, we anchor our analysis in data and literature specific to the GTHA, including using data provided by agencies in the GTHA. We supplement these sources with findings from other Canadian or developed-world studies. To the extent possible, we focus on studies that are comprehensive in nature, rather than associated with a single site or project.

Overview of Cycling Levels in the GTHA

The level of cycling in Toronto is highly variable depending on location. Figure 1 shows the variability in cycling mode share across the GTHA.

Figure 1: Cycling Mode Share by Distance Band, GTHA (All-Purpose Trips)

	0-1 KM	1-2.5 KM	2.5-5 KM	5-7.5 KM	7.5-10 KM	10-15 KM	15+ KM	Total	Tot. Trips (All Modes)
Central Part of Toronto	5.0%	6.3%	5.5%	3.3%	2.0%	0.9%	*	4.9%	1,664,635
Rest of Toronto	0.8%	0.9%	0.4%	0.2%	0.1%	0.1%	0.0%	0.5%	1,805,276
GTHA Outside Toronto	0.8%	0.8%	0.4%	0.2%	0.1%	0.1%	0.0%	0.4%	6,873,034
Peel Region	0.7%	0.6%	0.3%	0.1%	0.1%	0.1%	0.0%	0.3%	2,000,661
York Region	0.7%	0.7%	0.3%	0.2%	0.1%	0.1%	0.0%	0.4%	1,492,198
Durham Region	0.8%	0.5%	0.4%	0.2%	0.1%	0.2%	0.1%	0.4%	1,000,322
Halton Region	0.9%	1.3%	0.6%	0.2%	0.0%	0.1%	0.1%	0.7%	777,034
Hamilton	1.2%	1.4%	0.7%	0.3%	0.2%	0.2%	0.0%	0.8%	876,236

Source: CPCS analysis of TTS (2011). All trips per weekday, regardless of purpose.*insufficient data

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[1] Metrolinx (2015), Business Case Development Handbook, Tier 3 Guidance: Technical Notes and Methods. Version 0.3

[2] University of Toronto, Data Management Group: Transportation Tomorrow Survey. Accessed electronically.

[3] The concerns arise from the landline-based nature of participant recruitment, and the associated underrepresentation of millennials in particular among respondents. As a result trip data are scaled depending on the participation rate of different age groups: for example, trips by 18-32 year-olds are scaled by a factor of 1.535. This corrects for overall underrepresentation by age group; however, data quality issues may persist as a result of the undersampling, particularly at disaggregate levels. An overview of the TTS methodology is provided in: DMG (2013), "Version 1.0 Data Expansion & Validation"

As shown in the table, cycling is significantly more popular in the central part of Toronto compared to other parts of the GTHA. In addition, the attractiveness of cycling compared to competing modes is highly dependent on trip distance. Cycling achieves a mode share of over 5% for trips up to 5 kilometres in length, in the central part of Toronto. Outside of the central part of Toronto, cycling is most popular under 2.5 km but even here does not achieve 1% of mode share area-wide.

To account for this variability, this study segments trips into seven distance bands as indicated in Figure 1, and also distinguishes between broad geographic areas:

- The Central Part of Toronto. This area corresponds to "Area 1" of the City of Toronto's recent Cycling Network Plan" materials[4] - corresponding to roughly a 10-km radius around downtown Toronto. The area is characterized by medium-to-high density, generally 4-lane arterial roads and high transit mode share (largely subway or streetcar).

- Rest of Toronto and GTHA outside Toronto. The former consists of the remainder of the City of Toronto, including most of Etobicoke, Scarborough, and North York. The GTHA outside Toronto consists of the other regions comprising the GTHA ("outer suburbs" i.e. Durham, Halton, Peel and York Regions and Hamilton). These areas are characterized by generally low density with pockets of high-rises, typically wide arterial roads, and high auto mode share (also high bus mode share in the City of Toronto).

In terms of TTS planning districts, the central part of Toronto corresponds to most of PD1, PD2, PD4, and PD6, as well as parts of other planning districts. However, the analysis does not rely on planning districts but rather the much more granular traffic zones.

Figure 2 shows the boundary between the central part of Toronto and the rest of Toronto, as defined for this study. The map also shows the existing cycling mode share for trips under 10 kilometres in length, originating in the traffic zones indicated.

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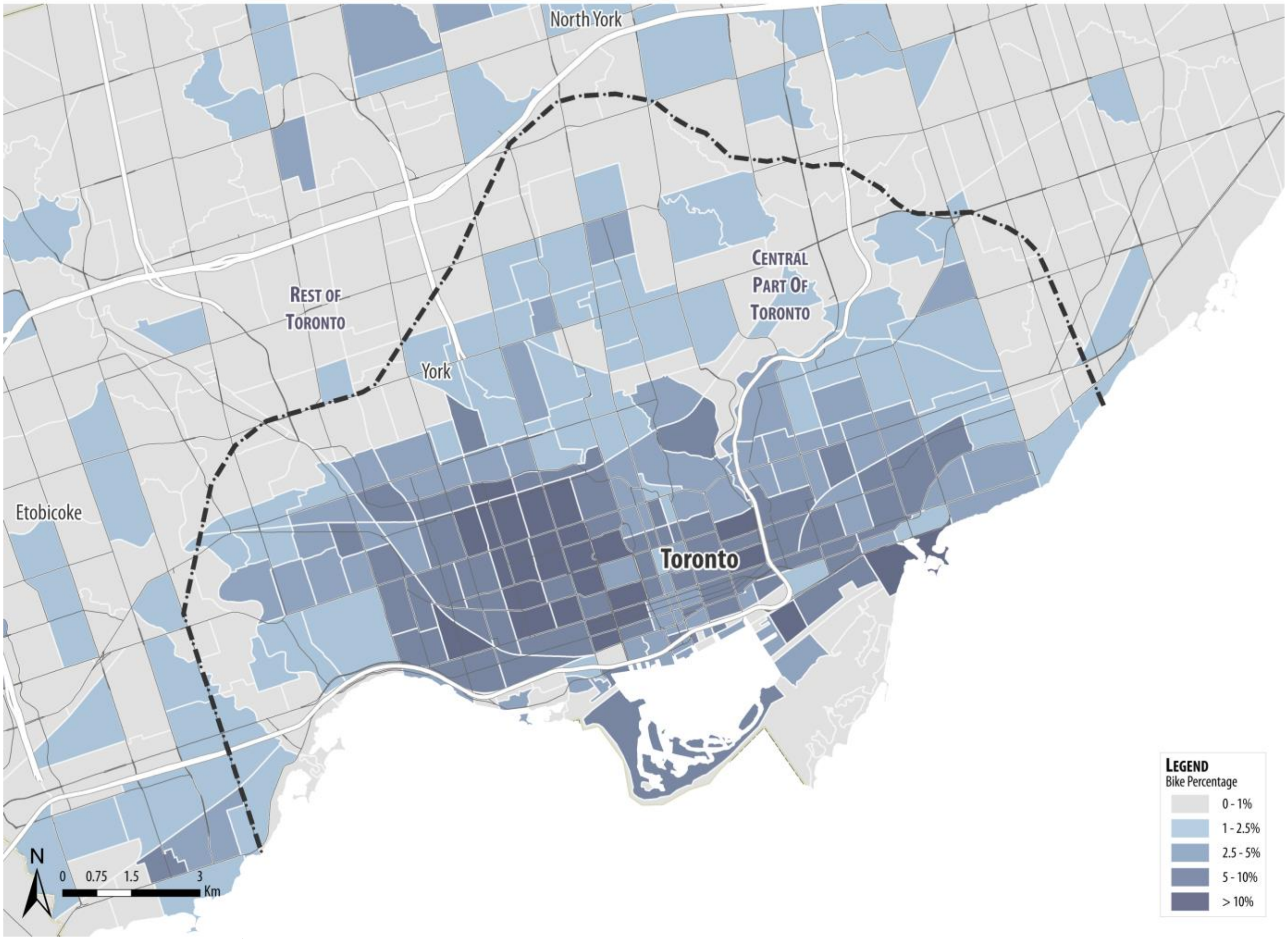
[4] City of Toronto, Toronto Cycling Network Plan: Cycling Impact Analysis. "Potential Cycling Demand" (map)

Figure 2: Cycling Mode Share for Trips under 10 Kilometres, in the Central Part of Toronto



Source: CPCS analysis of TTS data (2011).

The objective in this segmentation scheme is to apply different factors to each area. In essence, instead of individually identifying each variable that might cause cycling benefits to vary (e.g. roadway travel speeds, attractiveness of alternate modes, etc.) we assume that each area is internally consistent. This is obviously a simplification, since Downtown Toronto is not the same as Midtown, and Square One is not the same as Meadowvale in Mississauga. Given the high-level nature of this study, the intent is not to identify local factors that would lead to different cycling levels or impacts at a municipality or corridor level; but rather to capture the key area-wide differences in the region.

As was observed in Figure 1, the bike mode share is roughly similar in the Rest of Toronto and GTHA outside Toronto. Thus, similar factors are applied to these two areas unless there is a specific a priori reason to expect significantly differences (e.g. mode shift differs because the bus mode share is much higher in Toronto).

4.0 METHODOLOGY AND FACTORS

Outline of Factors

This section describes the methodology and assumptions used in the study. A simplistic diagram (Figure 3) outlines the structure of the key factors used in the study.

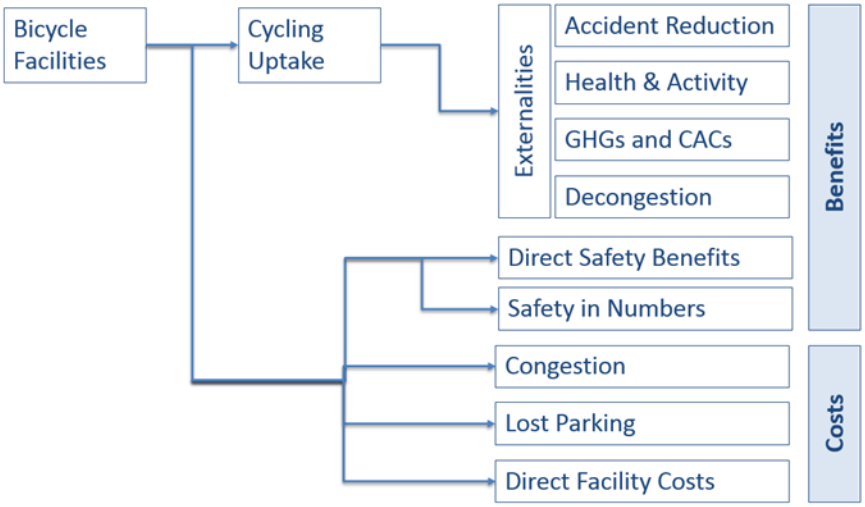
A shift of trips from other modes to cycling (cycling uptake) results in net societal benefits in the form of externalities. An externality is a positive or negative impact on other parties that is not fully “priced in” or factored into the decision-making process of the user, in this case the traveller. The externalities evaluated are accidents, health and activity, emissions (greenhouse gas and criteria air contaminant), and decongestion.

The impact of bicycle facilities such as bike lanes or cycle tracks can thus be broken down as follows:

- External benefits resulting from cycling uptake
- Direct benefits to users (existing and new), including the safety in numbers benefit
- Costs in the form of road congestion, lost parking spaces, and direct facility (construction, operations and maintenance) costs

In Figure 3, decongestion alludes to the time savings to remaining road users from some drivers switching to biking, whereas congestion refers to the extra time imposed on road users when general purpose road lanes are converted to bike-only lanes. These two impacts partly offset one another, although the mechanisms are different (for example, the former may impact travel on highways whereas the latter does not).

Figure 3: Benefit and Cost Diagram for Factors used in Study



Accidents

Literature

Metrolinx Tier 3 Guidance for accident costs is based on a paper by Zhang, Boardman et al (2004)[5] which estimates the external costs of various transportation modes. Since neither the Zhang/Boardman report nor Metrolinx Guidance assesses bicycle crashes specifically, the methodology in this report has been applied using more recent detailed bicycle crash evaluation frameworks as well as local accident data specific to the Toronto area.

In particular, the Zhang/Boardman report relied heavily on US crash cost evaluations that included detailed assessments of injury severity and source of payment, taking pains to avoid double counting. We use a more recent US study from the National Highway Traffic Safety Administration (NHTSA)[6] that uses a similar detailed methodology but additionally includes bicycle and pedestrian crashes.

Development of Method

The NHTSA report segments the economic costs of crashes into categories such as medical, emergency services, and productivity losses,[7] and for each category tabulates the percentage paid by government, insurers, crash victims, and other (e.g. third parties impacted by congestion). In addition to these economic costs, the total "comprehensive" costs also include a quality-of-life component, which takes into account the intangible value associated with loss of life or lifelong impairment (these are valued using studies that examine consumers' willingness-to-pay to avoid risk of death or injury, and built around the concept of quality-adjusted life years (QALY), a common health outcome measure).[8]

The NHTSA report breaks down cost categories by injury severity (six categories from minor injury to fatality) and examines the incidence of injuries and fatalities for motor vehicle crashes, as well as vehicle crashes with cyclists and pedestrians. From these data we infer the percentage of comprehensive costs for each mode borne by a crash participant (internal) versus other parties (external).

Overall, cyclists bear approximately 86% of comprehensive costs of crashes with motor vehicles, the vast majority of which are in the form of quality-of-life costs. Drivers bear 11% in the form of insurance costs, with the remainder accruing to government and other (society). It should be noted that this approach does not assign "blame" to parties but rather assesses the relative costs typically borne by the parties. The breakdown for all modes is shown in Figure 4:

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[5] Anming Zhang, Anthony E. Boardman et al for Transport Canada (2004), "Towards Estimating the Social and Environmental Costs of Transportation in Canada."

[6] US Department of Transportation, National Highway Traffic Safety Administration (2010), "The Economic and Societal Impact of Motor Vehicle Crashes, 2010" (Revised May 2015).

[7] The full cost categories are: medical, emergency services, market productivity, household productivity, insurance administration, workplace costs, legal costs, congestion costs, and property damage.

[8] Failing to consider quality-of-life costs may lead to the conclusion that "it is preferable to be dead over being held up in traffic," as Zhang/Boardman succinctly note. In the NHTSA report, quality-of-life costs are net of any actual economic costs incurred, i.e. overlapping economic costs are deducted to avoid double counting.

Figure 4: Breakdown of Crash Costs Borne by Various Parties, NHTSA Methodology

	Auto Driver Affected	Auto Passenger Affected	Bicyclist Affected	Pedestrian Affected
Internal to Auto Driver	93%	16%	11%	9%
Internal to Passenger, Cyclist, or Pedestrian		76%	86%	88%
Fully External (Government, Society)	7%	7%	3%	3%

Source: CPCS analysis of NHTSA (2010)

The total cost of accidents is a function of the cost per accident, the number of accidents in a particular geographic area, and the baseline amount of travel in that area (exposure).

We use the NHTSA study to evaluate the cost per fatality, adjusted for Canadian conditions.[9] This is the cost of all bicycle accidents (fatalities and others) normalized by the number of fatalities. Using this metric assumes that the ratio of fatalities to incidents of other severity levels is broadly the same in the GTHA as in the US. We used City of Toronto data on bike fatalities and major injuries to tweak this ratio for local conditions.[10] However, for minor injuries we assume the NHTSA rates hold (these notably include estimates of unreported injuries).

Fatality data are readily available from the City of Toronto[11] among other sources.[12] Since fatalities are relatively infrequent and variable year-to-year, we record 5 years of fatalities for other modes (2009-2013) and 9 years of fatalities for cycling (2007-2015), in both cases centred on 2011 (aligning with the TTS). We break out the fatalities as occurring in the central part of Toronto versus the rest of Toronto.

Exposure for the Toronto area was estimated using TTS data from 2011. It should be noted that the TTS measures utilitarian (i.e. non-recreational) trips, yet some cyclist fatalities are also associated with recreational bike travel. Not adjusting for this fact would lead to overestimating cyclist accident risk. A past study found that 63% of fatal bike collisions in Ontario occurred during recreational activities rather than commuting.[13] It is likely that this ratio is lower in the GTHA than elsewhere in Ontario. For context, in the City of Toronto 29% of residents consider themselves utilitarian cyclists with 25% self-reporting as recreational cyclists (46% are non-cyclists),[14] although this breakdown does not give an indication of frequency nor length of trips. We assume a 50-50 split of commuting versus recreational fatalities outside of the central part of Toronto, and a 75-25 split in the central part of Toronto (which has significant utilitarian travel per the TTS but also does include the Lower Don and waterfront area). This

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[9] Consistent with the Zhang/Boardman methodology, we adjust the US values for a Canadian income ratio and medical cost ratio. An income ratio of 0.85 is used. The medical cost ratio is taken as 0.56, per Zhang/Boardman.

[10] Specifically, the comprehensive cost of bicycle incidents per fatality is inflated by 1.11 relative to US conditions. This is an average of two assumption cases: a) assuming that the City of Toronto's "major injuries" correspond to levels 3-5 of the "MAIS" scale, and b) assuming that Toronto's major injuries correspond to A of the "KABCO" scale. This represents a best guess given that injury severity is not measured on a consistent scale. A similar adjustment is applied to pedestrian crash costs which are inflated by 1.20. An inflator above 1 indicates that the ratio of severe injuries to fatalities is greater in the GTHA than in the US as a whole. No inflator is used for auto accidents as the City's data do not cover the 400-series highway system. Source: City of Toronto's RSSP Roundtable Backgrounder

[11] City of Toronto, Road Safety, Injury & Fatalities leaflets (example).

[12] For bicycle fatalities, another resource is: Google Maps, Toronto Cyclist Fatalities

[13] Office of the Chief Coroner for Ontario (2012), "Cycling Death Review: A Review of All Accidental Cycling Deaths in Ontario from January 1st, 2006 to December 31st, 2010"

[14] Ipsos Reid (2010), "City of Toronto Cycling Study: Tracking Report (1999 and 2009)"

may in fact be somewhat conservative, although good data are lacking.[15] It should be noted that this assumption only affects the accident risk, not any other component of cycling costs or benefits.

Based on these assumptions cyclist fatality rates are found to be around 16.5 per billion passenger kilometres travelled (PKT) in the central part of Toronto, and 44 per bil. PKT in the rest of Toronto.

Factors

Figure 5 shows the internal and external accident costs (for fatal and non-fatal injuries) of travel by various modes, based on the NHTSA cost attribution and Toronto-specific risk data. Cyclist risk is greater than for other modes, though most of the cost is internalized by cyclists. A large share of auto accident costs is external, especially in the central part of Toronto, where the victims of auto-related incidents are highly likely to be pedestrians and cyclists rather than drivers.[16] For application, we assume that the GTHA outside of Toronto is similar to the Rest of Toronto.

Figure 5: Internal and External Accident Costs per Kilometre by Various Modes

	Central Part of Toronto			**Rest of Toronto**		
	Internal	External	Total	Internal	External	Total
Per Auto Driver PKT	$ 0.035	$ 0.115	$ 0.150	$ 0.058	$ 0.068	$ 0.126
Per Auto Passenger PKT	$ 0.044	$ 0.004	$ 0.048	$ 0.044	$ 0.004	$ 0.048
Per Cyclist PKT	$ 0.640	$ 0.026	$ 0.666	$ 1.726	$ 0.070	$ 1.796
Per Transit User PKT	$ -	$ 0.022	$ 0.022	$ -	$ 0.013	$ 0.013

Source: CPCS analysis

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[15] Initial communications with Toronto Police Services revealed that trip purpose is not tracked as a matter of course in accident reports. Future more detailed analysis would improve the understanding of commuter cyclist risk in the Toronto area.

[16] The auto driver total cost of $0.15 is identical to the value derived from Zhang/ Boardman of $0.15. The higher share of external costs compared to Zhang/Boardman is explained by declining vehicle accident rates in the years since the original studies, and also on the other higher shares of pedestrian and cyclist injuries/fatalities in the Toronto area compared to the US as a whole, likely due to greater levels of non-automobile travel.

Health and Activity

Literature

Metrolinx Tier 3 Guidance relies on a detailed study by the New Zealand Transport Agency (2008)[17] for estimating the health benefits of active transportation. This report assesses the benefits of a person changing from inactive to active health status, specifically with regard to cardiovascular disease, cancer, Type 2 diabetes and depression.[18] The authors segment the population into three categories (15% sedentary, 35% insufficiently active, and 50% active) and compute the benefits of additional physical activity by group, as shown in Figure 6.

Figure 6: Health Benefit of Cycling Relative to Driving, per Kilometre, NZ Methodology (2016 CAD)

	Sedentary	Inactive	Active	Weighted
Low	$ 2.21	$ 2.60	$ 0.66	$ 1.56
Mean	$ 2.67	$ 3.15	$ 0.80	$ 1.89
High	$ 3.13	$ 3.70	$ 0.94	$ 2.22

Source: CPCS analysis of NZ Transport Agency (2008). Presented in 2015 CAD, based on 2007 exchange rate and Canadian GDP Deflator

The NZ Transport study does not consider inhalation of pollutants, though several other studies have examined the link between air pollution and cyclists' health. According to de Hartog (2010),[19] auto drivers generally experience modestly greater exposure to pollutants than cyclists, but cyclists are at greater risk of pollutant inhalation because of increased minute ventilation attributable to physical exertion (around 2.1 – 2.3 times higher for cyclists vs. drivers). De Hartog finds that the health benefits of shifting from driving to cycling outweigh the pollution risks, by a factor exceeding 10 (plus-8 months versus minus-21 days, on a life-years basis).

Development of Method

We use the weighted "mean" health benefits from the NZ Transport study, scaling the benefits down based on the pollution risk findings of de Hartog. By using the NZ Transport values, we assume (consistent with Metrolinx Guidance) that the baseline health profile of the NZ population is generally applicable to the Toronto context, since there is an absence of directly comparable data that would allow for adjustments. We assume drivers and passengers switching to active transportation are representative of the general population, and transit users and pedestrians are representative of the 50% of the population that is "active."

The NZ Transport study explicitly differentiates between cyclists and pedestrians, finding that the latter gain twice the benefit on a per-kilometre basis. Although the metabolic equivalent (MET) intensity of cycling is double that of walking, cycling is roughly 4 times as fast as walking.

Factors

Metrolinx Guidance is to assume half the health benefits are internal and half external. These benefits (for various modes relative to driving) are presented in Figure 7.

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[17] New Zealand Transport Agency (2008), "Valuing the health benefits of active transportation modes." *NZ Transport Agency Research Report 359.*

[18] These are the conditions for which the authors were able to identify robust evidence of reduced risk resulting from increased physical activity; the authors note that there is evidence of physical activity reducing risks of other conditions, though more research is needed to identify robust relationships

[19] Jeroen Johan de Hartog et al (2010), "Do the Health benefits of Cycling Outweigh the Risks?" *Environmental Health Perspectives: 118(8): 1109-1116*

Figure 7: Health Benefits of Various Modes Relative to Driving, per Kilometre

	Internal	External	Total
Auto Driver	$ -	$ -	$ -
Auto Passenger	$ -	$ -	$ -
Transit User	$ 0.55	$ 0.55	$ 1.11
Cyclist	$ 0.86	$ 0.86	$ 1.73
Pedestrian	$ 1.92	$ 1.92	$ 3.84

Source: CPCS analysis of NZ Transport (2008), adjusted for de Hartog (2010)

Environmental (Greenhouse Gases and Criteria Air Contaminants)

Literature

Metrolinx Tier 3 Guidance suggests monetizing greenhouse gas (GHG) emissions reductions at $155/tonne, a benefit of $0.035 per vehicle-kilometre travelled (VKT). This value for GHG emissions is fairly high as it reflects the skewed nature of the probability distribution function for damages from global warming (i.e. the "tail risk" of extreme negative outcomes). Even with this consideration the per-km emissions reduction benefits are relatively low compared to other benefit categories such as health and safety.

Criteria air contaminants (CACs) such as particulate matter are associated with local rather than global impacts. For CACs Metrolinx Guidance is based on a Transport Canada study (2007)[20] that evaluates pollution costs at a provincial level and allocates these by transportation mode.

Method and Factors

We apply the $0.035 value for automobiles, and use a GTHA-specific study[21] on emissions and VKT by buses versus automobiles to generate an estimate of $0.083 per VKT for buses (buses represent roughly 0.3% of VKT but 0.8% of emissions). This value is applied to trips switching from bus to cycling (after conversion from VKT to PKT). No emissions impacts are deemed to be associated with pedestrian, subway, or streetcar travel.[22]

Based on the Transport Canada study, the Ontario-specific CAC impacts are estimated as $0.006 per PKT for automobiles, and $0.004 per PKT for buses.

For both GHG emissions and CACs, all benefits are assumed to be external in nature (despite the fact that auto drivers are exposed to tailpipe emissions as well, as noted earlier). Figure 8 shows the environmental benefits of various modes relative to driving, on a per-kilometre basis.[23]

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[20] Marbek Resource Consultants, prepared for Transport Canada (2007), "Evaluation of Total Cost of Air Pollution Due to Transportation in Canada."

[21] McMaster Institute for Transportation & Logistics, prepared for Environment Canada (2014), "Estimating Vehicular Emissions for the Toronto and Hamilton Census Metropolitan Area."

[22] McMaster Institute for Transportation & Logistics, prepared for Environment Canada (2014), "Estimating Vehicular Emissions for the Toronto and Hamilton Census Metropolitan Area."

[23] In the table, the transit user row is a weighted average of all transit modes (bus, streetcar and subway) based on estimated share of PKT for the GTHA. Bus VKT has been converted to PKT by using an assumed all-day average occupancy of 7.

Figure 8: Health Benefits of Various Modes Relative to Driving, per PKT

	GHG External	CAC External
Auto Driver	$ -	$ -
Auto Passenger	$ 0.038	$ 0.007
Transit User	$ 0.031	$ 0.004
Cyclist	$ 0.038	$ 0.007
Pedestrian	$ 0.038	$ 0.007

Source: CPCS analysis

Decongestion

Literature

The decongestion benefit refers to the value of time savings generated when auto drivers shift to other modes, freeing up road space for remaining users. Metrolinx Tier 3 Guidance indicates suggested values for the decongestion benefit for each of the six regions comprising the GTHA (ranging from $0.30 per VKT for Toronto to $0.11 per VKT for Hamilton). The Toronto estimate is derived by multiplying the value of time by a UK factor of 1.1 minutes congestion reduction per VKT. Estimates for other regions are a function of the relative level of congestion in the region, as per an HDR report[24] estimating the cost of congestion in the GTHA.

Method and Factors

We apply the decongestion benefits in the guidance to auto driver trips switching to cycling.

Figure 9: Decongestion Benefits of Switching from Driving, per PKT

	Central part of Toronto	Rest of Toronto	GTHA outside Toronto
Auto Driver to Cycling	$0.30	$0.30	$0.17

Source: CPCS analysis

It may be the case that mode shifts from driving to cycling may not reduce congestion as much as shifts to other modes, since the presence of cyclists may impose an offsetting reduction on road capacity (including where there are no bike lanes, due to the frictional effects of cyclists competing with motor vehicles for the same road space). However, this is site-specific and no generalizable studies or guidance were found on this topic.[25] Additionally, as is the case with any investment in capacity (whether it be in bike infrastructure, transit or otherwise), some of the "freed up" road space will likely be filled by new drivers, notably ones time-shifting from less convenient times. Thus, the full decongestion benefit is unlikely to materialize to existing drivers, although in exchange some benefit is experienced by the new drivers who are able to travel at more convenient times. The full interplay of these

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[24] HDR for Metrolinx (2008), "Costs of Road Congestion in the Greater Toronto and Hamilton Area: Impact and Cost Benefit Analysis of the Metrolinx Draft Regional Transportation Plan"

[25] This study does assume that the implementation of bike lanes or cycle tracks reduces road capacity in some cases (as described in the Congestion Costs section). However, no further road reduction is assumed due to additional frictional effects.

factors requires further detailed investigation, but is a general issue affecting all such studies which assume decongestion benefits.

Uptake from Bicycle Facilities

Literature

Several academic studies have sought to quantify the impact of bicycle infrastructure on cycling levels. Two notable cross-sectional studies, by Buehler and Pucher (2011)[26] and Dill and Carr (2003)[27] used data from a large number of US cities to estimate the marginal impact of bicycle infrastructure on cycling levels, controlling for other drivers of cycling demand. Buehler & Pucher found that every 10% increase in the amount of bike lanes is associated with a 3.1% greater (absolute) number of bike commuters. Using a slightly different methodology, Dill & Carr discovered that every additional mile of bike lanes per square mile land area is associated with a 1 – percentage point increase in city-wide bike mode share.

A recent study by Monsere et al (2014)[28] used a before-after approach for 8 recently installed cycle tracks in 5 large US cities (Austin, San Francisco, Chicago, Portland and Washington, DC). This study found that ridership on the routes increased by on average 75% compared to previous conditions (in some cases a bike lane, in others no bike infrastructure), though with variation among locations.

Development of Method

Applying the studies on a comparable basis requires a variety of adjustments, because the studies do not all use the same methodology or variables. For the Buehler & Pucher study we estimate the approximate existing kilometrage of bike lanes in the central area of Toronto and the rest of Toronto as of 2011 and use the existing bike shares and all-modes trip data from the TTS. In the case of Dill & Carr, the only conversion factor required is from imperial to metric.

Applying the Monsere study is more involved. This study estimates a point increase in ridership, where some of the uptake is simply cyclists diverting from other routes (rather than new cyclists). The Monsere study included a route intercept survey, the results of which can be applied to generate approximate estimates of trips by new users switching from other modes, trips by existing cyclists switching from other routes, trips by existing cyclists continuing to use the same facility, and new trips by existing cyclists (e.g. cycling four days a week instead of two). The distinction is not explicitly quantified in the study, but the information can be approximately backed out from a question on what percentage of users are biking “more often.” Using the numbers provided in the report, we estimate that close to half of the uptake (in terms of trips) is attributable to route shift, while the other half is due to mode shift (a negligible percentage is new trips that previously would not have been made by any mode). Thus, we estimate that a cycle track will add half of 75%, or 37.5%, of the pre-intervention ridership in new bicycle trips.

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[26] Ralph Buehler and John Pucher (2011), “Cycling to work in 90 large American cities: new evidence on the role of bike paths and lanes,” *Transportation (2012) 39:409-432.*

[27] Jennifer Dill and Theresa Carr (2003), “Bicycle commuting and Facilities in Major US Cities: If You Build Them, Commuters Will Use Them – Another Look,” *TRB 2003.*

[28] Chris Monsere et al for the National Institute for Transportation and Communities (NITC) (2014), “Lessons from the Green Lanes: Evaluating Protected Bike Lanes in the US,” *NITC-RR-583.*

The corridors in the Monsere study were on average approximately 1.1 kilometres in length. Assuming that the width of a corridor's catchment area is 1 km,[29] we conclude that a 1 km cycle track per sqkm land area contributes approximately a 35% increase in cycling. Since this 35% increase applies not just to the square kilometre subject to the improvement but also neighbouring areas further upstream or downstream, we multiply the 35% increase by the average length of a bike trip.

The three studies are calibrated to different baseline conditions. In order to apply all three study methods on a comparable basis, we first estimate the number of new bicycle trips generated per 1-kilometre of cycling facilities for a baseline mode share of 3% (rough average of the Monsere study cities), under all three sets of assumptions. Under these conditions we find that cycle tracks generate approximately 1.59 trips for every 1 trip generated by bike lanes, all else equal.

We apply the study findings[30] to generate estimates of new trips per kilometre of bike lanes, and use the 1.59 multiplier to translate this to cycle tracks. These calculations are performed for the central part of Toronto and for the rest of Toronto, for which land areas (in terms of sqkm) are well defined. Since the effective land area of the GTHA outside Toronto is not as straightforward to define, we assume the Rest of Toronto factors apply equally to other parts of the GTHA – these areas have similar baseline cycling levels and urban form (a few dense areas surrounded by general low density). Effectively the assumption is that the bike facilities will be installed in inhabited or built-up areas, rather than along uninhabited corridors.

Factors

The cycling uptake factors per 1-km bike facility investment are shown in Figure 10. These represent the average anticipated increase in weekday cycling trips, over the relevant area.

Figure 10: Increase in Weekday Cycling Trips for each 1-Kilometre Cycling Facility Investment

	Central part of Toronto	**Rest of Toronto**	**GTHA outside Toronto**
New Trips per 1 km Bike Lane	361	65	65
New Trips per 1 km Cycle Track	575	104	104

Source: CPCS analysis

To check whether these numbers are reasonable for the Toronto context, we examine existing bike volumes in the city, and then test an extreme case where the uptake is applied to an Amsterdam-style high shift scenario beyond even what is considered in this report. Figure 11 shows example 24-hour volumes taken for various parts of the GTHA.

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[29] A 1 km-wide catchment area (0.5-km buffer) essentially means that for a 4-km trip, a cyclist would not be expected to deviate more than 0.5 km laterally to complete the trip, corresponding to 25% (0.5 + 0.5)/(4). Indeed, the Monsere study finds that 20-30% is roughly the maximum deviation from the shortest route that cyclists will bear in using the cycle tracks. 500 m also corresponds to the buffer assumed by the City of Toronto in its recent Bike Network Plan

[30] We use the Buehler & Pucher study for the central part of Toronto, but not Dill & Carr as the latter largely predates the trend of increased cycling in large North American cities (the maximum bike mode share of all cities in the dataset is approximately half the level of cycling in central Toronto). In the case of the rest of Toronto, we find that both the Buehler & Pucher study produce very similar results and select the average.

Figure 11 Example 24-Hour Bike Volumes in GTHA

Corridor	Cross-Street	City	Bike Facilities	24-Hr Volume	Count Details
Richmond-Adelaide (comb.)	Spadina	Toronto	Cycle Track	6,541	9 days in June 2016
College	Spadina	Toronto	Bike Lane	4,496	5 days in Sept 2010
Sherbourne	Gerrard	Toronto	Cycle Track	2,914	8 days in June 2014
Simcoe	Adelaide	Toronto	Cycle Track	1,963	7 days in June 2015
Wellesley	Parliament	Toronto	Cycle Track	1,375	7 days in June 2015
Shaw	Harbord	Toronto	Bike Lane	1,198	4 days in Sept 2014
Dupont	Edwin	Toronto	Bike Lane	1,062	8 days in May 2012
Annette	Keele	Toronto	Bike Lane	833	4 days in August 2012
Poplar Plains (one-way)	Edmund	Toronto	Bike Lane	621	2 days in Sept 2013
Cannon	Chestnut	Hamilton	Cycle Track	432	28 days in Summer 2015
York	Park	Hamilton	Bike Lane	370	7 days in Summer 2015
Rogers	Caledonia	Toronto	Bike Lane	150	5 days in Sept 2014
Stinson	Victoria	Hamilton	Bike Lane	143	7 days in Summer 2015
Pharmacy (since removed)	St. Clair	Toronto	Bike Lane	125	2 days in June 2011
Hunter	Macnab	Hamilton	Cycle Track	104	14 days in Fall 2014
Bristol	River Grove	Mississauga	Bike Lane	61	16 days in May 2015
Camilla	King	Mississauga	Bike Lane	41	13 days in June 2015

Source: City of Toronto (Weekday), City of Hamilton (Avg Day), City of Mississauga (Avg Day)

The numbers appear to support the general magnitude of the factors shown in Figure 10. Naturally, the impact of any single facility may vary, depending on local supply and demand factors (e.g. the factors clearly underestimate bike uptake compared to a high-potential, previously poorly-served corridor like Richmond-Adelaide, but likely overestimate uptake compared to low-demand corridors).

A simple check of an extreme bookend can also be valuable in testing the general reasonableness of the factors from Figure 10. Suppose in the extreme case cycle tracks were installed in the central part of Toronto at the same density as currently exists in Amsterdam, an extreme bike-friendly city with bike mode shares in the 1-2.5 KM and 2.5-5 KM distance bands of approximately 55% and 51%, respectively.[31] Visual inspection of publically available maps suggests the density of cycle tracks in that city is on the order of 4 km/sqkm. Using the factors derived in this study, an Amsterdam-type density of cycle tracks in the central part of Toronto would generate bike mode shares in the same distance bands of 34% and 29%, or a little more than half of Amsterdam levels.[32] That these estimates remain well below Amsterdam-levels seems generally reasonable, given that Amsterdam also has other bike-supportive factors such as exceptionally flat terrain, zealous traffic calming, and a more modest metro (subway) system compared to Toronto.

It should be noted that the uptake factors apply where bike facilities are installed in reasonably direct and continuous corridors, at reasonable density. The maximum target density for this study is 2 km bike facilities per sqkm land area (i.e. bike facilities spaced at roughly 1-km intervals both north-south and east-west). This corresponds to the catchment area reflecting assumed 500-m buffers for each facility. At greater density it is likely

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[31] Rene Meijer (2012), "Traffic planning in Amsterdam: Shared Spaces, Shared Mobility" (presentation)

[32] In 2011 (the year corresponding to the TTS) there were no cycle tracks in the central part of Toronto. Given a land area of 154 sqkm, a 4x154 = 616 increase in cycle tracks would lead to 575x616 = 354,200 increase in bike trips over the baseline level of 81,000 weekday trips, representing a 535% increase. Such an increase would take the mode share in the 1-2.5 KM and 2.5-5 KM distance bands to 34% and 29%, respectively.

the marginal uptake from new bike facilities decreases, as the facilities are no longer serving "new" markets; however, this level of intensity is not modelled in this study. For reference, Figure 12 shows an example of 1-km spacing (the routes are illustrative and not meant to imply preference for any particular corridors).

Figure 12: Maximum Bike Facility Density Modelled – 1-Kilometre Spacing (Illustrative Routes)

Source: CPCS

Additionally, bike facilities are assumed installed bidirectionally in a single corridor (km refers to centre-line kilometres).

Safety in Numbers

Literature

"Safety in numbers" is a term used to describe the well-documented correlation between high cycling levels and lower unit injury or fatality rates, the implication being that high cyclist volumes are possibly causing drivers to drive more cautiously and be more attentive and aware of their surroundings. For example, a report from the OECD[33] shows that the United States (with an annual cycling rate of 47 km per capita) has a high fatality rate of 44

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[33] OECD/International Transport Forum (2013), "Cycling, Health and Safety"

per bil. PKT; while the Netherlands (864 km/capita/yr) has a fatality rate of only 10.7 per bil. PKT. In a seminal study of this phenomenon, Jacobsen (2003)[34] found that analysis of five data sets (three cross-sectional and two time-series) supported the conclusion that as the amount of kilometres of walking or cycling per capita doubles, the injury rate declines by 34%.

Less clear are the drivers of such a shift. For example, it may be that improvements in cycling infrastructure are driving both an increase in cycling and an increase in bike safety (in a similar vein, countries or cities with high bike mode share and low injury rates may be those with better bike infrastructure, bike supportive culture and policies, and so on). Thus, it is not necessarily accurate to conclude that a doubling of the cycling rate all else equal makes biking safer by 34%.

One recent study that sought to control for such unseen variables analyzed cycling activity at constant locations over three good-weather months of a year (April, June, and September), as cycling levels varied due to seasonal factors. This study by Fyhri (2016)[35] used video analysis to measure the frequency of conflicts between car drivers and cyclists, where the frequency of conflicts is seen as a surrogate for traffic safety.

Method and Factors

Although it is not perfect especially in terms of comprehensiveness, we use the Fyhri study (specifically, the average of the April-to-June and April-to-September differences in bike volumes and conflicts) to estimate that a twofold increase in cycling is responsible for a 9% improvement in bicycle safety. This is the impact of increased cycling levels on safety above and beyond any effects associated with bicycle infrastructure. This level of impact is broadly consistent with Jacobsen's finding in that it is greater than 0 but less than the full 34% (which would include the effects of infrastructure).

Direct Benefits of Bicycle Facilities

Literature

Bike facilities lead to direct benefits to existing users as well as to new users of the facilities. However, it is important to not double count any benefits, including any offsetting disbenefits. Metrolinx Guidance indicates benefits to new users should be valued according to the "rule of a half," in other words at half the value of benefits to existing users. This is because any gains in benefits are partly offset by other losses. For example, someone switching from driving to cycling might gain health benefits but lose some of the comfort of driving (among the many other variables distinguishing the modes). In general, all of these impacts are unseen, so an assumption is made that new users are evenly distributed – some of them were almost willing to switch to cycling before the intervention (thus get nearly the full benefits) while others are barely willing to switch after the intervention (and get almost no benefits from switching).

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[34] Peter Jacobsen (2003), "Safety in numbers: more walkers and bicyclists, safer walking and bicycling," *Injury Prevention 2003;9: 205-209.*

[35] Aslak Fyhri et al (2016), "Safety in numbers for cyclists – conclusions from a multidisciplinary study of seasonal change in interplay and conflicts," *Accident Analysis & Prevention (Online).*

A key direct benefit of bicycle facilities is safety. Several studies have examined the impact of bicycle infrastructure on cyclist safety, including some notable Canadian papers. One such paper by Teschke (2012)[36] examined 14 different route types (including bike lanes and cycle tracks) and interviewed 690 residents of Toronto or Vancouver who had required hospitalization due to a cycling injury. By tracing their paths and identifying the specific locations where the injuries occurred, and comparing this site to a randomly selected control site from the same trip, the authors were able to control for trip and cyclist characteristics (e.g. time of day, age, cycling frequency) and for exposure to various route types.

Another study by Lusk (2011)[37] examined six cycle tracks and comparable reference streets in Montreal to determine the relative risk of using the cycle tracks. The analysis took advantage of injury data from an emergency medical response database and automated 24-hour bicycle counts on each of the corridors.

One of the strengths of both the Teschke and Lusk studies, aside from their Canadian context, is that these studies examine the entirety of bike corridors, rather than just segments at or between intersections. Although bike facilities reduce dangerous vehicle overtaking risks, they are still subject to high safety risks at intersections – to the point where bike facilities can be ineffective or even counterproductive from a safety standpoint where intersections are poorly designed.[38]

Development of Method

The primary direct benefit (i.e. user benefit, or internal benefit) of bicycle facilities is that they improve safety for cyclists relative to no bicycle facilities (mixed traffic). Although there may be other direct benefits, such as increased comfort, these are more nebulous and difficult to quantify. Thus, we use the internal safety benefits as representative of the direct benefits of bike facilities. External benefits (such as reductions in GHG emissions associated with increased cycling levels), are as described in the previous sections.

Teschke finds that bike lanes have a relative risk of 0.69 compared to mixed traffic if parked cars are present, and 0.86 if no parked cars are present. Taking a straight average of these two figures produces a relative risk of 0.77 or -23% (bike lane vs. no bike lane). For cycle tracks Teschke finds these to be almost 9 times as safe as no bike facilities and parked cars (relative risk 0.11), an almost inconceivably high rate. However, at the time of this study there were very few cycle tracks in Vancouver or Toronto, as confirmed by the very low number of injury sites and control sites designated cycle tracks, compared to other types of facilities. Furthermore, this category was dominated by the Burrard Bridge in Vancouver, which represented a very large proportion if not the entirety of the cycle track stock at the time of the study[39] and is dissimilar from arterial roads with frequent cross-streets.

The Lusk study specifically considers cycle tracks and finds these to have a relative risk of 0.72 compared to mixed traffic. It should be noted that these facilities are all two-way cycle tracks largely along one-way roads – an arrangement common in Montreal but not in much of the GTHA (aside from Hamilton).

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[36] Kay Teschke et al (2012), "Route Infrastructure and the Risk of Injuries to Bicyclists: A Case-Crossover Study." *American Journal of Public Health, 102(12): 2336-2343.*

[37] Anne Lusk et al (2011), "Risk of injury for bicycling on cycle tracks versus in the street." *Injury Prevention, 17(2): 131-135.*

[38] Beth Thomas (undated), "The Safety of Urban Cycle Tracks: A Review of the Literature." (Presentation)

[39] John Forester (2012), "Review of: Route Infrastructure and the Risk of Injuries to Bicyclists: A Case-Crossover Study."

We use the bike lane findings from Teschke as representative of the safety benefit of bike lanes. We consider the cycle track findings of Teschke and Lusk for context but do not apply them directly because of the shortcomings described. Instead, we apply the uptake multiplier of 59% (from the Uptake section) to the safety benefits of cycle tracks relative to bike lanes. This can be considered reasonable if it is assumed that safety benefits are the predominant benefit of cycle tracks, and that the elasticity of uptake with respect to unit benefits is constant. This assumption results in a relative risk reduction of 36% (23% times 1.59) for cycle tracks compared to mixed traffic, which is somewhat better than Lusk's finding and well lower than Teschke's finding.

Factors

As described in the Accidents section, a large portion (but not all) of accident costs are considered to be internal. The internal savings only account for the internal portion of accident costs. Figure 13 shows the reduction in internal costs for the central part of Toronto. As mentioned, these values are applied to existing bicycle users, and half-benefits are applied to new cycling uptake.

Figure 13: Reduction in Internal Costs, Central Part of Toronto

	Bike Lanes	Cycle Tracks
Pct. Reduction in Safety Costs	-23%	-36%
Baseline Internal Cost per KM Bike Facility per Trip (Before Intervention)	$ 0.640	$ 0.640
Internal Cost Savings per KM Bike Facility per Trip	$ 0.147	$ 0.230

Source: CPCS analysis

Thus, every existing user gains approximately 14.7 cents for each new kilometre of bike lanes, or 23 cents for each new kilometre of cycle tracks, while new users gain the equivalent of 7.4 cents and 11.5 cents respectively. Essentially, in the central part of Toronto the value to existing users is equal to 6.4 cents per km for every 10% safety improvement. In the rest of Toronto and elsewhere in the GTHA, the value is even greater at 17.3 cents per km for every 10% safety improvement, owing to the higher baseline rate of fatalities and crashes per PKT.

Taking into account the uptake assumptions, it is implied that a 10% safety improvement is associated with 157 new trips per km for the central part of Toronto, or 28 new trips per km for the rest of Toronto and elsewhere in the GTHA.

Congestion Costs of Bicycle Facilities

Removal of lanes results in potential increased congestion, particularly in the peak periods when road space is at a premium. We estimate the economic value of a traffic lane in use as a function of the increased travel time associated with its removal. To do so we pursue two complementary methods.

First, we employ a simple experiment in which we compare the speed performance of corridors when functioning with variable numbers of lanes. Specifically, we examine six corridors in Toronto where parking restricts roads to a single (directional) lane of traffic except at rush hour, when two lanes are available for traffic. We hypothesize that at the margin, demand is similar (for example) just before and just after 6 PM, i.e. conditions are otherwise similar such that the only difference is available road capacity: after 6 PM travel speed is reduced because only half the road space is available for travel. Using this method we find that removal of a lane results in the loss of 0.7 min (0.012 hrs) per vehicle, per kilometre.[40]

Second, we apply the findings of a forthcoming paper by Burke[41] to estimate the total network travel time increase associated with removing a traffic lane for dedicated cycling facilities. The author runs a scan of the Toronto arterial road network to identify the impact of removing each individual segment on total network travel time; as well as a case study of the Bloor-Danforth corridor. In the case of the latter, the author finds that removing one lane from the full corridor across the City would result in a travel time increase of 56 hours, or roughly 3 seconds per trip in the AM peak. The author also provides maps showing that Bloor-Danforth is relatively sensitive to lane removal, compared to other corridors in the city.

We apply the first method by assuming that all vehicles on a corridor are forced to travel at the reduced speed after the removal of a lane. In reality, some would shift to more convenient routes; thus, this is considered to be more representative of cases where a large network of bike facilities is added and/or faster alternatives are not readily available. For the second method, we perform a simple weighting procedure to approximate the relative delay on an average corridor, compared to the Bloor-Danforth example given – producing an estimated travel time loss of 0.045 min per vehicle per km in the central part of Toronto, and 0.014 min per vehicle per km in the rest of Toronto.

The wide discrepancy between the two methods is as expected. The second method more closely approximates real commuting behaviour, as it takes into account that commuters are willing to not only shift routes but also shift departure times,[42] electing to leave earlier or later than ideal if congestion is chronically poor. However, there is a cost associated with shifting travel to less ideal times, one that is not captured when aggregating to the level of a peak period.[43] Since the degree to which commuters are willing to time-shift is variable, we apply the "rule of a half" to the difference between the two methods – i.e. we assume that the "shifted" drivers face a marginal disbenefit somewhere between zero (completely willing to time-shift) and the full marginal congestion cost (nearly not willing to time-shift and bear the added travel time).

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[40] We choose the PM peak period because PM demand tends to be more dispersed, such that traffic volumes on these roads are still considerable even after 6 PM. In other words, demand is more or less equal before 6 PM and after 6 PM (whereas in the AM peak period demand is likely more "peaky"). We choose roads with heavy volumes and parking restrictions between 4-6 PM and track the outbound speeds of cars along roughly 3-km stretches at 20-minute intervals using Google Maps (average of max and min). The six corridors selected are Queen West, Bloor, Dupont, Bathurst, Danforth, and Queen East. The impact ranges from 0.36 to 1.5 min per vehicle per kilometer. These findings are for two-lane roads reduced to one lane; it is possible a reduced impact would be observed for roads with wider lanes or roads with more than two lanes. Roads with multiple competing alternatives would have a lower impact than those without. Also, it is possible traffic demand is still higher in the "peak of the peak" (say at 5 PM), leading to underestimation of the full peak impacts. The full net impact of all these factors would require further investigation.

[41] Charles Burke (forthcoming), "Identifying 'sensible locations' for separated bike lanes on a congested urban road network: A Toronto case study."

[42] Occasionally users are also willing to shift modes. This is not captured in the Burke paper, but this is generally associated with a similar kind of disbenefit as switching travel times (i.e. the user loses benefit by selecting a less ideal travel alternative, but finds this to be less of a disbenefit than experiencing the full effects of congestion).

[43] For example, at the margin, if a commuter elects to shift their trip from 8 AM to 7 AM (still within the peak period), the commuter's travel time may improve but they may experience an overall disbenefit from the less convenient time.

We apply both cases using an estimate of 2,500 vehicles/peak period per corridor and a peak value of time of $24/hour.[44] We also follow Burke's assumption that a cycling facility would require the removal of one lane (although in practice different configurations may be in play). Since the findings were computed variously for the central part of Toronto and/or rest of Toronto, we extend the results to all areas of the GTHA by weighting by the relative level of congestion (from the Decongestion section).

The value of a lost lane of traffic using this method is as shown in Figure 14. In order to apply these findings for arterial roads to a network level, we apply two factors: the road width factor and the arterial percentage. The road width factor reflects the estimated percentage of arterials that would not have space to accommodate a bike facility without requiring the loss of a lane. For cycle tracks this is assumed to be 100% (i.e. always requires loss of a lane), while for bike lanes the rate is assumed to be lower in the central part of Toronto where road rights-of-way are more narrow. The arterial percentage is the estimated percentage of plausible candidate corridors that are arterial roads, as opposed to local/collector roads that could accommodate a bike lane with minimal traffic impact. This percentage is higher in more outlying areas where the road network is more curvilinear and secondary corridors are not as attractive in terms of providing direct routes for cyclists. These factors are multiplied by the arterial road per-km measure to generate a per-km network-wide cost.

Figure 14: Cost of Traffic Congestion, per km Bike Facility

	Central part of Toronto	**Rest of Toronto**	**GTHA outside Toronto**
Lost Value for Arterial Roads, per km	$ 95,721	$ 91,734	$ 51,845
Road Width Factor (Bike Lane)	85%	67%	67%
Road Width Factor (Cycle Track)	100%	100%	100%
Arterial Percentage	60%	80%	80%
Lost Value, Network-Wide (Bike Lanes), per km	$ 98,083	$ 98,790	$ 55,833
Lost Value, Network-Wide (Cycle Tracks), per km	$ 115,392	$ 147,448	$ 83,333

Source: CPCS analysis

Cost of Lost Parking Spaces

If parking is removed for cycling facilities (or other uses), there is an economic cost in the form of the value of the lost parking spaces. Many arterial roads in the central part of Toronto have paid curbside parking, ranging from $1.50 per hour to $4 per hour.[45] In these locations paid parking is generally enforced for most of the day (often 8 AM to 9 PM Monday to Saturday, and 1 to 9 PM on Sunday), with the exception of rush hour (2 hrs directional in most cases; 3 hrs bidirectional downtown). The prices charged for the use of these parking spots can provide some indication of their value in use.

Along most arterial roads in the central part of Toronto, cross-streets are generally spaced at roughly 100 metres, though there are also many cases where the spacing is higher. As an approximation, we assume a scenario with 1 street spaced at 200 m for every 3 streets spaced at 100 m (i.e. 8 cross-streets per kilometre). Taking into account space allowances for bus stops, hydrants and cross-street setbacks, and assuming 6 metres per parking space, we

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[44] Metrolinx Guidance for commuting VOT

[45] Toronto Parking Authority (Green P) website (accessed July 2016)

estimate 96 spaces per roadway directional kilometre. We also use a rudimentary assumption for level of vacancy (one-third the signed hours at 10% vacancy, two-thirds at 50% vacancy) and assume that the Green P rates are broadly representative of the market value of the parking spots (although this may be an underestimate). For the central part of Toronto, we select a weighted average of the four hourly price classes.

Using this methodology we derive a value of $54/week per space, or $2,840/year per space. This translates to $273,000 annually per linear kilometre, for roads with paid parking in the central part of Toronto. We multiply this value by the arterial percentage (from the Congestion Costs section) and the estimated percentage of arterials subject to paid parking, to generate a network-wide estimate of the economic cost of lost parking, per km.

Figure 15: Cost of Lost Parking, per km Bike Facility

	Central part of Toronto	Rest of Toronto	GTHA outside Toronto
Lost Value where Paid Parking, per km	$ 272,594	$ 219,262	$ -
Arterial Percentage	60%	80%	80%
% of Arterials subject to Paid Parking	50%	5%	0%
Lost Value, network-wide, per km	$ 81,778	$ 8,770	$ -

Source: CPCS analysis

Direct Costs of Bicycle Facilities

Unit construction costs were obtained from the City of Toronto, which has the most experience of any GTHA municipality building bicycle facilities of various kinds; these are assumed to be broadly representative of costs in the GTHA.

Figure 16: Unit Construction Costs of Bike Lanes and Cycle Tracks

Cost Category	Per-km Cost
Buffered bike lane, restriping only	$ 50,000
Buffered bike lane, as part of road reconstruction and widening (co-ordinated with transportation project)	$ 530,000
Cycle track, remove travel lane to retrofit road with buffer and separators (flexible posts, curbs and planters)	$ 220,000
Cycle track, as part of road reconstruction and widening (concrete curb separator, co-ordinated with transportation project)	$ 720,000

Source: City of Toronto – Toronto Cycling Network 10-Year Plan (2016)

Using the City of Toronto's Cycling Network 10-Year Plan[46] as a guide, we estimate an additional complement of one-time costs equivalent to $69,000 per km to cover major barrier crossings, study-engineering costs,

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[46] City of Toronto (2016), "Ten Year Cycling Network Plan," notably Appendix 8 – Scenario 3: $15 Million/Year (Staff Recommended)

intersections and renewal, and bike parking.[47] The costs are averaged over a large-scale bike network implementation.

In addition, from discussions with the City of Toronto, there are marginal operations and maintenance costs associated with cycle tracks in excess of what is required to maintain the roadways. These annual costs equal $14,000/km for winter maintenance and $24,000/km for sweeping.

Other Benefits and Costs, Not Considered

In a review of other similar studies, several categories of benefits or costs were identified that are not included in this study. These include:

- Wider Economic Benefits: It may be the case that cycle-friendly urban form is conducive to agglomeration benefits compared to auto-friendly "sprawl." However, cycling remains a relatively space-inefficient mode of transportation compared to high-capacity modes such as subways. Thus, it is unlikely that increased cycling would lead to agglomeration economies for Toronto, unlike investments in mass transit. In fact, in downtown Toronto, cycling is likely to divert more travellers from public transit than from automobiles. For more suburban parts of the GTHA, agglomeration benefits are likely to not be significant.

- Local Economic Benefits: Cyclists may visit local shops more frequently and/or spend more at these shops. On the other hand, in some cases reduced parking availability may harm local shops. In Toronto, the literature suggests that the former is more accurate, at least in the Annex neighbourhood along Bloor Street.[48] Whichever is true, such local benefits are considered to be distributional impacts rather than region-wide economic impacts, since any revenues gained or lost by businesses along the affected corridor are most likely offset by losses or gains for businesses elsewhere. While local economic benefits may be of interest to a neighbourhood debating installation of a bike lane, they are not germane in the larger (regional) economic context.

- Land Use, Tourism or Employment Benefits: It has been posited[49] that cycling investments increase regional livability, increase tourism, or improve economic performance through increased productivity (for example due to reduced illness and absenteeism). No detailed studies quantifying such impacts in a systematic fashion were identified, so these benefits are not included.

- Reduced Vehicle Operating Costs or Public Transit Agency Costs: It can be argued that when travellers switch to cycling from driving or transit, they "save" capital and operating costs relating to vehicle ownership or use, either for themselves or for public transit agencies. In this case, one has to be careful to avoid double counting. For example, cost savings from not driving may be offset by reduced benefits. Similarly, agency cost savings may be offset by foregone fare revenues. In fact, this study does include

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[47] Specifically, for a network of 512 kilometres (the city's proposal), we assume 5 major barrier crossings (e.g. highway crossings) valued at $1 million each; $18.4 million for studies and engineering, $3.1 million for upgraded signage and intersection safety improvements, and $9 million for expanded bike parking. We divide this total by 512 km for the per-km cost.

[48] Toronto Centre for Active Transportation (2009), "Bike Lanes, On-Street Parking & Business: A Study of Bloor Street in Toronto's Annex Neighbourhood."

[49] Phil Jones Associates (2016), "The Value of Cycling"

these benefits, but they are "baked in" to the net user benefits for new cyclists (i.e. the direct user benefit for new users is a catch-all covering the effects of time savings/losses, health/safety impacts, cost savings, comfort, etc.). In the case of switching from transit to cycling, there would be an additional net benefit if the marginal agency cost of the trip was greater than the marginal revenue. Although public transit in general is subsidized, it is not clear that this is true of the short trips for which a switch to cycling is most likely. There are many relevant factors (including type of transit vehicle, whether the line is overcapacity, whether the portion of the trip is a free transfer, etc.) and much more detailed analysis would be required. There is also debate over what percentage of vehicle operating costs are truly internalized by drivers (e.g. whether a driver accounts for depreciation and injury risk, or just fuel and parking, or just parking), in deciding whether to drive or use another mode. Since this study deals with long-run decision-making, we assume these costs are fully internalized, and that travellers by all modes behave rationally and correctly perceive – at least in a general sense – the various costs and benefits of their chosen mode.

- Land Value and Public Infrastructure Costs: If increased cycling reduces auto use, there may be a reduction in the amount of land needed for roads and/or parking, which may free up that land for a more beneficial use. However, in central Toronto bike infrastructure is not the most space-efficient travel mode (as discussed under Wider Economic Benefits) and relatively little land is devoted to parking compared to comparable North American cities. Thus, even a large increase in cycling is unlikely to have a transformative impact on developable land. In the remainder of the GTHA, more land is dedicated to roads and parking, but land values are lower and cycling uptake is generally small compared to displaced motor vehicles, even for the "high shift" considered in this study. Additionally, the double-counting argument is germane for parking as well, as the unlocked land value to a parking structure owner must be weighed against lost parking revenues. An exception is made in this study for parking at commuter rail stations. Such parking is generally heavily subsidized and occupies potentially higher value land, at least in the long run. At the margin, each vehicle diverted from a GO parking lot saves GO Transit money without representing much of an offsetting cost savings for the user. Thus, this is considered as an additional benefit.

- Network Effects: Bike network connectivity (i.e. having few "gaps") and density may have outsized impacts on cycling. One recent study found that beyond a network's size, its connectivity, density, fragmentation and directness all affect usage, with density having the largest impact;[50] the paper used factor analysis with complex inputs such as subgraph and vertex density and is not applied in this study. However, this study does consider the safety in numbers benefit, which also likely correlates with increased network density. All scenarios in this study assume a reasonably continuous and connected network.

- Freight Impacts: Cargo cycles have been proposed as an alternative for urban deliveries.[51] However, these remain a niche solution and no studies were found identifying the comprehensive benefits and costs of such solutions. On the other hand, freight vehicles may be disproportionately affected by bicycle infrastructure and/or congestion. The Metrolinx value of time may not reflect the value of time of freight vehicles, and further research is needed.

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[50] Jessica Schoner and David Levinson (2014) "The Missing Link: Bicycle Infrastructure Networks and Ridership in 74 US Cities." *Transportation 41:1187 (requires subscription)*

[51] Gabriele Schliwa et al (2015), "Sustainable city logistics – Making cargo cycles viable for urban freight transport." *Research in Transportation Business & Management (RTBM-00178) (requires subscription)*

Mode Shift

In the absence of more detailed data, cycling uptake is assigned from other modes in proportion to the baseline mode shares from the TTS. These trips are segmented by distance band and geographic area (central Toronto, rest of Toronto, remainder of GTHA, and the attendant inter-region categories). The proportional increase in bike trips is assumed equal for all distance bands.

Figure 17 shows the baseline mode share distribution for trips with the central part of Toronto. By means of explanation, if 39% of trips 2.5-5 kilometres in length are made by driving, then 42%[52] of the bicycle uptake in that distance band is assumed to come from drivers.

Figure 17: Baseline Weekday Trip Distribution by Distance, for Trips within Central Part of Toronto

Distance	Trips	Bike	Auto-D	Auto-P	Transit	Walk	Other
0-1 KM	292,441	5%	36%	9%	6%	42%*	2%
1-2.5 KM	497,093	6%	40%	12%	21%	18%	3%
2.5-5 KM	434,254	6%	39%	11%	40%	2%	2%
5-7.5 KM	260,735	3%	35%	8%	51%	0%	2%
7.5-10 KM	136,569	2%	34%	8%	54%	0%	1%
10-15 KM	40,081	1%	45%	10%	43%	0%	1%
15+ KM	3,462	2%	57%	14%	27%	0%	0%
TOTAL	1,664,635	5%	38%	11%	31%	13%	2%

Source: CPCS analysis of 2011 TTS data. *For the 0-1 km distance band, no mode shift is assumed from walking to cycling.

Seasonality and Annualization

TTS data were collected from September to December 2011, with a follow-up collection effort from September to December 2012. Also, the TTS records weekday rather than weekend trips. Since cycling levels vary significantly throughout the year and on weekdays relative to weekends, an annualization factor was developed for converting weekday trip volumes to annual volumes taking into account seasonality. Data were obtained for a permanent counter centrally located on Sherbourne Street (northbound and southbound at Wellesley). As shown in Figure 18, cycling levels are highest on an average July weekday, and lowest on December weekends. Assuming that this profile is broadly representative of the GTHA as a whole, the TTS survey period is slightly under-representative of typical weekdays but slightly over-representative of the average day. The annualization factor for converting TTS weekday cycling trips to annual cycling trips was found to be 341.

Figure 18: Seasonal Variability in Cycling Levels (100 = Annual Daily Average)

Month	M	J	J	A	S	O	N	D	J	F	M	A
Weekday	141	173	178	165	175	126	82	44	53	37	67	102
Weekend	96	120	103	103	102	68	38	27	43	35	41	65

Source: CPCS analysis of data provided by City of Toronto for Sherbourne St. permanent counter (2014-2015)

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[52] Equal to 39% / (100% - 6%), where 6% is the baseline bicycle mode share.

Multiuse Paths

Multiuse paths are not investigated in the same level of detail as bike lanes and cycle tracks; however, it is recognized that for many suburban municipalities these facilities may represent a more suitable solution. For the purpose of this study we define a multiuse path as a 3-m wide paved asphalt path in the boulevard along a generally linear road corridor.

To investigate the relative merits of multiuse paths we rely on the Teschke study described earlier, for its evaluation of the relative safety risk of paved multiuse paths. In suburban municipalities, it is likely that sidewalks (rather than on-street mixed traffic) are the main alternative to multiuse paths; according to Teschke the relative risk of multiuse paths versus sidewalks is 0.91 (i.e. multiuse paths are 9% safer).

Consistent with our assumptions for bike lanes and cycle tracks described in Direct Benefits of Cycling Facilities section, we assume that each 10% safety improvement delivers 17.3 cents per km per trip in user benefits and 28 new trips per day per km in the suburbs; thus for a 9% improvement these values are 15.9 cents and 26 trips, respectively. We apply all benefits in the same manner as described in the preceding subsections.

For costs, we assume congestion and lost parking costs to be zero given that the paths are installed in the boulevard without infringing on the roadway. We also assume that the corridor right-of-way can accommodate the boulevard with no land acquisition required, and that the opportunity cost of the land is marginal. Construction costs are taken as $450,000 per km.[53]

Station Access and Bike Parking

GO commuter rail stations represent a potential opportunity for increasing cycling. As shown in Figure 19, existing bicycle mode share to GO Transit stations is very low, at 1.0%. Around 60% of GO Transit riders arrive at the station by driving.

Figure 19: Modal Access to GO Stations

	Auto Driver	Auto Passenger	Bus	Walk	Bike
Mode Share	60%	20%	10%	9%	1%

Source: CPCS analysis of data provided by GO Transit (2013)

GO Transit weekday ridership was 197,000 as of April 2014,[54] corresponding to 98,500 two-way trips. GO also has 69,080 auto parking spots, including in ten parking structures. As structured parking is expensive, shifts toward other modes such as cycling can save the transit agency money in operating costs, as well as in capital costs as overall ridership increases.

GO Transit at present has 2,540 bike parking spots at stations. According to a comprehensive recent survey, 20% of those spots were used at a given time, with the highest usage in stations on the Lakeshore West line (Figure 20).

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[53] Unit costs from the City of Mississauga – constructing a 3-metre-wide asphalt trail in the road boulevard, including utility relocations and removal of the existing concrete sidewalk ($450,000/km lasting 20 years).

[54] GO Transit (August 2014), "Quick Facts"

Figure 20: Top GO Stations for Bicycle Access

GO Station	Rank	Line	Capacity	Usage	Pct. Usage	Pct. Biking
Oakville	1	Lakeshore West	161	39	24%	1.5%
Appleby	2	Lakeshore West	64	31	48%	1.1%
Streetsville	3	Milton	88	30	34%	1.0%
Clarkson	4	Lakeshore West	64	28	44%	1.0%
Bronte	5	Lakeshore West	96	26	27%	1.5%
All Stations			2540	510	20%	1.0%

Source: CPCS analysis of data provided by GO Transit. Percent biking is from Station Access Survey.

A recent study by GO Transit investigated why more GO patrons do not access the commuter rail network by bike. The primary reason identified by each participant is shown in Figure 21.

Figure 21: Primary Reason for Not Cycling to GO Station, GO Riders

Primary Reason for Not Biking	Share
Too far	15%
Safety concerns cycling to station	12%
Bikes not allowed on train in rush hour	7%
Security of bicycle in station	11%
Maintain professional appearance	19%
Do not want to be sweaty during ride	17%
Carry too much equipment	11%
Other	7%

Source: Léa Ravensbergen (2016), "Cycling to GO: Social and Environmental Determinants"

The most promising source for new bicycle trips appears to be the 30% of riders for whom the main barrier is safe access to the station, security of bikes at the station, or rush hour bike restrictions on trains. These barriers could be overcome by identifiable improvements such as bike lanes on nearby roads, improved theft deterrence at stations, and expanded bike share at the destination end. The remaining 70% of riders represent a relatively less likely source for new cyclists. Even an increase in cycling equal to a fraction of the 30% would represent a massive shift from present conditions.

Future analysis could identify the expected increase in cycling associated with specific interventions, as well as the costs of these interventions. We support this analysis by providing a calculation of the potential benefits achievable from increased cycling.

For parking costs, we rely on Litman (2016)[55] who estimates total annual costs of parking facilities as the sum of annualized land cost, annualized construction cost, and annual O&M costs, normalized per parking space. We take the most appropriate facility types to be "Suburban, Surface" ($885 USD/yr) and "Urban, 3-Level Structure" ($2,844 USD/yr). We take the straight average, which assumes that GO would initially target its efforts equally at stations with structured and surface parking lots. Converted to Canadian dollars, the annualized cost per parking space is $2,453.

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[55] Victoria Transport Policy Institute (2016), "Transportation Cost and Benefit Analysis II – Parking Costs." Table 5.4.3-6

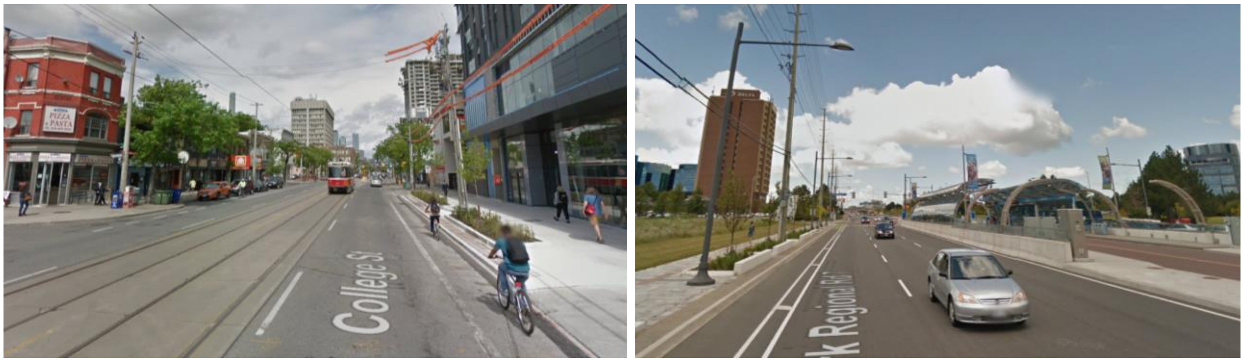
Congestion around GO parking lots in peak hours can be significant. We assume that both decongestion benefits and congestion costs around GO stations are more similar to the central part of Toronto as opposed to average roadways in the outer suburbs – thus we apply the instead apply the factors associated with the central part of Toronto. This acknowledges that on the one hand, reducing the amount of vehicle travel to GO stations can have an outsized benefit in freeing up road space for other users, but on the other hand removing a vehicle lane to build dedicated bike facilities can cause increased delay to remaining drivers.

5.0 ECONOMIC CASE

For all scenarios, results are shown on annual basis. All costs and benefits are annualized to 2031 using a real discount rate of 3.5% p.a., per Metrolinx Guidance. The findings are presented compared to a baseline scenario which assumes continuation of present conditions.

For reference, Figure 22 shows examples of existing bicycle facilities of various typologies in the GTHA.

Figure 22: Existing Bike Facilities in GTHA – Visual Examples



Bike lane on College St. in Toronto

Bike lane on Highway 7 in Markham

Cycle track on Sherbourne St. in Toronto

Cycle track on Cannon St. in Hamilton

Multiuse path on The Queensway in Mississauga

Multiuse path on Altona Rd. in Pickering

Source: Google Street View

Bike lanes are identified by striping but otherwise not separated from the roadway by any physical barriers. Cycle tracks generally have superior pavement markings and are physically separated from the roadway by barriers such as raised curbs, bollards, or planters. Multiuse paths are located in boulevards and are wider than typical sidewalks, often with signage or pavement markings at intersection crossings.

General Cycling High Shift

A general high shift assumes an increase in cycling levels, and is agnostic as to how the benefits are obtained (i.e. what drives the scenario). Such a high shift may result from changes in tastes and preferences (i.e. increased attractiveness of cycling relative to other modes).

Figure 23 shows the annual benefits for an assumed 50% increase in cycling from current levels. The net benefits add up to approximately $41 million per annum across the GTHA, largely in the form of health benefits. The 50% increase is taken to be approximately in line with the lower end of the shifts from Scenarios 1 and 2 below. Figure 22 is purely indicative of the benefits. In reality, these benefits would not be expected to be attainable absent specific interventions (which would generally have offsetting cost implications), detailed in subsequent sections.

Figure 23: Net Benefits for a 50% Increase in Cycling Levels

	Central part of Toronto	Rest of Toronto	GTHA outside Toronto
% Increase in Biking	50%	50%	50%
Increase in Bike Trips	14,319,271	2,165,893	5,958,607
Increase in Bike PKT	44,557,564	8,179,873	16,839,614
External Benefits			
External Accident Benefits	$ 1,144,879	$ (144,651)	$ (168,938)
External Health Benefits	$ 17,840,934	$ 4,202,132	$ 9,852,303
Decongestion Benefits	$ 4,190,049	$ 1,037,546	$ 1,563,291
CAC Emission Benefits	$ 105,958	$ 27,907	$ 64,144
GHG Emission Benefits	$ 570,744	$ 146,520	$ 358,727
Total Benefits			
Total	$ 23,852,564	$ 5,269,453	$ 11,669,527

Source: CPCS analysis

Investment in Bike Facilities

In reality, it is likely that investment in bike infrastructure is necessary to drive a high shift in cycling. Scenario 1 and 2 reflect an assumed 600-km investment in bike infrastructure region-wide. The new infrastructure is in the form of bike lanes (Scenario 1) and cycle tracks (Scenario 2). Either of these scenarios on its own tests the limit of investment in the central part of Toronto that is attainable before the marginal uptake from new facilities drops below the level identified in the Uptake section, even in the most high-demand areas. In other words, the benefits could be scaled down proportionally for a smaller level of investment (less dense network), but the benefits could not necessarily be scaled up for a larger level of investment (denser network). The two scenarios are not purely additive, although for example a 50-50 combination of the two is.

Also, for context, the City of Toronto's recent 2016 Ten-Year Cycling Network Plan identifies approximately 525 centreline kilometres of new bike infrastructure in the City alone. Thus, these scenarios represents a very large investment in bike infrastructure compared to existing levels but not one that exceeds the most optimistic of present plans.

A total benefit/cost ratio is calculated for each scenario. A benefit/cost ratio of greater than 1 technically means that the scenario is economically justified. However, it is noted that there may be other potential public projects (related to transportation or otherwise) that also have expected benefit/cost ratios in excess of 1. It is therefore not a given that such investments should go ahead given potential competing priorities. However, investments with expected benefit/cost ratios well in-excess of 1 demonstrate that at least the minimum hurdle has been cleared, at least warranting further consideration.

Scenario 1: 600 KM Increase in Bike Lanes

Scenario 1 assumes a 600-kilometre investment in bike lanes region-wide. Figure 24 shows the annual benefits and costs of Scenario 1. Of note, the 200 km of new bike lanes in the central part of Toronto roughly corresponds to the maximum density described in the Uptake section (i.e. 2 km per sqkm land area). In other words, above this density, the benefits per km bike lane would be expected to decline as the bike lanes are no longer serving "new markets." Such investments may still be economically justified, but extrapolating the figures in the table in a linear fashion may not be appropriate.

Under Scenario 1, net benefits are positive in all geographic areas and total $40 m. per annum across the GTHA. Most of the benefit is in the form of health benefits.

Figure 24: Scenario 1: 600 KM Investment in Bike Lanes

	Central part of Toronto	**Rest of Toronto**	**GTHA outside Toronto**
KM Installed	200	200	200
Increase in Bike Trips	25,363,825	5,675,160	5,716,338
Increase in Bike PKT	78,929,169	19,536,981	17,324,669
% Increase in Biking (Trips and PKT)	89%	119%	51%
Internal Benefits			
Direct Benefits to Users	$ 10,542,660	$ 3,625,937	$ 2,254,110
External Benefits			
External Accident Benefits	$ 2,363,968	$ (189,810)	$ (79,459)
External Health Benefits	$ 31,603,392	$ 10,036,460	$ 10,136,093
Decongestion Benefits	$ 7,422,243	$ 2,478,096	$ 1,608,320
CAC Emission Benefits	$ 187,693	$ 66,653	$ 65,991
GHG Emission Benefits	$ 1,011,014	$ 349,952	$ 369,060
Costs			
Congestion due to Loss of Lane	$ 15,062,173	$ 6,718,850	$ 3,797,266
Loss of Parking Space	$ 12,558,308	$ 1,346,843	$ -
Construction and Maintenance	$ 1,591,406	$ 1,591,406	$ 1,591,406
Total Benefits and Costs			
Total Benefits	$ 53,130,970	$ 16,367,289	$ 14,354,115
Total Costs	$ 29,211,887	$ 9,657,099	$ 5,388,672
Total Net Benefits	$ 23,919,082	$ 6,710,190	$ 8,965,443
Benefit/Cost Ratio	1.8	1.7	2.7

Source: CPCS analysis

Scenario 2: 600 KM Increase in Cycle Tracks

Figure 25 shows the annual benefits and costs of Scenario 2. This scenario is similar to Scenario 1 except reflecting investment in cycle tracks rather than bike lanes.

Annual net benefits in this scenario equal $66 million across the GTHA. Of note, combined scenarios with bike lanes and cycle tracks can be constructed by weighting Scenarios 1 and 2 as desired. However, the two scenarios are not considered additive because the total coverage of the bike facilities would exceed the maximum network density modelled in this study in the central part of Toronto.

Figure 25: Scenario 2: 600 KM Investment in Cycle Tracks

	Central part of Toronto	**Rest of Toronto**	**GTHA outside Toronto**
KM Installed	200	200	200
Increase in Bike Trips	40,328,482	9,023,504	9,088,977
Increase in Bike PKT	125,497,379	31,063,800	27,546,224
% Increase in Biking (Trips and PKT)	141%	190%	82%
Internal Benefits			
Direct Benefits to Users	$ 21,894,646	$ 7,862,829	$ 4,385,251
External Benefits			
External Accident Benefits	$ 4,135,257	$ 88,283	$ 201,950
External Health Benefits	$ 50,249,393	$ 15,957,971	$ 16,116,388
Decongestion Benefits	$ 11,801,367	$ 3,940,173	$ 2,557,229
CAC Emission Benefits	$ 298,432	$ 105,979	$ 104,926
GHG Emission Benefits	$ 1,607,512	$ 556,423	$ 586,806
Costs			
Congestion due to Loss of Lane	$ 17,720,203	$ 10,028,134	$ 5,667,561
Loss of Parking Space	$ 12,558,308	$ 1,346,843	$ -
Construction and Maintenance	$ 9,693,561	$ 9,693,561	$ 9,693,561
Total Benefits and Costs			
Total Benefits	$ 89,986,606	$ 28,511,658	$ 23,952,550
Total Costs	$ 39,972,073	$ 21,068,538	$ 15,361,123
Total Net Benefits	$ 50,014,534	$ 7,443,120	$ 8,591,427
Benefit/Cost Ratio	2.3	1.4	1.6

Source: CPCS analysis

Scenario 3: 200 KM Increase in Multiuse Paths

Scenario 3 assumes an investment in 200 kilometres of multiuse paths in the GTHA outside Toronto. The annual net benefits are $1.1 million and the benefit-cost ratio is 1.2. Although the net benefits of this alternative are smaller than for a similar implementation of bike lanes or cycle tracks, multiuse paths may be a superior alternative in certain settings, such as along busy traffic thoroughfares.

Figure 26: Scenario 3: 200 KM Investment in Multiuse Paths

	GTHA outside Toronto
KM Installed	200
Increase in Bike Trips	2,285,392
Increase in Bike PKT	6,926,404
% Increase in Biking (Trips and PKT)	21%
Internal Benefits	
Direct Benefits to Users	$ 696,247
External Benefits	
External Accident Benefits	$ 7,977
External Health Benefits	$ 4,052,411
Decongestion Benefits	$ 643,007
CAC Emission Benefits	$ 26,383
GHG Emission Benefits	$ 147,550
Costs	
Congestion due to Loss of Lane	$ -
Loss of Parking Space	$ -
Construction and Maintenance	$ 4,500,000
Total Benefits and Costs	
Total Benefits	$ 5,573,576
Total Costs	$ 4,500,000
Total Net Benefits	$ 1,073,576
Benefit/Cost Ratio	1.2

Source: CPCS analysis

Commuter Rail Station Access

10% Mode Shift to Cycling for GO Station Access

In suburban parts of the GTHA, one potentially promising strategy is to shift commuter rail access trips from other modes to cycling. As described in the Approach section, potentially 30% of access trips could be amenable to a switch to cycling. This scenario assumes that 10% of trips make the switch, which is a high shift compared to the current 1% of access trips that are by bicycle.

The annual benefits of a 10% mode shift are shown in Figure 26. There are significant external benefits, especially in terms of health. The major benefit is in the form of parking cost savings for GO Transit. Currently, these parking spots, many of which are structured, are offered free of charge to GO commuters.

This analysis does not account for the costs nor internal benefits of interventions. These benefits and costs are highly dependent on the specific intervention applied (e.g. bike lanes, enhanced theft deterrence, etc.). However, what the analysis does suggest is that an annual investment of around $20 million would be economically beneficial if it could result in a 10% shift of access trips to cycling.

The exact net benefit would depend on the interventions required. For example, based on the assumptions used in this study, a bike lane requiring the loss of a lane of traffic could have significant costs, at $75,000 per annum per lane (i.e. around 13 km would cost $1 million in increased driver delay). These costs should be considered in evaluating the effectiveness of any specific intervention that would remove vehicle travel lanes.

Figure 27: 10% Mode Shift to Cycling for GO Station Access

	GTHA outside Toronto
Mode Shift to Cycling (Percentage Points)	10%
Increase in Bike Trips	2,437,875
Increase in Bike PKT	6,877,565
External Benefits	
External Accident Benefits	$ (128,835)
External Health Benefits	$ 4,324,619
Decongestion Benefits	$ 1,237,962
CAC Emission Benefits	$ 30,398
GHG Emission Benefits	$ 165,807
Agency Benefits	
Parking Cost Savings	$ 14,498,941
Total Benefits	$ 20,128,892

Source: CPCS analysis

6.0 FINANCIAL CASE

The financial case is intended as a complement to the economic case. Whereas the economic case shows the total economic benefits and costs, the financial case looks specifically at the impact on public revenues and costs. The financial case excludes user benefits and costs as well as general societal benefits and costs. Given the high-level nature of this study, the financial case does is provided as a broad high-level overview of the expected financial impacts, and does not go into extensive depth on any of the particular items.

The anticipated financial impacts and costs can be categorized as follows:

Figure 28: Financial Impact Categories

Impact	Description
Foregone Transit Revenue	Foregone transit agency revenues from transit users switching to cycling
Foregone Fuel Taxes	Foregone federal and provincial gas tax revenues from auto drivers switching to cycling
Saved Transit Operating Expenses	Saved transit agency expenses from transit users switching to cycling
Foregone Parking Revenues	Foregone municipality revenues from loss of parking spaces
Bike Facility Direct Costs	Costs of constructing, operating and maintaining bike facilities
Saved Parking Expenses	Savings to GO Transit for parking expenses for auto drivers switching to cycling, for station access

Foregone transit revenues are assumed to be roughly $3 per trip in the GTHA, based on current regional fare rates. It is assumed most of the trips switching will be full-fare-paying passengers, rather than transfer trips. Foregone fuel taxes assume tax rates of $0.14 per litre (provincial), $0.10 per litre (federal), and an average fuel efficiency of 12.8 L/100 km. Transit agency operating expenses are assumed to be $2.32 per passenger, based on data available for the TTC.[56] The rate is found to not vary significantly for the central part of Toronto compared to the rest of Toronto. The remaining factors are the same as detailed in the economic case.

The annualized financial impacts of the various scenarios are presented in Figure 29. It should be noted that Scenario 3 and the GO Station Access scenario apply only to the GTHA outside of Toronto, whereas Scenarios 1 and 2 apply to the entire GTHA. For Scenarios 1 to 3, net financial impacts are negative, indicating that public agencies will lose money as a result of the initiatives. The reason for this is that most of the benefits of these scenarios accrue to users or to society as a whole. It should be noted, however, that public healthcare costs are not included as an explicit quantification of these benefits was not found. It is likely that much of the external accident and health benefits will impact public expenditures positively, by bringing down future public-sector costs. Thus the values provided in this section can be considered short-term impacts of the scenarios.

It is also possible that the loss of parking spaces will drive up demand for parking in remaining locations, possibly reducing the negative impact on city parking revenues. This effect is not modelled in this study.

The GO station access scenario produces positive financial impacts because of the savings associated with building fewer park and ride spaces. It should also be noted that this is not a complete scenario since no specific

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[56] Toronto Transit Commission, Surface Ridership 2012

interventions were costed out; these interventions would have an impact on public expenditures and should be deducted from the total financial impact.

Figure 29: Financial Impacts of Scenarios

	Scenario 1 (Bike Lanes)	Scenario 2 (Cycle Tracks)	Scenario 3 (Multiuse Paths)	GO Station Access
Foregone Transit Revenue	-$21,583,493	-$34,317,754	-$197,952	-$211,159
Foregone Fuel Taxes	-$1,128,039	-$1,793,582	-$100,690	-$99,980
Saved Transit Operating Expenses	$17,266,794	$27,454,203	$158,361	$168,927
Foregone Parking Revenue	-$13,905,151	-$13,905,151		
Bike Facility Direct Costs	-$4,774,219	-$29,080,683	-$1,333,333	
Saved Parking Expenses				$14,498,941
Total Financial Impact	**-$24,124,108**	**-$51,642,967**	**-$1,473,614**	**$14,356,729**

Source: CPCS analysis

7.0 SENSITIVITY ANALYSIS

Sensitivity to Variables

Figure 28 shows the results of a sensitivity analysis of key input factors. The top row ("baseline net benefit") corresponds to the net benefit calculated in the scenarios described in the Economic Case, under the assumptions described in this report. These baseline assumptions are listed as "medium" in the table. For each factor, a lower and higher value are tested to determine how the net benefit would be affected under different assumptions. In most cases, the low case is set as half of the value used, and the high case is set at twice the value used. For greenhouse gases, the low case is set to one-fifth to reflect a cost of carbon of $30/tonne.

In the table, the default value listed is that for bike lanes, for the central part of Toronto. This is purely for visual simplicity, as the sensitivity analysis does also assume proportional changes for other geographic areas and for cycle tracks

Figure 30: Sensitivity Results – Increase (Decrease) in Net Benefit Resulting from Change in any Single Factor

Factor		Value	Change	Central Part of Toronto	Rest of Toronto	Outside Toronto	Central Part of Toronto	Rest of Toronto	Outside Toronto
				Bike Lane			**Cycle Track**		
Baseline Net Benefit (Equivalent of all "Medium" Values)				**$23,919,082**	**$ 6,710,190**	**$ 8,965,443**	**$50,014,534**	**$ 7,443,120**	**$ 8,591,427**
External Safety Costs per 1 KM Cycling	Low	$0.013	x 0.5	$495,644	$394,652	$360,613	$570,696	$401,132	$377,677
	Med	$0.026	-	$0	$0	$0	$0	$0	$0
	High	$0.052	x 2.0	-$991,289	-$789,304	-$721,226	-$1,141,391	-$802,264	-$755,355
External Health Benefits per Shift of 1 PKT to Cycling	Low	$0.261	x 0.5	-$15,801,696	-$5,018,230	-$5,068,047	-$25,124,696	-$7,978,985	-$8,058,194
	Med	$0.521	-	$0	$0	$0	$0	$0	$0
	High	$1.043	x 2.0	$31,603,392	$10,036,460	$10,136,093	$50,249,393	$15,957,971	$16,116,388
External Decongestion Benefits per Shift of 1 PKT to Cycling	Low	$0.061	x 0.5	-$3,711,122	-$1,239,048	-$804,160	-$5,900,684	-$1,970,087	-$1,278,615
	Med	$0.122	-	$0	$0	$0	$0	$0	$0
	High	$0.245	x 2.0	$7,422,243	$2,478,096	$1,608,320	$11,801,367	$3,940,173	$2,557,229
External CAC Benefits per Shift of 1 PKT to Cycling	Low	$0.002	x 0.5	-$93,847	-$33,327	-$32,996	-$149,216	-$52,989	-$52,463
	Med	$0.003	-	$0	$0	$0	$0	$0	$0
	High	$0.006	x 2.0	$187,693	$66,653	$65,991	$298,432	$105,979	$104,926

Factor		Value	Change	Central Part of Toronto	Rest of Toronto	Outside Toronto	Central Part of Toronto	Rest of Toronto	Outside Toronto
				Bike Lane			**Cycle Track**		
External GHG Benefits per Shift of 1 PKT to Cycling	Low	$0.001	x 0.2	-$808,811	-$279,961	-$295,248	-$1,286,010	-$445,139	-$469,444
	Med	$0.003	-	$0	$0	$0	$0	$0	$0
	High	$0.006	x 2.0	$1,011,014	$349,952	$369,060	$1,607,512	$556,423	$586,806
Uptake (New Trips) per 1 KM Bike Lane or Cycle Track	Low	171	x 0.5	-$28,463,781	-$8,924,023	-$7,558,926	-$49,307,673	-$16,009,915	-$12,823,158
	Med	342	-	$0	$0	$0	$0	$0	$0
	High	684	x 2.0	$65,215,109	$21,355,773	$16,456,247	$119,567,096	$40,887,716	$29,029,911
Mode Shift per 1 KM Bike Lane or Cycle Track (taken as % from Auto-Driver*)	Low	20%	x 0.5	-$12,602,945	-$3,418,517	-$2,939,288	-$20,041,550	-$5,437,571	-$4,676,246
	Med	41%	-	$0	$0	$0	$0	$0	$0
	High	70%	x 2.0	$18,268,663	$2,789,628	$1,182,593	$29,051,329	$4,437,245	$1,881,441
Safety of Bike Facilities (Expressed as Relative Risk vs Mixed Traffic)	Low	0.86	x 0.5	-$3,261,183	-$902,379	-$908,926	-$5,348,268	-$1,610,201	-$1,621,884
	Med	0.72	-	$0	$0	$0	$0	$0	$0
	High	0.44	x 2.0	$6,522,365	$1,804,758	$1,817,853	$10,696,535	$3,220,402	$3,243,769
Safety in Numbers Benefit	Low	5%	x 0.5	-$2,793,199	-$1,172,306	-$447,302	-$7,061,485	-$2,963,707	-$1,130,823
	Med	9%	-	$0	$0	$0	$0	$0	$0
	High	18%	x 2.0	$5,586,397	$2,344,612	$894,603	$14,122,971	$5,927,414	$2,261,647
Congestion Costs to Other Road Users per 1 KM Bike Lane or Cycle Track	Low	$37,655	x 0.5	$7,531,086	$3,359,425	$1,898,633	$8,860,102	$5,014,067	$2,833,781
	Med	$75,311	-	$0	$0	$0	$0	$0	$0
	High	$150,622	x 2.0	-$15,062,173	-$6,718,850	-$3,797,266	-$17,720,203	-$10,028,134	-$5,667,561
Lost Parking Costs per 1 KM Bike Lane or Cycle Track	Low	$31,396	x 0.5	$6,279,154	$673,421	$0	$6,279,154	$673,421	$0
	Med	$62,792	-	$0	$0	$0	$0	$0	$0
	High	$125,583	x 2.0	-$12,558,308	-$1,346,843	$0	-$12,558,308	-$1,346,843	$0
Construction and O&M Costs per 1 KM Bike Lane or Cycle Track	Low	$3,979	x 0.5	$795,703	$795,703	$795,703	$4,846,781	$4,846,781	$4,846,781
	Med	$7,957	-	$0	$0	$0	$0	$0	$0
	High	$15,914	x 2.0	-$1,591,406	-$1,591,406	-$1,591,406	-$9,693,561	-$9,693,561	-$9,693,561
Value of Time	Low	$12.06	x 0.5	$7,531,086	$3,359,425	$1,898,633	$8,860,102	$5,014,067	$2,833,781
	Med	$24.11	-	$0	$0	$0	$0	$0	$0
	High	$36.17	x 1.5	-$7,531,086	-$3,359,425	-$1,898,633	-$8,860,102	-$5,014,067	-$2,833,781

Factor		Value	Change	Central Part of Toronto	Rest of Toronto	Outside Toronto	Central Part of Toronto	Rest of Toronto	Outside Toronto
				Bike Lane			Cycle Track		
Discount Rate	Low	1.75%	x 0.5	$3,648,907	$1,179,662	$1,488,478	$7,630,530	$1,624,557	$1,782,205
	Med	3.50%	-	$0	$0	$0	$0	$0	$0
	High	7.00%	x 2.0	-$5,580,577	-$1,804,155	-$2,276,454	-$11,670,005	-$2,484,571	-$2,725,675
Growth in Baseline Number of Daily Trips, 2016-2031 (Cumulative)	Low	4.2%	x 0.5	-$1,056,396	-$324,718	-$818,469	-$1,787,975	-$565,922	-$1,367,863
	Med	8.5%	-	$0	$0	$0	$0	$0	$0
	High	16.9%	x 2.0	$2,112,792	$649,436	$1,636,937	$3,575,950	$1,131,844	$2,735,727

Source: CPCS analysis. *for mode shift, the low case assumes half the shift from auto drivers compared to expected and high case assumes half the difference between the expected shift and a 100% shift. The remaining modes are redistributed proportionally.

As seen in the table, the factors with the largest impact on net benefit are external health benefits, uptake, and congestion costs. Uptake has the largest impact – if the number of new trips is only half of what is anticipated, the net benefits will be close to or below zero for each of the scenarios. For example, for cycle tracks in the central part of Toronto, the net benefit of $50.0 m. annually would be reduced by $49.3 m. annually, resulting in a negligible $0.7 m. benefit. On the other hand, factors like greenhouse gas externalities have a small impact on net benefit even if the assumptions used are disputed.

Example Corridor Typologies

Another way of examining the sensitivity of uptake, in particular, is by determining the minimum uptake necessary to make a scenario economically viable. Another benefit of this approach is that it can be applied to specific corridor typologies more detailed than what are described in the scenarios. Figure 27 shows a variety of corridor typologies, which are not meant to be exhaustive but to provide a sense of the situations in which bicycle infrastructure is supported to a greater or lesser extent.

The right-most column shows the number of breakeven daily trips (average across the year) that would be required in order to generate a benefit/cost ratio above 1. In other words, if each kilometre of the bike facility generates a number of new bike trips equal to or greater than this threshold, the facility will be economically justified. (Thus, for a two-kilometre facility, the number of trips generated would need to be double).

The first four typologies apply to urban streets similar to ones seen in the central part of Toronto. For the first case, the congestion cost is multiplied by two to account for two lost traffic lanes, and multiplied by two again to account for especially severe sensitivity to congestion. It is assumed that the lost lanes were used for car traffic at rush hour and parking at other hours. In this case each centreline-km (i.e. both directions combined) of cycle track would need to generate 1,462 new bicycle trips per day to be economically justified.

Four typologies apply to suburban streets, including one that considers widening the road to accommodate cycle tracks. One typology considers suburban boulevard multiuse paths, and one considers a suburban street accessing a GO station. In the latter case, bike lanes accessing a GO station that come at the expense of a vehicle lane would need to generate 104 new bike trips per day (e.g. 52 to the station, 52 from the station).

Figure 31: Minimum Increase in Daily Trips for Various Facility Implementation Typologies, per Kilometre

Setting – Facility Improvement, Loss of Traffic Lane/Parking	Congestion Cost	Parking Cost	Construction Cost	Total Costs (Annualized)	Breakeven Trips
Urban Street (Downtown) – 2 Lanes to wide Cycle Tracks. Lose two highly congested peak lanes & off-peak parking ($4/hr)	$ 590,673	$ 569,890	$ 48,468	$1,209,031	1,462
Urban Street – Cycle Tracks. Lose peak lane & off-peak parking ($1.50/hr)	$ 147,668	$ 251,741	$ 48,468	$ 447,878	542
Urban Street – Bike Lanes. Lose parking lane ($1.50/hr)		$ 311,507	$ 7,957	$ 319,464	412
Urban Street – Bike Lanes. No loss (wide ROW)			$ 7,957	$ 7,957	10
Suburban Street – Cycle Tracks. Lose 1 lane	$ 35,422		$ 48,468	$ 83,890	75
Suburban Street – Cycle Tracks. Road Expansion (no lanes lost)			$ 81,801	$ 81,801	73
Suburban St – Bike Lanes. Lose 1 lane	$ 35,422		$ 7,957	$ 43,379	41
Suburban Street – Bike Lanes. No loss (wide ROW)			$ 7,957	$ 7,957	8
Suburban (Boulevard) Multiuse Path. No loss			$ 6,667	$ 6,667	6
Suburban Street – Bike Lanes Accessing GO Station. Lose 1 lane	$ 147,668		$ 7,957	$ 155,625	104

Source: CPCS analysis

The typologies that best support bike infrastructure are those where the existing road right-of-way (ROW) is wide enough to support bike lanes without the loss of paid parking or traffic lanes. In such cases, there is very little downside to building bike infrastructure. Similarly, suburban multiuse paths do not need many new trips to justify themselves economically.

8.0 CONCLUSIONS

Summary

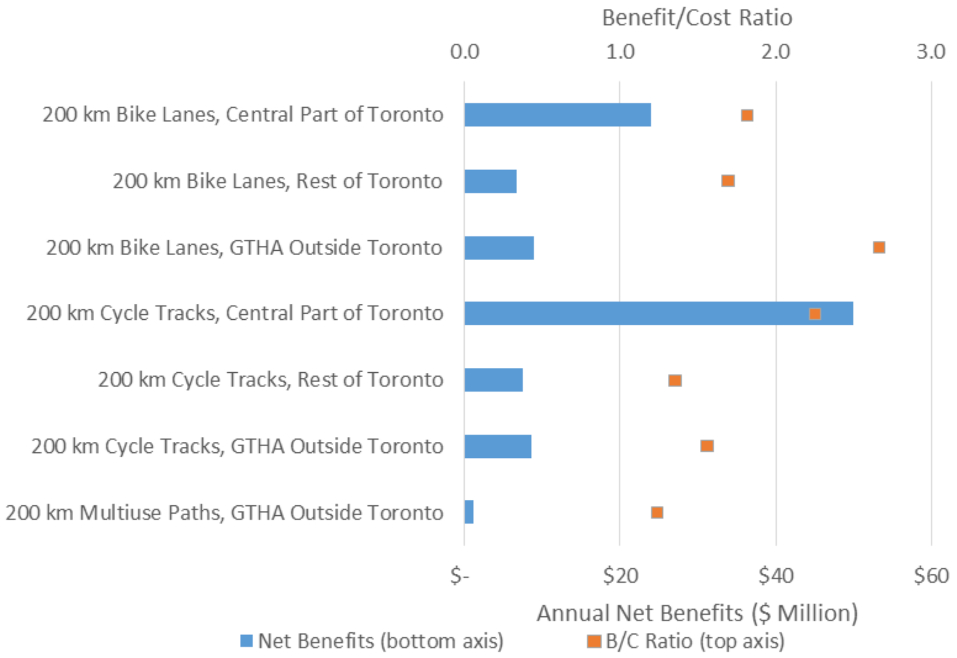
This study concludes that a large-scale investment in bicycle facilities in the Greater Toronto and Hamilton Area is, in general, economically justified. The benefits attainable from a "high shift" to cycling can be substantial, although it is unlikely that Toronto will ever reach extremely high levels of cycling mode share such as those in some European cities like Amsterdam or Copenhagen.

In general, the economic rationale is strongest for bike lanes and cycle tracks in the central part of Toronto. For these facilities the benefit/cost ratios are 1.8 and 2.3 (respectively), while net benefits range from $24 million to $50 million annually (for a 200-centreline-km implementation). This suggests a strong economic rationale for the implementation of a dense network of cycling facilities in the central part of Toronto.

For the rest of Toronto and the rest of the GTHA, benefit/cost ratios also exceed 1, suggesting bike facilities on average are economically justified. Compared to the central part of Toronto, the net benefits are smaller, mostly due to lower anticipated uptake. The benefit-cost outcome is also more sensitive to changes in input values. This suggests that bicycle facilities should be implemented strategically, starting with high-demand and/or low-cost settings. The fact that benefit-cost ratios are above 1 suggests that bike facilities are on balance economically worthwhile, even if a dense network may be less suitable than in the central part of Toronto.

Figure 30 shows the net benefits and benefit/cost ratios of the various scenarios, broken down by geographic area. (For example, Scenario 1 consists of 600 km of bike lanes, of which 200 km are in each of the three geographic areas – this figure breaks out each area separately). Not shown are a general increase in cycling (non-intervention specific) and GO station access, as these were evaluated for their external benefits alone.

Figure 32: Summary of Net Benefits and Benefit/Cost Ratios



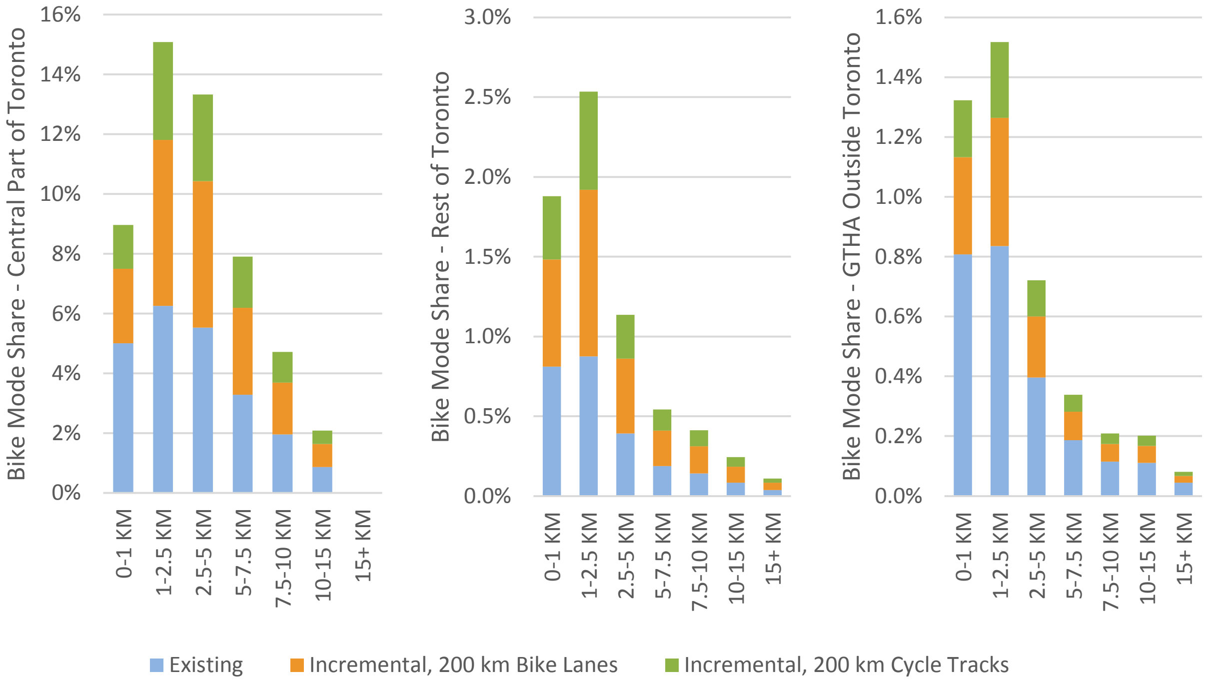
Source: CPCS analysis

There is a strong rationale for improving bike mode shares to GO stations (not shown), as these would save on subsidized parking costs and deliver health and other benefits; however, this benefit is offset if improved bike access comes at the expense of a lane of traffic.

Figure 31 shows the existing and anticipated bike mode shares based on 200-kilometre bike lane or cycle track implementations in each of the three geographic areas. Of note, the "Incremental, 200 km Cycle Tracks" category refers to the incremental mode shift if the 200-km implementation takes the form of cycle tracks rather than bike lanes (i.e. it does not imply 200 km of bike lanes plus 200 km of cycle tracks).

As seen in the graphs, bike mode share would be as high as 15% for 1-2.5 KM trips in the central part of Toronto in the 200-km cycle track case, although it would be (and already is) significantly higher in specific geographic pockets such as along College Street. In the rest of Toronto and elsewhere in the GTHA, bike mode share would remain fairly low in comparison to other modes, but would increase significantly in percentage terms. The smaller increase in the GTHA outside Toronto is explained by the higher number of baseline (all-mode) trips in this area.

Figure 33: Bike Mode Shares by Distance Band Before and After 200-KM Bike Facility Intervention



Source: CPCS analysis. Existing bike mode share based on 2011 TTS.

Areas for Future Inquiry

Uptake, health benefits, and congestion costs are the three variables with the largest sensitivity impacts, and further study would help to build on this analysis in the future:

- Uptake is estimated using comprehensive US studies. However, one of the shortcomings of this approach is that the US studies profiled have cycling levels similar to or lower than Toronto. The extent to which the findings can be extrapolated over a large increase in cycling is not entirely clear. On the other hand, the extent to which European cities might serve as a model for Toronto is also not clear. A future analysis may take a more nuanced international perspective. Alternatively, as cycling data continue to become more readily available, more detailed studies of uptake can be undertaken in the GTHA. It is important that these studies not only measure point volumes, but provide some breakdown of whether trips observed are entirely new, route-shifted, or pre-existing.[57]

- External health benefits are the dominant form of benefits for bike infrastructure interventions. Metrolinx's methodology relies on a comprehensive New Zealand study. A future similar study tailored to Canada/Ontario would be worthwhile to reaffirm the health benefits of physical activity, as well as to carefully allocate benefits internally and externally. As a rough check, in this study a 50% increase in cycling levels was found to generate external health benefits of $35 m. across the GTHA. This can be compared to the economic burden of physical inactivity or excess weight in Canada, assessed at $34.1 billion in 2013.[58] Thus the health benefits at least appear to be of a reasonable scale.

- Removing vehicle travel lanes from the roadway can have a significant cost in terms of increased congestion. This method extrapolated a congestion cost from analyses done at the margin; one of the shortcomings of this approach is that the marginal cost of removing lanes may in fact increase as road capacity continues to decrease and drivers are funnelled onto fewer and fewer available lanes or roads. Thus, a fuller and more detailed analysis of expected congestion impacts would be beneficial. This study presents a methodology for estimating these congestion costs, as the average of the added delay under a) a route-shift assumption (representing the worst case), and b) a route-, time- and mode-shift assumption (representing actual behaviour but not the full costs). If congestion impacts are to be modelled, both of these cases should be assessed and the results averaged. Ideally any modelling would also take into account the differences between simply removing a lane of traffic (naïve assumption) and replacing a lane of traffic with a bike lane or cycle track. In the latter situation, traffic flow is likely to be impeded to a greater extent, including not just on the corridor at hand but also on perpendicular roads from which drivers are trying to access the corridor (for example drivers queuing to turn from University Avenue onto Richmond Street in Toronto).

Conclusions

It is important to note that the findings of this report are not meant to be applicable at the corridor level. In particular, the traffic delay resulting from removal of traffic lanes may be highly dependent on the particular road. Uptake may also be highly variable even within the broad geographic areas defined in this study, as it depends on an interplay of demand and supply factors (demand for cycling, availability of other good bike routes). Any corridor study should take these factors into account in a more granular fashion than is done in this study.

Moreover, it may be the case that a certain network, tested as a whole, is economically beneficial, but that individual components of it are not. In general, policy should be to install bike infrastructure first in those places where its net benefits are greatest, and to continue until such a point is reached where the marginal costs of the next-best project exceed its marginal costs.

As new bicycle facilities are introduced, the benefits and costs of these facilities should be assessed so as to guide and inform future investment on an ongoing basis.

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[57] The Monsere study profiled in this study provides one example of how this can be approximated by means of a route intercept survey. More accurate methods may involve new data collection mechanisms such as smartphones.

[58] Hans Krueger et al (2015), "Variation across Canada in the economic burden attributable to excess weight, tobacco smoking and physical inactivity." *Canadian Journal of Public Health, 106(4) e171-e177*

This report does not explicitly provide a benefit-cost framework for assessing the merits of policies supporting bicycle use. Nonetheless, it is assumed such policies are generally in place in order to attain the benefits identified in this study.

It is also noted that this report does not cover e-bikes. In general, there is not enough historical data and evidence with these vehicles in North America to properly account for them, nor is it clear how significant usage will be in the future. Presently e-bikes are legal to operate in Ontario provided they weigh less than 120 kg and are operated at a maximum 32 km/h.[59] Municipalities are free to pass by-laws regulating their use; the City of Toronto prohibits e-bikes from being used on multi-use paths and in cycle tracks.[60] It is notable that external health benefits alone account for one-half to two-thirds of the benefits of bike lanes and cycle tracks, based on the methodology used in this study. Insofar as e-bike users do not gain the same level of health benefits as conventional cyclists, the economic rationale for bike lanes or cycle tracks would decrease significantly if many or most of the users were to travel by e-bike.

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[59] MTO website, "Electric bicycles: Frequently Asked Questions." Accessed September 2016

[60] City of Toronto website, "Cycling and the Law: Power Assisted Bicycles." Accessed September 2016