PARSONS

Addendum to

DOWNTOWN TORONTO CONGESTION STUDY

White Paper: Bottleneck Analysis and Best Practice Review

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Executive Summary

The Toronto Region Board of Trade (TRBOT) retained Parsons to conduct the Downtown Toronto Congestion Study, aimed at assessing the current state of traffic congestion and identifying its root causes. The initial findings of this study, completed on December 2, 2024, pinpointed key bottlenecks and specific causes of congestion at those locations. Following the initial study, and as requested by TRBOT, this white paper is prepared as an addendum to review specified high-impact locations with persistent, long-term congestion driven by chronic operational challenges where there may be traffic management solutions that are feasible within short timelines, and without the need for major construction. This report contains: **Bottleneck Analysis** at two specific locations identified in downtown Toronto, and **Best Practice Review** with a focus on Melbourne's ramp metering system and New York City's one-way street network.

Bottleneck Analysis

Harbour St at York St: The most critical issue is the queue spillback from York St onto Harbour St, driven by limited storage capacity on York St and high traffic demand. This is exacerbated by weaving conflicts as vehicles from the Gardiner Expressway off-ramp navigate multiple lane changes to access turning lanes, disrupting through movements heading east of York St.

Gardiner Expressway Westbound (WB) between York St On-Ramp and Spadina Ave Off-Ramp: The primary operational challenge stems from a substandard weaving section built in 1962, which no longer meets modern design standards. This results in frequent weaving and merging conflicts, limited capacity, and delays that propagate upstream of the expressway and on-ramp.

Best Practice Review

Melbourne Freeway Ramp System: Melbourne has successfully implemented ramp metering systems to manage freeway congestion and improve safety. The HERO algorithm is the name of a sophisticated traffic management method used to control the rate at which vehicles enter freeways through ramp meters. It dynamically adjusts metering rates based on real-time traffic data, maintaining optimal traffic density and preventing flow breakdowns. By doing so, it helps improve traffic flow, reduce travel time variability, and enhance overall safety on the freeway. Key benefits of the HERO algorithm include reduced travel time variability, improved traffic flow, and enhanced safety. Melbourne's experience demonstrates that ramp metering can effectively manage congestion and improve freeway efficiency.

New York City's One-Way Street Network: New York City has an extensive one-way street network, particularly in Manhattan, designed to streamline traffic flow, reduce conflicts at intersections, and improve safety. One-way streets have been effective in managing traffic in densely populated areas, enhancing signal progression, and reducing intersection conflicts. However, they also present challenges, such as increased travel distances, potential confusion for drivers, and impacts on local businesses. Many North American cities (ex. Cincinanati, Sacramento, Dallas, etc.) are converting one-way streets to two-way, citing enhanced livability, accessibility, and the ability to better support local economies as primary reasons.

Recommendations

Bottleneck Analysis

- **Harbour St at York St**
  - Minimize queuing spillback and weaving conflicts by introducing physical separation between Lake Shore Blvd and Gardiner Expressway off-ramp traffic, reconfiguring lane assignments, and implementing turn restrictions.
  - Adopt a coordinated approach that balances short-term improvements with long-term objectives to achieve sustainable and effective outcomes.
- **Gardiner Expressway WB between York St On-Ramp and Spadina Ave Off-Ramp**

- Implement and monitor quick-build solutions, such as lane reconfigurations and targeted traffic restrictions, to reduce weaving conflicts and balance expressway and ramp movements.
- Advocate for integrating long-term operational improvements into the Gardiner Section 4 rehabilitation project (2026–2028).

Ramp Metering

- **Toronto should consider implementing ramp metering on key freeway segments** along the Gardiner Expressway. A pilot project could be initiated to evaluate its effectiveness, using real-time data to dynamically adjust metering rates and monitor the impact on traffic flow and safety.
- Leveraging existing intelligent transportation systems (ITS) will be crucial for successful implementation, and the system must be designed to operate effectively in all weather conditions.
- Engaging with local stakeholders and providing clear communication will help ensure smooth adoption and address any concerns.

One-Way Streets

- Toronto should be cautious about converting more streets to one-way. While one-way streets can improve traffic flow and reduce intersection conflicts, they also present significant drawbacks, such as increased travel distances, potential confusion for drivers, and negative impacts on local businesses.
- Given these challenges and the trend of cities converting one-way streets to two-way to enhance livability**, it is not recommended for Toronto to pursue further one-way street conversions** of arterial roads in its downtown core.
- Instead, the city should explore other traffic management strategies, such as travel demand management and enhanced public transit options, to address congestion and improve overall livability.

This study underscores the importance of a comprehensive and data-driven approach to traffic management in downtown Toronto. By leveraging insights from successful implementations in other cities and tailoring them to Toronto's unique context, the city can develop effective solutions to mitigate congestion, enhance safety, and improve the quality of life for its residents and commuters. The recommendations provided in this study offer a clear path forward, emphasizing the need for innovative and adaptive traffic management strategies that align with Toronto's long-term vision of a sustainable and efficient transportation network.

Introduction

The Toronto Region Board of Trade (TRBOT) has retained Parsons to conduct the Downtown Toronto Congestion Study (referred to as the Study). The primary goals of the Study are to assess the current state of traffic congestion in downtown Toronto and to explore its root causes. The Final Report of the Study, dated December 2, 2024, indicates that Toronto's growing population, evolving travel patterns, and the limited capacity of its existing urban arterial and freeway networks have led to persistent congestion, particularly along major corridors that serve as vital arteries for the movement of commuters and goods.

Key downtown streets face frequent delays, bottlenecks, and safety concerns. The downtown core epitomizes these challenges, with peak-hour gridlock and unpredictable travel times becoming the norm. The Gardiner Expressway stands out due to its overwhelming impact on the broader transportation network. Congestion on the Gardiner Expressway contributes to spillover onto adjacent north-south arterials such as Spadina Ave, York St, Bay St, Yonge St, and Jarvis St, while vital east-west routes like Lake Shore Blvd and Harbour St face severe congestion near key intersections and major attractions. These bottlenecks collectively impact transportation efficiency, economic productivity, and the quality of life for Toronto's residents.

Following the completion of the initial study, TRBOT has requested an addendum to address two specific areas of concern. This white paper is prepared as an extension to the previous study report and aims to:

- Conduct an analysis of two specific bottlenecks: the Gardiner Expressway westbound from York St On-ramp to Spadina Ave Off-ramp, and Harbour St at York St. The analysis focuses on addressing persistent congestion at high-impact locations caused by capacity constraints, merging/weaving conflicts, and queue spillover. It aims to propose feasible traffic management solutions that are quick to implement and align with long-term transportation goals.
- Perform a best practice review of two cities that exemplify innovative traffic management: Melbourne's ramp systems and New York City's one-way street network.

This document is organized to present the study findings in response to the above items, primarily divided into two sections: **Bottleneck Analysis** and **Best Practice Review**. A summary and conclusion are provided at the end to encapsulate the findings and recommendations.

Bottleneck Analysis

Goal and Objectives

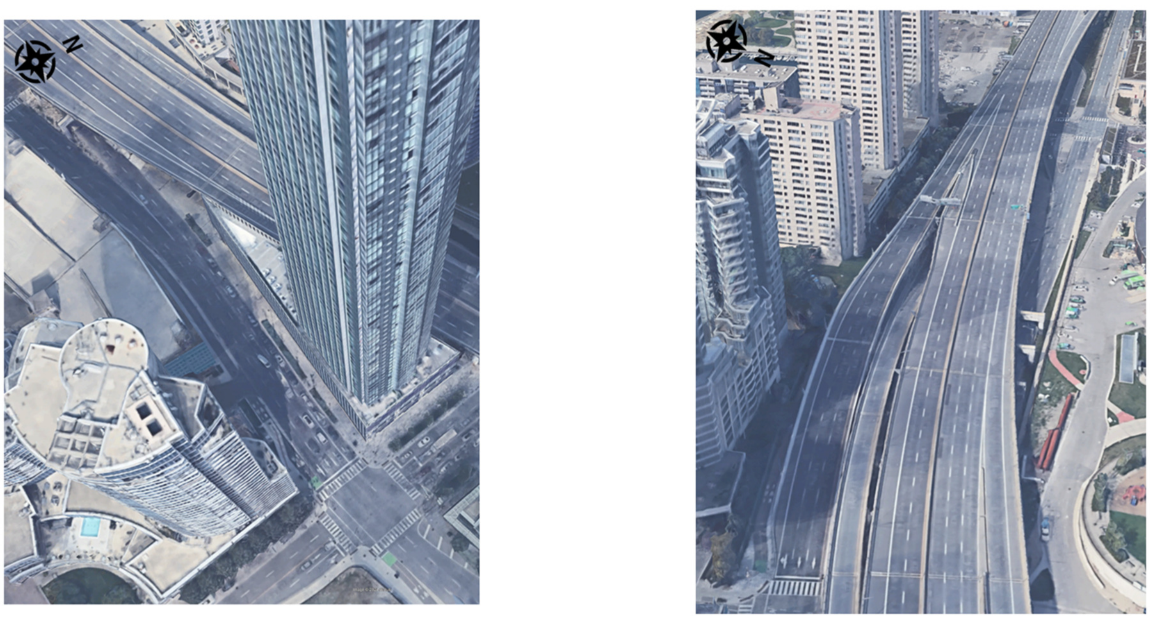
Congestion on the Gardiner Expressway stands out due to its overwhelming impact on the broader transportation network, contributing to congestion spillover onto adjacent north-south arterials like Spadina Ave, York St, Bay St, Yonge St, and Jarvis St. Harbourfront streets like Lake Shore Blvd and Harbour St, which, alongside the Gardiner, are vital east-west routes, also suffer from severe congestion, particularly near major sports and entertainment venues and key intersections. Two critical bottlenecks have been identified from these congested corridors for further analysis:

- Harbour St at York St
- Gardiner Expressway WB between the York St On-ramp and the Spadina Ave Off-ramp.

Based on travel time data, it is estimated that during the PM peak period, which is the busiest time of day for traffic, drivers on the westbound Gardiner Expressway take 5.5 times longer to travel the same distance compared to overnight hours with no congestion. Similarly, drivers on eastbound Harbour St take 3.12 times longer than they would during overnight, uncongested periods. These figures highlight the severe delays caused by congestion at these critical bottlenecks.

Building on the findings of the prior study, the bottleneck analysis reviews these high-impact locations with persistent, long-term congestion driven by chronic operational challenges, such as capacity constraints, spillover effects, and safety concerns. Addressing these critical areas provides foundations to resolve systemic issues in the transportation network.

The study's primary goal is to enhance traffic operations by reducing delays and congestion at key bottlenecks, thereby improving travel efficiency and supporting the economic and social vitality of downtown Toronto. To achieve this, the focus is on identifying and implementing traffic management solutions that are feasible within short timelines and require minimal or no major construction. These short-term measures aim to deliver tangible improvements while aligning with the long-term vision of a sustainable and efficient transportation network.



1 Harbour St at York St

2 Gardiner Expressway WB York St On-ramp – Spadina Ave Off-ramp

FIGURE 1: MAP OF STUDY AREA IN DOWNTOWN TORONTO

Harbour St at York St

CHALLENGES AND OPPORTUNITIES

The intersection of Harbour St and York St faces several challenges that impact traffic flow and operations as shown in **Figure 2**. These challenges include:

1. High levels of traffic demand from all directions at the Lake Shore Blvd W and York St intersection create capacity deficiencies, making it difficult to optimize signal timing for any specific leg of the intersection. This issue is further exacerbated during peak periods when congestion is at its highest.
2. Queuing space on York St is notably limited north of the intersection (40m), accommodating only about 12 vehicles even under moderate traffic conditions. This constraint leads to frequent spillback onto Harbour St, where queued vehicles disrupt eastbound traffic flow. While the City has coordinated signal timing since the York-Bay-Yonge ramp reconfiguration to minimize stopping for Harbour St vehicles, physical space limitations on York Street remain a challenge.
3. The spillback is particularly problematic because vehicles attempting to turn onto York St must compete for space with through traffic, further straining the limited capacity. The interaction between vehicles from the Lake Shore Blvd EB and the Gardiner off-ramp creates additional complications. While traffic from Lake Shore Blvd EB can easily access the left-turn lane with minimal lane changes, vehicles from the Gardiner off-ramp must make at least two lane changes to reach the same turn lane. This weaving conflict frequently blocks through traffic heading east of York St, causing significant delays and operational inefficiencies.
4. Despite these challenges, Harbour St has four one-way eastbound lanes, offering opportunities for potential reconfigurations to improve traffic flow. These could include changes to lane assignments or the introduction of physical barriers to better manage traffic movement and reduce conflicts.

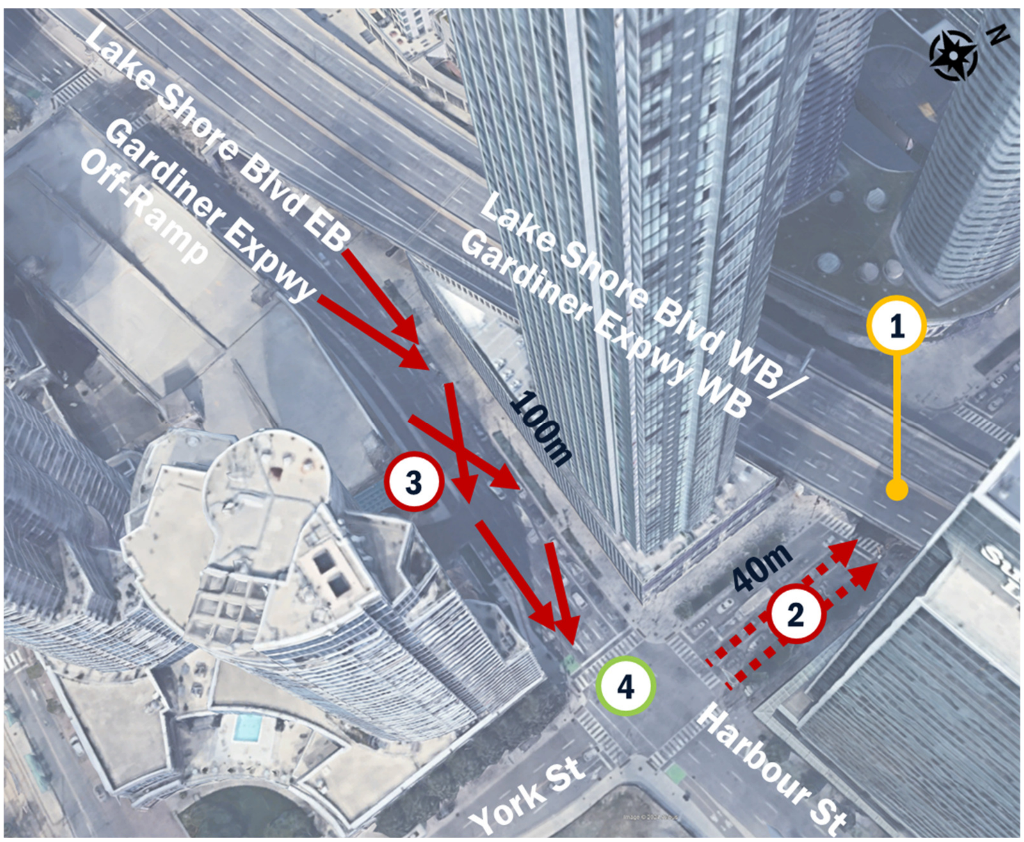


FIGURE 2: CHALLENGES AND OPPORTUNITIES NEAR HARBOUR ST & YORK ST INTERSECTION

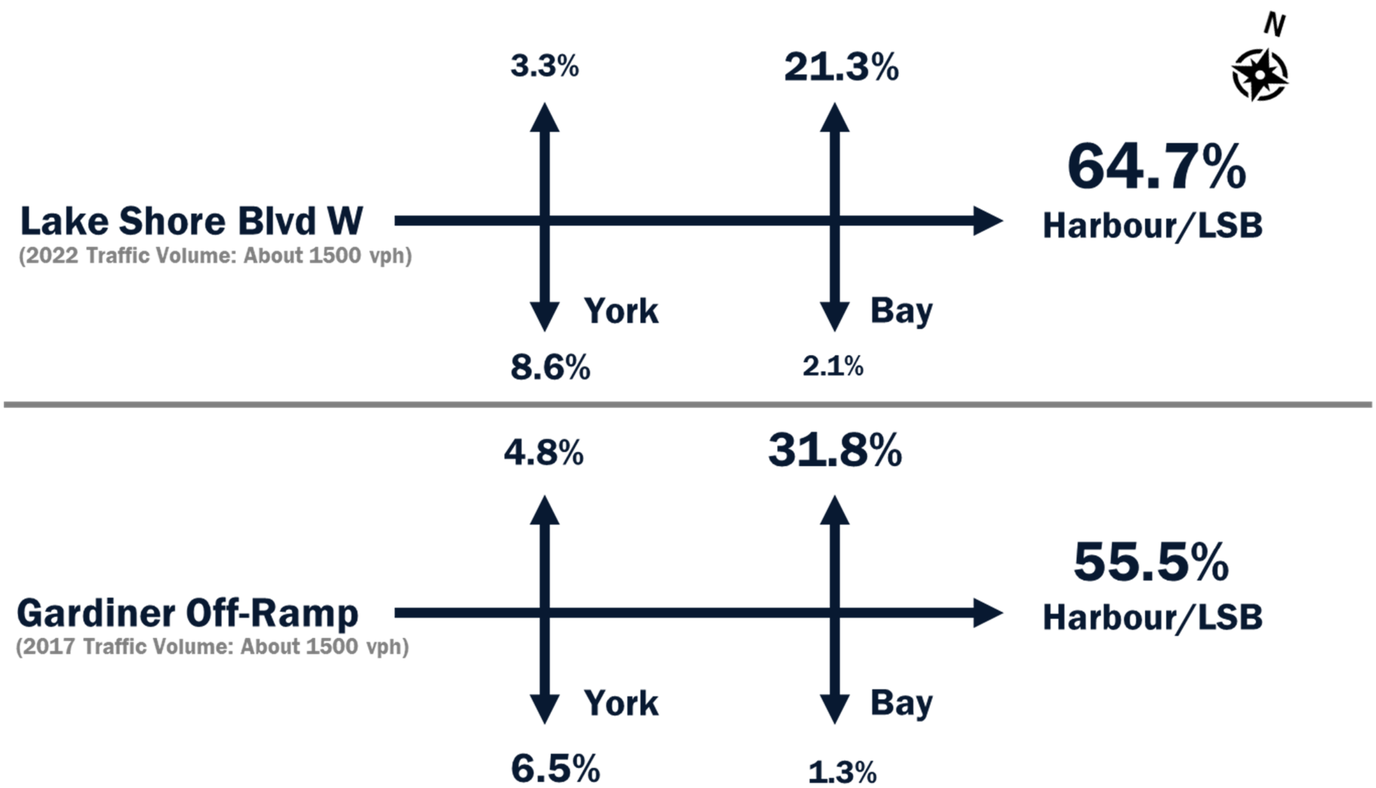
ORIGIN-DESTINATION PATTERNS

The analysis of origin-destination data indicates where vehicles are coming from and going to on this specific section of Harbour St. **Figure 3** shows that the majority of vehicles from **Lake Shore Blvd W (LSB)** and the **Gardiner Off-Ramp** are heading east of York St and Bay St. Traffic levels from Lake Shore Blvd W and the Gardiner are comparable, with **64.7%** and **55.5%** of traffic, respectively, continuing east along Harbour St and Lake Shore Blvd.

A smaller proportion of vehicles turn northbound onto Bay St, accounting for approximately 20–30% of the volume, while 3.3% of traffic from Lake Shore Blvd W and 4.8% from the Gardiner Off-Ramp turn northbound onto York St. Despite the low proportion of vehicles making this movement, the associated queuing and weaving interactions disproportionately affect eastbound throughput.

Most weaving issues are caused by spillback from northbound York St traffic, which blocks other movements, particularly for vehicles heading further east. The need for at least two lane changes for vehicles from the Gardiner Off-Ramp to access the left-turn lane further exacerbates congestion. This highlights how a relatively small volume of turning traffic to northbound York St disrupts the flow for the majority of vehicles continuing east.

Minimizing the impact of merging/weaving and prioritizing through traffic is necessary to improve overall operations. Addressing these issues forms the foundation for both long- and short-term solutions, as detailed in the following sections.



Data Sources: 2019 StreetLight Data (SLD) Origin-Destination (OD) Metrics. 2017 Gardiner Expressway Automated Traffic Recorder (ATR) Data (collected prior to Yonge-Bay-York ramp reconfiguration). 2022 Open Data Turning Movement Count (TMC) Data.
Note: PM Peak data are used as a reference. AM, PM, and Off-Peak volumes exhibit similar patterns.

FIGURE 3: ORIGIN-DESTINATION PATTERNS ON HARBOUR ST WEST OF YORK ST (SOURCE: STREETLIGHT DATA AND CITY OF TORONTO OPEN DATA)

LONG-TERM SOLUTIONS

The City of Toronto and Waterfront Toronto have completed the *Lower Yonge Precinct Environmental Assessment (EA)* to identify the transportation infrastructure required to support development within the Lower Yonge Precinct. The assessment recommends the following infrastructure improvements:

1. Conversion of Harbour St from one-way eastbound to two-way operations between York St and Yonge St.
2. Removal of the Bay St on-ramp to the eastbound Gardiner Expressway
3. Shortening of the Lower Jarvis St off-ramp from the eastbound Gardiner Expressway to touch down at Yonge St.
4. Realignment of the Yonge St/Harbour St intersection.
5. Extension of Harbour St eastward from Yonge St to Lower Jarvis St.
6. Addition of one eastbound lane on Lake Shore Blvd E.
7. Extension of Cooper St north to connect with Church St and The Esplanade.
8. Enhancement of the road network within the Lower Yonge Precinct, including the addition of New Street and various new intersection connections.

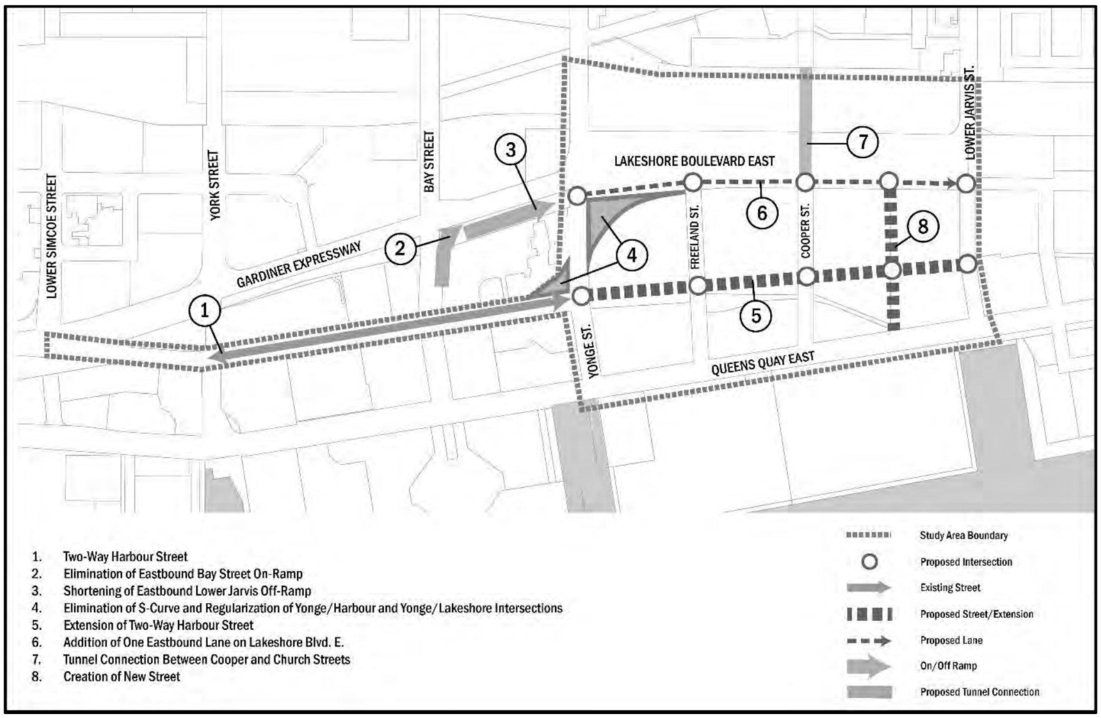


FIGURE 4: LOWER YONGE PRECINCT EA – RECOMMENDED TRANSPORTATION INFRASTRUCTURE IMPROVEMENT (SOURCE: WATERFRONT TORONTO)

These measures are designed to promote regional connectivity, improve local traffic circulation, and support sustainable transportation objectives. Reconfiguring the eastbound Gardiner Off-Ramp to Lower Jarvis St to land at Yonge St is expected to reduce through traffic on Lake Shore Blvd between Yonge and Lower Jarvis, while the planned two-way conversion of Harbour St will enhance local access and operations. Additionally, the Cooper St tunnel and network enhancements aim to balance regional and local vehicular circulation and accessibility.

Diverting regional traffic from Harbour St onto Gardiner Expressway and Lake Shore Blvd creates opportunities to improve pedestrian experience on local streets. The fine-grained street network planned for the precinct is expected to enhance connectivity, encourage a shift away from vehicle dependency, and promote overall mobility improvements. Full implementation of these measures, including the Yonge St off-ramp, is anticipated beyond 2035.

While these long-term solutions will address systemic issues in the area, their extended implementation timeline means that interim actions are needed to mitigate current operational challenges. The following section outlines potential short-term solutions designed to bridge the gap until full implementation of the long-term improvements.

POTENTIAL SHORT-TERM SOLUTIONS

The potential short-term solutions are developed based on selecting measures from the traffic management toolbox that can be implemented without major civil construction. These solutions aim to minimize the impact of weaving interactions and prioritize through movements east of York St to improve overall traffic operations. While all proposed measures meet this goal, they were developed and selected through a systematic process.

The basis for all options is to physically separate two streams of traffic from Lake Shore Blvd and the Gardiner Expressway Off-Ramp to eliminate the weaving and merging conflicts in the short section. Each option differs in terms of lane configuration, turn restrictions, and resulting signal timing design to balance trade-offs. Below are the proposed options:

Option 1: Physical Separation with Full Turn Restrictions (Figure 5)

- Provides two lanes for each traffic stream while prohibiting eastbound right (EBR) turns for Lake Shore Blvd W traffic and eastbound left (EBL) turns for Gardiner Off-Ramp traffic.
- Eliminates weaving interactions, reduces through-lane blockages, and maximizes through capacity for both streams.

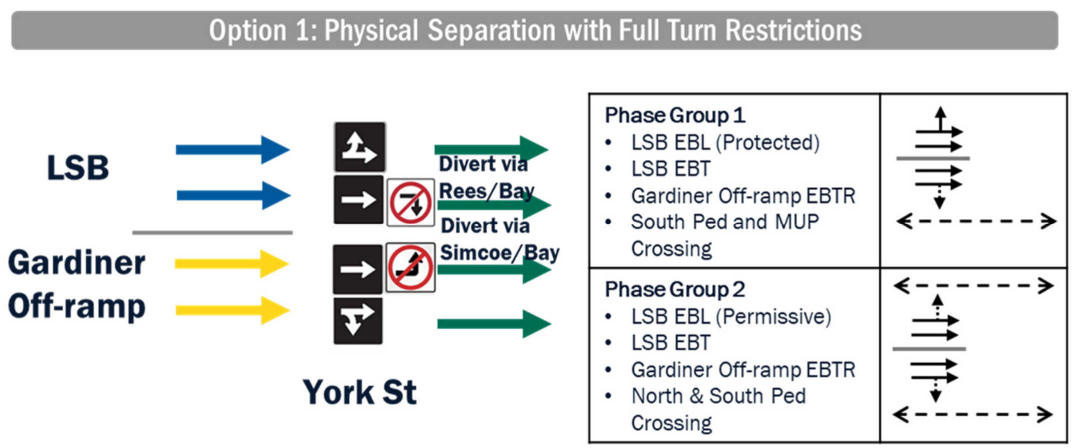


FIGURE 5: HARBOUR STREET AT YORK STREET POTENTIAL SHORT-TERM OPTION 1

Option 2: Physical Separation with Partial Turn Restrictions (Figure 6)

- Eliminates weaving conflicts and provides turning options for Gardiner Off-Ramp vehicles to northbound York St.
- Allowing the left turn reduces diversion but takes away one through lane to simplify signal phasing requirement.
- Requires dedicated signal phasing to separate conflicts, resulting in increased operational inefficiencies.

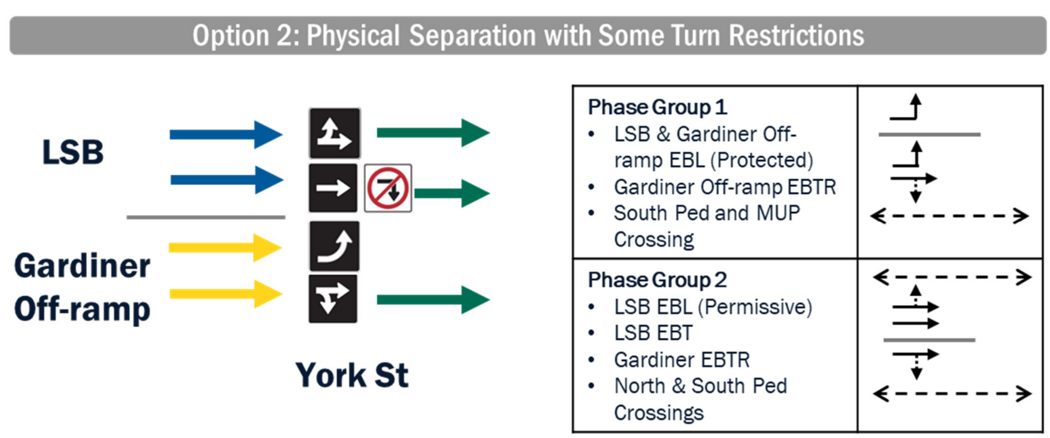


FIGURE 6: HARBOUR STREET AT YORK STREET POTENTIAL SHORT-TERM OPTION 2

Option 3: Physical Separation with No Turn Restrictions (Figure 7)

- Eliminates weaving interactions while maintaining all turns at York St intersection.
- Requires split signal timing, meaning through and turning movements occur simultaneously within the same phase but separately for each stream.

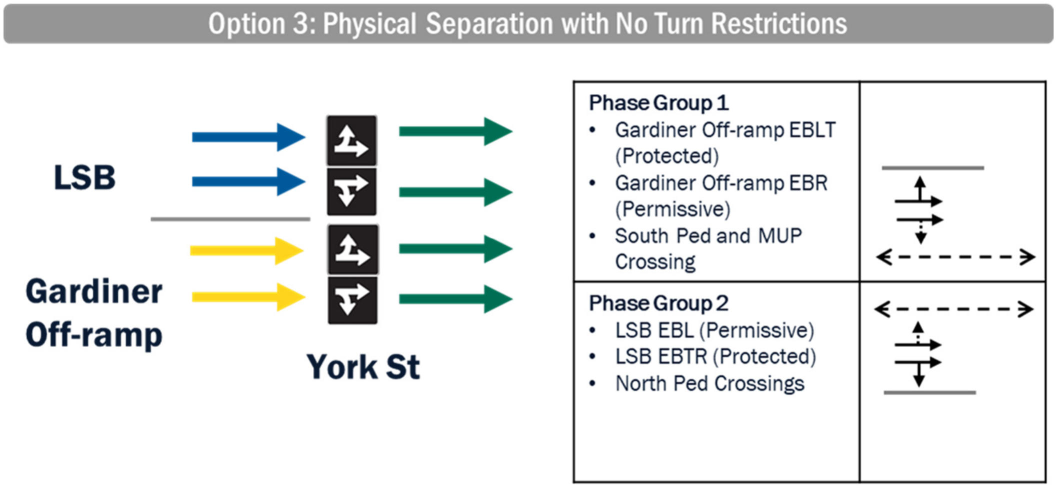


FIGURE 7: HARBOUR STREET AT YORK STREET POTENTIAL SHORT-TERM OPTION 3

RECOMMENDATIONS

Table 1 evaluates the potential short-term solutions and **Option 1: Physical Separation with Full Turn Restrictions** is recommended as the preferred alternative. This option offers several advantages:

- **Eliminates weaving conflicts**: By physically separating traffic streams, this option directly addresses the root cause of delays and congestion in the section.
- **Prioritizes through movements**: Maximizing eastbound throughput ensures that the majority of vehicles benefit from improved traffic flow.
- **Simple and efficient implementation**: The straightforward design minimizes construction requirements and aligns with existing traffic management practices in the City of Toronto.

While Option 1 requires turn restrictions that may increase trip lengths and vehicle kilometers traveled, the overall benefits to traffic operations, safety, and implementation feasibility is expected to outweigh these trade-offs.

TABLE 1: EVALUATION OF SHORT-TERM OPTIONS FOR HARBOUR STREET AT YORK STREET

Criteria	Option 1: Full Turn Restrictions	Option 2: Partial Turn Restrictions	Option 3: No Turn Restriction
Weaving Conflict	Eliminates weaving interactions.	Eliminates weaving interactions.	Eliminates weaving interactions.
Through Movement	Maximizes through-lane capacity by providing two lanes for each traffic stream.	Reduces through-lane capacity to one lane for Gardiner Off-Ramp traffic due to dedicated left-turn lane.	Maintains existing through-lane capacity but introduces timing inefficiencies.
Turning Movements	Prohibits EBR for Lake Shore Blvd traffic and EBL for Gardiner Off-Ramp traffic, increasing trip length and overall vehicle distance travelled.	Allows left-turns for Gardiner Off-Ramp traffic but restricts EBR for Lake Shore Blvd traffic.	Maintains all turn movements, accommodating all traffic but increasing intersection delay.

Criteria	Option 1: Full Turn Restrictions	Option 2: Partial Turn Restrictions	Option 3: No Turn Restriction
Signal Phasing	Simple and efficient phasing design.	Requires protected left-turn phasing, increasing operational complexity.	Requires split timing, reducing efficiency for through movements.
Safety	Minimizes intersection conflicts by prohibiting turn movements. Less workload for drivers at intersection.	More potential for conflict at intersection and introduces unconventional designs. More workload for drivers at intersection.	Increases potential for vehicle-vehicle and pedestrian-vehicle conflicts due to accommodating all turn movements. Most workload for drivers at intersection.
Implementation	Simple to implement with minimal design adjustments.	Moderately complex implementation due to new signal design and lane reconfiguration.	Complex implementation requiring new signal design and increased timing inefficiencies.

To ensure the successful implementation of Option 1 and align it with broader transportation goals, the following steps are recommended:

Collect and analyze updated traffic data

- Validate the assumptions used in this analysis by gathering more recent traffic volume, flow, and origin-destination data. This will refine the recommendations and strengthen their effectiveness.

Evaluate traffic diversion impacts

- Assess how turn restrictions and lane configurations may affect adjacent intersections and the surrounding road network. This evaluation will help mitigate impact of diversion traffic and refine mitigation strategies.

Engage key stakeholders

- Collaborate with the City of Toronto's Transportation Services and other relevant stakeholders to align short-term measures with long-term goals. This engagement will ensure smooth implementation and public acceptance.

Monitor and adjust for further optimization

- Post-implementation monitoring will be essential to measure the performance of the selected option. Continuously collect post-implementation data to inform further adjustment and optimization on traffic operations.

While implementing local solutions can address immediate challenges, it is critical to adopt a broader, corridor-wide perspective. Addressing congestion in one area without considering the interconnected nature of the transportation network may inadvertently shift problems elsewhere. A coordinated approach, balancing short-term improvements with long-term objectives, will deliver the most sustainable and effective outcomes.

Gardiner Expressway WB between York St On-ramp and Spadina Ave Off-ramp

CHALLENGES AND OPPORTUNITIES

This section of Gardiner Expressway faces several challenges that impact traffic operations as shown in **Figure 8**.

1. **Substandard Weaving Area Length:** Originally constructed in 1962, this section of the expressway no longer meets modern design standards for weaving areas. The short weaving section causes peak-period congestion as merging and weaving traffic exceed capacity, resulting in delays that propagate upstream. Additionally, frequent merging and weaving interactions increase the collision risk, contributing to non-recurring congestion that further disrupts traffic.
2. **Ramp Lane Reductions:** The two-lane York St on-ramp narrows to a single lane to maintain lane balance on the expressway. This reduction creates a bottleneck, limiting the efficiency of the on-ramp and contributing to congestion during peak periods.
3. **Downstream Congestion at Spadina On-ramp:** Capacity constraints persist downstream at the Spadina On-ramp, further restricting throughput and compounding delays in this section of the expressway.
4. **Wide Ramp Structure:** The existing ramp structures are approximately 8 meters wide, potentially accommodating two travel lanes. This presents an opportunity for reconfiguration to improve capacity and operational efficiency.
5. **Unused Eastbound Travel Lane:** One eastbound travel lane remains unused to maintain lane balance. The eastbound direction generally experiences less recurring congestion, as indicated by travel time data. While this configuration helps optimize overall traffic flow, it leaves eastbound capacity underutilized.

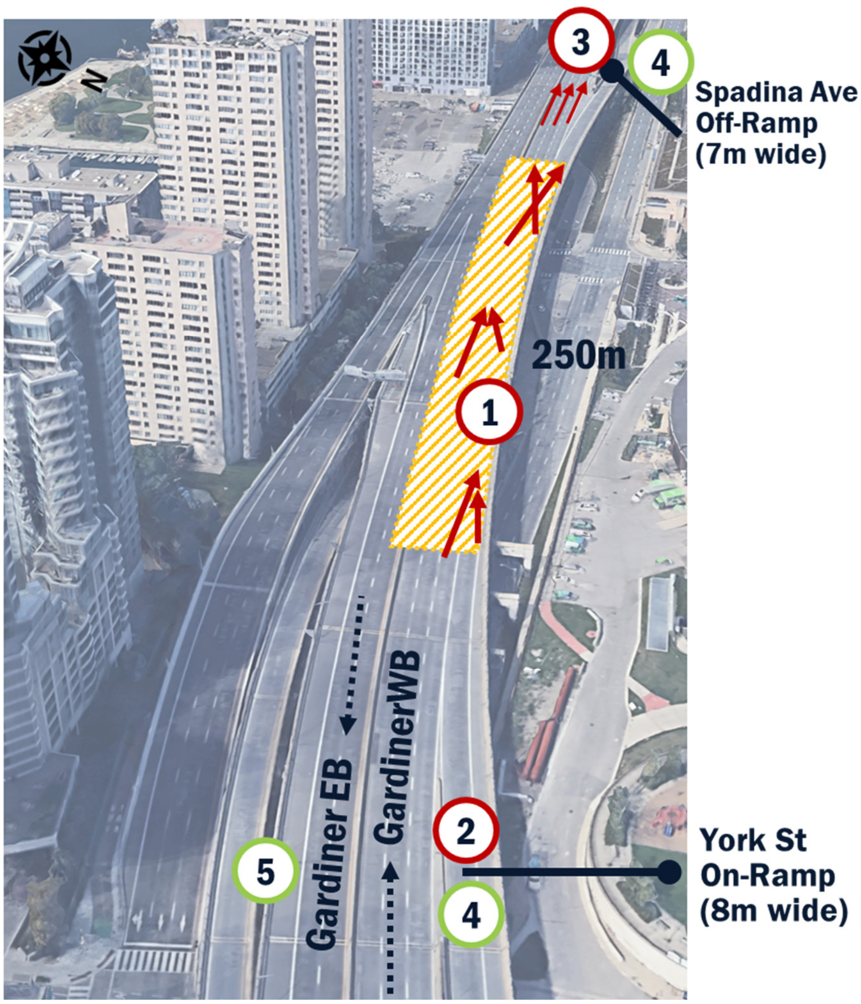


FIGURE 8: CHALLENGES AND OPPORTUNITIES ON GARDINER EXPRESSWAY WB BETWEEN YORK ON-RAMP AND SPADINA OFF-RAMP

ORIGIN-DESTINATION PATTERNS

The analysis of origin-destination data provides insight into the movements of vehicles within this section of the Gardiner Expressway. **Figure 9** shows that the York St On-ramp sees approximately 1,137 vehicles per hour (vph) heading onto westbound Gardiner. Out of all Gardiner exiting traffic, 563 vph exit onto Lake Shore Blvd WB, while 166 vph exit at Spadina Ave NB. Additionally, 451 vph and 990 vph represent weaving interactions between the mainline Gardiner WB and the York St On-ramp.

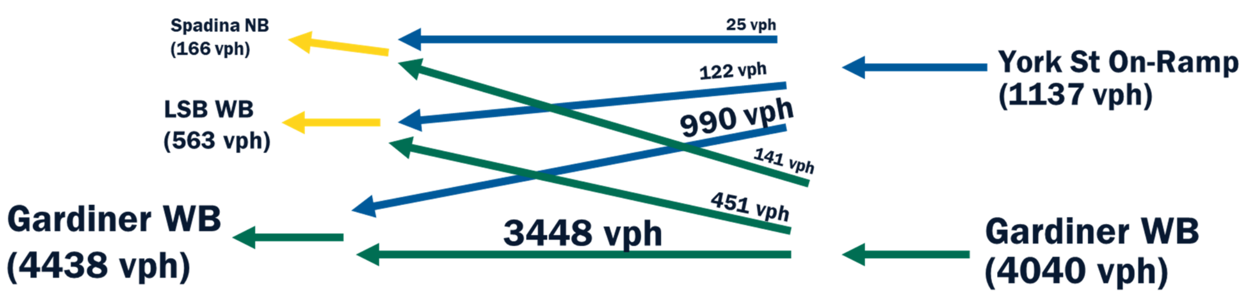
Most conflicts are merging interactions that occur between the Gardiner Expressway through traffic and York St On-ramp traffic. Vehicles entering the expressway from the on-ramp compete for space with through traffic, creating delays that propagate upstream. Weaving conflicts between off-ramp traffic exiting at Spadina Ave and on-ramp traffic entering from York St further strain the system.

The section operates near its maximum capacity, with a volume-to-capacity (V/C) ratio of 0.97, resulting in Level of Service (LOS) F, as defined by the Highway Capacity Manual[1].

A V/C ratio of 0.97 in a highly congested freeway segment usually indicates demand over capacity and the excess demand leads to extended queuing and congestion upstream. These conditions reflect recurring delays and significant throughput limitations.

LOS on freeways is a measure of traffic density, ranging from A (free flow with minimal delays) to F (severe congestion where demand exceeds capacity). LOS E represents operations at or near capacity, where delays become significant, and any small increase in demand can cause increased congestion. The boundary between LOS E and F marks the transition from stable to unstable flow—when demand exceeds the segment's capacity, resulting in severe queuing, delays, and breakdown of traffic flow, characteristic of LOS F.

The operational challenges in this section stem from merging and weaving interactions, with the York St On-ramp contributing significantly to congestion. Addressing these issues is crucial to improving westbound throughput and mitigating delays. Strategies to reduce weaving and merging conflicts will form the basis of potential solutions, as detailed in subsequent sections.



Data Sources: 2019 StreetLight Data (SLD) Origin-Destination (OD) Metrics. 2017 Gardiner Expressway Automated Traffic Recorder (ATR) Data (collected prior to Yonge-Bay-York ramp reconfiguration). 2022 Open Data Turning Movement Count (TMC) Data.
Note: PM Peak data are used as a reference. AM, PM, and Off-Peak volumes exhibit similar patterns.

FIGURE 9: ORIGIN-DESTINATION PATTERNS ON GARDINER EXPRESSWAY WEST OF YORK ST (SOURCE: STREETLIGHT DATA AND CITY OF TORONTO DATA)

LONG-TERM SOLUTIONS

Since 2018, the City of Toronto has been undertaking a multi-stage rehabilitation of the Gardiner Expressway. Stage 4, which encompasses the 2-kilometer elevated section between Grand Magazine Street and York Street, is tentatively scheduled for reconstruction between 2026 and 2028. While the current strategic plan does not include specific traffic

[1] Highway Capacity Manual 2010: Chapter 12/Freeway Weaving Segments – Methodology. Page 12-9 to 12-23
https://www.trb.org/Main/Blurbs/164718.aspx

operation improvements for the section between York St and Spadina Ave, this project offers a valuable opportunity to bundle related traffic operational enhancements during the reconstruction phase.

Weaving issues between the York St On-ramp and Spadina Ave Off-ramp are a primary source of congestion and operational inefficiency. Several potential long-term strategies could address these challenges:

1. **Close One of the Ramps**
   a. Eliminating either the York St On-ramp or the Spadina Off-ramp would reduce conflicts but may shift congestion elsewhere, necessitating careful analysis of network-wide impacts.
2. **Reduce or Control Ramp Entry and Exit Volumes**
   a. Ramp or Mainline Metering: Signalized controls could regulate vehicle flow onto the expressway, balancing demand with capacity.
   b. Encourage Diversion to Lake Shore Boulevard: Redirect traffic to alternative routes to improve the overall efficiency of the transportation network.
   c. Implement Transportation Demand Management (TDM): Encourage modal shifts toward public transit, cycling, or walking to reduce vehicle volumes.
3. **Increase the Weaving Section Length**
   a. Extending the weaving section would allow more space for vehicles to safely change lanes. However, this is highly constrained by the fixed entry and exit points of the elevated bridge structure, even during reconstruction.
4. **Reduce the Number of Required Lane Changes**
   a. Simplifying lane change requirements through reconfiguration within the existing bridge deck width offers the most feasible approach. By reducing the complexity of merging and weaving, this strategy can mitigate congestion and improve safety in the short term.

Given the constraints of long-term solutions and the absence of immediate plans for operational improvements in this segment, the fourth approach forms the most sensible basis for potential short-term solutions. By focusing on lane reconfigurations and operational adjustments, the potential short-term solutions aim to address the weaving issues and congestion in a practical and cost-effective manner, as detailed in the following sections.

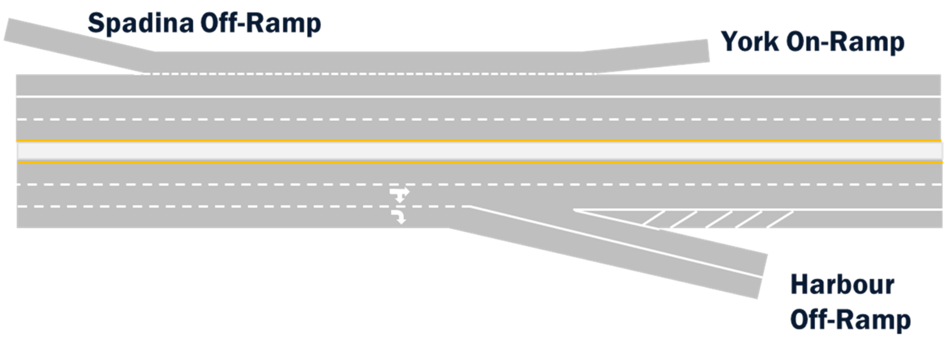
POTENTIAL SHORT-TERM SOLUTIONS

The potential short-term solutions aim to address the operational challenges between the York St On-ramp and Spadina Ave Off-ramp by minimizing the impact of merging and weaving interactions. These measures focus on balancing Gardiner through movements and York St On-ramp traffic while avoiding major civil construction. Each solution differs in its approach to lane configurations, traffic restrictions, and expected outcomes.

Option 1: Lane Change Restrictions (Figure 10)

This option retains the existing lane configurations and through-traffic capacity while restricting merging and weaving interactions to the rightmost lane. A solid line separates the two leftmost Gardiner lanes from the York St On-ramp, directing merging traffic to the right lane only.

With full compliance, this option may provide slight improvements in congestion compared to current conditions. However, non-compliance would likely result in performance similar to existing operations.



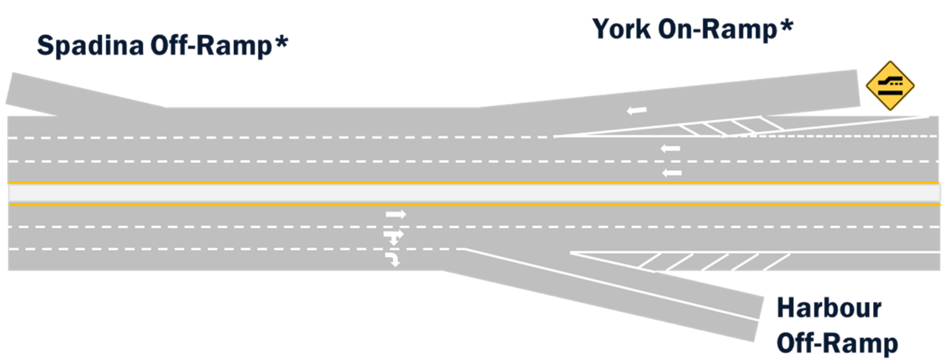
*Preliminary analysis suggests that the number of lanes on ramps (one or two) does not significantly improve the capacity of the weaving section.

FIGURE 10: GARDINER EXPRESSWAY BETWEEN YORK AND SPADINA - POTENTIAL SHORT-TERM OPTION 1

Option 2: Westbound Mainline and Ramp Reconfiguration (Figure 11)

This option prioritizes York St On-ramp traffic by directly feeding it into the Gardiner WB rightmost lane, eliminating the need for lane changes for vehicles entering the expressway. This prioritization addresses significant queuing and spillback issues on York St On-ramp, Lake Shore Blvd, and north-south arterials in Downtown Toronto.

To accommodate this configuration, one westbound Gardiner mainline lane is dropped before the York St On-ramp. While this adjustment eliminates weaving conflicts, the lane drop significantly reduces Gardiner WB throughput, resulting in a Level of Service (LOS) of F and increasing the Volume-to-Capacity (V/C) ratio to 1.42. This trade-off reflects worsened congestion for through traffic, despite benefits for on-ramp vehicles.

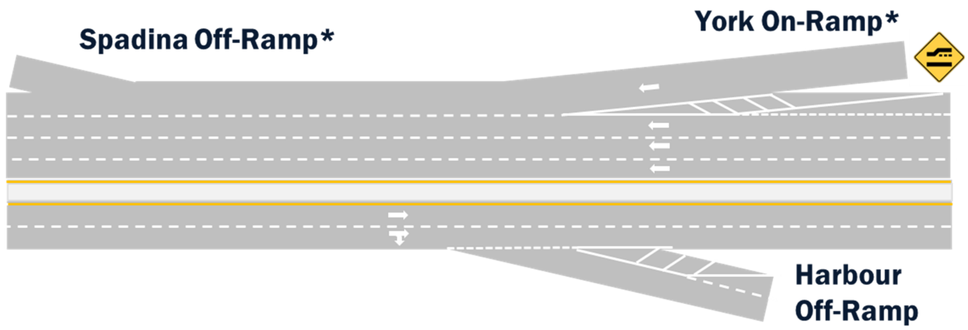


*Preliminary analysis suggests that the number of lanes on ramps (one or two) does not significantly improve the capacity of the weaving section.

FIGURE 11: GARDINER EXPRESSWAY BETWEEN YORK AND SPADINA - POTENTIAL SHORT-TERM OPTION 2

Option 3: Westbound & Eastbound Mainline and Ramp Reconfiguration (Figure 12)

This option builds upon Option 2 by maintaining York St On-ramp traffic's direct merge into the Gardiner WB rightmost lane while preserving the Gardiner WB's existing through-lane capacity by adding an additional lane. The additional lane is achieved by reallocating an unused shoulder in the current configuration. This reallocation improves the Level of Service from F to E and reduces the V/C ratio to 0.91. Additionally, upstream and downstream sections could benefit from extended lane rebalancing, particularly as EB travel lanes are less congested than WB lanes, pending further design investigation.



*Preliminary analysis suggests that the number of lanes on ramps (one or two) does not significantly improve the capacity of the weaving section.

FIGURE 12: GARDINER EXPRESSWAY BETWEEN YORK AND SPADINA - POTENTIAL SHORT-TERM OPTION 3

RECOMMENDATIONS

Table 2 evaluates the three options across several criteria, highlighting the trade-offs and benefits of each approach. Based on the evaluation, Option 1 or Option 2 is recommended as a pragmatic short-term solution while longer-term improvements, such as Option 3, are being investigated. Option 1 offers a low-impact, quick-build solution with minimal disruption, making it suitable for immediate implementation. Option 2 provides more benefits for York St On-ramp traffic but sacrifices Gardiner WB mainline capacity, potentially increasing congestion upstream, which requires more close monitoring and assessment.

TABLE 2: EVALUATION OF SHORT-TERM OPTIONS FOR GARDINER EXPRESSWAY BETWEEN YORK AND SPADINA

Criteria	Option 1: Lane Change Restrictions	Option 2: WB Mainline and Ramp Reconfiguration	Option 3: WB/EB Mainline and Ramp Reconfiguration
Weaving Conflict	Restrict merging and weaving interaction to the rightmost lane but does not reduce the number of conflicts.	Reduces weaving conflicts by directing York St On-ramp traffic to a dedicated Gardiner WB lane but does not address conflicts between Spadina off-ramp and York on-ramp traffic.	Reduces merging and weaving conflicts by adding a dedicated York St On-ramp lane while maintaining three WB Gardiner lanes. Weaving conflicts between Spadina off-ramp and York on-ramp traffic remains unaddressed.
Gardiner Expressway Capacity	Maintains existing WB Gardiner through-lane capacity.	Reduces WB Gardiner mainline capacity due to the lane drop.	Preserves existing WB Gardiner capacity by reallocating an unused shoulder.
Ramp Capacity	Minor improvement with full compliance; non-compliance results in minimal change.	Increases York St On-ramp capacity.	Increases York St On-ramp capacity.
Weaving Section Performance	LOS F (0.97 V/C ratio), indicating continued heavy congestion.	LOS F (1.42 V/C ratio) due to reduced WB Gardiner capacity.	LOS E (0.91 V/C ratio), reflecting improved capacity and reduced congestion.
Implementation	Simple to implement with minimal infrastructure changes.	Moderate complexity requiring lane reconfiguration and new signage.	Higher complexity requiring shoulder reallocation, concrete median shifts, and upstream/downstream lane rebalancing.

Criteria	Option 1: Lane Change Restrictions	Option 2: WB Mainline and Ramp Reconfiguration	Option 3: WB/EB Mainline and Ramp Reconfiguration
Overall	Quick to implement with minimal disruption but limited operational improvement.	Improves York St On-ramp access but worsens WB Gardiner congestion, creating trade-offs.	Balances operational trade-offs effectively, maintaining existing capacity while addressing weaving issues. Greatest implementation challenge

The recommendations from this study guide potential future actions, focusing on advancing short-term measures while laying the groundwork for long-term improvements. Quick implementation of the selected option can offer immediate relief from weaving conflicts, but ongoing evaluation and collaboration with stakeholders will be critical to ensuring sustained benefits. These efforts will help bridge the gap until the Gardiner Section 4 reconstruction project provides an opportunity for more comprehensive solutions. Key steps to guide implementation and monitoring include:

- **Pilot Implementation:** Explore the feasibility of implementing Option 1 or Option 2 as a pilot project to address weaving conflicts and improve operational efficiency.
- **Impact Monitoring:** Continuously evaluate the effectiveness of the implemented option, assessing its impact on upstream and downstream traffic flow, safety, and overall performance.
- **Advocacy for Long-Term Improvements:** Advocate for integrating long-term operational improvements, such as Option 3, into the Gardiner Section 4 rehabilitation project (2026–2028).
- **Stakeholder Collaboration:** Work closely with the City of Toronto, MTO, and other stakeholders to align short-term measures with the long-term vision for the Gardiner Expressway and the broader transportation network.

Short-term, quick-build options are inherently limited in addressing the fundamental weaving issues and may introduce operational or safety trade-offs. While these solutions can provide temporary relief, a coordinated approach that integrates both short-term and long-term improvements is essential to fully resolve congestion and operational challenges in this critical segment.

Best Practice Review

Melbourne Freeway Ramp System

BACKGROUND

Toronto’s freeways are vital for the regional movement of commuters and goods but are frequently plagued by delays, bottlenecks, and safety concerns. The Gardiner Expressway (also referred to as “the Gardiner”), a key downtown artery, consistently experiences peak-hour gridlock, and unpredictable and long travel times have become the norm. The congestion issues on the Gardiner are further exacerbated by the heavy traffic on routes such as Spadina Avenue, York Street, Jarvis Street and other downtown core streets, all of which serve as critical access points to the expressway. This has led to significant delays and bottlenecks, impacting not only the efficiency of the transportation network but also economic productivity and the quality of life for Toronto’s residents.

This portion of the white paper aims to explore how Melbourne’s innovative ramp metering system, with its focus on congestion mitigation and safety improvements, can inform solutions for downtown Toronto. This includes examining the design, implementation, and operational strategies that have contributed to the success of Melbourne’s traffic management system, and identifying potential benefits, challenges, and strategies for implementing a similar system in Toronto. Key consideration has been given to leveraging Toronto’s existing intelligent transportation systems (ITS), identifying high-impact pilot locations, and adapting system design to account for Toronto’s unique conditions.

Melbourne and Toronto Comparison

Toronto and Melbourne are both dynamic metropolitan centres with growing populations and intricate transportation networks. Toronto, with a metropolitan population nearing 6.5 million, and Melbourne, with approximately 5 million residents, share urban characteristics that make them comparable in terms of traffic congestion and transportation planning challenges. Both cities feature centralized urban cores with dense road networks, which are critical for accommodating commuter, commercial, and freight traffic. These downtown areas serve as economic and cultural hubs, hosting a mix of residential, commercial, and institutional activities that create diverse and high-demand travel patterns. Table 3 provides an overarching summary of the two cities with respect to their demographic and transportation characteristics.

TABLE 3: COMPARISON OF MELBOURNE AND TORONTO'S DEMOGRAPHICS AND TRANSPORTATION CHARACTERISTICS

Component	Toronto	Melbourne
Population	Metropolitan population nearing 6.5 million	Approximately 5 million residents
Urban Characteristics	Centralized urban core with dense road networks	
Transportation Networks	Grid-like street layout in downtown core	
Multimodal Travel	Private vehicles, public transit, cycling, walking	
Congestion	Dense network of intersections causing congestion during peak periods	
Demographics	Diverse and rapidly growing population	
Urban Growth	Increasing densification with high-rise developments	
Public Transit	Extensive urban and commuter rail networks, streetcars in *mixed traffic*	Extensive urban and commuter rail networks, largest tramway network in the world, mostly in *dedicated lanes*
Cycling Infrastructure	Expanding downtown cycling network, bike-sharing programs, *evolving connectivity*	*Well-connected network* of bike lanes and cycling paths, active transportation programs
Traffic Demand Management	*No tolls* on downtown streets, no comprehensive congestion pricing mechanisms	*Tolls* on several major freeways, ramp metering systems to manage congestion
Climate Challenges	*Harsher winters* with snow and ice, substantial investment in winter maintenance	*Milder climate*, challenges with heavy rain and flooding during peak weather events
Intelligent Transportation Systems (ITS)	*Beginning to implement* ITS solutions, relies on traditional traffic management systems	*Further along* in integrating advanced technologies like adaptive traffic signals and real-time monitoring

FREEWAY RAMP METERING SYSTEM IN MELBOURNE

Melbourne has successfully implemented ramp metering systems to manage congestion and improve safety on its freeway network. The city introduced ramp metering in the early 2000s, initially as a pilot project on key freeways such as the Monash Freeway and the West Gate Freeway. The success of these pilot projects led to a broader rollout across Melbourne's freeway network.

What Are Ramp Meters?

Ramp meters are dynamic traffic control devices installed at freeway entrance ramps to regulate the flow of vehicles merging onto the mainline. These systems function as traffic signals, allowing vehicles to enter the freeway at staggered intervals rather than in surges. By controlling the timing of vehicle entry, ramp meters prevent abrupt increases in traffic density that can lead to flow breakdowns, stop-and-go conditions, and reduced travel speeds. They are a cornerstone of modern intelligent transportation systems (ITS), integrating real-time data collection and adaptive control algorithms to enhance freeway efficiency and safety.

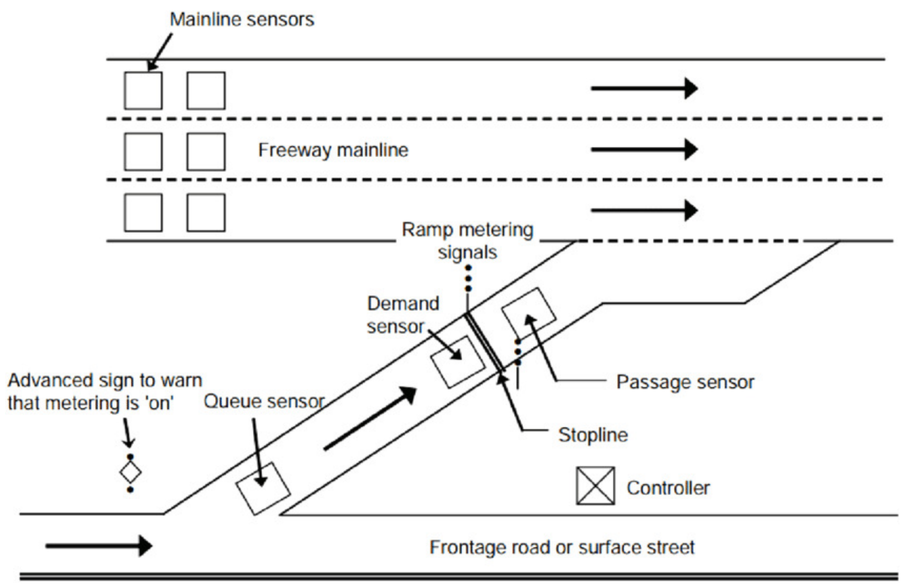


FIGURE 13: SCHEMATIC OF RAMP METERING DETECTION SYSTEM CONFIGURATION (SOURCE: TRAFFIC DETECTOR HANDBOOK - VOL. 2 NO. FHWA-HRT-06-139. 2006)

How Ramp Meters Work

Ramp meters operate through a sophisticated process that involves detection, monitoring, and dynamic adjustment. Induction loop detectors are installed on both the ramp and the main road to measure traffic flow, speed, and occupancy levels, providing real-time data on current traffic conditions. Based on the collected data, ramp meters adjust the signal timing dynamically.

When the mainline traffic approaches critical density, the ramp meter increases the duration of the red signal, thereby reducing the rate at which vehicles are allowed to enter the freeway. Conversely, if the mainline traffic is below the optimal density, the ramp meter shortens the red signal duration, permitting more vehicles to merge onto the freeway. This dynamic adjustment ensures that the traffic density on the mainline remains within an optimal range, thereby maintaining smooth traffic flow and preventing congestion.

Signal Controllers

In the most common configuration, each on-ramp entrance lane has two sets of signals: a red-yellow-green signal perched overhead over each lane (or mounted high on a pole for a single lane), and a two-phase lamp mounted low on a pole next to the stop line. The overhead lights are for cars approaching the metering point; the low-mounted two-phase lights are intended for the vehicle at the front of the queue. Typically, only the red and green lamps are used during normal operation. However, when ramp metering is about to be enabled, the overhead lamps may show flashing or solid yellow to warn drivers to prepare to stop. Once ramp metering is activated, the yellow lamp is no longer needed. The simplest form of control is fixed-time operation, which sets an upper limit on the flow rates entering the freeway based on average traffic conditions. More advanced systems are traffic-responsive, establishing metering rates based on real-time freeway conditions using detectors and microprocessors.

Ramp meter signals are set according to current traffic conditions on the road. Detectors, generally induction loops, are installed in the road on both the ramp and the main road to measure and calculate traffic flow, speed, and occupancy levels. These data are used to adjust the number of vehicles allowed to leave the ramp, with more congested conditions resulting in longer red times at the signals.

Traffic Flow Optimization

Ramp metering is grounded in traffic flow theory, which examines the relationship between vehicle density, flow, and speed. Density is the number of vehicles per unit length of the roadway, usually expressed in vehicles per mile or kilometre. When density exceeds the 'critical' range, even minor disturbances—such as excessive merging or sudden braking—can trigger cascading breakdowns, resulting in congestion and significant delays.

Flow refers to the number of vehicles passing a point per unit time, typically measured in vehicles per hour. The goal of ramp metering is to optimize this traffic flow, which is achieved when the traffic density remains within an optimal range. The fundamental relationship between these parameters is given by: flow = density × speed.

Flow can be categorized into two groups: non-critical (uncongested) flow and critical (congested) flow.

Uncongested Flow: In this regime, vehicles can travel at or near their desired speeds. The flow increases with density up to a critical point. The fundamental diagram of traffic flow shows that as density increases, flow also increases up to a critical density (k_c). This critical density represents the maximum flow rate (q_max) the roadway can handle, known as the capacity of the roadway. The capacity of the roadway is determined by several factors and is slightly different depending on geometric configuration and jurisdiction.

Congested Flow: Beyond the critical density, the flow begins to decrease with increasing density. This is because vehicles are forced to reduce their speeds due to the close proximity of other vehicles, leading to a higher probability of disturbances such as sudden braking or merging. The flow in this regime is unstable and highly sensitive to small perturbations, which can lead to cascading breakdowns and severe congestion.

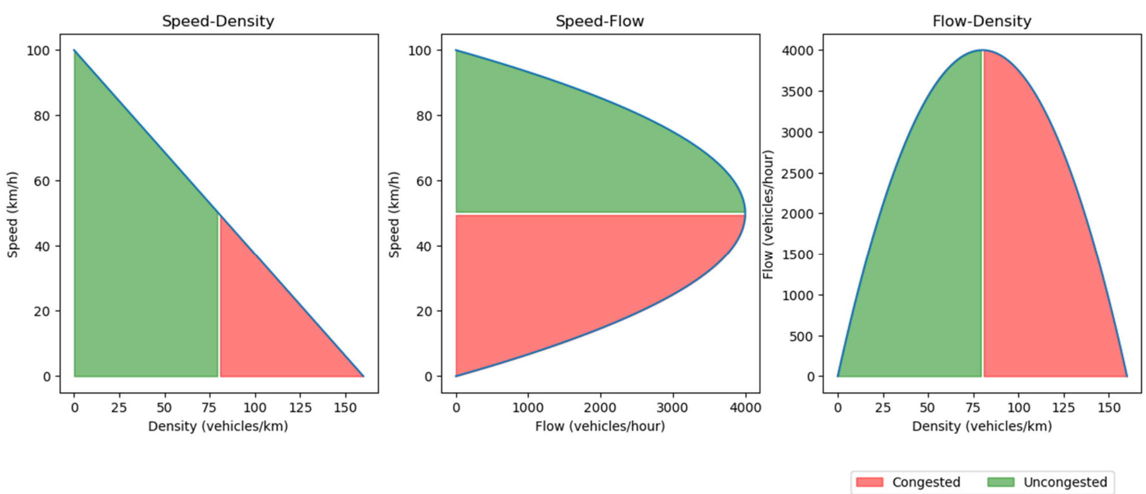


FIGURE 14: SAMPLE FUNDAMENTAL TRAFFIC FLOW DIAGRAMS

Ramp meters address the issue of congestion by managing the inflow of vehicles to maintain stable traffic conditions on the mainline. By regulating demand to match available capacity, these systems reduce bottlenecks, smooth traffic patterns, and help prevent the flow breakdowns that typically occur at high-demand merge points.

In Figure 14, traffic conditions are represented by red for congested flow and green for uncongested flow. The critical density, typically about half of the jam density, represents the point where maximum traffic flow is achieved, even though average vehicle speed may decrease. Ramp metering aims to maintain freeway traffic near this critical density to maximize efficiency and prevent congestion. When vehicle density exceeds the critical point, the freeway mainline transitions into congested flow, causing a drop in flow rates. Thus, managing mainline density effectively is essential for maintaining optimal traffic conditions and ensuring steady throughput.

The congested flow conditions are shown in red, while the uncongested conditions are in green. Although the exact shape of the curves and the values associated with the flows, speeds, and densities may differ, generally, the critical density is approximately half of the jam density, which is the point at which the maximum flow is achieved (even though the average speed of vehicles may be less).

Dynamic Ramp Metering Algorithms

Melbourne Freeway Ramp System: Melbourne has successfully implemented ramp metering systems to manage freeway congestion and improve safety. Various algorithms, such as ALINEA, demand control, and fuzzy algorithms, are used to determine optimal signal timings for ramp metering. Melbourne’s system uses the dynamic HERO (Highway Efficiency and Reliability Optimisation) algorithm and real-time data to optimize traffic flow and enhance efficiency.

The HERO algorithm (Heuristic Ramp Metering Coordination) is a sophisticated traffic management method designed to optimize freeway entry rates through ramp meters. It continuously monitors real-time traffic conditions, such as vehicle speeds and densities, and dynamically adjusts the metering rates at on-ramps to prevent congestion and maintain smooth traffic flow. By coordinating the metering rates across multiple ramps, the HERO algorithm helps to balance traffic demand and capacity, reduce travel time variability, minimize stop-and-go conditions, and enhance overall safety on the freeway network.

The system responds to changing traffic patterns and incidents using data from traffic sensors, cameras, and other monitoring devices. Real-time data allows for continuous monitoring and adjustment, enhancing the system’s effectiveness. HERO continuously analyses data from sensors upstream and downstream of ramps, monitoring vehicle speeds, traffic densities, and queue lengths. Based on this data, HERO dynamically adjusts metering rates to balance traffic flow and prevent congestion. This responsive approach ensures Melbourne’s freeways remain operational under varying conditions, minimizing delays.

Ramp metering also reduces collision likelihood by managing vehicle flow entering the freeway, reducing merging conflicts and improving safety. Additionally, it smooths traffic flow, reducing stop-and-go conditions that can lead to collisions.

MELBOURNE’S RAMP METERING IMPLEMENTATION

Since 2000, Melbourne's freeways have experienced significant congestion with extended periods of flow breakdown. The Monash Freeway, a six-lane dual carriageway that accommodates over 160,000 vehicles daily, including up to 20% commercial vehicles, faces long periods of congestion lasting between 3 and 8 hours each day. To address this issue, VicRoads, the responsible road authority, implemented the HERO system at six consecutive inbound on-ramps of the Monash Freeway in early 2008.

The Monash Freeway pilot project was critical in demonstrating the effectiveness of the HERO system. This project focused on six inbound ramps, particularly during peak morning traffic hours. Prior to implementation, the Monash Freeway was notorious for severe congestion, with vehicles often experiencing stop-and-go conditions that led to travel time unpredictability and increased accident rates. One of the significant test sites was the Wellington Road on-ramp. Before the introduction of ramp metering, this on-ramp saw long queues spilling back onto local roads, creating additional congestion and safety hazards. After the HERO system was introduced, the ramp meter regulated the flow of vehicles entering the freeway, significantly reducing the queue lengths and preventing local road spillover. The result was a smoother merge onto the freeway, minimizing disruptions to the mainline traffic flow.

At the Blackburn Road on-ramp, the HERO system was instrumental in managing heavy commuter traffic. The dynamic adjustment of signal timing helped in distributing the entry of vehicles more evenly. This balance prevented abrupt surges in traffic density on the freeway, thus reducing the likelihood of flow breakdowns. Post-implementation studies indicated a 20% reduction in travel time variability and a notable decrease in rear-end collisions, which were common due to sudden stops and merges.

In addition to Wellington Road and Blackburn Road, other key on-ramps where the HERO system was implemented included Forster Road, Ferntree Gully Road, and Warrigal Road. Each of these locations had unique traffic patterns and congestion challenges that the HERO system effectively addressed. For instance, at the Forster Road on-ramp, the system's ability to dynamically adjust metering rates based on real-time traffic conditions helped in managing the high volume of vehicles from nearby industrial areas.

Similarly, the Ferntree Gully Road on-ramp benefited from the HERO system's adaptive capabilities. This on-ramp, which serves a significant number of vehicles from residential and commercial zones, experienced smoother traffic flow and reduced congestion spillbacks onto local roads. The system's real-time data analysis and response mechanisms ensured that vehicles entered the freeway at optimal intervals, maintaining a steady flow and minimizing disruptions.

The Warrigal Road on-ramp, another critical entry point, saw improvements in traffic management and safety. The HERO system's implementation helped in mitigating the effects of heavy traffic volumes during peak hours. By spacing out vehicle entries and preventing sudden surges, the system contributed to a more predictable and safer driving environment on the freeway.

Following the success on the Monash Freeway, the HERO system was expanded to the West Gate Freeway, another critical corridor in Melbourne's freeway network that experienced substantial congestion, especially during evening peak periods. During periods of heavy traffic, the ramp meters would extend red signal durations, effectively spacing out vehicle entries and maintaining a steady flow on the mainline. This adaptation significantly reduced the occurrence of congestion-induced delays and improved overall freeway throughput.

At the Williamstown Road on-ramp, the HERO system addressed congestion by preventing the accumulation of vehicles at the merge point. The dynamic metering ensured that the mainline traffic maintained optimal speeds, reducing the instances of abrupt braking and subsequent flow breakdowns. These implementations across various on-ramps demonstrated how the HERO system's real-time adaptability could effectively manage and mitigate congestion, improving travel times and safety on Melbourne's freeways.

Overall, the HERO system's deployment on Melbourne's key freeways, including the Monash and West Gate Freeways, showcased the transformative impact of dynamic ramp metering. By continuously analyzing real-time data and adjusting metering rates, the system maintained optimal traffic conditions, reducing delays and enhancing safety. Melbourne's experience provides valuable insights into the potential benefits of implementing similar ramp metering strategies in other cities facing comparable congestion challenges.

The success of the HERO system in Melbourne also highlights the importance of integrating advanced traffic management technologies with existing infrastructure. The system's ability to leverage real-time data from various sources, including traffic sensors, cameras, and historical traffic patterns, enabled it to make informed decisions that optimized traffic flow. This integration not only improved the efficiency of the freeway network but also enhanced the overall driving experience for commuters.

Furthermore, the positive outcomes of the HERO system's implementation have encouraged further research and development in the field of intelligent transportation systems. Ongoing studies aim to refine and expand the capabilities of ramp metering systems, exploring new algorithms and technologies that can further enhance traffic management. As cities around the world continue to grapple with increasing traffic congestion, the lessons learned from Melbourne's experience with the HERO system serve as a valuable blueprint for future initiatives.

BENEFITS OF RAMP METERING

While the benefits of coordinated ramp signals (CRS) have been extensively documented for Melbourne, it is worth noting that additional detailed studies have been conducted in Queensland. These studies are particularly valuable because Queensland uses the same HERO system as Melbourne, and they provide more comprehensive before-and-after data. By examining results from both Melbourne and Queensland, more robust conclusions can be drawn about the effectiveness of ramp metering in improving traffic flow, safety, and overall freeway efficiency.

Safety Improvements

Ramp metering significantly enhances safety on freeways, particularly at merge points where traffic flow from entrance ramps meets mainline traffic. By regulating the rate at which vehicles enter the freeway, ramp meters create smoother and more predictable merging conditions. This reduces the potential for conflicts and collisions caused by abrupt merging or stop-and-go behaviour. Research supports these safety benefits, with studies showing reductions in collision rates near on-ramp exits by as much as 36% following the implementation of ramp metering systems. These safety improvements extend to secondary effects, such as fewer secondary incidents caused by congestion-related collisions, further contributing to smoother traffic flow and reduced delays.

Travel Time Savings

Ramp metering reduces congestion by maintaining optimal traffic density on freeways, resulting in shorter and more predictable travel times for drivers. By preventing flow breakdowns and bottlenecks, ramp meters help sustain higher speeds and ensure consistent traffic movement. This is particularly beneficial during peak travel periods when freeway demand is at its highest. Drivers experience less time spent idling or in stop-and-go conditions, making their journeys more efficient and less stressful. For commercial vehicles and freight operations, the predictability of travel times enhances operational efficiency and cost-effectiveness.

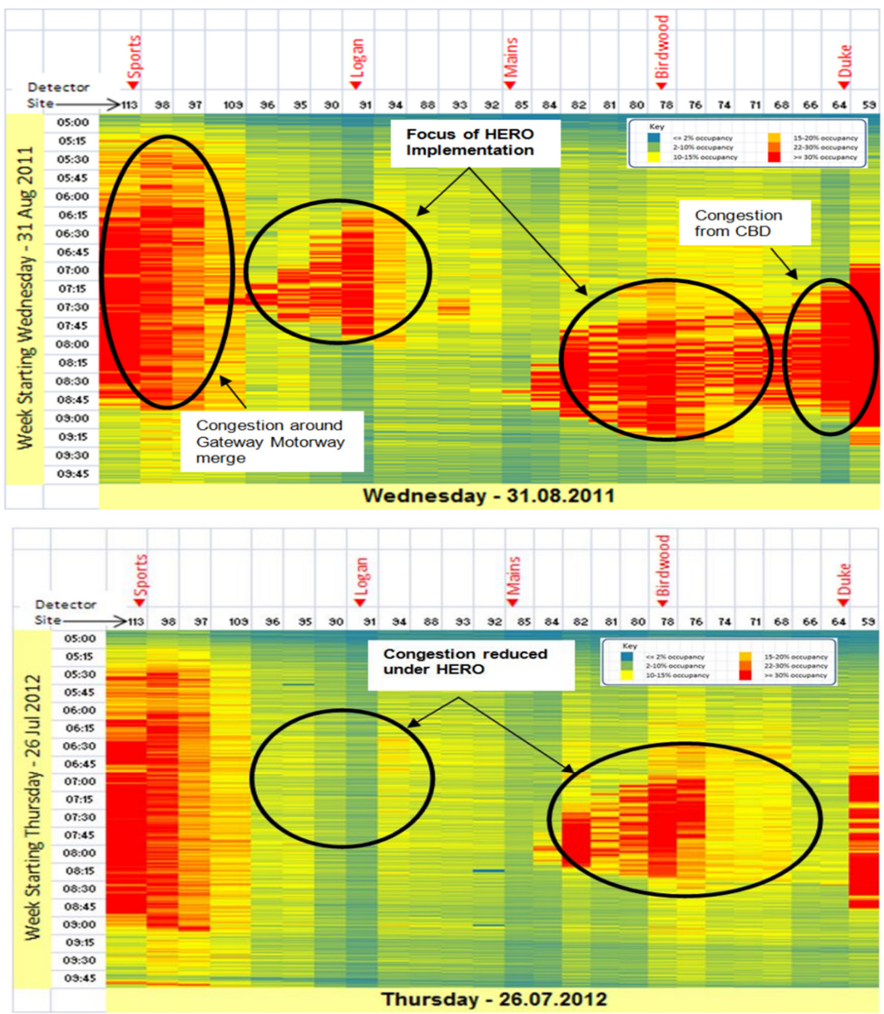


FIGURE 15: COMPARISON OF CONGESTION HOTSPOTS (ROADWAY OCCUPANCY) BEFORE AND AFTER THE IMPLEMENTATION OF HERO RAMP METERING (SOURCE: FAULKNER, L., DEKKER, F., GYLES, D., PAPAMICHAIL, I., & PAPAGEORGIOU, M., 2013)

Figure 15 showcases the effectiveness of ramp metering in reducing congestion at specific freeway on-ramps over a span of nearly a year. In the first image, dated August 31, 2011, there is noticeable congestion during the morning peak hours, with heavy traffic buildup, particularly near the Gateway Motorway merge, as highlighted by the extensive red and orange zones. This indicates high traffic density and significant delays. In contrast, the second image, dated July 26, 2012, reveals a substantial decrease in congestion following the implementation of ramp metering. The previously congested areas show a marked reduction in red and orange zones, indicating improved traffic flow and reduced bottlenecks. This comparison highlights how ramp metering has effectively managed traffic density, leading to smoother and more predictable travel times, especially during peak periods.

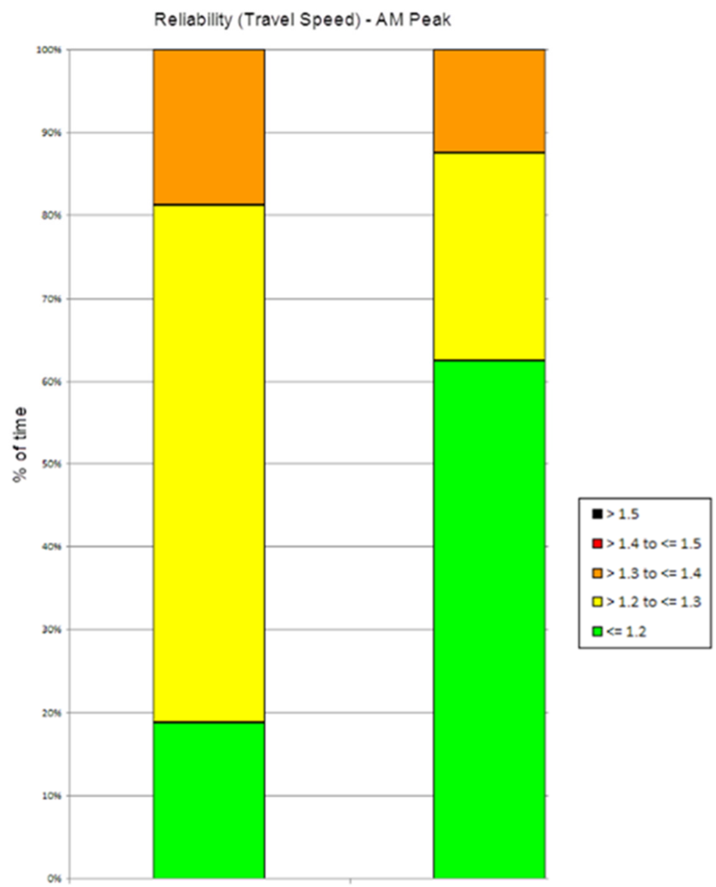


FIGURE 16: TRAVEL SPEED RELIABILITY FOR THE AM PEAK PERIOD BEFORE AND AFTER THE IMPLEMENTATION OF THE HERO ALGORITHM (SOURCE: FAULKNER, L., DEKKER, F., GYLES, D., PAPAMICHAIL, I., & PAPAGEORGIOU, M., 2013)

Figure 16 illustrates the reliability of travel speed during AM peak hours before and after the implementation of ramp metering. The left chart shows the distribution of travel speed reliability before ramp metering, with a significant portion of time spent at less reliable speeds (indicated by red and black segments). Over 30% of travel time fell into the least reliable categories (>1.3), denoting frequent delays and slow travel speeds. In contrast, the right chart, depicting the period after ramp metering implementation, reveals a substantial improvement in travel speed reliability. The green segment, representing the most reliable travel speeds (<=1.2), has expanded considerably, indicating that vehicles are experiencing smoother and more consistent travel conditions.

Efficiency Gains

Ramp metering optimizes freeway operations by increasing vehicle throughput and maintaining traffic flow within its most efficient range. This improves the spacing between vehicles, reduces turbulence in traffic patterns, and allows the freeway to operate closer to its maximum capacity without overloading. For instance, Melbourne's ramp metering system demonstrated throughput improvements of approximately 9% on the Monash Freeway, a tangible indication of how managing entry flow can enhance overall efficiency. These gains delay the need for costly infrastructure expansions by maximizing the use of existing roadways.

An economic appraisal was conducted of the HERO program pilot, revealing an ex-post benefit-cost ratio of 13:1 over a 10-year period. Given the limited number of field evaluations for coordinated ramp metering (CRM) systems, these results highlight the specific benefits of the HERO algorithm and provide a valuable contribution to the ongoing development of methodologies in this area.

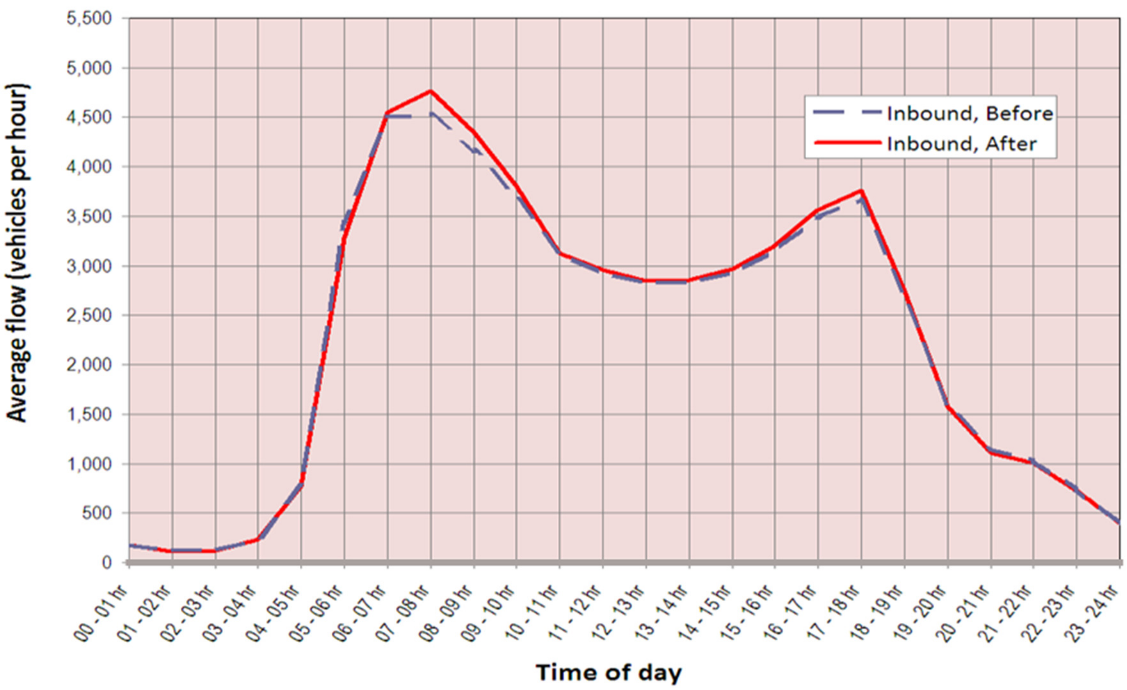


FIGURE 17: AVERAGE FLOW OF VEHICLES ON THE MAINLINE BEFORE AND AFTER THE IMPLEMENTATION OF HERO RAMP METERING (SOURCE: FAULKNER, L., DEKKER, F., GYLES, D., PAPAMICHAIL, I., & PAPAGEORGIOU, M., 2013)

Figure 17 illustrates the average vehicle flow per hour throughout the day, comparing inbound traffic before and after the implementation of ramp metering. The blue line represents traffic flow before ramp metering, while the red line shows the flow after its implementation. The data reveals that the peak morning traffic flow, occurring approx. 08:00 to 09:00 AM, initially experienced a slight dip below 4,500 vehicles per hour before ramp metering was implemented. After the ramp metering, the red line demonstrates a more consistent traffic flow, maintaining levels close to 5,000 vehicles per hour during peak times. This indicates that ramp metering has successfully smoothed out the traffic flow, reducing sharp fluctuations and maintaining higher vehicle throughput during peak hours.

Observational analysis shows that there has been no additional delay or increase in queuing at freeway on-ramps under the HERO algorithms. HERO effectively monitors on-ramp queue lengths along the corridor and dynamically adjusts metering rates to balance demand. For instance, when the queue length at a particular on-ramp (the “master”) reaches 60% of its maximum storage capacity, HERO activates upstream on-ramp signals (“slaves”) to help manage bottleneck conditions and relieve pressure from the master on-ramp. Once the queue length at the master on-ramp decreases, HERO disengages the upstream ramp signals and reverts to local control. Additionally, HERO has been configured to allow ramp signals to operate with cycle times between 4.8 seconds and 6 seconds when needed for congestion control. This tight control helps manage delays and queuing experienced by road users at the on-ramps.

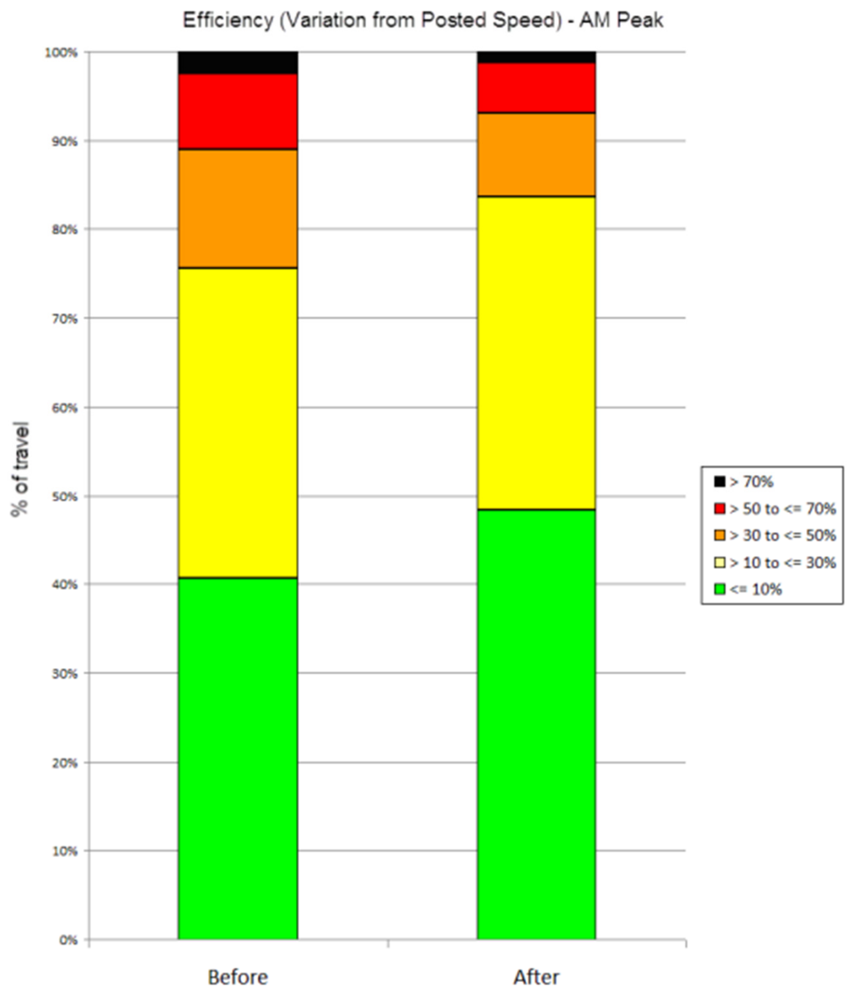


FIGURE 18: VARIATION IN POSTED SPEED BEFORE AND AFTER THE IMPLEMENTATION OF THE HERO RAMP ALGORITHM (SOURCE: FAULKNER, L., DEKKER, F., GYLES, D., PAPAMICHAIL, I., & PAPAGEORGIOU, M., 2013)

A before and after study of the Monash-CityLink-West Gate (M1) upgrade project over a 5 year period, before and after the installation of ramp metering signals, showed reduced congestion and improved safety performance, as shown in Figure 18.

Environmental Impact

Ramp metering significantly enhances environmental sustainability by curbing vehicle emissions and fuel consumption. Congested freeways, characterized by frequent stop-and-go traffic, are substantial contributors to air pollution and greenhouse gas emissions. Ramp meters help alleviate these issues by smoothing traffic flow, thereby reducing idling and minimizing excessive acceleration and deceleration. This leads to more fuel-efficient driving conditions, which not only diminishes the carbon footprint of freeway travel but also improves air quality for communities situated near highways.

Broader Community and Economic Benefits

Ramp metering offers broader community and economic benefits by reducing accident costs, such as emergency response, medical expenses, and vehicle repairs, through lowering collision frequency. It also provides significant time savings by ensuring shorter and more predictable travel times, thereby increasing productivity for commuters and freight operators. Additionally, smoother commutes contribute to improved quality of life by reducing driver stress and supporting urban sustainability goals, enhancing the overall liability of metropolitan areas.

DRAWBACKS OF RAMP METERING

Potential for Increased Local Congestion

While ramp metering can improve freeway flow, it can lead to increased congestion on local streets and surrounding areas near on-ramps. During peak hours, queues at metered ramps can extend significantly, blocking intersections and driveways, and limiting traffic movement on nearby roads and corridors. This spillover effect can exacerbate traffic conditions on surface streets, leading to higher travel times and increased driver frustration. Additionally, ramp metering often prioritizes the movement of traffic already on freeways—typically longer-distance commutes that may originate from other jurisdictions—while penalizing local traffic trying to enter the freeway.

Melbourne has implemented several strategies to mitigate these issues. One key approach is the use of queue overrides for ramp meters, which temporarily deactivate the meters when local street congestion reaches critical levels. This helps prevent excessive backup on surface streets. Additionally, Melbourne has seen an overall increase in traffic throughput due to ramp metering, which benefits both local roads and freeways, although the primary advantage is observed on the freeways.

Impact on Adjacent Freeway Segments

Ramp metering on one segment of a freeway can lead to increased congestion on adjacent segments not equipped with metering systems. Traffic may flow smoothly where meters are in place, only to encounter significant delays once it reaches unmetered sections. This can create a ripple effect, where improvements in one area lead to new congestion issues in another. For instance, vehicles that have been efficiently metered onto the freeway might create bottlenecks further downstream, particularly at points where the freeway narrows or where high-traffic interchanges are located. This shift in congestion can negate some of the benefits of ramp metering by simply relocating the problem rather than resolving it. Freeway segments without ramp meters might also experience increased traffic volumes as drivers seek to bypass the metered sections, further complicating traffic management efforts.

Melbourne has adopted a comprehensive approach by extending ramp metering systems to cover more segments of the freeway network. This ensures a more consistent flow of traffic across the entire freeway, reducing the likelihood of bottlenecks forming in unmetered sections. Additionally, Melbourne employs adaptive traffic management systems that monitor real-time traffic conditions and adjust ramp metering rates accordingly, helping to balance traffic loads across different freeway segments.

APPLICABILITY TO TORONTO

Toronto, with its larger metropolitan population and similar traffic management challenges, could benefit from adopting ramp metering systems similar to those used in Melbourne. A study conducted at the University of Toronto demonstrated the potential benefits of implementing adaptive ramp control on the Gardiner Expressway. The study highlighted that a significant portion of congestion on downtown key arterial roadways is due to limited access and reduced flow along the Gardiner Expressway, especially during the afternoon peak period. These studies were done prior to the expressway's reconstruction, where capacity was reduced.

In comparison to Melbourne, Toronto experiences more extreme weather conditions, including harsh winters. Therefore, any implementation of ramp metering systems would need to be designed to operate effectively in all weather conditions, including snow and ice. Inclement weather conditions also disrupt regular traffic flow and reduce freeway capacities, and therefore any system adapted for a Toronto climate would require adjustments to its algorithm to reduce on-ramp flows to prevent congested conditions.

Additionally, there are several other implementation considerations for Toronto. The cost of installing and maintaining ramp metering systems can be significant, including the expenses for traffic sensors, cameras, and other monitoring devices, as well as the software and hardware required to run the system. Funding and budget allocations would need to be carefully planned. There is also the consideration of roadway downtime to install and test these systems, which would need to be planned around peak traffic periods.

Legal and regulatory barriers may also need to be addressed. Implementing ramp metering may require changes to traffic laws and regulations, as well as coordination with various governmental and transportation agencies. Public acceptance and understanding of the benefits of ramp metering would be crucial, and a comprehensive public outreach and education campaign might be necessary to gain support.

Existing Technology and Tools

Toronto has a variety of existing technologies and tools that can be leveraged to implement a coordinated ramp metering system. However, there are also gaps that need to be addressed to ensure the successful deployment and operation of such a system.

Toronto has a well-established network of traffic sensors and cameras that monitor traffic conditions in real-time. The city's Traffic Operations Centre (TOC) utilizes over 400 camera feeds to monitor traffic across the city 24/7. These cameras provide valuable data on traffic flow, congestion, and incidents, which can be used to inform ramp metering algorithms. Toronto's traffic signal control system includes nearly 2,500 traffic lights, many of which are already equipped with adaptive signal control technology. This technology uses real-time data to adjust signal timings dynamically, helping to manage traffic flow more efficiently. The integration of ramp metering with these adaptive signal systems can further enhance traffic management capabilities.

The city also has access to various data collection and analysis tools that can support ramp metering. These tools include induction loop detectors, which are installed on roads to measure traffic flow, speed, and occupancy levels. Additionally, Toronto uses software platforms for traffic data analysis, which can be integrated with ramp metering systems to provide real-time insights and adjustments.

One of the primary gaps in Toronto's current infrastructure is the lack of ramp metering hardware. This includes the traffic signals and controllers specifically designed for ramp metering, as well as the associated detection systems. While Toronto has some adaptive signal control technology, the city needs advanced algorithms and software specifically designed for ramp metering. Some research papers have pointed to the suitability of the ALINEA algorithm for Toronto because of or its simplicity and efficiency in controlling the inflow of vehicles onto freeways. It adjusts the ramp metering rate based on real-time traffic conditions, particularly focusing on maintaining optimal occupancy rates on the mainline freeway.

For ramp metering to be effective, it must be seamlessly integrated with existing traffic management systems. This includes the Traffic Operations Centre, adaptive signal control systems, and data analysis platforms.

Cost and Timeline for Implementation

The cost of installing ramp metering systems includes expenses for traffic sensors, cameras, monitoring devices, software, and hardware. Based on data from other jurisdictions, the cost of installing a single ramp meter can range from $250,000 to $500,000. For a comprehensive system covering multiple ramps, the total cost can be substantial. For example, the HERO system in Melbourne cost approximately 25 million AUD (around 23 million CAD) to implement across key freeways. This large-scale investment reflects the extensive infrastructure and technology required to manage and monitor traffic effectively. The substantial upfront investment in ramp metering systems can be justified by the long-term benefits they provide. Improved traffic flow can lead to reduced travel times, lower fuel consumption, and decreased emissions, contributing to both economic and environmental goals. Additionally, enhanced safety resulting from more orderly merging patterns can reduce the frequency and severity of accidents.

Ongoing maintenance costs for ramp metering systems include regular calibration of sensors, software updates, and hardware repairs. These costs can vary but are generally estimated at around 10-15% of the initial installation cost annually. For Toronto, assuming a similar scale to Melbourne's implementation, this could translate to an annual maintenance budget of approximately 2.3 million to 3.5 million dollars.

The planning and design phase involves conducting feasibility studies, securing funding, and designing the system. This phase can take 12-18 months. During this time, detailed traffic analysis, environmental impact assessments, and public consultations are conducted. The installation phase includes the physical installation of sensors, cameras, and ramp meters, as well as the integration of software systems. Based on examples from other jurisdictions, this phase can take 6-12 months per ramp, depending on the complexity of the site and the extent of required roadwork. After installation, a testing and calibration phase ensures that the system operates correctly and efficiently. This phase typically lasts 3-6 months and involves fine-tuning the algorithms and making necessary adjustments based on real-time data. In total, the implementation of a comprehensive ramp metering system in Toronto could take approximately 2-3 years from initial planning to full operation. This timeline is consistent with other large-scale implementations, such as the HERO system in Melbourne.

Technologically, Toronto must adopt advanced algorithms, such as the ALINEA algorithm, and ensure integration with existing traffic management systems. Additionally, the city must address potential legal and regulatory hurdles, such as obtaining the necessary permits and coordinating with various stakeholders, including local communities and transportation agencies.

Moreover, one of the significant challenges cited by city staff is the limited space available for queuing vehicles on off-ramps. This spatial constraint necessitates innovative solutions, such as optimizing ramp meter timings to minimize queuing or redesigning certain ramps to accommodate additional vehicles

The Benefits of Coordinated Ramp Metering in Toronto

Studies suggest an under-utilization of the Gardiner Expressway corridor and the wider arterial road network in Toronto due to both recurrent and non-recurrent congestion. In this context, under-utilization means that the roads are designed to carry more volume at a certain throughput speed, but due to constant congestion and inadequate traffic management, the actual output of traffic on the Gardiner is less than its capacity. High demand on the Gardiner Expressway often leads to flow breakdown and congestion, resulting in a significant loss of capacity. This congestion can cause downstream stretches of the expressway to remain underutilized, as traffic is unable to move freely. Additionally, congestion frequently leads to the blockage of off-ramps, leaving vehicles stuck on the expressway. The suboptimal utilization of parallel arterial roads, such as Lake Shore Boulevard, further exacerbates the issue, as traffic is not optimally distributed across the network.

The implementation of ramp metering on Toronto's Gardiner Expressway could have several benefits, which have been documented in detail through a study conducted by the University of Toronto. This study found that, firstly, coordinated ramp metering can help pace demand to avoid congestion that occurs when demand exceeds capacity, which can lead to capacity breakdowns. By regulating the flow of vehicles entering the freeway, ramp metering ensures that traffic remains within manageable levels, preventing the onset of severe congestion. Secondly, coordinated ramp metering helps avoid the blockage of exit ramps by maintaining a steady flow of traffic, thus preventing queues from spilling back onto the freeway and causing further disruptions. This is shown in Figure 19.

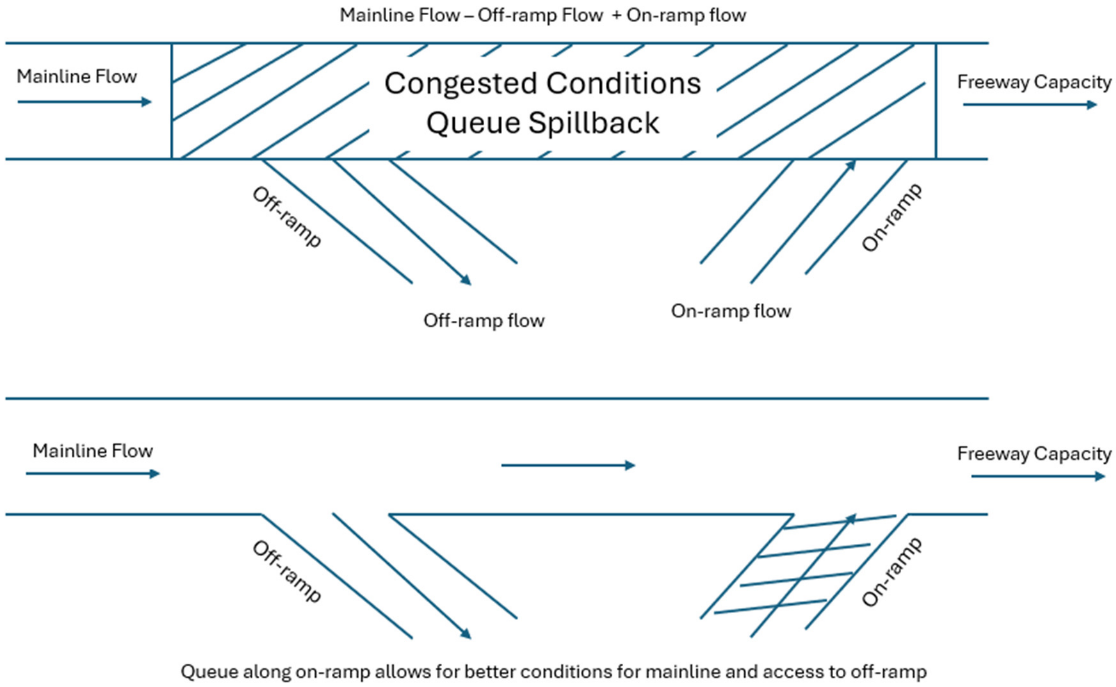


FIGURE 19: QUEUING ISSUES AND OFF-RAMP ACCESS WITH AND WITHOUT RAMP METERING

Additionally, it is possible to influence route choice behaviour by encouraging drivers to use alternative routes or travel at different times, thereby distributing traffic more evenly across the network, which is especially important in downtown Toronto. Finally, ramp metering enhances traffic safety by reducing congestion and creating safer merging conditions. With less stop-and-go traffic and smoother merging, the likelihood of collisions decreases, contributing to a safer driving environment for all road users.

The conclusion of that study, which should be explored for Toronto, can be summarized by Figure 20. The first set of four columns show the travel time from the on-ramps located at Don Valley Parkway, Jarvis Street, York Street, and Spadina Avenue, to the west end of the network around Parkside Drive. The base case compared to various versions of ramp metering including a version of ramp metering that is isolated (RLRM-I), a version with queue override for the side streets (RLRM-IWQQ), and a version that is coordinated amongst the different on-ramps (RLRM-C) shows that in ramp metering significantly reduces the travel time and improves mainline flow and output.

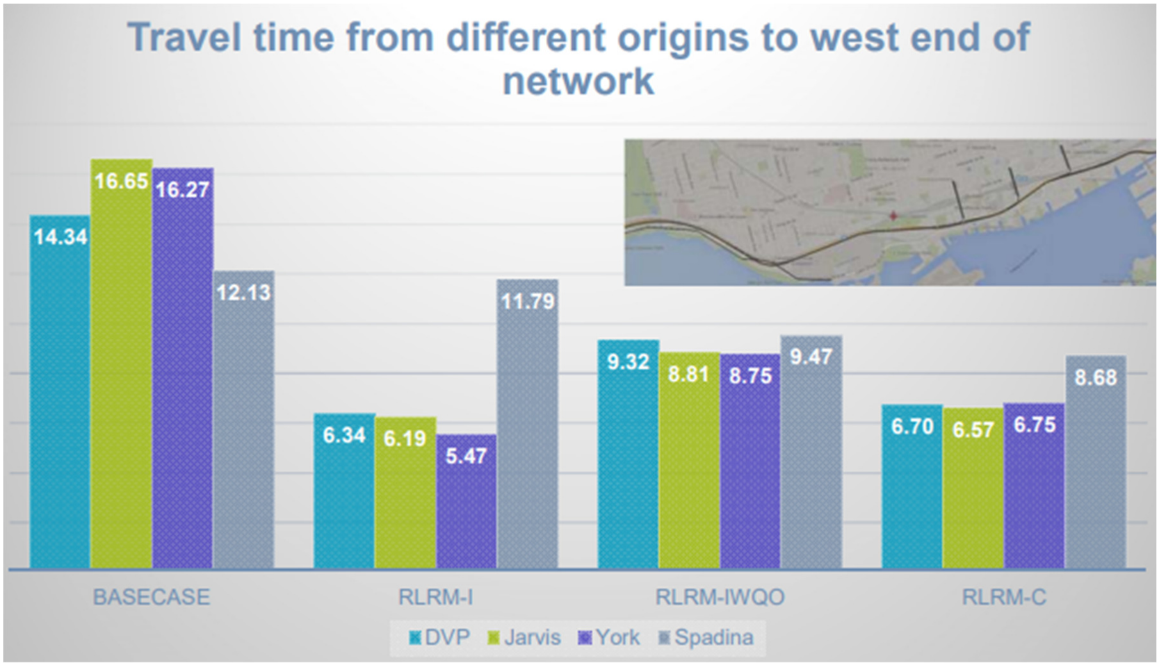


FIGURE 20: TRAVEL TIME ACROSS THE GARDINER EXPRESSWAY COMPARISON WITH RAMP METERING (UNIVERSITY OF TORONTO TRANSPORTATION RESEARCH INSTITUTE, 2016)

The traffic speeds can also be seen to increase and improve with ramp metering as shown in Figure 21. The color scale indicates traffic speed, with green representing higher speeds and red indicating lower speeds. The base case shows significant congestion (red areas) around the 18:00 mark. In contrast, the scenarios with ramp metering demonstrate improved traffic flow, with fewer red areas and more consistent green, particularly in the coordinated ramp metering scenario (RLRM-C), indicating that ramp metering effectively reduces congestion and enhances traffic speeds.

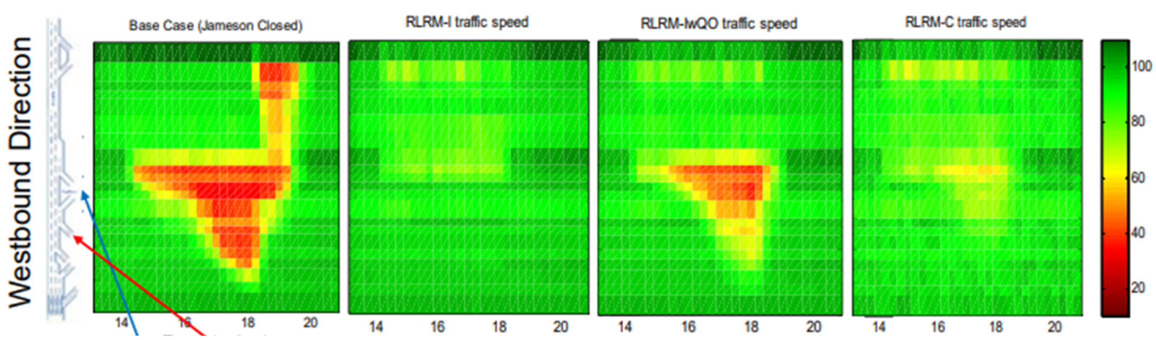


FIGURE 21: TRAFFIC SPEEDS ON WESTBOUND GARDINER EXPRESSWAY THROUGH THE IMPLEMENTATION OF RAMP METERING (UNIVERSITY OF TORONTO TRANSPORTATION RESEARCH INSTITUTE, 2016)

New York City's One-Way Street Network

BACKGROUND

Toronto's increasing population and reliance on its urban street network have resulted in persistent congestion, particularly along major corridors. These arterial roadways are vital for the movement of commuters and goods within downtown but are frequently plagued by delays and bottlenecks. The downtown core, with its dense grid of streets, much like Toronto's highway network, experiences peak-hour gridlock and unpredictable and long travel times. The congestion issues are felt most on key arterials which serve as critical access points to and from the downtown area.

This review aims to explore how New York's one-way street system can inform solutions for downtown Toronto. This includes examining the design, implementation, and operational strategies that have contributed to the success (or challenges) of New York's one-way streets and identifying potential benefits, challenges, and strategies for implementing a similar system in Toronto. Key consideration has been given to leveraging Toronto's existing street network grid, identifying high-impact pilot locations, and adapting system design to account for Toronto's unique conditions.

New York City and Toronto Comparison

New York City and Toronto are both bustling metropolitan hubs with extensive street networks and vibrant downtown cores. New York City, with a population of around 8.4 million, and Toronto, with a metropolitan population nearing 6.5 million, share several urban characteristics that make them comparable in terms of traffic congestion challenges and opportunities. Both cities feature a grid-like street network in their downtown cores, which facilitates traffic flow but also creates numerous intersections that can become congestion points. This grid structure supports diverse transportation modes, including cars, public transit, cycling, and walking. Table 4 provides an overarching summary of the two cities with respect to their demographic and transportation characteristics.

TABLE 4: COMPARISON OF NEW YORK CITY AND TORONTO'S DEMOGRAPHICS AND TRANSPORTATAION CHARACTERSITICS

Component	Toronto	New York City
Population	Metropolitan population nearing 6.5 million	Approximately 8.4 million residents
Urban Characteristics	Centralized urban core with dense road networks	
Transportation Networks	Grid-like street layout in downtown core	
Multimodal Travel	Private vehicles, public transit, cycling, walking	
Congestion	Dense network of intersections causing congestion during peak periods	
Demographics	Diverse and rapidly growing population	
Urban Growth	Increasing densification with high-rise developments	
Public Transit	Considerable urban and commuter rail networks, streetcars in *mixed traffic*	Extensive urban and commuter rail networks
Cycling Infrastructure	Expanding downtown cycling network, bike-sharing programs, *evolving connectivity*	*Well-connected network* of bike lanes and cycling paths, active transportation programs
Traffic Demand Management	*No tolls* on downtown streets, no comprehensive *congestion pricing* mechanisms	*Tolls* on several major freeways and newly adopted downtown *congestion pricing*
Climate Challenges	*Harsher winters* with snow and ice, substantial investment in winter maintenance	

Component	Toronto	New York City
Intelligent Transportation Systems (ITS)	*Beginning to implement* ITS solutions, relies on traditional traffic management systems	*Further along* in integrating advanced technologies like adaptive traffic signals and real-time monitoring

ONE-WAY STREETS IN NEW YORK

New York City has an extensive one-way street network, particularly in Manhattan, which has been instrumental in managing traffic flow and reducing congestion. The one-way street system was implemented to streamline traffic, reduce conflicts at intersections, and improve overall safety. By controlling the direction of vehicle travel, one-way streets prevent head-on collisions and reduce the number of conflict points and complexity of traffic movements at intersections. New York City has been able to achieve a comprehensive network of one-way streets due to the high density and close spacing between parallel roads in its layout.

What Are One-Way Streets and How do they Work?

One-way streets are roadways that allow vehicles to travel in only one direction. These are designed to streamline traffic flow, reduce conflicts at intersections, and improve overall safety. By controlling the direction of vehicle travel, one-way streets significantly reduce the likelihood of head-on collisions and reduce the complexity of traffic movements at intersections. They are an important tool for modern urban traffic management, particularly in densely populated areas like New York City.

One-way streets operate through a combination of signage, enforcement, and dynamic adjustment. Traffic signs and signals are installed to indicate the direction of travel, providing clear guidance to drivers. These signs are typically placed at intersections and along the street to ensure that drivers are aware of the one-way designation. Signage is a critical component of one-way streets in New York City. Clear and visible signs are placed at the beginning of the one-way street and at regular intervals to remind drivers of the direction of travel. In addition to standard one-way signs, pavement markings and arrows are often used to reinforce the direction of travel.

FIGURE 22: 1ST AVENUE, NEW YORK CITY (SOURCE: NATIONAL ASSOCIATION OF CITY TRANSPORTATION OFFICIALS)

Traffic signals on one-way streets are coordinated to facilitate smooth traffic flow. By synchronizing the signals, traffic engineers can create "green waves" that allow vehicles to travel through multiple intersections without stopping. This reduces stop-and-go conditions, minimizes delays, and improves overall travel times. For example, along major one-way corridors like Fifth Avenue and Seventh Avenue, signal coordination helps maintain a steady flow of traffic during peak hours.

Enforcement measures are essential to ensure compliance with one-way street regulations in New York City. Traffic cameras, police patrols, and other enforcement tools are used to monitor and enforce the one-way street rules. Violations, such as driving in the wrong direction, are subject to fines and penalties to deter non-compliance. The New York City Police Department (NYPD) plays a significant role in enforcing these regulations to maintain order and safety on the streets.

One-Way Street Network in New York City

One-way streets in New York City have proven to be effective in optimizing traffic flow and enhancing roadway efficiency. The system allows for smoother traffic movement by eliminating the need for vehicles to cross paths at intersections, thereby reducing delays and improving travel times. Additionally, one-way streets facilitate better traffic signal coordination, allowing for longer green phases and reducing stop-and-go conditions.

Manhattan, one of the five boroughs of New York City, has an extensive one-way street network that plays a crucial role in managing traffic flow and reducing congestion. In Manhattan, the avenues generally run north-south and are a mix of one-way and two-way streets. The one-way avenues are designed to complement each other by alternating directions, which helps balance traffic flow across the borough. The streets in Manhattan generally run east-west and also follow a pattern of alternating one-way directions.

Major routes such as Broadway, Fifth Avenue, and Seventh Avenue are integral parts of Manhattan's one-way street network. Broadway, one of the most famous streets in the world, serves as a key north-south artery. It was converted to one-way traffic in the early 20th century to reduce congestion and improve safety. The conversion has been largely successful, with smoother traffic flow and fewer conflicts at intersections. However, Broadway still faces challenges, particularly during peak hours and special events.

Fifth Avenue, another major north-south route, was also converted to one-way traffic to address congestion issues. The conversion has improved traffic flow and reduced travel times for vehicles. However, the street's high pedestrian volumes and frequent commercial deliveries continue to pose challenges for traffic management.

Seventh Avenue, a key southbound route, was converted to one-way traffic to complement the southbound flow on Broadway and Fifth Avenue. This conversion has helped balance traffic volumes and reduce congestion in the area. However, the street still experiences significant delays during peak hours, particularly at major intersections.

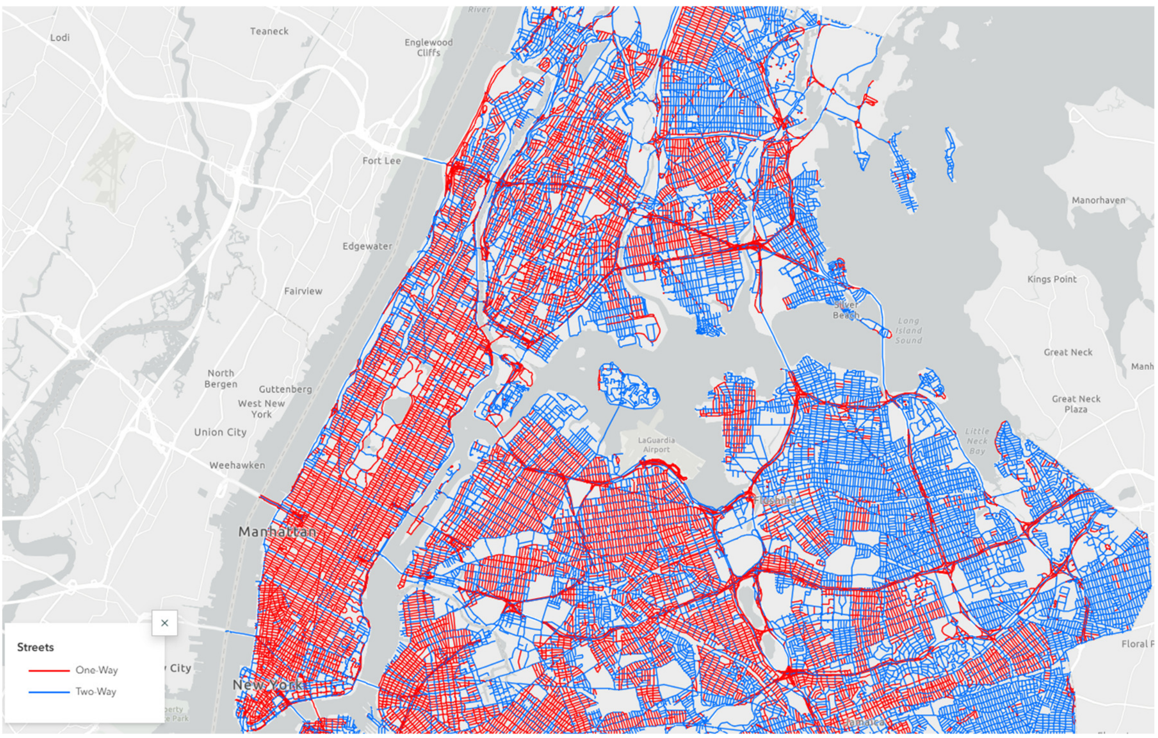


FIGURE 23: COMPARISON OF ONE-WAY AND TWO-WAY STREETS IN NEW YORK CITY (SOURCE: SIEVER & SALMAN, 2023)

Figure 23 shows a high concentration of one-way streets (indicated in red) throughout Manhattan, particularly in the densely populated midtown and downtown areas. One-way streets are prevalent in neighbourhoods such as the Upper East Side, Upper West Side, Midtown, Chelsea, and Lower Manhattan. These one-way streets create a grid-like pattern that facilitates traffic flow and helps manage congestion in the busy urban environment. In contrast, fewer one-way streets are observed in the northern parts of Manhattan, such as Harlem and Washington Heights.

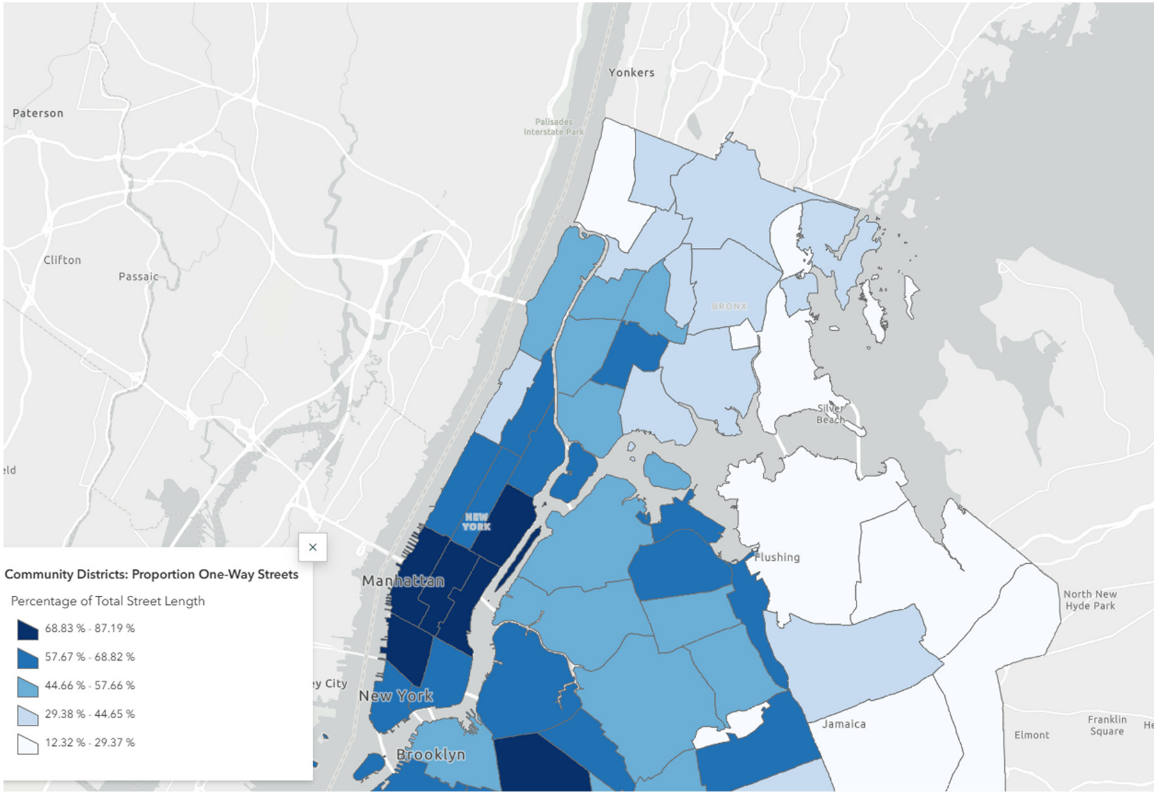


FIGURE 24: PROPORTION OF ONE-WAY STREETS WITHIN THE COMMUNITY DISTRICTIONS OF NEW YORK CITY (SOURCE: SIEVER & SALMAN, 2023)

Figure 24 highlights the proportion of one-way streets across various community districts in New York City, with darker shades of blue representing higher percentages. In Manhattan, the darkest blue areas indicate that a significant portion of the street network consists of one-way streets, particularly in districts such as Midtown and Lower Manhattan, where the percentage of one-way streets ranges from 68.83% to 87.19%. In the northern areas and into the Bronx, the prevalence of one-way streets decreases, with lighter blue shades indicating lower percentages. Similar patterns are observed in Brooklyn, where districts closer to Manhattan show higher proportions of one-way streets, while those further away have fewer one-way streets.

CONSIDERATIONS FOR ONE-WAY STREET CONVERSION

New York City goes through a rigorous and detailed process when deciding whether to convert streets to one-way. The conversion to one-way streets is a complex undertaking that requires careful consideration of various factors unique to each road. Each potential conversion involves a separate, detailed analysis to ensure that the change will effectively address traffic management goals without causing unintended negative impacts. This thorough approach helps to balance the needs of all road users, including drivers, pedestrians, cyclists, and public transit passengers. Some factors that New York City considers when deciding whether to convert streets to one-way are summarized in Table 5.

TABLE 5: CONSIDERATIONS FOR ONE-WAY STREET CONVERSION

Component	Consideration
Street Width	Streets narrower than 40 feet, especially with high traffic volumes, might be suitable for one-way conversion to reduce the risk of collisions. Many low-traffic local streets function safely with widths less than 40 feet due to infrequent opposing traffic and lower speeds.
Safety	Intersections where multiple two-way and one-way streets meet can be designed for safe operation using roadway design and signalization techniques. One-way intersections tend to have fewer conflicts, enhancing safety and simplifying traffic signal phases. "DO NOT ENTER" signs are used to discourage wrong-way travel at intersections with potential head-on conditions.
Future Multi-Modal Improvements	Converting streets to one-way can create opportunities for enhancing the streetscape with on-street parking, curb extensions, bicycle lanes, and expanded walking areas. Converting low-volume roads from one-way to two-way can help calm traffic and improve safety.
Traffic Circulation Patterns	Converting streets to one-way alters traffic patterns, potentially leading to longer and more indirect routes. NYC DOT mitigates this by pairing one-way streets in close proximity or establishing alternating directional patterns, such as in the Midtown Manhattan grid, to maintain accessibility and reduce out-of-direction travel.
Bus and Truck Routes	Changes to street directions must consider the impact on existing and planned bus routes, including city buses, school buses, intercity buses, and tourist buses. NYC DOT evaluates street direction changes involving truck routes to minimize negative impacts on goods movement while supporting local and regional goods movement.
Road Classification	Higher classification streets (Expressways, Arterials) provide greater mobility and are crucial for regional and neighborhood connectivity. These streets should support two-way traffic flow or be paired with a parallel street of similar classification to handle traffic in the opposite direction.

BENEFITS OF ONE-WAY STREETS

The following sections will examine the pros and cons of one-way street networks. The literature and review have shown that there are both advantages and disadvantages associated with the implementation of one-way streets. While some cities are converting their streets to one-way to improve traffic flow and safety, others, such as Sacramento, Cincinnati, and Dallas are converting their one-way streets back into two-way streets to enhance accessibility, livability and support local businesses. New York City, for the most part, is maintaining its extensive one-way street network, and is better positioned for its use. The following subsections attempt to summarize the literature review of one-way streets and provide specific references to New York City's system, wherever applicable.

Improved Traffic Flow

One of the primary advantages of one-way streets is the significant improvement in traffic flow. By eliminating the need for vehicles to cross paths at intersections, one-way streets can reduce delays and improve travel times. This streamlined flow has been particularly beneficial in densely populated areas like Manhattan, where high traffic volumes can lead to significant congestion. The Transportation and Traffic Engineering Handbook reports that the conversion to two-way operation generally increases capacity by about 10 to 20 percent.

In Manhattan, the grid layout of the streets combined with the high density of vehicles, pedestrians, and cyclists creates a complex traffic environment. One-way streets help to simplify this environment by reducing the number of conflicting movements at intersections. This reduction in conflicts allows for more efficient traffic signal timing and coordination, which further enhances the flow of traffic.

Major one-way corridors such as Fifth Avenue and Seventh Avenue are prime examples of how one-way streets can benefit traffic movement. Fifth Avenue, running southbound through the heart of Manhattan, experiences heavy traffic volumes throughout the day. The one-way configuration allows for smoother traffic movement by eliminating the need for vehicles to wait for oncoming traffic to clear before making turns. This not only reduces delays but also minimizes the potential for accidents at intersections.

Seventh Avenue, another key southbound route, benefits similarly from its one-way configuration. The avenue serves as a major thoroughfare for both local and through traffic, and the one-way design helps to manage the high volume of vehicles more effectively. By directing all traffic in a single direction, Seventh Avenue can accommodate more vehicles with fewer interruptions, leading to improved travel times and reduced congestion.

The benefits of improved traffic flow on one-way streets extend beyond just the major avenues. Many of the east-west streets in Manhattan, such as 14th Street, 23rd Street, and 34th Street, also utilize one-way configurations to enhance traffic movement. These streets are critical for crosstown traffic, and the one-way design helps to ensure that vehicles can move efficiently across the city. The reduction in conflicting movements at intersections allows for better synchronization of traffic signals, creating "green waves" that enable vehicles to travel through multiple intersections without stopping.

In addition to reducing delays and improving travel times, the improved traffic flow on one-way streets can also lead to environmental benefits. Smoother traffic movement means less idling and fewer stop-and-go conditions, which can reduce fuel consumption and lower vehicle emissions. This is particularly important in a densely populated urban area like Manhattan, where air quality can be a concern.

Corridors that undergo one-way conversions may see fewer bottlenecks, though the impact on a broader network is mixed. While specific streets might benefit, some traffic may be redistributed to parallel routes, which can become more congested without complementary measures.

Enhanced Safety

One-way streets can enhance safety by reducing the risk of head-on collisions and other conflicts at intersections. The reduction in intersection conflicts has contributed to lower accident rates in areas with one-way streets. Pedestrians only need to look in one direction when crossing, which can simplify crossing and improve safety. In New York City, the implementation of one-way streets has been associated with a decrease in traffic accidents and improved pedestrian safety. This improved safety can reduce the occurrence of collisions which are a primary reason behind excessive downtown congestion. However, total turning movements generally increase, which can raise the potential for collisions involving pedestrians and cyclists at intersections if not carefully managed. This can be mitigated with thoughtful intersection design, including visible crosswalk markings and protected signal phases.

Improved Signal Progression

Traffic signals on one-way streets can be synchronized to create "green waves," allowing vehicles to travel through multiple intersections without stopping. This synchronization is particularly effective in managing traffic flow on long stretches of one-way streets, reducing stop-and-go conditions, minimizing delays, and improving overall travel times.

In New York City, coordinated signals are a key component of the traffic management strategy, especially in Manhattan where the grid layout and high traffic volumes necessitate efficient traffic flow. One of the most notable examples of this is Broadway, a major north-south artery that benefits significantly from synchronized traffic signals. On Broadway, traffic signals are timed to allow vehicles to travel through multiple intersections with minimal stopping, creating a smoother and more predictable driving experience.

Another example is Fifth Avenue, which runs southbound through Manhattan. The synchronization of traffic signals on Fifth Avenue helps maintain a steady flow of traffic during peak hours, reducing congestion and improving travel times for commuters and residents. This coordination is particularly important given the high volume of both vehicular and pedestrian traffic in the area.

Seventh Avenue, a key southbound route, also benefits from coordinated signals. The synchronization of traffic lights along Seventh Avenue helps manage the flow of traffic, especially during rush hours when the volume of vehicles is at its peak. This coordination reduces the likelihood of traffic jams and ensures that vehicles can move more efficiently through the city.

In addition to these major avenues, many of the east-west streets in Manhattan also have coordinated signals. For example, 14th Street, 23rd Street, and 34th Street all have traffic signals that are timed to create green waves, allowing vehicles to travel across the city with fewer stops. This is particularly beneficial for crosstown traffic, which can otherwise be slowed down by frequent stops at intersections.

The New York City Department of Transportation (NYC DOT) has implemented advanced traffic signal systems to facilitate this synchronization. These systems use real-time data to adjust signal timings based on current traffic conditions, ensuring that the green waves are maintained even as traffic patterns change throughout the day. This dynamic adjustment helps optimize traffic flow and reduce delays, making the city's one-way street network more efficient.

Fewer Conflicting Turning Movements

One-way streets reduce the number of conflicting turning movements, which can be particularly challenging to manage on two-way streets. In two-way street configurations, left turn storage lanes can be difficult to implement due to limited right-of-way. This can lead to congestion and increased potential for accidents at intersections. One-way streets simplify turning movements, making it easier to manage traffic flow and reducing the likelihood of conflicts.

In New York City, the benefits of fewer conflicting turning movements are particularly evident in areas with high traffic volumes and limited space for dedicated turn lanes. For example, on major one-way avenues like Fifth Avenue and Seventh Avenue, the absence of opposing traffic allows for more straightforward and safer turning movements. Vehicles making right turns do not have to navigate around oncoming traffic, which reduces the complexity of the maneuver and the potential for collisions.

Additionally, the simplification of turning movements on one-way streets helps to alleviate congestion at intersections. In a two-way street configuration, left-turning vehicles often need to wait for a gap in oncoming traffic, which can create bottlenecks and slow down the overall flow of traffic. This is especially problematic in densely populated areas like Manhattan, where high traffic volumes can exacerbate delays. By contrast, on one-way streets, left turns are either eliminated or significantly simplified, allowing traffic to move more smoothly through intersections.

The reduction in conflicting turning movements also enhances pedestrian safety. On one-way streets, pedestrians only need to be aware of traffic coming from one direction when crossing the street. This reduces the cognitive load on pedestrians and decreases the likelihood of collisions. In New York City, where pedestrian traffic is substantial, this simplification is a critical safety benefit. For example, along Broadway and other major one-way streets, the reduced complexity of turning movements contributes to a safer environment for pedestrians.

Moreover, the design of one-way streets allows for better utilization of limited urban space. In areas with constrained right-of-way, such as the narrow streets of Lower Manhattan, implementing left turn storage lanes on two-way streets can be impractical. One-way streets eliminate the need for these storage lanes, freeing up space that can be used for other purposes, such as wider sidewalks, bike lanes, or additional travel lanes. This efficient use of space is particularly valuable in a densely built environment like New York City.

The benefits of fewer conflicting turning movements extend to public transit as well. Buses operating on one-way streets can navigate intersections more easily without the delays associated with left-turning vehicles. This can lead to more reliable and efficient bus service, which is essential in a city where public transit is a primary mode of transportation for many residents. For instance, bus routes along one-way streets like Madison Avenue benefit from reduced delays and improved travel times.

DRAWBACKS OF ONE-WAY STREETS

While one-way street networks offer several advantages, they also present significant challenges. This section will explore the various drawbacks associated with one-way streets, with specific references to New York City's experience.

Increased Travel Distances

One of the primary challenges of one-way streets is the potential for increased travel distances. In a one-way street network, drivers may need to take longer, indirect routes to reach their destinations. This can result in increased travel times and fuel consumption, potentially offsetting some of the benefits of reduced congestion. In Manhattan, the grid layout can force drivers to take circuitous routes, adding to travel distances and time.

For example, consider a driver on Fifth Avenue who needs to reach a destination on Sixth Avenue, just one block west. Due to the one-way configuration of these avenues, the driver cannot simply turn left onto Sixth Avenue. Instead, they may need to continue south on Fifth Avenue, turn right onto a cross street, and then turn right again onto Sixth Avenue, effectively making a loop around the block. This not only increases the distance traveled but also contributes to additional traffic on the surrounding streets.

The increased travel distances in a one-way street network can also impact delivery vehicles and service providers. For instance, a delivery truck that needs to make multiple stops along a one-way street may have to take longer routes to reach each destination. This can lead to increased fuel consumption and longer delivery times, which can affect the efficiency of logistics operations in the city.

Moreover, the increased travel distances can contribute to higher Vehicle Miles Traveled (VMT), which has environmental implications. More extended travel routes mean more fuel consumption and higher emissions, which can negatively impact air quality in densely populated areas like Manhattan. This is particularly concerning given the city's efforts to reduce its carbon footprint and promote sustainability.

The impact of increased travel distances is not limited to drivers and delivery vehicles. Public transit users can also be affected. For example, bus routes that operate on one-way streets may need to take longer, indirect routes to complete their journeys. This can lead to longer travel times for passengers and reduced reliability of transit services. In New York City, where public transit is a primary mode of transportation for many residents, this can be a significant inconvenience.

One of the specific challenges for bus routes on one-way streets is that they cannot operate in both directions on the same road. This means that the inbound and outbound routes must use different streets, which can complicate the transit network and make it less intuitive for users. For example, a bus route that travels southbound on Fifth Avenue may need to use Madison Avenue for the northbound return trip. This split routing requires passengers to walk to a different street to catch the bus in the opposite direction, which can be confusing and inconvenient, especially for infrequent users or tourists.

The need to use different streets for inbound and outbound routes can also lead to longer journey times for passengers. If the streets used for the return trip are not as direct or are more congested, the overall travel time can increase. This can reduce the reliability of transit services and make public transportation less attractive to users. The increased travel distances can also impact emergency response times. Emergency vehicles, such as ambulances and fire trucks, may need to take longer routes to reach their destinations, which can delay their response times. This drawback is felt less in areas like Manhattan where the dense grid network reduces the increased travel distance that drivers must traverse.

Pedestrians and Cyclist Impacts

One-way streets can create challenges for pedestrians and cyclists, who may need to navigate more complex routes and face higher vehicle speeds. Pedestrian safety is a concern, particularly at intersections where vehicle speeds may be higher. Multi-lane one-way streets can reduce pedestrian visibility, as vehicles in adjacent lanes may block the view of pedestrians. In New York City, where pedestrian traffic is substantial, this has led to increased risks for those on foot and contribute to congestion at busy intersections. Additionally, cyclists may find it more difficult to navigate one-way streets, as they may need to take longer routes to reach their destinations. The higher vehicle speeds on one-way streets can also make cycling less safe and less appealing, potentially leading to more cyclists using sidewalks and contributing to pedestrian congestion.

Potential for Confusion

Drivers unfamiliar with the area may find one-way streets confusing, leading to navigation difficulties and potential violations. Tourists and new residents in New York City cite struggling with the one-way road system, especially in areas with frequent changes. This confusion resulted in wrong-way driving, which posed significant safety risks and caused traffic disruptions. Additionally, the need to navigate around one-way streets made it more challenging for drivers to find parking or reach specific destinations, leading to frustration and increased travel times. This contributed to congestion as drivers circulated through the network looking for parking or simply trying to find their way.

Impact to Businesses

A specific way that one-way streets can negatively impact businesses, particularly those that depended on pass-by traffic, is related to storefront visibility. Figure 25 illustrates how one-way road networks can eclipse business frontages, reducing visibility and limiting potential customer engagement. On a one-way street, drivers only see what is directly across from them and adjacent to them, which means that many storefronts are obscured from view. This reduced visibility may lead to decreased foot traffic and sales, significantly affecting the economic vitality of these businesses. For instance, on Vine Street in downtown Cincinnati, nearly 40% of businesses closed after the street was converted from two-way to one-way traffic. In New York City, similar challenges were faced by businesses located on one-way streets, as potential customers often did not notice them while driving by. This was particularly detrimental for small businesses that relied on visibility and accessibility to attract customers.

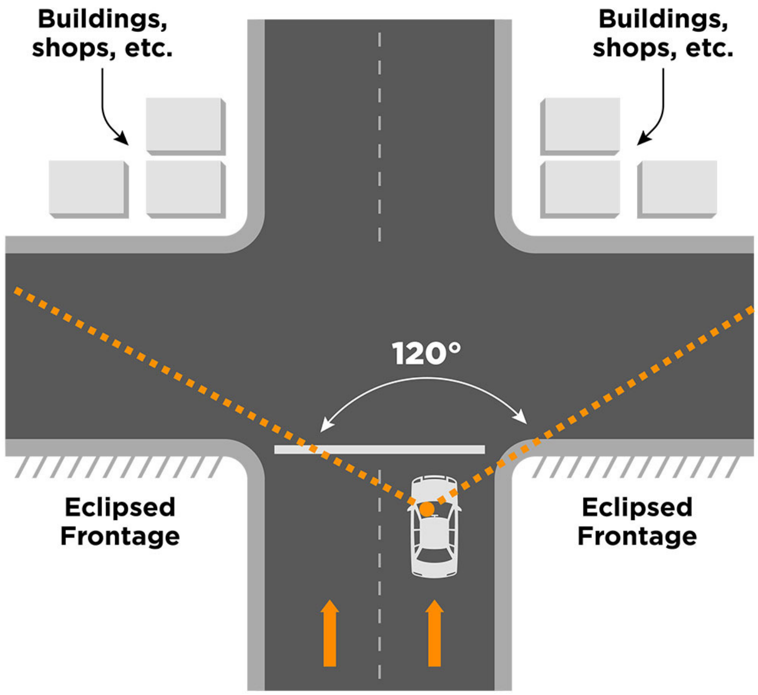


FIGURE 25: ECLIPSED FRONTAGE FOR BUSINSESSES ALONG ONE-WAY ROAD NETWORKS (KITTLESON & ASSOCIATES, 2024)

APPLICABILITY TO TORONTO

Toronto, with its larger metropolitan population and similar traffic management challenges, may consider adopting a one-way street network similar to that used in New York City. This section explores the current one-way streets in downtown Toronto, the potential need for more one-way streets, considerations for new locations, and the potential benefits of implementation.

Current One-Way Streets in Downtown Toronto

Toronto already has several one-way streets in its downtown core, which help manage traffic flow and reduce conflicts at intersections. Some of the notable one-way streets in downtown Toronto include the ones listed in Table 6.

TABLE 6: MAJOR ONE-WAY STREET LOCATIONS IN DOWNTOWN TORONTO

Street	Direction	From	To
Wellington Street	Westbound	Spadina Avenue	Church Street
Richmond Street	Westbound	Eastern Avenue	Bathurst Street
Adelaide Street	Eastbound	Bathurst Street	Eastern Avenue
Victoria Street	Northbound	Adelaide Street	Dundas Street
Simcoe Street	Northbound	Wellington Street	Queen Street
York Street	Northbound	Front Street	Queen Street

Portions of these streets in Toronto operate as two-way roads to provide access to and from certain buildings. These one-way streets have been effective in managing traffic flow and reducing delays in certain areas. However, there are still significant congestion issues in downtown Toronto, particularly during peak hours. The current one-way street network may not be sufficient to address the growing traffic demands and the simultaneous need for improved safety and efficiency.

Implementing New One-Way Streets in Downtown Toronto

Implementing additional one-way streets could help streamline traffic flow, reduce conflicts at intersections, and improve overall travel times. However, it is essential to consider the potential benefits and challenges and ensure that the design accommodates all road users. When considering the implementation of new one-way streets, several factors need to be taken into account:

- Traffic Volume: Streets with high traffic volumes and frequent congestion may benefit from being converted to one-way. This can help manage the flow of vehicles more effectively and reduce delays.
- Intersection Conflicts: Streets with complex intersections and high rates of turning movements may see improved safety and efficiency with a one-way configuration. Simplifying these intersections can reduce the potential for accidents and improve traffic flow.
- Pedestrian and Cyclist Safety: One-way streets can enhance safety for pedestrians and cyclists by reducing the number of conflicting movements. However, it is essential to ensure that the design of one-way streets accommodates non-motorized road users and provides safe and convenient routes for them.
- Public Transit: The impact on public transit routes must be carefully considered. One-way streets can complicate transit operations, especially for bidirectional routes, so it is crucial to plan for efficient and reliable bus routes that can navigate the one-way network effectively.
- Local Business Impact: The visibility and accessibility of local businesses must be considered. One-way streets can reduce storefront visibility and potentially impact foot traffic and sales.

Converting streets to one-way can help alleviate congestion, but Toronto's north-south roads are spaced too far apart to make this practical. While there are opportunities for east-west conversions, such as converting Front Street to eastbound to complement the westbound Wellington Street, these changes could disrupt access to major roadways and the Gardiner Expressway. Careful planning and coordination would be required to ensure these intersections continue to function effectively.

Many cities are reversing one-way streets to two-way to enhance livability and support complete streets initiatives. For example, in Lakeland, Florida, properties along a converted two-way stretch saw a transformation from 50% vacancy to a vibrant shopping and dining area. Similarly, in downtown Chattanooga, Tennessee, a four-mile pair of one-way streets was converted to two-way, facilitating university expansion and new developments with minimal impact on travel times. These conversions have often resulted in revitalized neighborhoods, increased economic activity, and safer, more accessible streets.

Given these outcomes, the benefits of one-way streets in Toronto may be marginal. Implementing one-way streets could lead to reduced network connectivity and negative impacts on local businesses and livability. Additionally, the unique layout of Toronto's road network, with its wider spacing of north-south roads, makes it challenging to find suitable pairs of streets for conversion. Therefore, further one-way street conversions in Toronto are not recommended.

Summary and Conclusion

Toronto's transportation network faces significant challenges in managing congestion, delays, and associated road safety concerns, particularly on key routes like the Gardiner Expressway and its intersecting downtown core streets. This study reviewed two critical bottlenecks identified in the downtown core and explored potential solutions for short-term implementation. Additionally, the study examined best practices from Melbourne's ramp metering system and New York City's one-way street network, assessing their applicability for implementation in downtown Toronto.

Summary of Findings

BOTTLENECK ANALYSIS

The study examined two critical bottlenecks in downtown Toronto, each contributing significantly to traffic congestion and operational inefficiencies. The first is Harbour St at York St, where the primary challenge arises from queuing spillback on York St that extends onto Harbour St. This issue is driven by the limited storage capacity on York St and high turning demand at the intersection. Compounding the problem are weaving conflicts, as vehicles from the Gardiner off-ramp navigate multiple lane changes to access turning lanes, disrupting through traffic heading east of York St.

The second bottleneck is the Gardiner Expressway westbound between the York St On-Ramp and the Spadina Ave Off-Ramp. The primary operational challenge in this segment stems from a substandard weaving section which no longer meets modern design standards. This design deficiency leads to frequent weaving and merging conflicts, severely limited capacity, and delays that propagate upstream, impacting the overall efficiency of the expressway.

BEST PRACTICE REVIEW

Melbourne has successfully implemented ramp metering systems to manage freeway congestion and improve safety. The HERO algorithm dynamically adjusts metering rates based on real-time traffic data, maintaining optimal traffic density and preventing flow breakdowns. The system has demonstrated significant benefits, including reduced travel time variability, improved traffic flow, and enhanced safety. Melbourne's experience shows that ramp metering can effectively manage congestion and improve freeway efficiency.

New York City has an extensive one-way street network, particularly in Manhattan, designed to streamline traffic flow, reduce conflicts at intersections, and improve safety. One-way streets have been effective in managing traffic in densely populated areas, enhancing signal progression, and reducing intersection conflicts. However, they also present challenges, such as increased travel distances, potential confusion for drivers, and impacts on local businesses. Many cities are converting one-way streets to two-way to enhance livability and support local economies.

Recommendations

To address the critical bottlenecks identified in this study, a combination of targeted short-term measures and long-term strategies is necessary. For Harbour St at York St, minimizing queuing spillback and weaving conflicts requires the introduction of physical separation between Lake Shore Blvd and Gardiner off-ramp traffic. Reconfiguring lane assignments and implementing turn restrictions can further optimize traffic flow. These measures should be part of a coordinated approach that balances immediate improvements with long-term objectives to ensure sustainable outcomes.

For the Gardiner Expressway WB between York St On-Ramp and Spadina Ave Off-Ramp, quick-build solutions, such as lane reconfigurations and targeted traffic restrictions, are recommended to reduce weaving conflicts and better balance expressway and ramp movements. These measures should be closely monitored to assess their effectiveness. At the same time, it is critical to advocate for integrating long-term operational improvements into the Gardiner Section 4 rehabilitation project, scheduled for 2026–2028, to address systemic issues more comprehensively.

While localized solutions provide immediate relief, they must be implemented within the context of a broader, corridor-wide perspective to avoid shifting congestion to adjacent areas. Short-term interventions, although valuable, are inherently limited in addressing fundamental issues like weaving conflicts and may introduce operational or safety trade-offs. To fully resolve these challenges, a coordinated approach that integrates short-term actions with long-term strategies is essential.

Toronto should consider implementing ramp metering on key freeway segments like the Gardiner Expressway. A pilot project could be initiated to evaluate its effectiveness, using real-time data to dynamically adjust metering rates and monitor the impact on traffic flow and safety. Leveraging existing intelligent transportation systems (ITS) will be crucial for successful implementation, and the system must be designed to operate effectively in all weather conditions. Engaging with local stakeholders and providing clear communication will help ensure smooth adoption and address any concerns.

On the other hand, Toronto should be cautious about converting more streets to one-way. While one-way streets can improve traffic flow and reduce intersection conflicts, they also present significant drawbacks, such as increased travel distances, potential confusion for drivers, and negative impacts on local businesses. Given these challenges and the trend of cities reversing one-way streets to two-way to enhance livability, it is not recommended for Toronto to pursue further one-way street conversions. Instead, the city should explore other traffic management strategies, such as travel demand management and enhanced public transit options, to address congestion and improve overall livability.

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