METROLINX

THE ECONOMIC VALUE OF REGIONAL STRATEGIES TO IMPROVE TRANSPORTATION OUTCOMES:

MANAGED HIGHWAY LANE NETWORK AND TRANSIT USE 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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THE ECONOMIC VALUE OF REGIONAL STRATEGIES TO IMPROVE TRANSPORTATION OUTCOMES

MANAGED HIGHWAY LANE NETWORK AND TRANSIT USE

ECONOMIC AND FINANCIAL PERSPECTIVE

FINAL REPORT

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TRANSPORTATION POLICY AND RESEARCH

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TABLE OF CONTENTS

Acronyms

AADT	Annual average daily traffic
BBS / BSL	Bus bypass shoulders / bus shoulder lane
BCA	Benefit Cost Analysis
BT	Brampton Transit
CAP	Criteria Air Pollutants
EB, NB, SB, WB	Eastbound, northbound, southbound, westbound (directions of travel on expressway lanes and interchange ramps)
Expressway	Controlled access, grade-separated, high-capacity and high speed highway
General purpose lanes	Lanes that normally are open to use by all motorized traffic that is eligible to use an expressway (some specific restrictions may apply - e.g., height restrictions)
GHG	Greenhouse gas emissions
GO	GO Transit
GRT	Grand River Transit
GTHA	Greater Toronto and Hamilton Area
HOT	High Occupancy Toll (lane)
HOV	High Occupancy Vehicle (lane)
HSR	Hamilton Street Railway
IC	Interchange (on expressways)
KPH	Kilometres per hour (speed)
ML	Managed Lane
MT	Mississauga Transit (MiWay)
NPV	Net present value
OD	Origin-destination (survey)
P-HR	Person-hours (time savings)
PKT	[Transit] Passenger-kilometres travelled
TTC	Toronto Transit Commission
TTS	Transportation Tomorrow Survey
VKT	Vehicle-kilometres travelled
YRT	York Region Transit

1.0 EXECUTIVE SUMMARY

Overview

This analysis investigates the potential economic value of a network of managed lanes on the Greater Toronto and Hamilton Area's (GTHA's) freeways. The investigation comprised a benefit-cost analysis (BCA) and a financial impact analysis. The investigation focused on the transit impacts of the managed lanes, thereby distinguishing itself from, and complementing, other managed lane impact analyses that are being conducted by the Ontario Ministry of Transportation (MTO). The analysis demonstrates how the transit benefits could add to benefits experienced by other managed lane users.

Key Findings

Many studies have examined the potential benefit of managed lanes for auto users. This focus is reasonable, given that auto users are the primary users of the highway network. At the same time, little is said about the benefits of managed lanes to other users, notably transit.

This study reviewed the potential benefits of several scenarios of managed lane networks for transit users on the GTHA's expressways. The study found clear benefits to transit users and operators of routes that currently use the expressways, because of reduced and more reliable journey times when general purpose lanes are converted to managed lanes. Moreover, some new riders likely would be attracted from other modes, mainly from the auto.

By design, the study looked only at transit, given the paucity of transit-focused analysis. Further analysis would be required to consider the impacts on transit benefits from the volumes of other traffic that would share the managed lane under different operational or tolling schemes.

An assessment of the infrastructure requirements for the different network scenarios was not within the scope of this study. Nonetheless, it is unlikely that the transit benefits alone could offset the annualized lifecycle costs of new managed lanes (construction, operations and maintenance), should new infrastructure be required. Accordingly, the transit benefits should be viewed as incremental benefits that should be added to those derived from other managed lane users, such as carpoolers in an HOV scheme or even single-occupant vehicles under a HOT lane regime. For newly constructed managed lanes, the benefits to transit users can add up to 16 basis points (+ 0.16) to the benefit-cost ratio for multi-user managed lanes, as long as these lanes are designed to support a high quality of transit service. As such, planners and policymakers should consider the potential benefits for transit users when making decisions regarding policies, investments, and facility design and operations related to managed lanes.

Definition of Scenarios

Four managed lane scenarios were examined:

- Scenario 1 includes a base scenario (existing and planned managed lanes, and the Highway 407 ETR), plus potential HOV / HOT initiatives being considered by MTO.

- Scenario 2 extends Scenario 1 to make continuous corridors, with managed lanes implemented at two strategic locations.
- Scenario 3 extends Scenario 2 to develop a continuous, circumferential managed lane network that provides suburb-to-suburb links, while connecting two key suburban employment growth clusters.
- Scenario 4 assumes a continuous managed lane system across the entire GTHA expressway network.

Approach

The analysis was based on estimates of transit travel time savings that could be gained through the implementation of managed lanes on the 400-series highways as well as the Don Valley Parkway and the Gardiner Expressway. These savings were derived from GPS-based travel time data that were provided by GO Transit from its buses. Specifically, achievable time savings were estimated by comparing actual travel speeds and target free-flow travel speeds. GO travel time data from the 2015 PanAm / Parapan Am Games temporary HOV lanes were used to calibrate projected time savings, specifically by accounting for the impacts of managed lane length and discontinuity by applying a merge penalty to reflect delays incurred by buses entering and leaving the lane from and to mixed traffic. The analysis differentiated travel time savings by time of day, thereby accounting for congested conditions.

By design, the scope of this analysis did not include carpooling, focusing instead on transit. Nor is this analysis intended to consider alternate structures and regimes for a managed lane structure, again by design and scope. However, the aforementioned GO Bus gains, on which this analysis is based, were observed in managed lanes that mostly were shared with HOV3+ vehicles. Further analysis, beyond the scope of this study, is required to assess the impacts of alternate managed lane structures on bus travel time savings (e.g., HOT versus HOV usage, or an HOV2+ regime, and so on).

GO Transit services make up the large majority of eligible bus routes. Where municipal transit agency data were not available, the GO-generated travel time savings and characteristics such as occupancies were also applied to the expressway portions of bus routes operated by municipal authorities (Brampton Transit, Mississauga Transit, TTC and York Region Transit).

The travel time estimates were applied to existing ridership and bus volumes on the eligible routes, in order to derive vehicle-hours and passenger-hours of savings. Population and employment forecast factors were used to generate ridership forecasts to 2031. In order to account for the potential attraction of the improved services, an elasticity of demand with respect to travel time was applied, using an elasticity value of 0.5, as derived from the literature.

Benefits and Costs

The benefits for each scenario were expressed in terms of travel time saved by transit passengers, accounting for both existing bus riders and new riders who are attracted from other modes to the improved transit service. Also taken into account were savings in operator costs and external benefits relating to decongestion, reductions in traffic accidents, reduced GHGs and reduced CAPs (where the external benefits arise from the diverted new riders who almost entirely formerly use personal autos). All benefits were monetized for input to the BCA, using values of time developed by Metrolinx. The BCA covered a fifteen-year period, from 2017 (the first year) through 2031.

It was recognized that some expressway sections and interchanges have significant geometric, structural or other existing constraints that limit the type of managed lane that actually could be implemented, or which in practical terms would preclude the introduction of a managed lane altogether. It also was recognized that some constraints could be addressed although only at a high, undetermined cost and/or at some undefined time in the future.

Because of the uncertain feasibility of many expressway segments, these geometric and structural constraints were set aside in order to develop meaningful scenarios for the BCA. Instead, the consultant developed high-level, per-kilometre "representative" capital and maintenance costs estimates, based on the available information. These estimates were deemed sufficient for the purpose of this analysis, while acknowledging that the estimates are generic and that detailed analyses would be required to support the implementation of a lane on any specific segment.

It should be noted that the scenarios were modelled on the basis of existing bus routes, adjusted for projected general population and employment growth. Note also that although most of the daily travel time benefits occur during the two commuter peak, a significant benefit does occur during the midday peak – i.e., the benefit is not just limited to commuter peak periods. Detailed projections of future bus route networks – for example, accounting for a potential shift from radial to circumferential bus routes accompanying the implementation of regional express rail – were not available for this study. Similarly, the elasticity of demand with respect to travel time is applied to current route configurations. Moreover, it is conceivable that the travel time savings could increase as highway and road congestion grows across the GTHA. Finally, it can be anticipated that GO Transit and other transit agencies may adjust their entire networks to make better use of corridors with managed lanes; however, such shifts are not modelled in this study. The study results may thus represent a conservative estimate of bus-associated benefits.

A financial case also was developed.

Conclusions

The benefits and costs are compared for each of the four scenarios in Table ES1 below. As noted, only transit benefits are considered (i.e., no benefits from other potential managed lane users, such as HOT single occupant vehicles or HOV multi-occupant vehicles), whereas the full annualized lifecycle costs are assessed, assuming new infrastructure is required. As a result, the benefit-cost ratio remains below 0.2 for each of the scenarios, although the benefit/cost ratio grows as the expansiveness of the network increases because of the "network benefits" associated with corridor continuity. This suggests that constructing a network of new managed lanes purely for bus-associated benefits would not be economically justified, and so the transit benefits are best viewed as an increment that should be added to those that would accrue from other users, such as carpoolers or HOT users. In this case, the benefits listed in the table below would supplement any other benefits to non-bus riders. Furthermore, the cost figures provided in the table apply to the case of new lane construction (i.e. roadway widening). If managed lanes are implemented in such a way as does not require new lane construction, the benefit-cost ratio may be more favourable to managed lanes, although such a scenario is not considered in this study and would have to take into account travel time impacts on other displaced users.

Table ES1: Benefits and Costs by Scenario

	Kilometres	NPV Benefits to 2016	NPV Costs to 2016	B/C Ratio
Scenario 1	352	$34,985,486	$281,474,635	0.12
Scenario 2	377	$40,672,552	$314,770,447	0.13
Scenario 3	545	$89,110,005	$534,851,816	0.16
Scenario 4	1,066	$203,604,524	$1,220,916,629	0.16

Note: Only transit benefits are considered, against full annualized lifecycle infrastructure costs.

Many studies that have examined the potential benefit of managed lanes have focused on the benefits for auto users. The usual focus on auto users is reasonable given that those users are the primary users of the road network. This study reviewed the potential benefits of a network of managed lanes for transit users in the GTHA and found that the benefits to transit users can add up to 16 basis points to the benefit-cost ratio. As such, planners and policymakers should consider the potential benefits for transit users when making decisions regarding policies, investments, and facility design and operations related to managed lanes.

2.0 INTRODUCTION

Background

CPCS and DKCI have been retained by Metrolinx to investigate the potential economic value of significant changes in transportation outcomes as well as the marginal impacts that discrete interventions/strategies would have in accomplishing these outcomes. As a whole, the research includes four broad types of interventions/strategies: managed highway lanes, cycling, surface transit amenities and frequent transit corridor improvements.

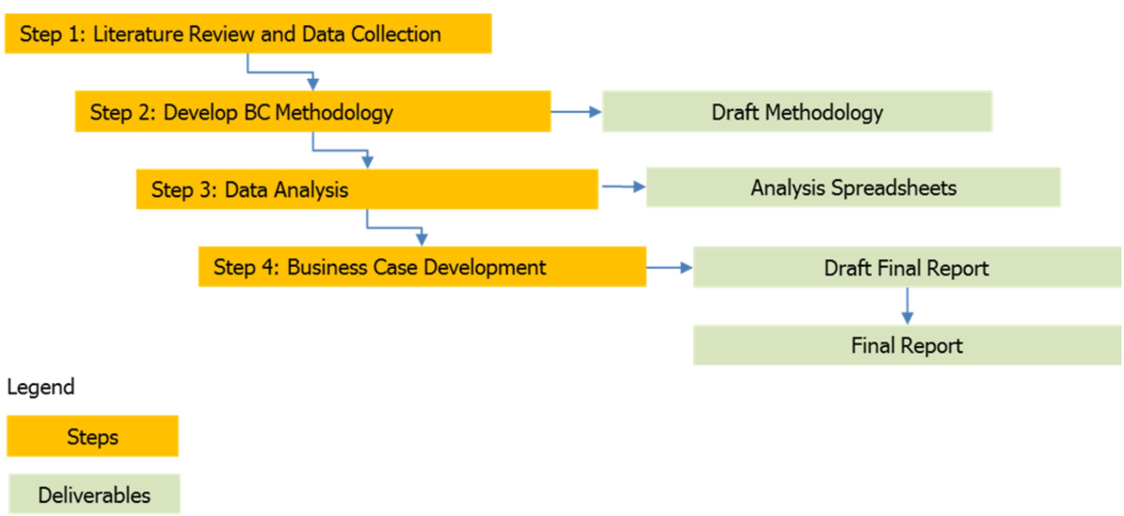
Objectives

The overall objective of the research is to contribute to the understanding of the relative values of different outcomes and how to prioritize investment strategies to achieve these outcomes through the identification of effective goals and support interventions. 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.

Project Structure

The project is being developed in two parallel phases. Phase 1 investigates the financial and economic implications of managed highway lanes and cycling interventions/strategies.[1] Phase 2 investigates the financial and economic implications of surface transit amenities and frequent transit corridor improvements. Each phase is broken into the following four steps with associated deliverables, as shown in Figure 1.

Figure 1: Approach – Economic Value of Regional Strategies to Improve Transportation Outcomes



[1] Note that these are two separate analyses that are conducted within the same Metrolinx project, using the same basic approach but having different inputs and methods.

Organization of this Report

This Draft Final Report describes the managed highway lanes analysis.[2] The report corresponds to Step 4 of the project approach.

The report is organized according to the structure used for Metrolinx's *Initial Business Case* studies,[3] modified to meet the focus of this project as described in the Objectives section above. It has eleven chapters:

1. Executive Summary
2. Introduction (this chapter)
3. Approach, including key assumptions, parameters, data sources and methodological basis
4. Description of the existing and potential future managed lane network
5. Method for estimating travel time savings
6. Definition of network options (scenarios) for testing
7. Estimation of benefits, covering travel time savings, incremental ridership and monetary benefits (value of time)
8. Sensitivity tests
9. Benefit cost analysis
10. Financial implications
11. Conclusions

A spreadsheet, which tabulates the data and the models and calculations upon which this report is based, is provided under separate cover.

What is a Managed Lane?

For the purposes of this analysis, a "managed lane" is defined as a lane, generally on an expressway, on which special access restrictions are imposed in order to provide priorities to certain types of traffic. The object is to improve the overall flow – that is, travel times and variability of the travel time - of expressway traffic. In most cases the managed lane is intended to operateat a higher speed (and with fewer vehicles) than general purposes lanes, although truck-only lanes might not operate at a higher speed but the primary benefit would come from the separation of trucks from automobiles and other vehicles. Depending on the type of managed lane, eligible traffic can include public transit vehicles, personal vehicles having a minimum number of occupants, single-occupant personal vehicles whose drives are willing to pay a toll and, in some cases, commercial vehicles.

Managed lanes have become an important component in increasing throughput and the performance of transit services on highways in many urban areas across North America and beyond. In the GTHA, GO Transit and several other municipal transit agencies operate scheduled bus services on the region's expressways – here defined as the 400-series Provincial highways and municipal expressways such as the Don Valley Parkway (DVP) and the Gardiner Expressway. In the GTHA, these facilities have taken the form of High Occupancy Vehicle (HOV) Lanes, Bus Shoulder Lanes, dedicated bus-only lanes adjacent to Highway 403 (Mississauga Transitway), and the use of the 407 ETR to increase the speed and reliability of services.

Temporary HOV lanes were introduced on selected GTHA expressways as part of the traffic management schemes for the 2015 Pan Am / Parapan Am Games. GO Bus users experienced significant reductions in journey times and in the variability of their trips through many (although not all) of these HOV lanes. The experience of the PanAm

[2] The other three analyses are documented separately. They are not considered further in this report.

[3] *Business Case Template, Initial Business Case*, provided by Metrolinx, March 2016.

Games suggests that transit users on local buses and GO buses that operate on GTHA highways could see significant benefits from enabling buses to operate in lanes managed to be congestion-free. The Ontario Ministry of Transportation (MTO) is now planning to introduce High Occupancy Toll (HOT) lanes, which allow single-occupant vehicles to use HOV lanes with the payment of a toll.

Note that this analysis focused on transit benefits only, by design. These benefits would complement those accrued by other users who might share the managed lanes. These users could include multi-occupant vehicles under an HOV scheme and single-occupant vehicles under an HOT regime.

Managed Lanes Working Group

A special Working Group was convened in order to provide guidance to the analysis, review assumptions and method, coordinate and provide data, and review the outputs and reports. Importantly, the Working Group also served as a forum to ensure that the managed lane analysis complemented and did not duplicate work in which MTO is currently engaged regarding managed lanes.

The Working Group comprised members of several Metrolinx groups and MTO offices:

- Metrolinx – GO Planning
- Metrolinx - Regional Planning
- Metrolinx – Planning Analytics
- GO Transit (Metrolinx) – Business Systems
- MTO – Passenger Transportation Office
- MTO – Transportation Economics Office
- MTO – Systems Analysis and Forecasting Office

Four Working Group meetings were held. They were staged strategically to introduce the project and the method (held on March 29, 2016), discuss proposed assumptions (May 18, 2016), review the preliminary analysis and scenarios (June 14, 2016) and review the final analysis and the interim Technical Memorandum (August 4, 2016).

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.

The primary authors of this report were David Kriger of DKCI and Veiko Parming of CPCS, under the direction of and with contributions from Vijay Gill of CPCS. This report does not represent any official policy or position of Metrolinx, MTO or GO Transit.

3.0 APPROACH

Objective

This chapter documents the approach and method for using benefit-cost analysis (BCA) to identify opportunities where managed highway lanes could benefit transit users in the GTHA, as well as the magnitude of benefit.

The objective of the analysis is to understand the potential economic value to transit users and agencies of being able to operate transit services on congestion-free managed lane facilities across the 400-series highways in the GTHA and on some City of Toronto expressways.

The BCA uses a Metrolinx template that is common to other initiatives. As noted, the BCA focuses primarily on the economic case, although a high level financial case also is documented in Chapter 10.0.

The economic value is derived from three types of outcomes:

- Benefits to existing transit users – the direct impacts to existing transit users associated with a reduction in journey times and improvements to journey time reliability.
- Benefits to new transit users – the direct impacts as a result of new transit users attracted to the reduced journey times and increased reliability of transit services on highways, including reduced auto operating costs, improved safety, reduced emissions and road congestion.
- Benefits to transit operators – the direct impacts of improved travel times, reliability and changes in ridership on vehicle operating costs and revenues.

The analysis also considers several types of costs. These comprise the costs associated with delay greenhouse gas (GHG) emissions, Criteria Air Pollutants (CAPs), fuel use, traffic accidents, vehicle operating costs and passenger delays. Most of these appear as reductions. However, a high-level, generic cost for new infrastructure also is taken into consideration. These are discussed in Chapter 7.0.

Premise

GO Transit and many other municipal transit services operate on the Ontario highway network. The province has committed to implementation of HOT Lanes across the 400 series highways. The experience from the PanAm Games suggests that transit users on local and GO buses that operate on 400-series highways could see significant benefits from reduced congestion on managed lanes.

Problem Statement

What is the potential economic benefit of congestion-managed lanes (HOT, HOV, tolled, etc.) on highways in the GO Transit service area that are designed to support existing/increased transit service? It is recognized that there are potential broader benefits; however, the focus of this analysis is on transit because that part of the equation is relatively unexplored. The paper will recognize the potential impacts to other users as well, but the focus of this assignment will be on impacts to transit users and agencies.

Key Assumptions and Parameters

The analysis was based on several assumptions and parameters:

- The intent of the analysis is to develop scenarios that are realistic while allowing for flexibility.

- The research focused on the benefits to transit users. Costs were based on high-level unit costs and the feasibility of different interventions in each corridor segment, in consultation with the Managed Lanes and Transit Working Group. The costs are described in Chapter 7.0.

- The term "managed lane" is not necessarily intended to refer to any specific improvement, other than to refer to an expressway lane that allows for free-flow travel by transit buses. Thus, truck-lane only lanes, which are a type of managed lane, are not considered in this study.

- The managed lane network options were defined at a high level. All Provincial expressways and key municipal roadways, such as the Don Valley Parkway and the Gardiner Expressway, were assumed to be eligible. The network was defined simplistically; that is, as connections between interchanges. Unless an obvious constraint was identified that would preclude the use of a section as a managed lane (e.g., a physical constraint between two interchanges), it was assumed that transit vehicles can enter or exit the managed lane at any interchange.

- Free flow speeds can vary depending on the configuration and length of the managed lane. For the purposes of this analysis, a single free flow speed was defined as a starting point, with possible subsequent variations to allow for the type of managed lane. The free-flow speed was determined using a segment-specific data-driven approach, as discussed in Chapter 5.0.

- GO Transit is by far the primary transit user of the existing managed lanes. However, several municipal transit operators also offer a limited number of services that use the existing managed lanes. These are the TTC, Brampton Transit, Mississauga Transit and York Region Transit. Their routes also are included in the analysis. Note that only services (routes) within the GTHA are included in the analysis.

- Only transit services (routes) that currently use the expressway system are considered as candidates for using the managed lane system, and it is assumed that these routes would use a managed lane if one is available. No reconfiguration of other routes is assumed, with one exception: it is assumed that GO Transit routes that formerly used the former Highway 7 in Durham have switch or will switch to the newly-opened Phase 1 extension of the Highway 407 ETR East and also to Phase 2, which is scheduled to open partially in 2017 and completely in 2020[4].

- The analysis is based upon observed data, trends and rates. It uses a spreadsheet, so as to allow quick updates in the event that a particular parameter value changes. The need to consider the short term and the focus on individual corridors and on services that have a relatively small mode share mean that the required analysis is too fine-grained to use the GGH model. Instead, an 'evidence-based' approach was deployed; that is, relying on observed conditions on individual corridors.

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4 Phase 1 opened to traffic on June 20, 2016. No information is available yet regarding the treatment of existing GO Bus service along this corridor.

- Given that the increase in ridership due to the improved travel conditions in managed lanes is modest (expected to be less than 10% increase under most conditions), this would generally not require additional transit vehicles on any route and thus this approach assumes transit headways to remain as they were prior to the introduction of managed lanes. The overall approach will slightly understate the benefits to auto drivers in the general purpose lanes given that the remaining volume of traffic will be reduced due to mode shifting to transit, leaving aside the issue of induced traffic demand.

- The ultimate time horizon is assumed to be 2031. Simple growth factors are developed from existing demographic, employment and travel forecasts, as available from MTO and Metrolinx. The growth factors assume the Places to Grow population and job distributions.

- The research is based on weekly totals, which are extrapolated to annual values for the BCA, by multiplying by 52 weeks. Time period data from GO Transit and the individual municipal operators were used to identify commuter peak period and off-peak period average travel speeds, bus service levels and bus occupants, in order to differentiate conditions by time of day.

- Ultimately, the network analysis should aim to identify where providing a congestion-free lane would offer the greatest benefit to transit users and agencies.

- The benefits to transit users are separated into two groups. The first group considers benefits to current riders. The second group considers benefits resulting from new riders (i.e. diversion of auto trips and the associated impacts).

- The diversions were estimated from elasticities of demand from elsewhere and from the consultants' and working group members' experiences. The elasticities were reviewed to ensure that they reasonably could be applied to the GTHA.

- The reporting for this analysis is being produced for both a technical and a non-technical audience, using a clear layout and plain language. All assumptions, methodologies and data are stated clearly and transparently.

- Throughout the course of the analysis, key assumptions and research parameters were discussed and agreed with the Working Group.

Data

The following data were used for this analysis:

- GO Bus CAD/AVL Data – primarily for identifying highway segment speeds, ridership, vehicle-kilometres and fleet requirements / frequencies. These data include 'with-and-without' analyses of GO Bus services on the temporary managed lanes that were put in place for the 2015 PanAm / Parapan Am Games.

- Similar tabulations for selected municipal transit routes, provided by Brampton Transit, Mississauga Transit (MiWay), the Toronto Transit Commission (TTC) and York Region Transit.

- PanAm OD Survey Reports – primarily for checking reasonableness of mode shift / elasticity assumptions as well as contextual information to help interpret analysis.

- GO Bus Passenger Survey Data and Summary Report – strategic and contextual information for describing the socio-economic characteristics of bus users, trip purposes and markets served.

- GIS files of GO and municipal transit service provider routes, from the respective agencies.

Other reports and data, notably the 2011 Transportation Tomorrow Survey (TTS), were consulted for reference or context.

The provision of these data sets to the consultant is acknowledged with appreciation, with a special thanks noted regarding the provision the GO Bus data and the municipal operators' data, which all required special tabulations, and for the GO Bus survey data, which similarly required special preparation. Note that the data were used as-is; that is, the scope of the analysis precluded any detailed review of the data sets.

Methodological Basis

The benefit-cost analysis uses Metrolinx's template. Accordingly, the key challenge of this analysis was to derive appropriate and meaningful inputs and assumptions. The methodological approach had the following tasks:

- Define key terms and assumptions: for example, "free flowing speeds."

- Identify the relevant (eligible) GO Transit and municipal bus routes that currently use the 400-series highways, the Gardiner Expressway and the Don Valley Parkway.

- Define network options to be tested. Scenarios were developed in consultation with Metrolinx and the Managed Lanes Working Group, taking into consideration the different managed lane options (HOV, HOT, Bus Shoulder Lanes, etc.), highway segment constraints that may impact feasibility, highway ownership, delivery and operating considerations and the relationship to other on-going highway programs and initiatives. These scenarios are described in Chapter 6.0.

- Use GPS travel time data gathered by GO Transit during and prior to the introduction of temporary HOV lanes during the PanAm and Parapan Am Games in the summer of 2015, in order to estimate [a] changes in journey time, from end-to-end (i.e., not just the HOV leg of the journey) and [b] changes in trip time variability (focusing on the HOV leg), hence in trip reliability. We also used GPS data from GO Transit and the municipal transit operators to define current characteristics.

- Estimate the current travel demand (ridership) for the relevant 'markets' served by the individual GO Bus and municipal routes, GO Bus on-board surveys, GO Bus boarding and alighting data, data from the municipal transit operators and other relevant data. This generated the "base" demand.

- Develop a spreadsheet that contains the data and formulae for all the above steps. This allowed each applicable route and bus run to be tagged with the appropriate highway section, so that individual sections could be easily switched on and off if a managed lane was added in a given scenario. Note that a travel demand network model was not intended for use in this analysis - that is, the assumed network configuration was intended to be at a high level. (i.e., details of the precise configuration of the network, its operation, locations of entry and exit points, etc., were less important or relevant.)

- For each network option, establish the type and length of the relevant improvement – for example, 4.5 kilometres of an HOV lane on Highway 401 between X and Y. This was used to estimate the anticipated travel time savings. It also identified sections to which the addition of an entry / exit penalty was needed, recognizing that some shorter sections would not necessarily achieve their full potential due to operational constraints.

- Using values of time from Metrolinx's current guidance, estimate how current transit riders benefit with a managed lane network in place, using the GO Transit and municipal transit operators' data to estimate the current travel demand for the relevant 'markets.' Associated impacts also are estimated, as applicable, on fuel use, GHG emissions, CAPs and traffic accidents.

- Develop an elasticity of demand with respect to changes in travel time and reliability, using observed rates from the consultants' experience and elsewhere. This elasticity was used to estimate the potential mode shift to GO Bus and potentially municipal buses, based on the assumed managed lane network options (scenarios). Elasticities were used to estimate changes in ridership, for two reasons: [a] they are most relevant to the scale of the analysis; and [b] a mode choice model is not available for this analysis in any event.

- Estimate the potential changes in transit ridership by applying the elasticity to the base demand, according to each option, as well as the associated monetary benefit. The analysis also considered the associated impacts on decongestion, GHG emissions, CAPs and traffic accidents.

- Develop and apply growth factors to estimate forecasts to the 2031 horizon year, using system-wide demographic or employment forecasts, or travel forecasts from Metrolinx's GGH model. High level assumptions regarding the future network, future levels of highway congestion and associated impacts on bus speeds will be informed by existing GGH modelling outputs where possible.

- Review the network options and the current and forecasted estimates of ridership and impacts to determine the network option of greatest benefit, while also considering the locations within individual options where the greatest benefits are achieved (e.g., the sections where the greatest travel time reductions are achieved).

- Consider the configurations that the network options could take, and – depending on the available data – develop high-level cost estimates.

- Prepare a benefit-cost analysis using the aforementioned high-level cost estimates, and accounting for the GHG, CAP, fuel use and other benefits. As noted, the focus will be on an economic BCA, with a high level financial BCA also being conducted, within the context of Metrolinx's Business Case Framework. (Note that the feasibility of conducting this analysis will depend on the usability of the findings of the previous step.)

- Conduct sensitivity tests to test the robustness of key factors and assumptions regarding the growth factors, values of time and/or elasticities, and how they impact the cost, revenue and diversion analysis.

- Integrate the findings into Metrolinx's template and report the findings.

Relationship With Other Studies and Tools

The literature allows for different approaches for benefit-cost analyses of transportation improvements, including network travel demand forecasting models, such as the one developed by MTO for the Greater Golden Horseshoe. The approach selected for this analysis is tailored to the scope and scale of the expected transit user and operator benefits. The approach takes advantage of the availability of unique short-term 'before and after' data from the PanAm / ParaPan Am Games HOV lanes. For all these reasons, a network travel demand forecasting model was not used for this analysis.

Other stakeholders might have an interest in assessing a broader range of impacts, according to their needs, and may wish to use a network travel demand forecasting model or other analytical approaches to meet their needs. For example, MTO and the City of Toronto are conducting managed lanes analyses of their own. The specific transit focus of the current initiative and its analytical basis are designed explicitly to complement these other analyses. However, it is important to acknowledge certain other benefits and costs that are not included in the current initiative:

- There may be additional benefits (and costs) associated with transit services that connect to the buses that use the managed lanes, if their efficiency improves or if additional local bus service is required to meet increased demand of the express services.

- Reduced auto operating costs and reduced congestion are cited in the Chapter 3.0 Objectives as benefits to new transit users. However, there also can be time and cost benefits to auto users who do not switch modes, if more efficient bus service allows for the better flow of automobiles on the managed lane corridors and the network. The time benefits to auto users can be substantial. In general, there can be both positive and negative impacts to other highway users. The analysis does consider positive benefits (specifically, decongestion); however, negative benefits are not considered because these would depend on specific interventions (see Chapter 9.0).

- There also may be benefits for commercial / truck traffic alongside auto users.

4.0 NETWORK DESCRIPTION

Introduction

This chapter describes the components of the existing managed lane system in the GTHA. It also notes planned and potential managed lanes that are now under study. The chapter also inventories the bus routes that use the GTHA's expressway system currently.

This information was used to define and assemble the necessary data and to develop the scenarios for analysis.

Inventory of Managed Lanes

Existing

HOV lanes exist today on Highway 403 in Mississauga, Highway 404 in York Region and Toronto and the QEW in Burlington and Oakville.[5]

- Highway 403 EB – from west of Winston Churchill IC to Matheson Blvd E (approach to Highway 401 IC).
- Highway 403 WB – from south of Highway 401 / 410 (north of Matheson Blvd E) to approach to Winston Churchill IC WB off-ramp.
- Highway 404 SB – from north of Highway 7 to the DVP.
- Highway 404 NB – from north of Van Horne Ave (north of Sheppard Ave E IC) to north of Highway 407 ETR (to Highway 7 IC NB off-ramp).
- QEW EB – from Guelph Line IC to Trafalgar Road IC.
- QEW WB – from Trafalgar Road IC to approach to Guelph Line WB off-ramp.

Temporary HOV Lanes for the PanAm / Parapan Am Games

Several temporary HOV lanes were implemented on Provincial and City of Toronto expressways from late June to mid August 2015, as part of the traffic management scheme for the 2015 Pan Am / Parapan Am Games. Even though the lanes no longer are designated for HOV, the Games HOV initiatives are noteworthy for the transit Managed Lanes study because of the observed benefits they offered to GO Bus trip times. The temporary HOV lanes were located as follows:[6]

- Don Valley Parkway NB and SB – between Dundas Street E and York Mills Roads.
- Gardiner Expressway EB and WB – between Highway 427 and west of York Street.
- Highway 401 EB and WB – between Warden Avenue and Westney Road.

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5 Source: http://www.mto.gov.on.ca/english/traveller/trip/map.shtml

6 Source: https://www.ontario.ca/page/pan-amparapan-am-games-transit-driving-and-traffic-routes#section-1

- Highway 401 WB – from Highway 427 to Kennedy Road.
- Highway 427 NB and SB – between Highway 401 and terminus at QEW/Gardiner.
- QEW EB and WB – between Brant Street in Burlington and Highway 427.

HOT Lanes

In December 2015, MTO announced its intention to convert the existing QEW HOV lanes to High-Occupancy Toll (HOT) lanes, as a pilot to test the HOT concept. The announcement also noted that HOT lanes would be introduced on a section of Highway 427 starting in 2021, as part of "broader HOT lanes implementation." The proposed HOT sections are as follows:[7]

- QEW EB and WB – between Guelph Line and Trafalgar Road (replacing existing HOV lanes, as above) – to be implemented in the summer of 2016.
- Highway 427 NB and SB – from south of Highway 409 to north of Rutherford Road, starting in 2021. Note that the section of HOT lanes between Highway 7 and Rutherford Road will be on the Highway 427 expansion to Major Mackenzie Drive, the tendering for which is now underway.

Bus Lanes on Shoulders

Bus bypass lanes (BBL) exist in two locations today:

- Mississauga Transit (MiWay) and MTO introduced Bus Bypass Shoulders (BBSs) on Highway 403 in 2003, between Erin Mills Parkway and Mavis Road. The BBSs have saved up to 10 minutes per trip during peak times.[8]
- BBLs were introduced on the shoulders of the Don Valley Parkway in 2010, between Lawrence Avenue and a point 458 metres (approximately 1,500 feet) north of York Mills. The BBLs are open to use by GO Buses only.

Buses can use the BBLs only when traffic on the general purpose lanes is travelling at 60 kph or less. Note that for reasons of traffic safety, once on the BBL, they cannot travel at speeds faster than 20 kph greater than that of the general purpose traffic – meaning the speed on the BBL cannot exceed 80 kph.

Note that the Highway 403 BBLs co-exist with a section of the aforementioned HOV lanes, and GO Bus operators use the HOV for most trips, except during slow traffic conditions, when they have the option of using the BBLs.

[7] Source: https://news.ontario.ca/mto/en/2015/12/ontarios-plan-for-high-occupancy-toll-lanes.html

[8] Source: http://www.mississauga.ca/portal/residents/brtbasics?paf_gear_id=9700018&itemId=102600573n

Planned HOV Initiatives

MTO's *Southern Highways Program 2015-2019* identifies several GTHA HOV initiatives that the Ministry plans to implement or are now underway. As can be seen in Table 1, four initiatives are new HOV lanes on Highways 400, 401 and 410, one is an extension of the existing Highway 404 HOV lanes, and one is the introduction of a new HOT lane on Highway 427.

Table 2 lists four potential future (post-2019) HOV expansions that might be considered for future development. Two are on Highway 400 in York Region, and the other two are on Highway 403 and the QEW in the City of Hamilton, Halton Region and Niagara Region. None of these initiatives has status currently. All are subject to further study and prioritization.[9]

Table 1: Planned HOV Initiatives

Highway	Status	Location	Type of Work	Target Completion Date*
400	Underway	Major Mackenzie Drive to King Road, York Region	New HOV	2019
401	Underway	Hurontario to Credit River Bridge, Peel Region	New HOV	2018
401	Planned	Credit River Bridge to Regional Road 25, Halton and Peel Region	New HOV	Beyond 2021
404	Planned	Highway 407 ETR to Stouffville Road, York Region	HOV expansion	2021
410	Underway	Highway 401 to Queen Street, Peel Region	New HOV	2018
427	Underway	Highway 409 to Rutherford Road, York Region	New HOT	2021

* The timing of projects in the following lists is subject to change based on funding, planning, design, environmental approval, property acquisition and construction requirements.

Table 2: Potential Future HOV Expansions

Highway	Location
400	Langstaff Road to Major Mackenzie Drive, York Region
400	King Road to Highway 9, York Region
403	Brant / Hamilton boundary to Highway 403 / QEW interchange, City of Hamilton and Halton

9 Source*: Southern Highways Program 2015-2019*, Ontario Ministry of Transportation, 2015. See http://www.mto.gov.on.ca/english/highway-bridges/pdfs/southern-highways-program-2015-2019.pdf. Information updated per M Brewer (MTO) e-mail to consultant, August 5, 2016.

	Region
QEW	Highway 406 to Guelph Line, Niagara Region, City of Hamilton and Halton Region

Inventory of Bus Routes

Table 3 lists the existing bus routes that use the expressways for all or part of their itineraries. This list is important for the estimation of ridership as well as for informing the development of the network options.

The list comprises GO Transit as well as the six municipal transit operators that are known to operate at least one route on an expressway.

The list is detailed by expressway. Note that Highway 401 is divided into sections east and west of Yonge Street (with one route – GO Route 92 – using both sections). Highway 427 is divided into sections north and south of Highway 401.

GO Transit has by far the greatest number of eligible routes (25), which is consistent with its role as an inter-regional carrier. Among the municipal operators, Mississauga Transit and York Region Transit have the greatest number of eligible routes (10 and 9, respectively), followed by the Toronto Transit Commission (4) and Brampton Transit (1).

Note that Grand River Transit operates two routes on Highway 401. However, these routes operate entirely within the Region of Waterloo, and so it is not considered further. Hamilton Street Railway has one route that uses only a short portion of the Red Hill Creek Parkway, and is not considered further.

It can be seen that the expressway network in the western GTHA (that is, west of Yonge Street), especially Highway 401, Highway 403, the Highway 407 ETR and Highway 427, support the greatest number of routes.

Table 3: List of Current Routes that Use Expressways

Highway	GO	BT *	GRT	HSR	MT *	TTC *	YRT *
400	60, 66						360
401 (w of Yonge)	19, 25, 27, 29, 34, 36, 38, 40, 47, 48, 60, 66, 92		200, 203 **		57, 70, 108		360
401 (e of Yonge)	51, 67, 88, 92, 93, 96						
403	16, 19, 25, 29, 40, 45, 46, 47				109, 110		

404	51, 67						320
407	20, 25, 29, 32, 36, 40, 45, 46, 47, 48, 51, 52, 54	501A					77A, 300, 301, 302, 303, 304, 760
409	34						
410	32, 45, 46, 47						
427 (n of 401)	36, 40	501A					
427 (s of 401)					11, 35, 57, 70, 71, 76, 108, 109	191, 192, 300A	
QEW	12, 16, 40, 47				4, 71		
DVP						144	
Gardiner	16				71		
Red Hill				11			

* List of routes for BT, MT, TTC and YRT provided by the respective operators.

** Operates on Highway 401 within Region of Waterloo only. No GRT routes operate within the GTHA.

Key: GO = GO Transit (bus), BT = Brampton Transit, GRT = Grand River Transit, HSR = Hamilton Street Railway, MT = Mississauga Transit (MiWay), TTC = Toronto Transit Commission, and YRT = York Region Transit.

Segments for Data Assembly

The network descriptions and inventories were used to define ‘segments’ for the purposes of data collection and analysis. Segments normally started and ended at managed lane start and end points or at interchanges. In some cases, the segments combined groups of interchanges, if buses did not enter or exit the intermediate interchanges. Over 100 segments were identified, and data were collected in each direction of the segments. As well, the 16 expressway-to-expressway interchanges were identified as separate segments, given their complexity and the fact that some of these have geometrical or structural constraints that could preclude their ability to support a managed lane.

5.0 METHOD FOR ESTIMATION OF TRAVEL TIME SAVINGS

General

Time Periods

To account for temporal variation in speeds and occupancy (loadings), the time savings were computed separately for five time periods and then summed to yield daily totals. The time periods are defined in Table 4.

Table 4: Definition of Time Periods

Period	Definition
AM Peak	6 AM – 9 AM
Midday	9 AM – 4 PM
PM Peak	4 PM – 7 PM
Evening	7 PM – 11 PM
Overnight	11 PM – 6 AM

Estimation of Travel Time Savings

The amount of time that travellers would theoretically save as a result of managed lanes is dependent on the following factors:

- The current travel speeds without the managed lanes (i.e. actual speeds)
- The potential achievable travel speeds with the managed lanes (i.e. target speeds)
- The number of buses on each highway segment
- The occupancy of the buses

Actual Speeds

GPS travel speed data were obtained from GO Transit for all highway segments in the GTHA. The data were retrieved for a one-week period in October 2015. October is commonly used as a representative month, given the lack of anomalous factors influencing travel (school breaks, summer vacations, holiday travel patterns, winter weather and so on). This study focuses on working weekday travel: the “week” was defined as Monday to Friday.

Since the data are from GO Transit, they represent actual bus trips, as distinct from trips by all highway vehicles. Speeds were calculated using the recorded travel time and segment distances obtained from an accompanying KML file. Anomalous (low) speeds were rejected a) if they were in the 1^{st} percentile, or b) if they were under 10 kph. The low speeds were likely caused by extreme incidents or by vehicles exiting and entering the highway within a single segment, such as at park & ride lots (though in almost all cases the latter was controlled for through segment definition). At the high end, speeds were rejected if they exceeded 120 kph, although anomalously high speeds were not overall a significant concern.

Actual speeds were calculated as the average of all speeds over the week for a given segment, by direction and by time period.

Target Speeds

Target speeds were initially set at the free flow speed (FFS), which was defined as the 95th percentile speed for the directional segment (across all observations for the week). However, the target speed was reduced in some cases in which the FFS seemed inflated compared to the average speeds achieved throughout the day.[10] As well, for the bus bypass shoulder lanes on Highway 403 and the DVP, the maximum allowable speed was set according to the criteria defined in Chapter 4.0, meaning that this speed could never exceed 80 kph.[11]

Using free-flow speed alone as the target would imply that the buses are able to make full use of the entire length of the managed lane. This is not the case where buses must enter and exit the highway to make stops (e.g. at 401-Yonge Street to access TTC stations), or where managed lanes are discontinuous, such as at highway-to-highway interchanges (e.g. from the DVP to Highway 401). In such situations buses typically are forced to merge with general-purpose traffic, creating a "merge penalty." Although the magnitude of such a penalty depends on a

[10] In a few cases, the FFS was well above the average speed in all periods of the day, including the overnight period when it would generally be expected that FFS could be reached. Thus, in cases where the average travel speed for each period of the day was less than 90% of the calculated free flow speed, the target speed was defined as the maximum of the five period-averages, which was deemed to be a more realistic value than the FFS. This correction was applied for 26 of the 297 directional segments. In addition, as discussed there were a few cases in which buses exited and entered the highway mid-segment, such as at a park & ride facility, although most of these were controlled for through segment definition. Using the FFS or even the modified target for these segments would have posed a problem in situations where some buses travelled express through the segment (possibly achieving close to FFS), and others stopped, achieving speeds well below the FFS (though possibly still above the anomaly threshold). This would have led to a false sense of congestion and achievable time savings. These segments were identified manually; the relevant locations were Allen Road - Highway 401 interchange, Highway 407 at Trafalgar, and Highway 400 at Major Mackenzie. In the first two cases an arbitrarily low target speed was set so that no travel time savings are attainable from managed lanes. This was deemed reasonable because the vast majority of GO buses exit the highway at Yorkdale (thus having no advantage from managed lanes through the interchange) and buses generally do achieve close to the FFS elsewhere on the 407. In the third case the target speed was set at the average of the AM peak, midday, and PM peak period speeds. This is likely conservative but ensures that some travel time savings are attainable for the peak period and peak direction (e.g. southbound in the AM peak).

[11] As noted in Chapter 4.0, on Highway 403 GO buses usually use the HOV lane rather than the BBL. The consultant reviewed the available GPS data, and found that the speeds on the relevant sections already were fairly high, with the lowest period's average speed being 76 kph. This suggests that the HOV lane in fact is preferred by operators over the BBL. However, the actual choice of lane cannot be determined with complete certainty. In any event, no improvements are planned or envisioned for this section of Highway 403, and so none of the scenarios results in any time savings. Accordingly, the choice of lane on this section of Highway 403 does not matter for the purposes of this analysis.

variety of contextual factors, such as the type of managed lane, its relative location within the highway, and the frequency of merge points, we use a simplified approach applying a formulaic merge penalty that is a function of the underlying congestion level.

Merge Penalty

This analysis uses data from the temporary HOV lanes that were in place during the 2015 Pan Am / Parapan Am Games to generate an estimate of a "merge penalty" applied to buses entering and exiting the managed lanes. These data were obtained from GO Transit for a three-week period in July 2015 during which the temporary HOV lanes were in effect. The data were obtained for 14 HOV facilities (7 times two directions), each of which was non-continuous with others (i.e. required merging with general traffic at both ends).

Many of the facilities achieved speeds close to free-flow speed, but others did not. According to GO Transit, the primary reason for not achieving FFS was due to having to merge with general-purpose traffic.

For the purpose of estimating a merge penalty, the hypothesis is that the greater the level of congestion on a corridor, the more time would be lost to merging. The level of congestion was measured as the ratio of actual speed to FFS (defined as 95th percentile speed over the Games period). The 14 facilities were broken out by time period to distinguish between variable congestion levels throughout the day.

Through linear regression it was determined that 100% FFS was associated with 0.1 minutes of delay, with an additional 0.5 minutes of delay for every 10% below FFS (e.g. 90% of FFS – 0.6 min). Implicitly this formulation assumes that the delay is a function of the number of times the bus has to merge with general purpose traffic (i.e. twice) and does not depend on the length of the segment. This is intuitively logical, as a longer HOV lane likely has more efficacy than a short one. Thus, the effect of the penalty is that it dissipates over long segments but takes away much or all of the benefit of short segments.

The application of the penalty depends on the continuity of bus travel from segment to segment. For any two successive segments, some buses will travel "straight through" while others will have to exit the highway. The data retrieved from GO Transit are not arranged by route and thus the exact patterns of bus movements were not known. Instead, continuity is estimated by analyzing bus volumes on successive segments. For example, if successive segments A, B, and C have 750, 1,000 and 1,250 buses respectively, the middle segment B is assigned a 25% penalty at its start point (1 – 750 / 1,000) and a 0% penalty at its end point, for an average penalty of 12.5%.[12] In other words, it is assumed 75% of the buses on segment B are continuing from segment A (and 25% are entering anew), and all 100% of the buses are continuing to segment C.

The above application assumes a continuous network of managed lanes. If a managed lane ends (such that the next segment has no such lane), the end penalty is assumed to be 100% irrespective of bus volumes, as all buses must exit the managed lane. For simplicity, managed lanes are assumed to be discontinuous for all highway interchange turning movements (e.g. northbound to eastbound), but are assumed possibly to be continuous (depending on the scenario) for through movements.

[12] In other words, if the highway segment is at 80% of FFS and has a potential 1.1-minute merge delay, only 12.5% of this delay is assigned to the segment (0.125*1.1 minutes), reflecting the share of traffic that is assumed to require merging.

There are also locations where some buses exit the highway and re-enter at the same interchange, notably to serve park & ride stops. In this case the volume method described above would not indicate any buses leaving the managed lane. Detailed route data are not available, but a simple survey of GO's route schedules was used to estimate a proportion of buses (rounded to the nearest 25%) that are using these stops, compared to travelling express past the stops.

Overall, this method is an approximation that makes use of many simplifying assumptions. The purpose of this method is to reflect at a high-level, and using available local data, that managed lanes are most effective where:

- Congestion is high.
- The managed lane is continuous rather than disjointed.
- The buses use the lane for long stretches rather than frequently entering and exiting.

A more detailed, granular analysis would be required to evaluate the benefits of any single individual proposed managed lane. For example, this method is not so detailed as to evaluate the optimality of merge locations with regard to bus routes; implicitly it is assumed such locations are equally optimal for buses as the ones in place during the Pan Am / Parapan Am Games.

Time Savings per Vehicle

The potential achievable time savings per vehicle is calculated as the segment distance divided by the difference between the target and actual speeds. This is the time savings assuming full continuity from segment-to-segment.

The anticipated time savings is determined by subtracting the merge penalty, to a minimum of zero time savings (a negative value would indicate that the bus is losing time using the managed lane, in which case it is assumed the bus will use general-purpose lanes instead).

Number of Buses on Highway Segments

The GO bus sample represents a complete sample of bus travel on the given segments for the given week. The volume for each segment is calculated by counting the number of observations for the segment, direction, and time period.

The time savings per vehicle is multiplied by the bus volume to determine the total vehicle-hour savings per week. This is done separately for all five time periods of the day and then summed.

Bus Occupancy

Bus occupancy (loading) data were also obtained from GO Transit. The coverage is much more variable than for the speed data, because not all of the automatic passenger counters functioned properly. On some routes and for some time periods, this resulted in a very small number of observations. Where sample size was an issue (taken as a threshold of 15 observations), the system-wide occupancy for the relevant time period was applied. Although this method does not account for directionality, it is deemed less problematic than using occupancy values derived from only a handful of (potentially anomalous) trips. Table 5 lists the calculated average occupancies.

For each segment and time period, occupancy is calculated as the average of all observations for which data were available. The bus volumes include deadheads, so zero values are retained for consistency. It is assumed that counters are no more or less likely to malfunction for deadhead trips than for revenue service trips.

Table 5: Bus Occupancies by Time of Day

Period	Average Occupancy (ppl/bus)
AM Peak (6 AM – 9 AM)	22.1
Midday (9 AM – 4 PM)	18.7
PM Peak (4 PM – 7 PM)	25.6
Evening (7 PM – 11 PM)	15.2
Overnight (11 PM – 6 AM)	8.9
Total	19.5

Other Municipal Agencies

The methodology for time savings was applied similarly to other municipal transit agencies as to GO Transit. In general, the portion of trips made by these other agencies on the highway network was small compared to the coverage of GO buses, except for certain specific corridors (e.g. Highway 427 in Etobicoke).

Schedule, route and occupancy data were obtained from TTC, MiWay (Mississauga), York Region Transit, and Brampton Transit for all routes that operated at least partly on the highway network. For the latter three systems, the occupancy (passenger load) data were available for all runs and were specific to the last stop before the bus enters the highway segment. In the case of TTC, only peak period peak direction volumes were provided. Because this could not be reconciled with the study methodology, average system-wide occupancies for GO were applied instead - in any case TTC's operations on highways are not as extensive and mostly limited to the DVP and 427 corridors. Performance (travel time) data were also obtained from these other agencies, but these were generally in the form of scheduled rather than actual travel times and often rounded to the minute. Since the GPS data obtained from GO were much more robust and precise, these data were applied to routes from all agencies.

The highway segmentation scheme most appropriate to GO routes did not necessarily align with the routes of other agencies – for example, in many cases buses enter and exit mid-segment. To account for this issue, non-GO routes are assigned a fraction of the benefit for each segment as a function of the share of the segment distance covered by the route. (The merge penalty is still applied as a function of continuity, as with the GO routes.)

Results

General Results

Table 6 shows how the typical travel time savings of centre-road managed lanes vary by segment distance and baseline bus travel speeds. Baseline travel speed refers to the actual observed bus speed under present conditions (i.e. assuming no availability of a managed lane) and is a measure of the degree of congestion. (For this study, these speeds were obtained from GO Bus GPS data as detailed in the previous section). For convenience, the calculations in Table 6 reflect intervals of 10 kph and distances of 2.5 km, using interpolations of the aforementioned source data.

Table 6 is a simplified expression of the following formula:

$$\left(\frac{D}{v} - \frac{D}{100}\right) \times 60\,\frac{min}{hr} - \; 2 \times \left(2.52 - 2.47 \times \frac{v}{100}\right)$$

where D is the segment distance in kilometres, v is the speed in kph, 100 is the target speed in kph, and 2.52 and 2.47 are penalty factors derived from the analysis of the HOV data (x2 for both ends of the segment).

The calculations and the penalty factors are derived from the GO PanAm / Para Pan data, for all seven corridors and all directions for which data were provided to the consultant (i.e., including data for the sections that successfully reduced GO Bus travel times and those – Highway 427 and Highway 401 between Warden and Brimley – that were less successful due to operational constraints).

Table 6: Travel Time Savings (minutes) per Bus, for Centre Travel Lane

	Baseline (Actual GPS-Observed) Bus Travel Speed on Highway Segment under Present Conditions (no Managed Lane), kph						
Distance (km), below / speed (kph), right	30	40	50	60	70	80	90
2.5	0	0	0	0	0	0	0
5	3.4	1.4	0.4	0	0	0	0
7.5	6.9	3.7	1.9	0.9	0.3	0.0	0
10	10.4	5.9	3.4	1.9	1.0	0.4	0.1
12.5	13.9	8.2	4.9	2.9	1.6	0.8	0.2
15	17.4	10.4	6.4	3.9	2.3	1.2	0.4

As shown, the achievable travel time savings are a function of the baseline travel speed on the highway, as well as the length of the managed lane. For a managed lane of only 2.5 km, there is little or no benefit from managed lanes, and a 5-km lane is only useful if travel speeds are under 60 kph.

The table shows the importance of network continuity. The efficacy of managed lanes may be hampered by:

- Buses having to cross general-purpose traffic lanes to enter or exit the highway.
- Backups that form as a managed lane ends and vehicles are forced into the adjoining general purpose lane.
- Heavy use of the managed lane by other road vehicles.
- Slowdowns caused by other road vehicles entering or exiting the managed lane at merge locations or (depending on highway design) illegally at mid-segment locations.

All of these issues are magnified by short lanes and/or congested general-purpose traffic. It is not possible in this study to disentangle the various causes of a "merge penalty," and future studies must identify the traffic impact of individual parameters specific to the design of a managed lane. However, it is clear that a disjointed network is highly unlikely to have benefits approaching those of a long, continuous lane. It also should be noted that bus route designs also have a significant impact on the efficacy of managed lanes. If a centre-road managed lane is 15 km in length but bus routes require entering and exiting the highway every 5 km, the effective length of the managed lane is also only 5 km.

Finally, it should be noted that the aforementioned analysis and data sources all reflect current conditions. It is conceivable that the benefits actually would grow if and as congestion gets worse over time.

6.0 DEFINITION OF NETWORK OPTIONS

Introduction

This chapter defines the network options that were tested. The scenarios were developed in consultation with Metrolinx and the Working Group, taking into consideration the different managed lane options, highway segment constraints that may impact feasibility, highway ownership, delivery and operating considerations and the relationship to other on-going highway programs and initiatives. The development of the scenarios also was informed by an analysis of the travel time data.

Assumptions

The options are intended to reflect fundamental differences while also remaining plausible and meaningful. Key assumptions were:

- As noted, managed lanes can refer to different types of lanes - HOV, HOT, bus shoulder lanes, and so on. For the purposes of this analysis, all of these types are eligible for consideration, with the key point being that they are available to transit. The lanes might or might not be open to other, non-transit vehicles: This is immaterial so long as the bus level of service is not impeded by other traffic, and this is assumed to be the case. The managed lane can also be a new lane (i.e., through the widening of the highway) or it can represent the re-use of an existing general purpose lane – again, the key point is that it supports transit at higher, less variable speeds. The rationale for this broad and generic definition is to obviate the need to develop specific details for each managed lane network scenario: This is not possible in light of the many possibilities for planned and potential HOV expansions, described in Chapter 4.0, and the fact that MTO is currently examining the feasibility of converting all or part of its GTHA HOV network to HOT lanes.

- Any segment of the GTHA expressway network was considered as being a candidate for the introduction of managed lanes for transit, irrespective of ownership – i.e., all Provincial and municipal expressways are eligible. This allows for the potential development of a seamless and integrated network.

- However, managed lanes were not be included on Highway 407 ETR, given that the facility is assumed always to operate at an acceptable level of service, with additional general purposes lanes to be added at strategic intervals in order to maintain this level of service. As a result, it is assumed that the addition of managed lanes would not add meaningful savings in travel time.

- Transit buses will be eligible to use the planned / potential HOT lanes with no toll being charged (or, at least, the bus will always use the HOT lane even if a toll is charged).

- The additional (or expanded) managed lanes for transit will not extend beyond the current transit itineraries that are on the facility today.

- Managed lanes were not added on the section of Highway 403 that parallels the Mississauga Transitway, which is now under construction. For the purposes of this analysis, it was assumed further that no other bus rapid transit infrastructure will be implemented along the rights of way of any of the expressway corridors.

Scenarios

The scenarios were developed in consultation with the Working Group. Five scenarios were proposed. These are described and illustrated below.

- Base Case: Existing HOV lanes and BBLs, plus the HOV / HOT initiatives that are now underway or are planned, as described in Chapter 4.0 and listed in Table 1. The base scenario is illustrated in Figure 2. Note that the existing lanes are shown in red, the planned or underway initiatives are shown in green, and interchanges with existing lanes are shown in yellow.

  In addition, insofar as this analysis is concerned, the Highway 407 ETR effectively acts as a managed lane over its entirety – meaning that there is no benefit to adding a managed lane to this facility hence no travel time benefits will accrue on Highway 407. As a result, the Highway 407 ETR is included in the Base Case for its entire length, including the newly opened and under-construction sections in Durham and the Highway 412 and 418 connectors to Highway 401. These are all shown in maroon on the figure. Dashed lines depict the sections that are currently under construction.

- Scenario 1: Base case, plus the potential HOV / HOT initiatives listed in Table 2. Figure 3 shows this scenario, with the potential additional segments shown in purple. Note that in three locations, it is understood that managed lanes also will be included through the interchanges: Highway 403/410/401, QEW/Gardiner at 403, and Highway 400 at 407.

- Scenario 2: Scenario 1 extended to make continuous corridors, through the extension of managed lanes at two locations: Highway 403 between the QEW/Gardiner/403 interchange in southwest Mississauga and the HOV / BBS lanes at Winston Churchill Drive, and the connection of the Highway 404 and DVP managed lanes through the Highway 401 interchange. These improvements are shown or outlined in blue in Figure 4.

- Scenario 3: Based on Scenario 2, this scenario proposes a continuous, circumferential managed lane network that provides suburb-to-suburb links. It also connects two key suburban employment growth clusters: These are the Meadowvale – Hurontario - Airport Corporate Centre Cluster in Mississauga along Highway 401, and the Richmond Hill / Markham Cluster, centred about Highways 404/407.

  Figure 5 shows the concept in light blue. The concept is defined mainly by Highway 403 and Highway 401. It beings on Highway 403 from King Street in Hamilton, follows the QEW corridor from Burlington through Highway 403 in Mississauga, connects to Highway 401, and extends east to the Waverly Road (Martin Road) interchange in Bowmanville (where GO buses would access the Bowmanville GO station). There is also a western Highway 401 leg, extending to Milton. The key employment growth nodes are shown in orange, and the clusters are depicted by the yellow ovals.

  Note that Figure 5 also shows a third employment growth node, in downtown Toronto. Given that this node is well served by GO Rail, GO Bus and the TTC, it is not included in the concept. The three employment growth nodes were identified in a 2015 study as being the top three locations for growth in office space.[13] These are illustrated in Figure 7.

[13] *The Future of Office Development in the GTHA, The Nodal Study*, Strategic Regional Research Alliance, Toronto, March 2015.

- Scenario 4: Based on Scenario 2, this scenario assumes that all expressways are connected, from the urban limits in Hamilton and Highway 401 at the Halton / Wellington boundary, through the limits of all existing and planned expressway extensions in Peel and York, the completion of Highway 407 East Phase 2, and Highway 401 as far as its interchange with Highway 35/115. The scenario also includes managed lanes through the relevant interchanges. The potential extensions are shown or outlined in orange, in Figure 6.

Scenarios 1 and 4 are described as 'bookend' scenarios, in that they portray the minimum and potential maximum extents of any managed lane network. Scenario 2 is conceptually close to Scenario 1, in that it seeks to make continuous managed lane corridors through investments at two strategic locations. Scenario 3 aims to improve suburb-to-suburb transit service levels, complementing other Metrolinx transit initiatives.

Figure 2: Base Scenario – Existing + Planned/Underway

Figure 3: Scenario 1 – Base + Initiatives Under Study

Figure 4: Scenario 2 - Corridors

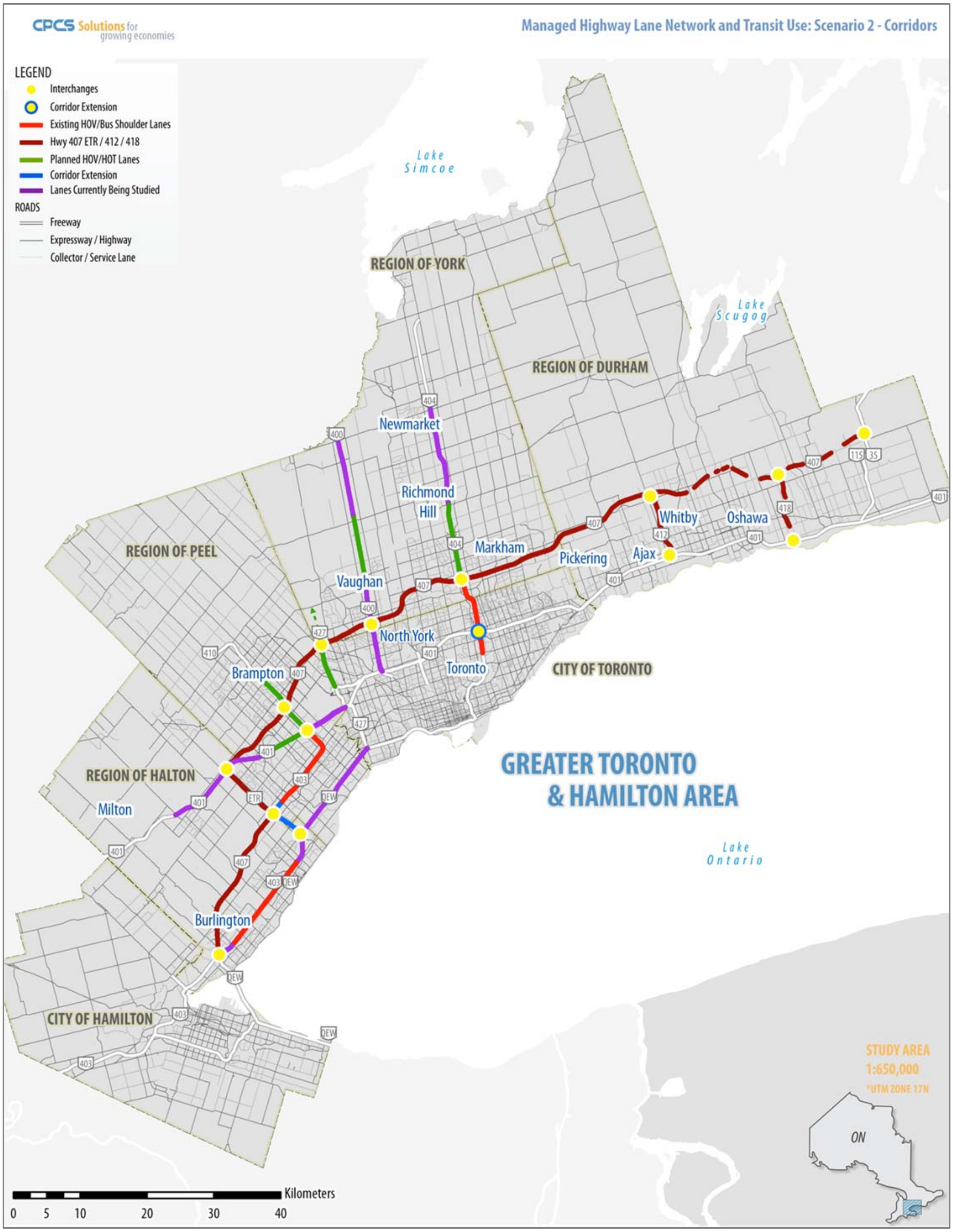


Figure 5: Scenario 3 – Circumferential / Employment Growth Nodes

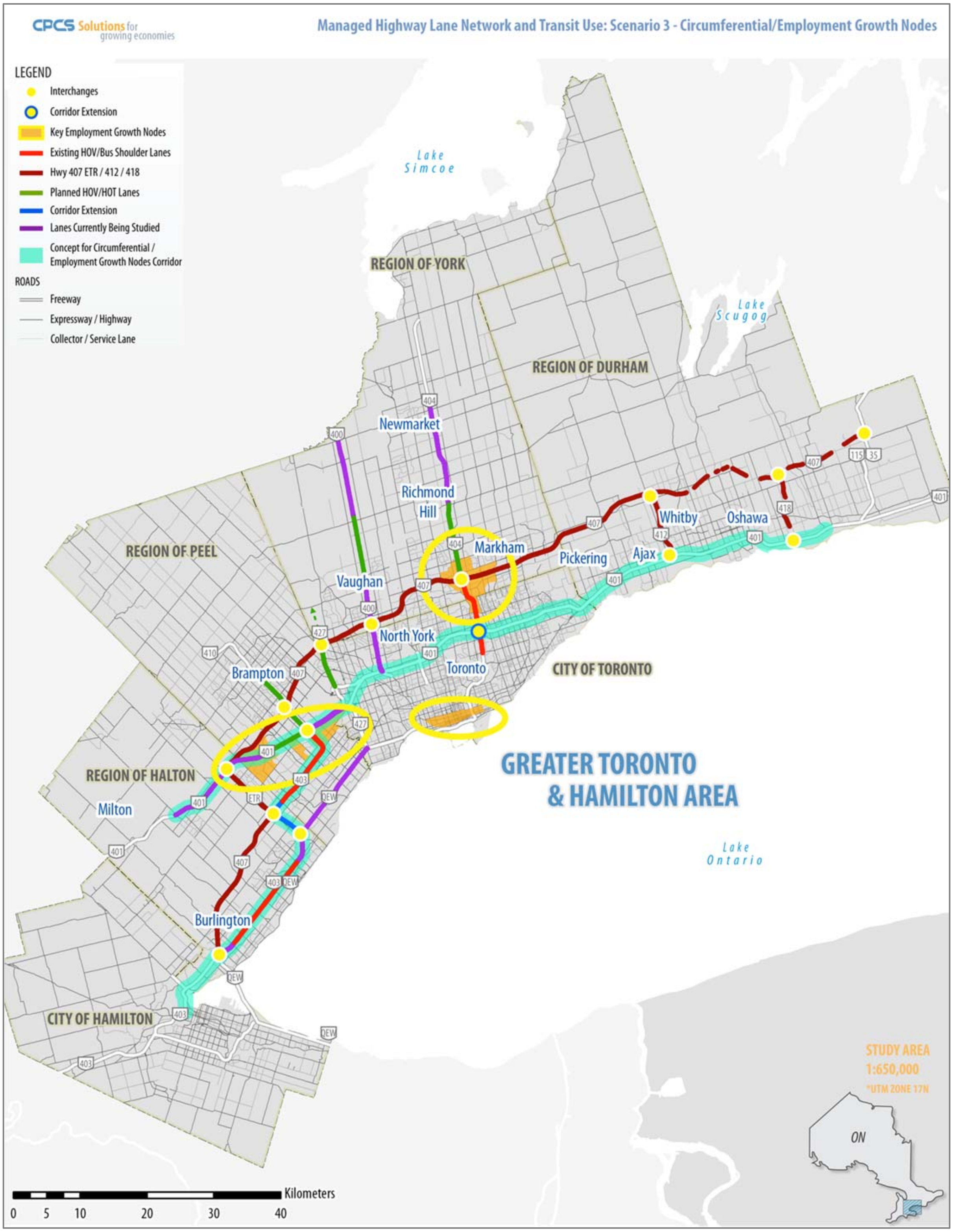
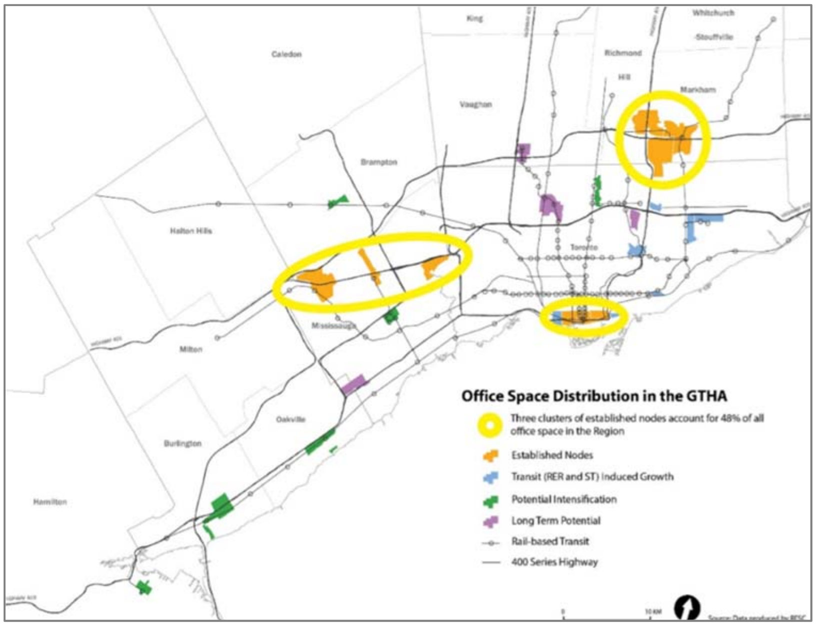


Figure 6: Scenario 4 – Complete Network (All Segments and Interchanges)

Figure 7: Employment Growth Nodes



Source: The Future of Office Development in the GTHA, The Nodal Study, Strategic Regional Research Alliance, Toronto, March 2015.

Treatment of Geometric, Structural and Other Constraints

It is recognized that some expressway sections and interchanges have significant geometric, structural or other existing constraints that limit the type of managed lane that actually could be implemented, or which in practical terms would preclude the introduction of a managed lane altogether. It also was recognized that some constraints could be addressed although only at a high, undetermined cost and/or at some undefined time in the future.

However, in order to develop meaningful scenarios for the BCA, it was necessary to set aside these constraints. In other words, the analysis proceeds as through any constraint could potentially be addressed and does not preclude the introduction of a managed lane.

7.0 ESTIMATION OF BENEFITS

Introduction

This chapter estimates the travel time savings for the five scenarios. The discussion:

- Estimates the increase in ridership from other modes (i.e., auto) that would accrue from the improved travel times.
- Estimates growth in ridership to 2031, all else being equal.
- Applies values of time, to calculate the monetary benefit gained by bus riders and others.

Parameters

Values of Time

Metrolinx's draft *Business Case Development Handbook, Tier 3 Guidance* provides guidance regarding the application of values of time to travel time savings, as well as on the values to use.[14] The *Handbook* first categorizes trips into two categories. The first category is business trips that are conducted as part of one's business (that is, the time spent in travelling is counted as productive time). The second category is 'non-business' trips (i.e., everything else), which in turn is divided into commuting trips and all other trips. It can reasonably be assumed that the proportion of users of the eligible bus routes who are in the first category is negligible; and, in fact, this group comprises only 3% of all GTHA trips by all modes, according to the TTS.

Therefore, values for the second category should be applied to this analysis. For 2015, the *Handbook* estimates the following values of time, which were derived from MTO's GGH travel demand forecasting model:

- Commuting: $24.11/hour.
- Other: $15.94/hour.

These values are deployed in this analysis.[15]

Corresponding trip purpose data are not available for each bus trip record. However, the most recent (2014/2015) *GO Bus Survey* can serve as a reasonable proxy for the attributes of the riders of the GO Bus routes as well as of the municipal routes. This survey reports that 57% of all trips are for the work commute.[16] Accordingly, it was

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[14] *Business Case Development Handbook, Tier 3 Guidance: Technical Notes and Methods*, draft report, Metrolinx, September 2015. See Section 3.2.3.3 and Appendix E.

[15] These are not Metrolinx's official values of time. Metrolinx is in the process of estimating new official values of time. However, these were not yet available for this analysis, and it was agreed that the consultant would use the values cited here.

[16] *2014/15 GO Transit Bus Passenger Survey, Processing and Results, Draft Report*, prepared for GO Transit, April 2015. See Section 4.2.1, page 28.

determined to use this split (57% commute – 43% other) as the basis for developing a weighted average value of time for all purposes combined.[17] It is noted that many students also use GO to commute to school (27% of all trips). However, it is reasonable to assume that their values of time should be lower than those of workers hence they have been included in the Other group. The resultant weighted value of time is $20.60, for 2015.

Finally, the *Handbook* notes that Metrolinx BCA studies have used an escalation factor of 1.6% per annum, and these have been used as the basis for this analysis. However, Metrolinx noted that future BCA studies will use updated escalation factors that are derived from expected GDP growth and from Ontario Ministry of Finance and Statistics Canada data. Table 7 lists the factors by year.[18] These were considered as part of a sensitivity analysis, which is presented below.

Table 7: Value of Time Escalation Factors

Year	Non-Business
2010-2014	1.425%
2015-2019	1.05%
2020-2024	0.90%
2025-2030	0.825%
2010-2030	1.05%

Elasticity of Demand wrt Travel Time

Changes in ridership are estimated by applying an elasticity of demand with respect to travel time. This is consistent with Metrolinx's *Handbook*. The *Handbook* notes that there is "no standard guidance on the selection of appropriate elasticities" for analyzing the impacts of changes in travel time and other attributes.[19] As a result, other sources were investigated in order to derive a reasonable rate. Two sources in particular were important:

[17] By comparison, the splits derived from the TTS are 44% commuting and 56% other, for all modes. Given that the bus services that are the subject of this analysis (especially the GO Bus services) have a strong role in serving commuters, it can be said that the sets of splits are consistent.

[18] *Business Case Development Handbook, Tier 3 Guidance: Technical Notes and Methods*, draft report, Metrolinx, September 2015. See Table 6, section 3.2.3.3.

[19] *Business Case Development Handbook, Tier 2 Guidance: "How to Complete a Business Case"*, draft report, Metrolinx, September 2015. See Section 10.4.3.

TCRP Report 95, Chapter 10 – Bus Routing and Coverage (2004)[20] and *Transit Price Elasticities and Cross-Elasticities (2004, reissued 2016)*.[21] In addition, the consultant's experience also was considered.

The second paper recommends a range of "generic" elasticities with respect to transit service (which includes changes in travel time). For the short term, a range of 0.50 to 0.70 is recommended. For the long term, a range of 0.7 to 1.1 is recommended.[22] Given, however, that these elasticities cover several types of transit improvement, and based on the consultant's experience elsewhere, an **elasticity of 0.5** was used for this analysis. Moreover, given the scale of the improvement and the basis for forecasting ridership (see next section), this value was retained throughout the time horizon.[23]

This value, at the lower end of the generic range, also recognizes that the travel time savings accrue only over a portion of a given bus itinerary and a given passenger itinerary: The complexities of matching individual bus and passenger itineraries to the available information, which is well beyond the scope and intent of this high-level analysis, mean that assumptions must be made in order to derive a reasonable approximate journey duration. An **average trip duration of 17 minutes per person** was derived for GO Transit from the available data on the number of bus trips and their itineraries (durations), and from average bus occupancy factors. The duration reflects only the portion of the trip that was made on the eligible highways. (See also Table 11 and the accompanying text, below, for details.)

Source of New Riders (Diversion Factors)

Diversion factors reflect the probability of the original mode formerly used by new transit riders, who are attracted to transit because of the improved service. The diversion factors vary by geography (trip origin), trip length and the type of intervention. The *Handbook* calculates three sets of factors for different trip lengths, with a single category representing all trips having a distance greater than 5 km. These factors were calculated by Metrolinx from the 2011 TTS for individual GTHA municipalities and, within the City of Toronto, by Planning District.[24]

Given the generally long-range nature of the trips that are considered in this analysis, it is reasonable to assume that shorter distances are not competitive for the bus options. Accordingly, the consultant developed similar factors for trips having a distance greater than 10 km, drawing from the 2011 TTS. It is reasonable to assume that the trip origins that would be impacted by the managed lanes initiatives would be distributed across the GTHA.

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[20] RH Pratt et al., *Chapter 10 – Bus Routing and Coverage*, *Traveler Response to Transportation System Changes*, TCRP Report 95, Transportation Research Board, Washington, DC, 2004.

[21] T Litman, *Transit Price Elasticities and Cross-Elasticities*, Journal of Public Transportation, Volume 7 Number 2, 2004. Republished by the Victoria Transport Policy Institute, May 2016.

[22] T Litman, *Transit Price Elasticities and Cross-Elasticities*, Table 15.

[23] Metrolinx is in the process of estimating elasticities of demand, using data from recent service changes on selected GO Bus routes. However, these elasticities were not yet available for this analysis.

[24] *Tier 3 Guidance: Technical Notes and Methods*, draft, v0.3, Metrolinx, September 2015. Note that Metrolinx is in the process of reviewing these factors, and it was agreed that the consultant would use the factors calculated in Table 8.

Accordingly, for the purposes of this analysis, a simple GTHA-wide average was calculated, and is summarized in Table 8.

The private automobile is the source of almost all new transit trips (99.9%), with the bicycle being the source of the remaining 0.1% of new transit trips. No walk trips are diverted, which is reasonable given the distance involved. It can be seen that the proportions are consistent with the 5+ km category cited in Metrolinx's *Handbook*. Note that the proportions vary by municipality and Planning District, although generally only within small amounts, hence the use of a single GTHA-wide average for this analysis is reasonable. Note also that Metrolinx's diversion calculation assumes that there is no diversion from other transit routes, and it is reasonable to assume that this also holds true for the types of transit services that are considered in this analysis.

Table 8: Diversion Factors (Original Mode of New Transit Riders)

Original Mode	Diversion Factor - > 5 km *	Diversion Factor - > 10 km *
Auto driver	81.82%	85.12%
Auto passenger	17.69%	14.75%
Walk	0.00%	0.0%
Cycle	0.48%	0.13%
Total	100.00%	100.0%

* Average across the GTHA.

Source: Consultant's calculation, from data provided in Table 74 Diversion Factors for Trips > 5k, Appendix G.2 Diversion Factors, *Tier 3 Guidance: Technical Notes and Methods*, draft, v0.3, Metrolinx, September 2015, and from the 2011 TTS.

Growth Factors

In consultation with the Working Group, it was determined that growth factors would be applied to the base year ridership gains in order to derive future benefits. In other words, forecasts to the year 2031 were derived by factoring the base year ridership benefits – calculated as a function of current segment ridership, current segment travel time savings and the aforementioned elasticity of demand over the average trip duration – with growth factors. The use of growth factors to achieve these ridership forecasts recalls that no service changes (schedule, frequency, etc.) are implied with any of the scenarios – i.e., the forecasts are an extrapolation of current ridership and operations.

For this analysis, GTHA demographic (population) and employment growth rates were used as the basis. These parameters are published and – using the Places to Grow forecasts – they reflect current Provincial policy. The rates are summarized in Table 9. It can be seen that the rates vary over time, and while the population and employment growth rates are reasonably similar to 2021, they diverge after that year, with employment growth slowing considerably more than population growth. For this reason, a blended growth rate was used, based on the simple average of the population and employment growth rates. This also allowed growth rates to be differentiated post-2021.

Table 9: GTHA Population and Employment Forecasts

Year	Population			Employment			Blended (simple avg)	Blended CAGR wrt 2016
	Total GTHA	Growth wrt 2016	CAGR wrt 2016	Total GTHA	Growth wrt 2016	CAGR wrt 2016		
2006	6,322,000	--	--	3,185,000	--	--	--	--
2011	6,837,000	--	--	3,464,000	--	--	--	--
2016 *	7,353,000	--	--	3,735,000	--	--	--	--
2021	7,881,000	1.072	1.40%	4,011,000	1.074	1.44%	1.073	1.42%
2031**	9,010,000	1.225	1.36%	4,380,000	1.173	1.07%	1.199	1.22%

* Estimated

** Updated per Proposed Growth Plan for the Greater Golden Horseshoe, 2016.

Source: Table 1, *Greater Golden Horseshoe Growth Forecasts to 2041, Technical Report (November 2012) Addendum*. Places to Grow, June 2013, and Schedule 3, *Proposed Growth Plan for the Greater Golden Horseshoe*, 2016. Places to Grow, May 2016.

The study does not include any assumptions about growth in the level of highway congestion, this being a function of not just increased trips but also other factors such as changes in the capacity of highways or competing modes, or demand management. For the purpose of this study the travel time savings achievable from individual segments are kept constant at current levels.

Non-User (External) Benefits

The factors used for estimating external benefits were consistent with the Metrolinx *Handbook* and with other recent studies that the consulting team has prepared for Metrolinx. Table 10 shows the unit benefits (i.e. per-passenger-kilometre) of switching to transit from other modes. Three modes were considered: auto driver, auto passenger, and cycling. The weighting by mode was done using existing mode shares for the GTHA as a whole from the 2011 TTS, for trip distances longer than 10 km, as listed in Table 8.

The factors are taken from the *Handbook*, with the following adjustments: [25]

- External accident costs are borrowed from a recent study by the consultant for Metrolinx, which included an expanded detailed analysis of accident costs for cycling and other modes in the GTHA, using the same source material as the Metrolinx *Handbook*. It was found that outside the central part of Toronto, the external accident costs for transit are $0.011, compared to $0.060 for auto driver. The external crash cost includes non-internalized costs to the driver, plus non-internalized costs to other travellers, including non-motorized travellers.

[25] Note that although the consultant's adjustments to the accident reduction factors and the GHG reduction benefits are acceptable to the Metrolinx, they are not official Metrolinx parameters.

- Decongestion benefits are taken as the average across the GTHA, using the values provided in the *Handbook*. Trips are assumed to be distributed proportional to overall travel in the GTHA.
- Criteria air pollutant CAP) and greenhouse gas (GHG) factors are as listed in the *Handbook*, adjusted for fuel efficiency and occupancy (determined to be 20 people per bus, per Table 5).

Table 10: Unit Benefits of Switching to Transit ($ / passenger-km)

Mode	Accident Reduction Benefits	Decongestion Benefits	CAP Reduction Benefits	GHG Reduction Benefits
Auto Driver	$0.05	$0.21	$0.003	$0.034
Auto Passenger	$(0.01)	--	$(0.004)	$(0.004)
Bike	$0.05	--	$(0.004)	$(0.004)
Weighted	$0.04	$0.18	$0.002	$0.028

Bus Operating Costs

Bus operating cost savings are assumed to be $50 per hour, as determined from consultations with GO Transit. This is a high-level estimate reflecting long-run assumptions such as the ability to shorten trip times and condense schedules reliably.

Estimation of Current Benefits

This section tabulates the key values underlying the benefits calculations. Table 11 shows key baseline trip characteristics. Of note:

- Weekly bus- and person-hours, as well as VKT and PKT, are calculated from disaggregate segment-level data. Bus trips are computed from trip-level data.
- Person-trip data are not known with certainty, because the available data obtained do not include boardings and alightings. For GO, a published fact sheet[26] was used to generate a ratio of boardings to bus-trips, which was applied to estimate weekly person-trips. For Non-GO, the ratio of PKT to VKT was used to estimate person-trips.
- It should be noted that trip duration and trip length reflect only the portion of *on-highway* time, and only for the specified highways in the geographic region covered in this study. Thus, for example, neither the arterial portion of these trips nor, for example, the portion along Highway 401 to Guelph, is included. Therefore, the trip duration and length are lower than the full system-wide average.

[26] *GO Transit, Quick Facts: Info to GO*, August 2014. Available data include 53,000 bus boardings per weekday and 2,516 weekday bus trips.

Table 11: Baseline Summary Characteristics

	GO Only	Non-GO	Total
Total Weekly Bus-Hours	4,887	566	5,453
Total Weekly Person-Hours	95,002	11,424	106,426
Total Weekly VKT	385,827	53,370	439,196
Total Weekly PKT	7,605,398	1,124,810	8,730,208
Total Weekly Bus-Trips	15,560	10,570	26,130
Total Weekly Person-Trips	327,774	222,772	550,546
Avg. Trip Duration per Person (min)	17	3	12
Avg. Length of Person-Trip (km)	23.2	5.0	15.9

Table 12 shows the person-hour savings by scenario, as well as the managed lanes kilometrage for reference. It can be seen that the time savings accrue in sequence as additional managed lanes are added.

Table 12: Person-Hour Savings by Scenario

	Base	Sc1	Sc2	Sc3	Sc4
KM (network-km)	138	352	377	545	1,066
Time Savings, p-hr (GO only)	348	1,685	1,918	3,909	8,382
Time Savings, p-hr (Non-GO)	--	80	80	82	300
Time Savings, p-hr (GO + Non-GO)	348	1,765	1,997	3,991	8,682

Table 13 shows the distribution of person-hour savings by time period, for each scenario. The distributions shown are also representative of the distribution of benefits by time period. As shown, the majority of travel time savings and benefits are obtained in the peak periods, especially the PM Peak. However, there are also significant savings in the midday period, driven by midday congestion on many GTHA highways as well as fairly high GO Bus occupancies in the midday period (as indicated in Table 5). For scenarios 1, 2 and 3, the PM peak benefits are almost half the total daily benefits. Together with the AM peak, the peak period benefits represent of the order of 80% of total daily benefits for the three scenarios. Under Scenario 4, the region-wide network scenario, the proportion of AM/PM peak period benefits drops to 62%, with the midday now taking up 30% of the benefits (which reflects the pervasive congestion across the region-wide expressway network). The evening and overnight benefits are always very small, except in Scenario 4, in which the evening represents 7% of total daily benefits. In sum, most of the benefits accrue in the two commuter peak periods; however, significant benefits still occur during the midday inter-peak period as well.

Table 13: Distribution of Person-Hour Savings by Time Period

	Base	Sc1	Sc2	Sc3	Sc4
AM Peak (6 AM – 9 AM)	-	31%	29%	36%	25%
Midday (9 AM – 4 PM)	-	17%	20%	15%	30%
PM Peak (4 PM – 7 PM)	-	49%	48%	46%	37%
Evening (7 PM – 11 PM)	-	2%	2%	2%	7%
Overnight (11 PM – 6 AM)	-	1%	1%	1%	1%

Estimation of Benefits

This section describes the procedure for estimating the benefits of managed lanes scenarios. The categories of benefits are the following:

- *Direct Travel Time Savings:* The value of travel time savings to existing users. These are calculated by applying the value of time (VOT) as described above, to the difference in travel time savings between the base scenario and the scenario at hand.

- *Direct Benefits to New Users:* Since bus travel times improve, there is expected to be a corresponding increase in ridership, with the uptake determined by applying the elasticity of demand with respect to travel time (described above). Consistent with *Tier 3 Guidance*, the unit benefits are assumed to apply at half the rate as for existing users, to account for other trade-offs involved in switching modes.

- *Operator Cost Savings:* Cost savings are experienced by the operator (GO Transit or municipal agencies) if, in the long run, route trip times are cut reliably. The benefits are determined by applying the hourly value of time savings to the number of bus-hours saved. It is assumed that the $50/hr GO value applies equally to other agencies. By applying the operator cost savings it is assumed that the agencies do not increase service as ridership increases. Alternatively, if there was no reduction in operator cost savings, there would be an additional benefit to new and existing users from increased schedule frequency.

- *External Benefits*: These benefits are experienced as travellers divert from other modes to bus transportation. The data sources for the four categories of external benefits – accident reductions, decongestion, CAP reductions, and GHG reductions – are noted above. These are applied per passenger-kilometre travelled (PKT), where PKT is calculated by multiplying uptake by the average trip length.

The annual benefits are determined for 2016. The net present value (NPV) of benefits from 2017 to 2031 is subsequently calculated assuming a discount rate of 3.5% to reflect that future benefits (or costs) are worth less than current-day benefits and this reduction increases for each year forward in time. In addition, the real value of time is assumed to increase at 1.6% p.a ., and anticipated baseline travel growth rates are assumed to be 1.42% p.a. to 2021 and 1.22% p.a. from 2021 to 2031. These parameters are taken from the *Metrolinx Business Case Development Handbook.*

The results for Scenario 1 are summarized in Table 14. All values are shown in 2016 $.

Table 14: Monetary Benefits Compared with Base – Scenario 1 (2016 $)

Benefit	NPV	Current Year (2016) Benefits
Time Saved, Existing Users (GO)	$20,917,864	$1,460,402
Time Saved, Existing Users (Non-GO)	$1,246,472	$87,024
New User Benefits (GO)	$805,803	$56,258
New User Benefits (Non-GO)	$28,654	$2,000
Operator Cost Savings (GO)	$2,265,401	$178,797
Operator Cost Savings (Non-GO)	$134,993	$10,654
External Accident Reduction Benefit	$1,554,232	$122,668
External Decongestion Benefit	$6,893,769	$544,091
External CAP Reduction Benefit	$59,919	$4,729
External GHG Reduction Benefit	$1,078,380	$85,111
Total NPV of Benefits	**$34,985,486**	**$2,551,734**

The benefits estimation procedure is described for Scenario 1; other scenarios follow the same method. Note again that all values are provided in 2016 $.

- *Direct Travel Time Savings*: These are the benefits to existing users. For GO, Scenario 1 saves 1685 hours per week, compared to 348 for the base case, a difference of 1,337 hours per week (69,787 hrs annually). For Non-GO, the difference is 80 hrs per week (3,576 per year). Valued at $20.96/hr, the annual benefits are $1.46 million and $87 thousand for GO and non-GO, respectively.
- *Direct Benefits to New Users*: New users gain benefits at half the rate of existing users. Thus, the per-hour time saving for existing trips is established as (1,337)/(29,947) = 2.7 min per trip for GO, and (80)/(16,901) = 0.3 min per trip for Non-GO. The denominator is taken as the number of "person-trips affected," which is the total baseline person-trips multiplied by the marginal percentage of segments affected by managed

lanes, weighted by travel time. The assumption underlying this calculation is discussed below.[27] Valued at half the baseline VOT, the per-user benefits are $0.47 per trip for GO, and $0.05 per trip for non-GO. These values are applied to the marginal uptake, calculated as follows: for GO, (0.50 elasticity)*(15.4% time savings)*(29,947 trips affected) = 2,307 new trips per month or 120,390 per year;[28] and for non-GO, (0.50 elasticity)*(9.2% time savings)*(16,901 trips affected) = 777 new trips per month or 40,545 per year. Applying the per-user benefits to the uptake produces benefits of $56,000 for GO and 42,000 for non-GO.

- *Operator Cost Savings:* The difference between the base case and Scenario 1 for vehicle time savings is 69 hours for GO and 4 hours for non-GO (weekly) or 3,576 hours and 213 hours annually. Valued at $50 per vehicle-hour, the annual benefits are $179,000 for GO $11,000 for non-GO.

- *External Benefits:* The difference in uptake between the base case and Scenario 1 is 120,390 trips/year for GO and 40,545 trips/year for non-GO. At an average length of 23.2 km and 5.0 km respectively, that makes 3.0 million PKT annually (93% from GO trips). Each of the per-PKT benefits is then applied directly.

The benefits for Scenarios 2, 3 and 4 are summarized in Table 15, Table 16 and Table 17, respectively.

[27] The assumption is that affected trips fall fully within the managed lanes affected. This is obviously not the case, because in reality the managed lanes are not necessarily contiguous and at any rate they affect only portions of trips. However, the true relationship is not clear because this study is not so detailed as to assess actual trip patterns. The relationship assumed is an extreme optimistic case, but this category of benefits is very small compared to the other categories. It should be noted that this assumption affects only the per-user benefit level, not the uptake (where this effect is cancelled out) or any other categories of benefits.

[28] For greater specificity, there are 327,774 weekly GO bus trips. In the base case it is assumed that 12% of weekly trips (38,074 trips) save 0.5 min each, while in Scenario 1 21% of trips (68,021 trips) save 1.5 min each. This implies that the margin between the two scenarios involves 29,947 trips each saving 2.7 minutes, which is equal to 15.4% of the baseline trip time of 17 minutes. If it is assumed that the trips are more dispersed, the uptake would be unchanged (e.g. more trips offset by lower time savings per trip).

Table 15: Monetary Benefits Compared with Base – Scenario 2 (2016 $)

Benefit	NPV	Current Year (2016) Benefits
Time Saved, Existing Users (GO)	$24,549,938	$1,713,979
Time Saved, Existing Users (Non-GO)	$1,246,472	$87,024
New User Benefits (GO)	$916,582	$63,992
New User Benefits (Non-GO)	$28,654	$2,000
Operator Cost Savings (GO)	$2,658,754	$209,842
Operator Cost Savings (Non-GO)	$134,993	$10,654
External Accident Reduction Benefit	$1,805,673	$142,513
External Decongestion Benefit	$8,009,035	$632,113
External CAP Reduction Benefit	$69,612	$5,494
External GHG Reduction Benefit	$1,252,839	$98,880
Total NPV of Benefits	**$40,672,552**	**$2,966,492**

Table 16: Monetary Benefits Compared with Base – Scenario 3 (2016 $)

Benefit	NPV	Current Year (2016) Benefits
Time Saved, Existing Users (GO)	$55,699,774	$3,888,737
Time Saved, Existing Users (Non-GO)	$1,274,898	$89,008
New User Benefits (GO)	$1,487,451	$103,848
New User Benefits (Non-GO)	$24,769	$1,729
Operator Cost Savings (GO)	$6,032,276	$476,098
Operator Cost Savings (Non-GO)	$138,071	$10,897
External Accident Reduction Benefit	$3,964,539	$312,901
External Decongestion Benefit	$17,584,650	$1,387,869
External CAP Reduction Benefit	$152,841	$12,063
External GHG Reduction Benefit	$2,750,735	$217,102
Total NPV of Benefits	**$89,110,005**	**$6,500,252**

Table 17: Monetary Benefits Compared with Base – Scenario 4 (2016 $)

Benefit	NPV	Current Year (2016) Benefits
Time Saved, Existing Users (GO)	$125,650,571	$8,772,423
Time Saved, Existing Users (Non-GO)	$4,691,956	$327,574
New User Benefits (GO)	$2,992,177	$208,902
New User Benefits (Non-GO)	$38,232	$2,669
Operator Cost Savings (GO)	$13,607,936	$1,074,007
Operator Cost Savings (Non-GO)	$508,138	$40,105
External Accident Reduction Benefit	$9,098,037	$718,063
External Decongestion Benefit	$40,354,196	$3,184,956
External CA Reduction Benefit	$350,748	$27,683
External GHG Reduction Benefit	$6,312,534	$498,217
Total NPV of Benefits	**$203,604,524**	**$14,854,597**

Table 18 summarizes the benefits for the four scenarios. The benefits accrue in sequence as additional managed lanes are added. The benefits range from $35m in Scenario 1 to $204m in Scenario 4, the full network-wide implementation.

Table 18: Monetary Benefits Compared with Base – All Scenarios (2016 $)

	Kilometres	NPV	Current Year (2016) Benefits
Scenario 1	352	$34,985,486	$2,551,734
Scenario 2	377	$40,672,552	$2,966,492
Scenario 3	545	$89,110,005	$6,500,252
Scenario 4	1,066	$203,604,524	$14,854,597

Note: Kilometres are tabulated for each scenario, always including the base. Monetary benefits are for the scenario net of the base.

Travel Time Benefits

Figure 8 through Figure 11 plot the weekly travel time benefits for the four scenarios, respectively. The benefits are expressed in person-hours of travel per week, gained by the transit passengers who use the managed lanes. All benefits are relative to the base scenario. The results are colour coded in ranges, according to their magnitudes. As noted, the aforementioned analysis and data sources all reflect current conditions, and so it is conceivable that the benefits actually would grow if and as congestion gets worse over time. Detailed benefits by individual highway segment and interchange are tabulated in the spreadsheets on which this analysis is based, provided separately.

Figure 8: Travel Time Benefits by Segment – Scenario 1 (person-hours / week)

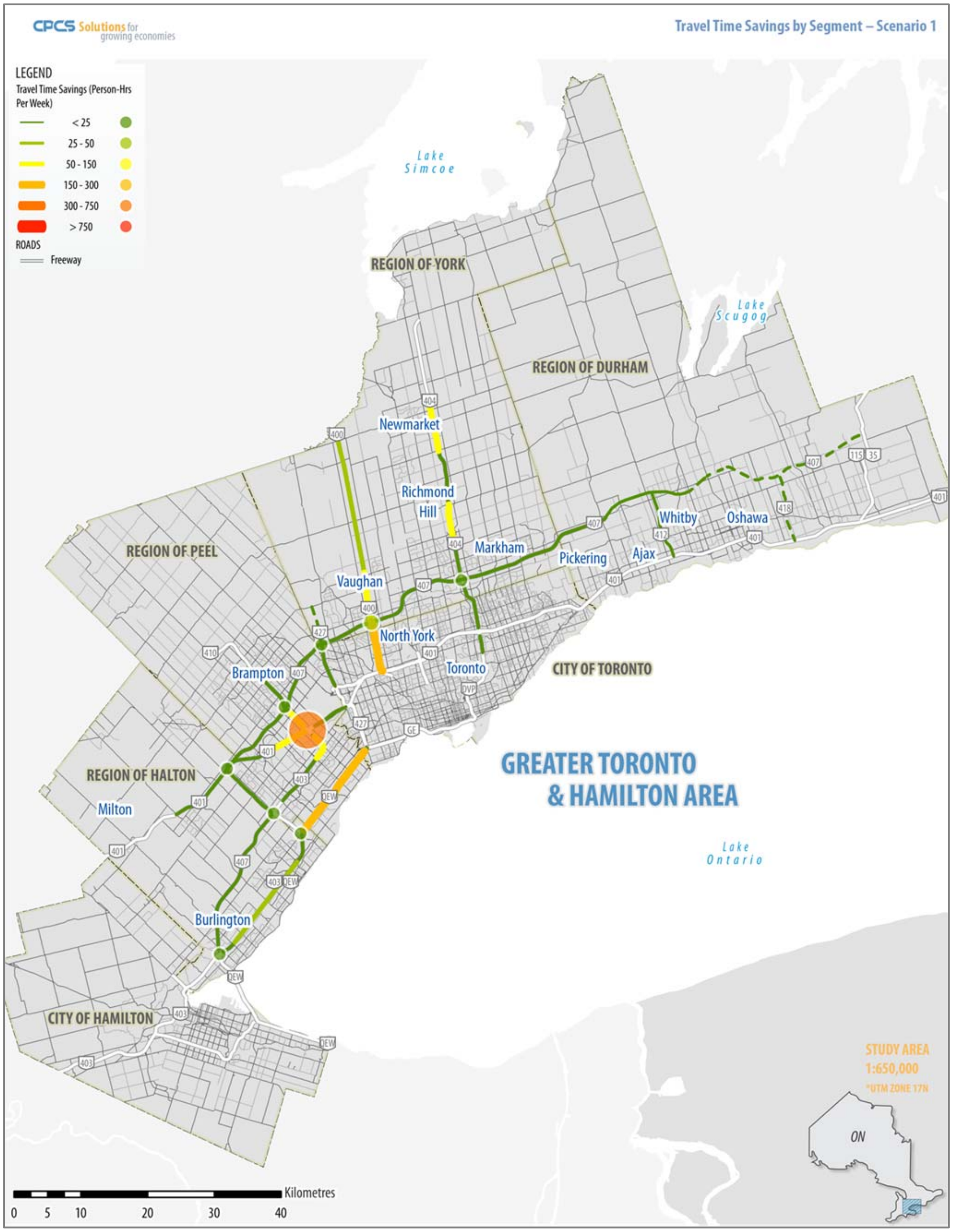


Figure 9: Travel Time Benefits by Segment – Scenario 2 (person-hours / week)

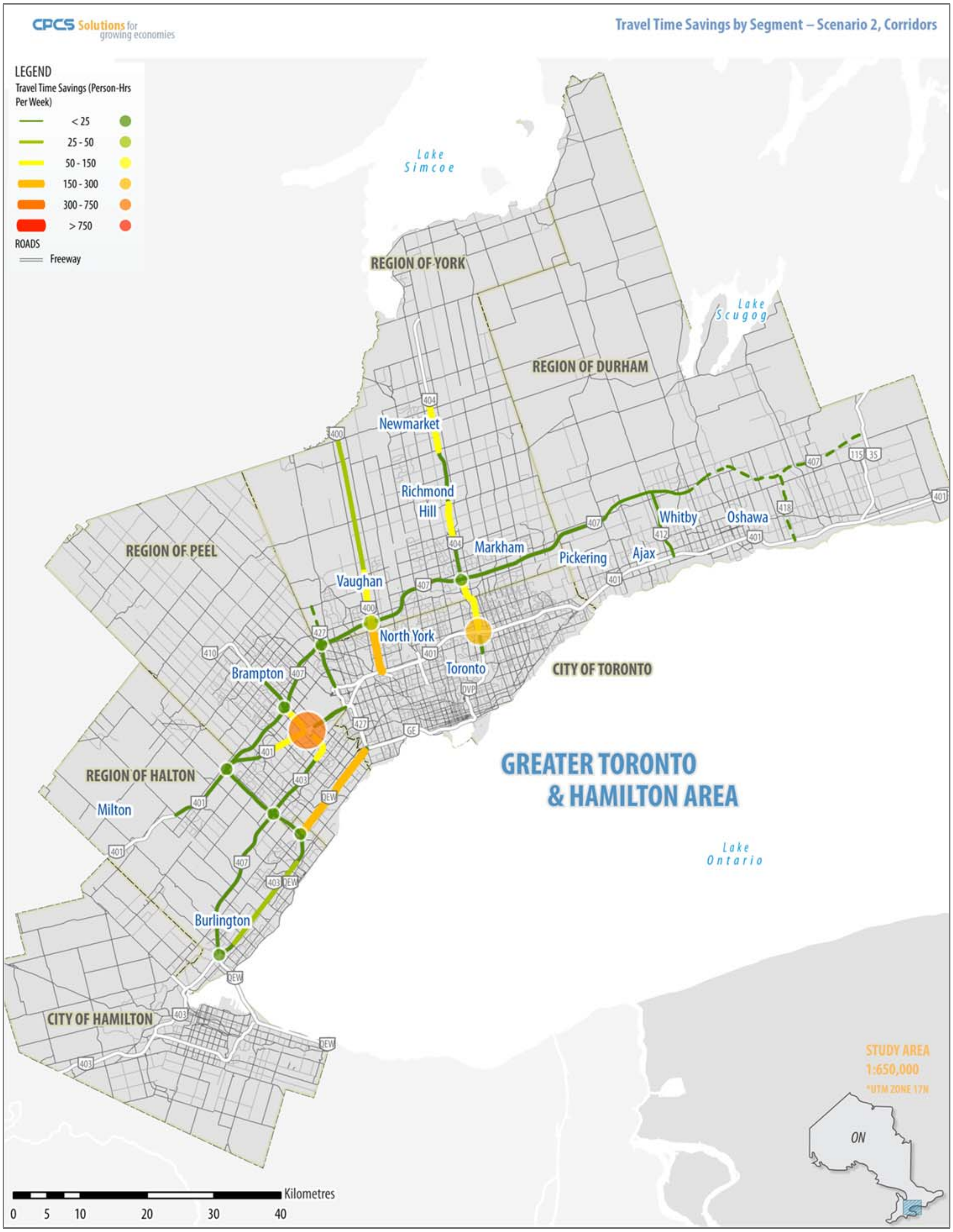


Figure 10: Travel Time Benefits by Segment – Scenario 3 (person-hours / week)

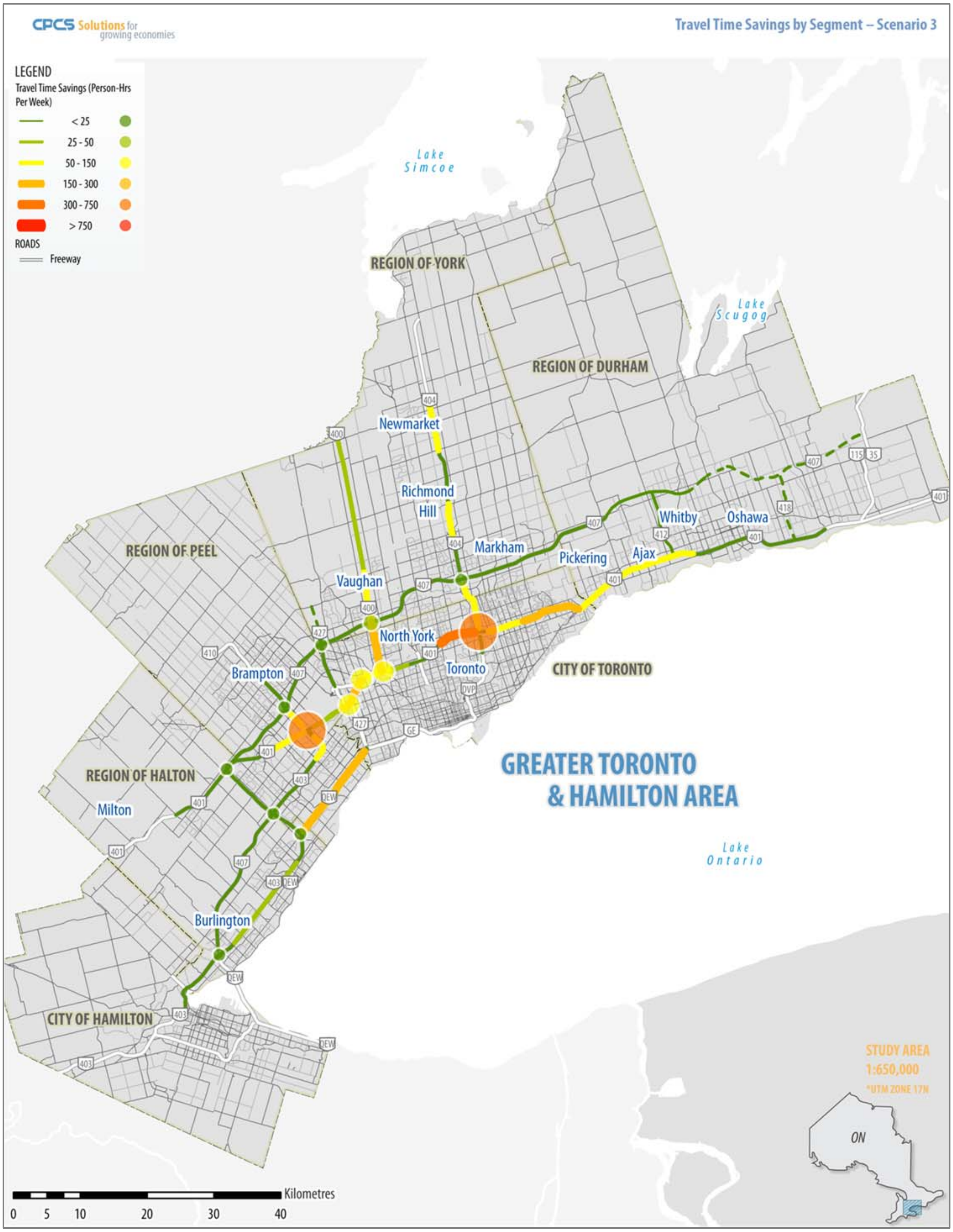


Figure 11: Travel Time Benefits by Segment – Scenario 4 (person-hours / week)

8.0 SENSITIVITY TESTS

This section summarizes the results of several sensitivity tests, in which different parameters and factors of interested have been examined in order to assess their impact on the findings. The tests cover the range of key parameters that drive the analysis, excluding some that clearly are not meaningfully changed (e.g., the factor that expands weekly data to annual values). Of note, the two escalation factor tests address specific requests made by the MTO.

Each test was conducted with all other parameters held at their initial values. The results are described below. To allow for a comparison, the results for all the tests are expressed in the same way, in terms of the impacts on NPV and on annual monetary benefits for the four scenarios.

VOT Escalation Factors

Two sensitivity tests were conducted of the VOT escalation factors. Table 19 assumes no escalation factor (0% growth), compared with the base 1.6% p.a. escalation factor. This results in reductions for each scenario of 8.5% in the NPV and of 1.0% in the annual benefit. Table 20 uses the new *Tier 3* escalation factors, noted in Table 7. This results in reductions for each of the scenarios of 3.6% in NPV and of 0.3% in the current year annual benefit.

Table 19: Escalation Factor Sensitivity Test – 0%

	Original		0% Escalation Factor		% Difference (wrt Original)	
	NPV	Current Year (2016) Benefits	NPV	Current Year (2016) Benefits	NPV	Current Year (2016) Benefits
Scenario 1	$34,985,486	$2,551,734	$32,010,736	$2,526,448	-8.5%	-1.0%
Scenario 2	$40,672,552	$2,966,492	$37,213,687	$2,937,091	-8.5%	-1.0%
Scenario 3	$89,110,005	$6,500,252	$81,545,091	$6,435,948	-8.5%	-1.0%
Scenario 4	$203,604,524	$14,854,597	$186,353,567	$14,707,959	-8.5%	-1.0%

Table 20: Escalation Factor Sensitivity Test – *Tier 3* Factors

	Original		Tier 3 Escalation Factors		% Difference (wrt Original)	
	NPV	Current Year (2016) Benefits	NPV	Current Year (2016) Benefits	NPV	Current Year (2016) Benefits
Scenario 1	$34,985,486	$2,551,734	$33,720,450	$2,543,042	-3.6%	-0.3%
Scenario 2	$40,672,552	$2,966,492	$39,201,642	$2,956,386	-3.6%	-0.3%
Scenario 3	$89,110,005	$6,500,252	$85,892,965	$6,478,147	-3.6%	-0.3%
Scenario 4	$203,604,524	$14,854,597	$196,268,417	$14,804,190	-3.6%	-0.3%

Elasticity of Demand

This test examined the impact of a lower or higher take-up in the diversion to the improved transit service. Table 21 summarizes the impact of halving the elasticity rate, to 0.25. Table 22 summarizes the impact of doubling the elasticity rate, to 1.0. Both values are indicative of the range of elasticity of demand values found in the literature. It can be seen that halving the elasticity reduces the NPV by 15% and the annual benefit by 16%. The impact on NPV is slightly less pronounced because the present user time saving benefits, which are not impacted by the elasticity assumption, are subject to an increasing VOT, whereas the external benefits are impacted by the elasticity assumption and are not subject to an increasing VOT. Doubling the elasticity results in a 29%-30% increase in NPV and a 31%-32% increase in the annual benefit. Note that the absolute percentage changes for the benefits are identical for the same relative increase or reduction in the elasticity value. The impacts are for both vary slightly among the four scenarios, with the smallest differences being recorded in Scenarios 3 and 4.

Table 21: Elasticity of Demand Sensitivity Test – Halved (0.25)

	Original		½ Elasticity Rate		% Difference (wrt Original)	
	NPV	Current Year (2016) Benefits	NPV	Current Year (2016) Benefits	NPV	Current Year (2016) Benefits
Scenario 1	$34,985,486	$2,551,734	$29,775,108	$2,144,306	-14.9%	-16.0%
Scenario 2	$40,672,552	$2,966,492	$34,631,355	$2,493,996	-14.9%	-15.9%
Scenario 3	$89,110,005	$6,500,252	$76,127,513	$5,482,496	-14.6%	-15.7%
Scenario 4	$203,604,524	$14,854,597	$174,031,563	$12,534,353	-14.5%	-15.6%

Table 22: Elasticity of Demand Sensitivity Test – Doubled (1.0)

	Original		2x Elasticity Rate		% Difference (wrt Original)	
	NPV	Current Year (2016) Benefits	NPV	Current Year (2016) Benefits	NPV	Current Year (2016) Benefits
Scenario 1	$34,985,486	$2,551,734	$45,406,242	$3,366,592	29.8%	31.9%
Scenario 2	$40,672,552	$2,966,492	$52,754,947	$3,911,486	29.7%	31.9%
Scenario 3	$89,110,005	$6,500,252	$115,074,990	$8,535,764	29.1%	31.3%
Scenario 4	$203,604,524	$14,854,597	$262,750,448	$19,495,087	29.0%	31.2%

Diversion Factors

This test examines the impact of using Metrolinx's > 5 km diversion factors from the *Tier 3 Handbook* (see Table 8), instead of the > 10 km factors developed by the consultant. The primary difference between the two sets of diversion factors is that the bicycle share is 0.5% under the > 5km factors, compared with 0.1% in the >10 km factors. As can be seen in Table 23, this results in a slight reduction in the NPV (-1.1%) and in the annual benefit (-1.2%), which is consistent with the slightly reduced auto share in the > 5 km factors. The differences are the same among all four scenarios.

Table 23: Diversion Factors Sensitivity Test - > 5 km Factors

	Original		> 5 km Diversion Factors		% Difference (wrt Original)	
	NPV	Current Year (2016) Benefits	NPV	Current Year (2016) Benefits	NPV	Current Year (2016) Benefits
Scenario 1	$34,985,486	$2,551,734	$34,600,569	$2,521,355	-1.1%	-1.2%
Scenario 2	$40,672,552	$2,966,492	$40,225,363	$2,931,198	-1.1%	-1.2%
Scenario 3	$89,110,005	$6,500,252	$88,128,157	$6,422,760	-1.1%	-1.2%
Scenario 4	$203,604,524	$14,854,597	$201,351,326	$14,676,764	-1.1%	-1.2%

Unit Benefits

This test examines the impact of changing increasing or decreasing the unit benefits of switching to transit (Table 10). For this test, the unit benefits and their weighted sum were halved or doubled. Table 24 indicates that halving the benefits reduces the NPV by 14% and the annual benefit by 15%. Table 25 indicates that doubling the benefits increases the NPV by 27% - 28% and the annual benefit by 30%. There are slight differences among the scenarios, though with no discernible pattern among them. The absolute percentage changes for the NPV and annual benefit are identical for the same relative increase or reduction in the unit benefits.

Table 24: Unit Benefits Sensitivity Test – Halved

	Original		½ Unit Benefits (Weighted)		% Difference (wrt Original)	
	NPV	**Current Year (2016) Benefits**	**NPV**	**Current Year (2016) Benefits**	**NPV**	**Current Year (2016) Benefits**
Scenario 1	$34,985,486	$2,551,734	$30,192,337	$2,173,435	-13.7%	-14.8%
Scenario 2	$40,672,552	$2,966,492	$35,103,973	$2,526,992	-13.7%	-14.8%
Scenario 3	$89,110,005	$6,500,252	$76,883,623	$5,535,285	-13.7%	-14.8%
Scenario 4	$203,604,524	$14,854,597	$175,546,767	$12,640,139	-13.8%	-14.9%

Table 25: Unit Benefits Sensitivity Test – Doubled

	Original		2x Unit Benefits (Weighted)		% Difference (wrt Original)	
	NPV	**Current Year (2016) Benefits**	**NPV**	**Current Year (2016) Benefits**	**NPV**	**Current Year (2016) Benefits**
Scenario 1	$34,985,486	$2,551,734	$44,571,785	$3,308,333	27.4%	29.7%
Scenario 2	$40,672,552	$2,966,492	$51,809,712	$3,845,493	27.4%	29.6%
Scenario 3	$89,110,005	$6,500,252	$113,562,770	$8,430,187	27.4%	29.7%
Scenario 4	$203,604,524	$14,854,597	$259,720,039	$19,283,515	27.6%	29.8%

Bus Operating Costs

This test examines the impact of higher and lower bus operating costs. Table 26 shows the impact of halving the $50 base hourly bus operating cost to $25 reduces the NPV by 3.4% - 3.5% and the annual benefit by 3.7% - 3.8%. Doubling the hourly cost to $100 yields increases of 6.9% in the NPV and 7.4% - 7.5% in the annual benefit, as summarizes in Table 27. There are slight differences among the scenarios, with the greatest percentage changes occurring in Scenarios 3 and 4. The absolute percentage changes for the NPV and annual benefit are identical for the same relative increase or reduction in the unit benefits

Table 26: Bus Operating Costs Sensitivity Test – Halved ($25/hr)

	Original		½ Bus Operating Cost		% Difference (wrt Original)	
	NPV	**Current Year (2016) Benefits**	**NPV**	**Current Year (2016) Benefits**	**NPV**	**Current Year (2016) Benefits**
Scenario 1	$34,985,486	$2,551,734	$33,785,289	$2,457,009	-3.4%	-3.7%
Scenario 2	$40,672,552	$2,966,492	$39,275,679	$2,856,244	-3.4%	-3.7%
Scenario 3	$89,110,005	$6,500,252	$86,024,831	$6,256,755	-3.5%	-3.7%
Scenario 4	$203,604,524	$14,854,597	$196,546,487	$14,297,542	-3.5%	-3.8%

Table 27: Bus Operating Costs Sensitivity Test – Doubled ($100/hr)

	Original		2x Bus Operating Cost		% Difference (wrt Original)	
	NPV	**Current Year (2016) Benefits**	**NPV**	**Current Year (2016) Benefits**	**NPV**	**Current Year (2016) Benefits**
Scenario 1	$34,985,486	$2,551,734	$37,385,880	$2,741,185	6.9%	7.4%
Scenario 2	$40,672,552	$2,966,492	$43,466,299	$3,186,989	6.9%	7.4%
Scenario 3	$89,110,005	$6,500,252	$95,280,353	$6,987,247	6.9%	7.5%
Scenario 4	$203,604,524	$14,854,597	$217,720,598	$15,968,709	6.9%	7.5%

Discount Rate

This test examines the impact of lowering and raising the 3.5% discount rate specified in the *Metrolinx Business Case Development Handbook*. Table 28 indicates that a reduction of 0.5% (to 3.0%) increases the NPV by 3.9%. Table 29 indicates that an increase of 0.5% (to 4.0%) reduces the NPV by 3.7%. The results are the same for all scenarios. There are no impacts on the annual benefits.

Table 28: Discount Rate Sensitivity Test – Reduction (-0.5%)

	Original		**Reduced Discount Rate (-0.5%)**		**% Difference (wrt Original)**	
	NPV	**Current Year (2016) Benefits**	**NPV**	**Current Year (2016) Benefits**	**NPV**	**Current Year (2016) Benefits**
Scenario 1	$34,985,486	$2,551,734	$36,335,318	$2,551,734	3.9%	0.0%
Scenario 2	$40,672,552	$2,966,492	$42,241,812	$2,966,492	3.9%	0.0%
Scenario 3	$89,110,005	$6,500,252	$92,547,966	$6,500,252	3.9%	0.0%
Scenario 4	$203,604,524	$14,854,597	$211,459,419	$14,854,597	3.9%	0.0%

Table 29: Discount Rate Sensitivity Test – Increase (+0.5%)

	Original		Increased Discount Rate (+0.5%)		% Difference (wrt Original)	
	NPV	**Current Year (2016) Benefits**	**NPV**	**Current Year (2016) Benefits**	**NPV**	**Current Year (2016) Benefits**
Scenario 1	$34,985,486	$2,551,734	$33,706,543	$2,551,734	-3.7%	0.0%
Scenario 2	$40,672,552	$2,966,492	$39,185,705	$2,966,492	-3.7%	0.0%
Scenario 3	$89,110,005	$6,500,252	$85,852,592	$6,500,252	-3.7%	0.0%
Scenario 4	$203,604,524	$14,854,597	$196,162,126	$14,854,597	-3.7%	0.0%

Population and Employment Growth

The last test examines "Low" and "High" alternatives to the "Reference" *Places to Grow* population and employment growth scenario that was used as the basis for this analysis. The two alternatives are taken from the *Places to Grow* forecasts, and are summarized in Table 30. The Low 2031 population and employment forecasts are 8.2% and 7.1% lower than their Reference equivalents, respectively. The High 2031 population and employment forecasts are 7.9% and 6.6% greater than their respective Reference equivalents.

Table 30: Low and High Population and Employment Growth Scenarios – *Places to Grow*

Year	Population – Total GTHA			Employment – Total GTHA		
	Reference Scenario	Low Scenario	High Scenario	Reference Scenario	Low Scenario	High Scenario
2006	6,322,000	6,322,000	6,322,000	3,185,000	3,185,000	3,185,000
2011	6,837,000	6,837,000	6,837,000	3,464,000	3,464,000	3,464,000
2016 *	7,353,000	7,260,000	7,449,00	3,735,000	3,690,000	3,772,000
2021	7,881,000	7,631,000	8,138,000	4,011,000	3,900,000	4,123,000
2031 **	9,010,000	8,274,000	9,721,000	4,380,000	4,069,000	4,669,000

* Estimated.

** 2031 values for Reference Scenario are updated per *Proposed Growth Plan for the Greater Golden Horseshoe*, 2016. 2031 values for Low and High Scenarios reflect the values cited in the *Greater Golden Horseshoe Growth Forecasts to 2041, Technical Report (November 2012)*.

Source: Tables 1, 2 and 3, *Greater Golden Horseshoe Growth Forecasts to 2041, Technical Report (November 2012) Addendum*. Places to Grow, June 2013, and Schedule 3, *Proposed Growth Plan for the Greater Golden Horseshoe*, 2016. Places to Grow, May 2016.

Table 31 summarizes the impacts of the Low scenario. It can be seen that the lower population and employment growth scenario reduces the NPV by 4.2%, consistent among all scenarios. Table 32 indicates that a 4.1% increase in the NPV is associated with the High scenario. In both cases, the proportional impact on the NPV is less than that of the changes in the population and employment growth. Because the growth forecasts only impact subsequent years past the first one, there is no impact on the first year (2016).

Table 31: Population / Employment Growth Sensitivity Test – Low *Places to Grow* Scenario

	Original		Low Pop/Emp Growth Scenario		% Difference (wrt Original)	
	NPV	Current Year (2016) Benefits	NPV	Current Year (2016) Benefits	NPV	Current Year (2016) Benefits
Scenario 1	$34,985,486	$2,551,734	$33,520,412	$2,551,734	-4.2%	0.0%
Scenario 2	$40,672,552	$2,966,492	$38,969,317	$2,966,492	-4.2%	0.0%
Scenario 3	$89,110,005	$6,500,252	$85,378,513	$6,500,252	-4.2%	0.0%
Scenario 4	$203,604,524	$14,854,597	$195,078,944	$14,854,597	-4.2%	0.0%

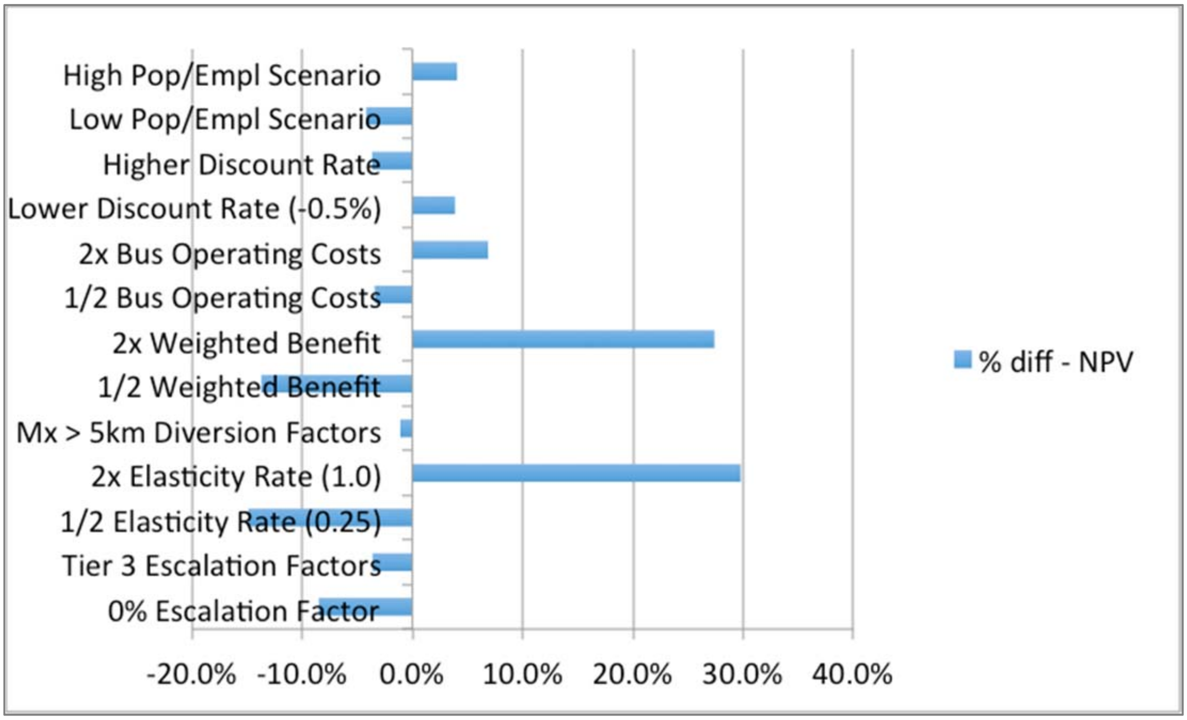
Table 32: Population / Employment Growth Sensitivity Test – High *Places to Grow* Scenario

	Original		High Pop/Emp Growth Scenario		% Difference (wrt Original)	
	NPV	Current Year (2016) Benefits	NPV	Current Year (2016) Benefits	NPV	Current Year (2016) Benefits
Scenario 1	$34,985,486	$2,551,734	$36,403,383	$2,551,734	4.1%	0.0%
Scenario 2	$40,672,552	$2,966,492	$42,320,942	$2,966,492	4.1%	0.0%
Scenario 3	$89,110,005	$6,500,252	$92,721,343	$6,500,252	4.1%	0.0%
Scenario 4	$203,604,524	$14,854,597	$211,855,595	$14,854,597	4.1%	0.0%

Comparison

Figure 12 compares the results for all of the tests. While the extents of the changed values are not directly comparable, the results suggest that the benefits are especially sensitive to the input assumptions for the elasticity rate and for the unit benefits and their weighted sums. In no case does the proportional impact on the NPV or the annual benefit exceed the proportional increase in the tested parameter. Note also that for all tests, the results did not vary significantly, or at all, among the four scenarios. This is because the factors are in general linear, such that increasing the size of the managed lane network increases the magnitude but not the *rate of increase* of benefits and costs.

Figure 12: Comparison of Sensitivity Tests – Impact on NPV



9.0 BENEFIT COST ANALYSIS

Costs

This chapter presents the results of the benefit cost analysis for each scenario. The benefits are described in Chapter 7.0, recalling that this analysis considers only those benefits that accrue to transit and its users.

The costs are those of constructing and maintaining the individual lanes, recognizing that the configuration of the lane is not determinable at this high level of analysis. Moreover, it is recognized that the lane configuration and function could support other vehicles, meaning that the costs might be allocated among other, non-transit beneficiaries. The same is true for other related infrastructure, such as a new overpass, which would benefit other travellers as well.

In working with MTO on the feasibility assessment of the four scenarios, it became apparent that construction costs cannot be determined for the individual sections, without detailed separate studies of the specific characteristics of each section. In many cases critical information, such as the configuration, form and cost of a potential interchange improvement, does not yet exist. For these reasons, an alternative cost estimate method was developed by the consultant — a high-level, per-kilometre “representative” capital and maintenance cost estimate using a 2008 Transport Canada study.[29] These estimates provide the necessary input to the BCA, sufficient for the purposes of this analysis, while acknowledging that they are generic and that detailed analyses would be required to support the implementation of a lane on any specific segment.

The 2008 Transport Canada study categorized road infrastructure in several ways, notably by facility functional type, the physical features of the facility (e.g., geometric design and pavement type), province, location within the province, including a distinction between urban and rural locations, and AADT. Data were provided by individual provincial Ministries of Transport, including the MTO. Note that the data, including costs, represent the year 2003. Two geographies were considered for Ontario: northern and southern Ontario. The latter includes the GTHA.

The study developed cost reporting sheets for each geography. The sheets developed costs for one kilometre of a single traffic lane of each facility type, comprising:

- Initial construction costs and maintenance and rehabilitation costs for pavements, bridges and all other road infrastructure.
- Routine maintenance and winter maintenance costs.

Note that these costs do not include land acquisition. For an urban freeway in southern Ontario, the combined per-kilometre, per-lane road costs were tabulated as **$56,464** annually, based on 2003 $. These annual costs assume a 60-year lifecycle and use a 6% discount. The detailed sheet is reproduced in Figure 13.

[29] Applied Research Associates, Estimation of the Representative Annualized Capital and Maintenance Costs of Roads by Functional Class, Revised Final Report, report TP-14743, prepared for Transport Canada, August 7, 2008.

Figure 13: Cost Reporting Sheet for Southern Ontario

Table 53. Cost Reporting Sheet for Southern Ontario

Ontario - South

Pavements - Initial Construction Costs

Functional Class	Provincial Rural	Provincial Urban	Municipal Rural	Municipal Urban
Freeway	$ 24,627	$ 25,602		
Arterial	$ 14,827	$ 16,739	$ 14,779	$ 18,079
Collector	$ 13,436	$ 15,590	$ 12,146	$ 15,209
Local	$ 9,301	$ 7,936	$ 2,947	$ 11,450

All Other Road Infrastructure - M&R Costs

Functional Class	Provincial Rural	Provincial Urban	Municipal Rural	Municipal Urban
Freeway	$ 389	$ 1,439		
Arterial	$ 449	$ 1,012	$ 459	$ 1,104
Collector	$ 461	$ 1,076	$ 493	$ 1,190
Local	$ 442	$ 1,150	$ 492	$ 1,283

Pavements - Maintenance and Rehabilitation Costs

Functional Class	Provincial Rural	Provincial Urban	Municipal Rural	Municipal Urban
Freeway	$ 3,026	$ 2,182		
Arterial	$ 3,877	$ 3,877	$ 2,881	$ 2,881
Collector	$ 3,686	$ 3,478	$ 2,155	$ 2,155
Local	$ 2,720	$ 2,720	$ 314	$ 2,007

Routine Maintenance Costs

Functional Class	Provincial Rural	Provincial Urban	Municipal Rural	Municipal Urban
Freeway	$ 1,925	$ 2,063		
Arterial	$ 1,788	$ 1,925	$ 1,788	$ 1,925
Collector	$ 1,650	$ 1,788	$ 1,650	$ 1,788
Local	$ 1,513	$ 1,650	$ 550	$ 1,650

Bridges - Initial Construction Costs

Functional Class	Provincial Rural	Provincial Urban	Municipal Rural	Municipal Urban
Freeway	$ 4,283	$ 5,139		
Arterial	$ 3,854	$ 3,854	$ 2,537	$ 2,537
Collector	$ 3,426	$ 4,283	$ 2,255	$ 2,819
Local	$ 2,141	$ 1,499	$ 282	$ 564

Winter Maintenance Costs

Functional Class	Provincial Rural	Provincial Urban	Municipal Rural	Municipal Urban
Freeway	$ 3,300	$ 3,300		
Arterial	$ 2,750	$ 3,025	$ 2,475	$ 2,750
Collector	$ 2,200	$ 2,750	$ 1,925	$ 2,200
Local	$ 2,200	$ 2,750	$ 1,375	$ 1,925

Bridges - Maintenance and Rehabilitation Costs

Functional Class	Provincial Rural	Provincial Urban	Municipal Rural	Municipal Urban
Freeway	$ 545	$ 654		
Arterial	$ 436	$ 436	$ 245	$ 245
Collector	$ 315	$ 394	$ 218	$ 273
Local	$ 164	$ 115	$ 27	$ 55

All Other Road Infrastructure - Initial Construction Costs

Functional Class	Provincial Rural	Provincial Urban	Municipal Rural	Municipal Urban
Freeway	$ 15,516	$ 16,084		
Arterial	$ 11,247	$ 12,437	$ 8,273	$ 9,698
Collector	$ 7,320	$ 10,576	$ 6,158	$ 9,117
Local	$ 3,883	$ 5,656	$ 3,667	$ 6,210

Total Road Costs

Functional Class	Provincial Rural	Provincial Urban	Municipal Rural	Municipal Urban
Freeway	$ 53,610	$ 56,464		
Arterial	$ 39,228	$ 43,305	$ 33,438	$ 39,221
Collector	$ 32,494	$ 39,935	$ 27,000	$ 34,750
Local	$ 22,364	$ 23,476	$ 9,655	$ 25,144

Note: *All costs reported in the above tables are annualized costs (using 6 percent discount rate and 60-year analysis period) for one one-km-long traffic lane.*

Source: Applied Research Associates, *Estimation of the Representative Annualized Capital and Maintenance Costs of Roads by Functional Class, Revised Final Report*, report TP-14743, prepared for Transport Canada, August 7, 2008.

To develop a 2016 value, the consultant developed a two-part calculation, to reflect the available construction inflation data: MTO construction cost data to 2010 and then Statistics Canada construction inflators to 2016. The calculation is detailed below.

First, with the 2003 unit cost as a basis, MTO's *Tender Price Index* (TPI) was used to inflate the values to 2010, which is the latest year for which full TPI data were available.[30] The TPI reflects construction costs compiled from data in bids that were received for MTO tenders. The costs comprise grading, materials, drainage, electrical, structures and miscellaneous items (e.g., traffic control devices). The available information covers only data to the end of 2010, based on which an inflator of 37.1% can be derived, to yield a 2010 unit cost of $77,416.[31]

Next, Statistics Canada construction inflators were used to bring the values to 2016 levels. These inflators are cited in a 2016 Peel Region synopsis of trends that influence construction prices for Regional infrastructure (which include arterial roads among other infrastructure).[32] The Peel synopsis cites Statistics Canada's Non-Residential Construction Price Indexes (NRCPI) for the Toronto Census Metropolitan Area (CMA), among other indexes such as the price of gasoline, natural gas and asphalt. The NRCPI cover a range of types of construction, and it is not clear the extent to which, or even if, they include road construction. Nonetheless, the NRCPI for the Toronto CMA between 2003 and 2010 compares well with the TPI indicator for the same period, at 40.1% versus 37.1%, respectively. Accordingly, in the absence of any other information, for the purposes of this analysis it is reasonable to use the NRCPI inflator to extent the 2010 values to 2016, which yields a value of 13.3%. Applying this value in turn yields a 2016 annualized unit cost, per-kilometre and per lane, of **$87,736**. This represents a compounded annual cost escalation rate from 2003 to 2016 of 3.5%, which compares to Canadian CPI growth of 1.8% p.a. over the same time period.[33]

Benefit Cost Analysis

The benefits and costs are compared for each of the four scenarios in Table 33. As can be seen in the table, the benefit/cost ratio grows as the expansiveness of the network increases, because of the "network benefits" associated with corridor continuity. However, the benefit-cost ratio remains below 0.2 for each of the scenarios, indicating that the costs exceed the benefits by a factor of five or greater. This suggests that constructing a network of new managed lanes purely for bus-associated benefits would not be economically justified. However, in the event that a managed lanes project also benefits other road users (aside from bus riders) at the same construction and maintenance cost, these bus-associated benefits may be only a fraction of the total benefits. In such a case, the benefits listed in the table below would supplement any other benefits to non-bus riders. Furthermore, the cost figures provided in the table apply to the case of new lane construction (i.e. roadway widening), and do not include the cost of land acquisition as referenced in Chapter 9.0. If managed lanes are implemented in such a way as does not require new lane construction, the benefit-cost ratio may be more favourable to managed lanes, although such a scenario is not considered in this study.

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30 *Tender Price Index*, Ministry of Transportation of Ontario, October 13, 2011.

31 The inflator is calculated as the growth in the TPI composite index between the 2003/2004 fiscal year index for Q4 (137.01, where the 1992/1993 index was 100.0) and 2010/2011 (187.85), yielding an inflator of 1.371. Multiplying this inflator by the base unit cost of $56,464 yields a 2010 unit cost of $77,416.

32 *Construction Price Trends, Major influences on commodity prices 2015*, prepared by Business Intelligence Center of Excellence, Region of Peel, July 2016.

33 *Consumer Price Index, historical summary (1996 to 2015),* Statistics Canada, January 22, 2016.

Table 33: Benefits and Costs by Scenario

	Kilometres	NPV Benefits to 2016	NPV Costs to 2016	B/C Ratio
Scenario 1	352	$34,985,486	$281,474,635	0.12
Scenario 2	377	$40,672,552	$314,770,447	0.13
Scenario 3	545	$89,110,005	$534,851,816	0.16
Scenario 4	1,066	$203,604,524	$1,220,916,629	0.16

10.0 FINANCIAL IMPLICATIONS

The financial case considers implications for public-sector revenues and costs, as distinct from the overall economic impacts.

Four types of financial implications are considered:

- Construction, operation, and maintenance costs of the new facilities (as described in Chapter 7.0).
- Operator cost savings (as described in Chapter 7.0) from faster travel.
- Operator fare revenues from new transit riders (uptake).
- Foregone fuel taxes from motorists shifting to transit.

The total financial impacts (in terms of net present value from 2017-2031) are detailed in Table 34. For construction, operation and maintenance costs of the managed lanes and operator cost savings, the financial impacts are equal to the economic impacts described in the previous chapter. For operator fare revenues, assumed revenues per passenger of $6.38 (GO) and $2.74 (non-GO) are applied to the anticipated uptake for each scenario. In the case of foregone fuel taxes, a rate of $0.03/kilometre is applied to the estimated PKT diverted from automobile trips to transit. This is based on fuel taxes of $0.14/L (provincial) and $0.10/L (federal) and an assumed average passenger vehicle fuel economy of 12.8 L/100 km

As can be seen in the table, the cost of constructing, operating and maintaining new lanes is significantly larger than other financial impacts associated with all scenarios.

Table 34: Financial Impacts by Scenario ($ Millions, Total NPV)

	Construction, Operation and Maintenance Costs	Operator Cost Savings	Operate Fare Revenues	Foregone Fuel Taxes	Total Financial Impact (NPV)
Scenario 1	-$281.47	$2.40	$14.61	-$1.32	-$265.78
Scenario 2	-$314.77	$2.79	$16.83	-$1.53	-$296.68
Scenario 3	-$534.85	$6.17	$35.87	-$3.37	-$496.17
Scenario 4	-$1,220.92	$14.12	$83.62	-$7.73	-$1,130.90

11.0 CONCLUSIONS

Summary

This analysis investigates the potential economic value of a network of managed lanes on the Greater Toronto and Hamilton Area's freeways. The investigation comprised a benefit-cost analysis (BCA) and a financial impact analysis. The investigation focused on the transit impacts of the managed lanes, thereby distinguishing itself from, and complementing, other managed lane impact analyses that are being conducted by the Ontario Ministry of Transportation.

Four managed lane scenarios were examined:

- Scenario 1 includes a base scenario (existing and planned managed lanes, and the Highway 407 ETR), plus potential HOV / HOT initiatives now being considered by MTO.
- Scenario 2 extends Scenario 1 to make continuous corridors, with managed lanes implemented at two strategic locations.
- Scenario 3 extends Scenario 2 to develop a continuous, circumferential managed lane network that provides suburb-to-suburb links, while connecting two key suburban employment growth clusters.
- Scenario 4 assumes a continuous managed lane system across the entire GTHA expressway network.

The benefits for each scenario were expressed in terms of travel time saved by transit passengers, accounting for both existing bus riders and new riders who are attracted from other modes to the improved transit service. Also taken into account were savings in operator costs, and external decongestion, reductions in traffic accidents, reduced GHGs and reduced CAPs (where the external costs arise from the diverted new riders who almost entirely formerly use personal autos). All benefits were monetized for input to the BCA. The BCA covered a fifteen-year period, from 2017 (the first year) through 2031.

It was recognized that some expressway sections and interchanges have significant geometric, structural or other existing constraints that limit the type of managed lane that actually could be implemented, or which in practical terms would preclude the introduction of a managed lane altogether. It also was recognized that some constraints could be addressed although only at a high, undetermined cost and/or at some undefined time in the future. To this end, the MTO rated the candidate sections in each scenario according to the feasibility of actually implementing a managed lane.

Because of the uncertain feasibility of many expressway segments, these geometric and structural constraints were set aside in order to develop meaningful scenarios for the BCA. Instead, the consultant developed high-level, per-kilometre "representative" capital and maintenance costs estimates, based on the available information. These estimates were deemed sufficient for the purpose of this analysis, while acknowledging that the estimates are generic and that detailed analyses would be required to support the implementation of a lane on any specific segment.

Conclusions

The benefits and costs are compared for each of the four scenarios in Table 33 above. As noted, only transit benefits are considered (i.e., no benefits from other potential managed lane users, such as HOT single occupant vehicles or HOV multi-occupant vehicles), whereas the full annualized lifecycle costs are assessed, assuming new infrastructure is required. As a result, the benefit-cost ratio remains below 0.2 for each of the scenarios, although the benefit/cost ratio grows as the expansiveness of the network increases because of the "network benefits" associated with corridor continuity. This suggests that constructing a network of new managed lanes purely for bus-associated benefits would not be economically justified, and so the transit benefits are best viewed as an increment that should be added to those that would accrue from other users, such as carpoolers or HOT users. In this case, the benefits listed in the table below would supplement any other benefits to non-bus riders. Furthermore, the cost figures provided in the table apply to the case of new lane construction (i.e. roadway widening). If managed lanes are implemented in such a way as does not require new lane construction, the benefit-cost ratio may be more favourable to managed lanes, although such a scenario is not considered in this study and would have to take into account travel time impacts on other displaced users.

Many studies that have examined the potential benefit of managed lanes have focussed on the benefits for auto users. The usual focus on auto users is reasonable given that those users are the primary users of the road network. This study reviewed the potential benefits of a network of managed lanes for transit users in the GTHA and found that the benefits to transit users can add ad up to 16 basis points to the benefit-cost ratio. As such, planners and policymakers should consider the potential benefits for transit users when making decisions regarding policies and investments related to managed lanes.