IS THE BLOOR DANFORTH CORRIDOR A 'SENSIBLE LOCATION' FOR A SEPARATED BIKE LANE?

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"My number one priority is tackling traffic and transit congestion. Adding separated bike lanes in sensible locations will give cyclists more alternatives to get around the city quickly and more safely." Toronto Mayor John Tory (Tory, 2014)

Introduction

What exactly defines a 'sensible location' for a separated bike lane? Although not specifically stated the first sentence clearly gives some clue to what is meant by the concept. Set within the context of the Mayor's "top priority" in all likelihood a 'sensible location' for a separated bike lane is one that does nothing to exacerbate existing traffic congestion. Cyclist demand and cyclist safety is also clearly part of that definition, but within the framework of the larger statement it appears almost a secondary concern. In short a 'sensible location' for a bike lane in Toronto must not impact traffic flow or increase travel time for cars, and should facilitate demand and safety for cyclists.

Implementing bike lanes in Toronto has always been a challenge, and that test has been borne out by the state of its existing city cycling network. The last official bike master plan was presented to council in 2001 and in the decade following, less than half of that planned 1,004 kilometer city cycling network had been implemented (Ontario Medical Association, 2011). Separated bike lanes in particular are an underutilized design in Toronto, and at present make up just 15.1 kilometers of the city's 558 kilometer cycling network (City of Toronto, 2016). Moreover those 15 kilometers have been heavily criticized by cycling advocates for their lack of actual physical separation (Kuitenbrouwer, 2014). By contrast New York City will have installed over 110 kilometers of separated bike lanes by the end of 2016, 22.5 of which will have been installed this year alone (New York City Department of Transportation, 2016). At nearly 850 kilometers New York's total city cycling network is almost 300 kilometers larger than Toronto's (ibid).

The highest political hurdle to installing more and safer bike lanes in Toronto remains the threat of traffic congestion. Although much of the economic loss comes from congested freeway travel, traffic has been estimated to cost the Greater Toronto Area somewhere between $6 to $11 billion dollars a year (C.D. Howe Institute, 2013). Frustration by residents over this issue has led to a cars versus bikes dynamic in the city, one that has spilled over to create a contentious and divided city council when it comes to the issue of bike lanes. While some councilors are strong advocates of city cycling, others have called separated bike lanes "controversial" and "a disaster" (Grant, 2012). The political challenge of building bike lanes in the city has transcended administrations, and often led to long periods of inaction when decisions are necessary.

One example that highlights a particularly long period of inaction is the fate of bike lanes along the Bloor-Danforth corridor (see: Figure 1). This specific arterial road has amazingly been discussed as a possible site for bike lanes intermittently by council for 40 (!) years. The city commissioned its first bike lane consultation for the corridor in 1976 and then again in 1992; in 2010 council voted for a bike lane Environmental Impact Assessment (EA), and then voted to end that EA in 2011; in 2013 an updated EA was requested, yet by the end of 2015 work on that assessment had not yet begun (Davis, 2015). However 2016 brings new optimism for those seeking a conclusion to this saga, as a pilot separated bike lane will be installed on a small section of the Bloor-Danforth corridor this summer (CBC, 2016).

What is particularly troubling for cycling advocates in the city is that even if the trial succeeds there is no guarantee that the lane will become a permanent fixture of Toronto's cycling network. For example a separated lane that had made it through city council's approval and the entire planning process to actual implementation was later removed at a significant cost to the city, illustrating the potentially transient nature of Toronto's cycling network. In that particular incident, a separated lane was built on Jarvis Street in 2010 and then by 2011 it was removed at the behest of then Mayor Rob Ford who argued that, "the city should remove the bike lane as soon as possible and improve travel times for thousands of daily commuters" (Pagliaro, 2014). The lane subsequently resurfaced in another location, Sherbourne Street, a choice determined by its lower traffic flow, a potentially more 'sensible location' for a bike lane by the definition provided in the first paragraph above. Since that time two more separated bike lanes have emerged on Richmond and Adelaide Streets, but again these are considered pilot projects and may be removed. The plight of the Jarvis Street separated bike lane in particular serves as a reminder that no lane is safe in Toronto should traffic complaints arise.

Given the sheer length of time it took to reach just the pilot phase for a separated bike lane on the Bloor-Danforth corridor, the effort must be considered a major success for cycling in the city. All told it took the support of cycling advocates, local resident associations, and even one of Canada's largest environmental non-profits working in conjunction with the city planners to secure the trial (David Suzuki Foundation, 2016). The following study has no intention of undoing any of that much deserved and hard fought progress. However thanks to a unique applied transportation geography technique first developed by Scott et al. (2006), the traffic impact of a potential bike lane addition can be evaluated prior to its actual implementation[1].

Using a method called the Network Robustness Index (NRI), we simulate the change in network travel time following a road capacity reduction for each link across Toronto's road network. Since the addition of a separated bike lane is similar in theory and operation to a road capacity reduction we use the results of the NRI method to estimate potential travel time impact of adding a separated bike lane to the Bloor-Danforth corridor and other parallel alternatives. The goal of the study is to identify a 'sensible location' for a separated bike lane, one that facilitates safe east-west travel across the city's downtown core for cyclists while also maintaining the highest level of service for cars and transit traffic.

The paper is arranged as follows. The next section covers the necessary study materials, providing detail on the data and the software required to produce and reproduce the results. The section following that lays out the theory behind the Network Robustness Index and explains how the impact of reduced road capacity on network travel time is calculated. The method is then applied to the City of Toronto road network and the results of those simulations are presented and discussed in the penultimate section. The final section confers a brief conclusion to end the study.

It is the authors' hope that this type of modelled evaluation prevents the possible removal of trial lanes from the road network after they have been implemented. If successful as a preventative measure this type

[1] Still the actual placement of a pilot lane remains important for validation of the traffic simulations.

of prior evaluation will provide significant value all parties involved in the bike lane planning process and benefit the outlook of future cycling projects in the city. Moreover the advantage of this method over pilot projects is not only that it can evaluate the specific corridor in question but also test possible alternative locations without the need for several pilots.

Figure 1. Map of the Toronto road network that identifies several core east-west arterial roads.

Method and Materials

To conduct a Network Robustness Index evaluation and reproduce the study results an analyst must have access to a Transportation GIS software with the ability to perform traffic simulations. This study uses the latest TransCAD Transportation GIS software (version 6.0) to conduct a congested traffic assignment simulation. Performing this simulation requires two key inputs: a network file and an origin- destination (OD) matrix of the traffic sources and sinks within study area.

A network file of the Greater Toronto Hamilton Area was obtained from Desktop Mapping Technologies Inc. (DMTI). To this file the authors added an attribute for each road's design capacity based on the guidance of the Highway Capacity Manual (Transportation Research Board, 2000).
Additionally centroids were added to the network file to correspond with the center points of the Traffic Analysis Zones (TAZ) used by the OD matrix as units of geography. See Figure 2 below for an illustration.

Figure 2. DMTI Greater Toronto and Hamilton Area network file with added centroids.

An OD matrix was generated from the results of the Transportation Tomorrow Survey (TTS), a survey conducted to uncover the travel patterns of households in the Greater Toronto and Hamilton Area. The TTS survey has been conducted every five years since 1986, this study uses the 2006 survey sample which was the most complete sample available for analysis at the time. The 2006 TTS is comprised of 5253 Traffic Analysis Zones of which 5% of the population within those zones are surveyed. Respondents provide information on each trip made by every person 11 years or older in the household on the previous day. Since a quarter of daily trips occur during the peak morning commute from 6 am to 9 am (Data Management Group 2014), this study utilizes an OD matrix generated over the peak period to produce the table of origins and destinations required for the second necessary input into the traffic simulation.

Additionally, the authors use a self-developed Caliper script software tool that processes traffic simulations for each link in the road network within the Transportation GIS software. This tool is called the Network Robustness Index Calculator. The NRI Calculator simulates travel for the complete road network calculates total Vehicle Hours Travel and then iteratively reduces capacity for each link in the network and automatically calculating both the VHT and the difference in VHT between the complete network and the reduce link simulations. These calculations are described in detail in the section below. This tool assists the authors not only in measuring changes in travel time for the targeted location, but in identifying alternative locations by measuring travel time changes for each link across the road network. The tool is extremely useful in this capacity but not necessary to reproduce the results of a single location evaluation. The difference in VHT for a single location can easily be calculated by performing a complete network simulation, then manually reducing the capacity of the targeted link in the network file, then rerunning the simulation a second time to find the difference in VHT.

Theory and Calculations

The Network Robustness Index (NRI) method measures the impact of reduced road capacity by performing two traffic simulations that assign congested traffic flows to a road network via a Wardrop's (1952) User Equilibrium traffic assignment. In the first simulation, or base case scenario, network capacity is complete and total VHT is calculated. In the second simulation, road capacity is iteratively reduced for each road link in the network and the total VHT is calculated once again following the loss. The difference in VHT between the two scenarios is known as the road's NRI value, which can be defined as the impact of reducing capacity on a road link on network travel time. The greater the increase in VHT from the base case to the reduced capacity simulation, the more disruptive the loss of that link's capacity is for drivers. In the context of this paper, the NRI value estimates the cost of a separated bike lane on Bloor-Danforth corridor and alternatives on driver's travel time.

Calculation of the NRI can be explained by the following mathematical notation:

$$NRI_a = C_a - C$$

where

NRI_a is the aggregate network travel time measured as the difference before and after capacity is removed from a corridor. C_a is the aggregate network travel time of the disabled link on link *a* after traffic has reached a new equilibrium. C is the aggregate network travel time when all links are operational at full capacity in the network (i.e., base-case scenario).

$$C = \sum_{i \epsilon I} t_i x_i$$

where

t_i is the link travel time for all vehicles on link i, in minutes, and x_i is the traffic flow on link *i* for all vehicles at user equilibrium. I is the set of all links in the network.

$$C_a = \sum_{i \epsilon I/a} t_i{}^{(a)} x_i{}^{(a)}$$

where

$t_i^{(a)}$ is the new travel time across link i when link a has had some level of capacity removed, and $x_i^{(a)}$ is the new flow on link i.

Results and Discussion

The above method was applied to the Toronto road network at a road capacity reduction level of 25%. Much of the Bloor-Danforth corridor consists of 4 lanes of traffic, 2 lanes serving each direction. Furthermore this same 4 lane configuration covers most of the alternate routes. A 25% reduction of road capacity would reflect a 4 lane to 3 lane change in road capacity, a transition common to convert an arterial to a 'complete street', which often includes adding a separated bike lane and altering the center lane into a turning lane (Rosales, 2006). This is type of transition that the 25% reduction traffic simulation attempts to capture. See Figure 3 for further illustration.

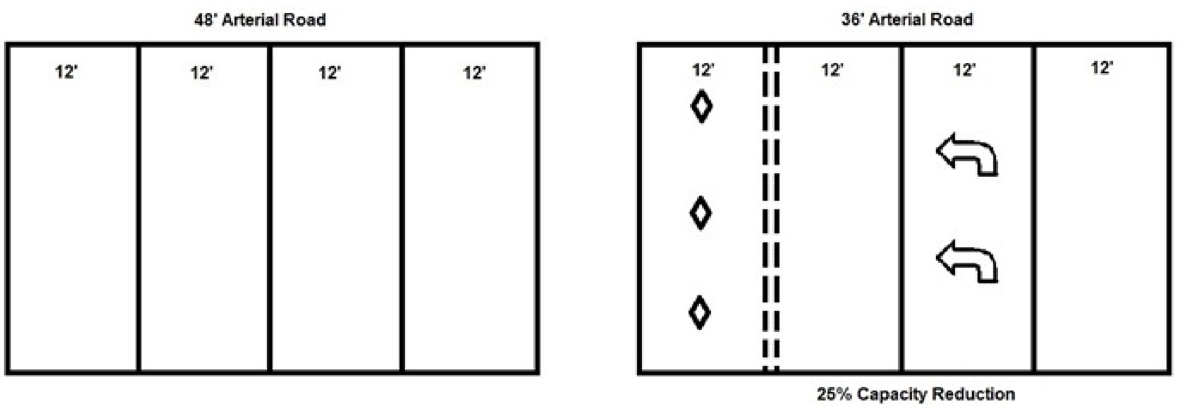

Figure 3. Illustration depicting the conversion of a 4 lane arterial road to a complete street with a separated bike lane (denoted by the diamonds).

Table 1 below shows the resulting NRI values displayed as a total change in VHT for each link on the Bloor-Danforth corridor and three alternative locations: Dundas Street, Queen Street, and Lakeshore Boulevard between Dufferin St and Woodbine Ave. Figure 4 is a map of the values from Table 1 across the network. Some of the roads have more links than others and thus the table is uneven. A negative change in VHT is what is called a Braess Paradox (Braess et al., 2005). Braess Paradoxes occur when network operations are improved when network capacity is reduced. This phenomenon occurs when individual travelers choose the least costly route from origin to destination until ultimately reaching a bottleneck that increases travel times for all travelers. Since adding a separated bike lane to a link that identifies a Braess Paradox when road capacity is reduced this is the optimal outcome for both cyclists and car drivers. These are by definition, the most 'sensible locations' for a bike lane.

Table 1. NRI Values for a 25% road capacity reduction on Bloor-Danforth and other parallel alternatives.
Bloor-Danforth Dundas Queen Lakeshore

Bloor-Danforth	**Dundas**	**Queen**	**Lakeshore**
-7.4	2.9	7.1	0.0
3.2	-2.7	6.9	0.0
-1.7	2.6	7.2	0.0
3.5	2.3	4.1	0.0
1.7	2.8	5.9	0.0
5.4	8.8	4.5	0.0
6.5	6.7	8.6	0.0
4.9	1.9	7.6	0.0
8.2	1.6	5.7	0.0
5.6	-6.0	4.4	0.0
1.8	-0.7	-0.4	0.0
6.1	7.6	-0.4	0.0
6.3	-1.6	-1.7	-4.5
5.1	2.7	0.0	0.0
6.9	0.5	4.5	0.0
10.2	9.0	9.2	0.0
6.2	-0.2	3.6	0.0
4.5	-3.2	10.8	0.0
8.2	-2.4	7.4	0.0
-2.1	1.7	3.7	10.8
14.2	6.2	7.2	1.4
7.1	4.9	2.0	4.0
0.1	3.0	N/A	8.0
2.0	4.2	N/A	0.0
11.1	7.4	N/A	0.0
3.9	N/A	N/A	8.6
Avg. change in VHT	Avg. change in VHT	Avg. change in VHT	Avg. change in VHT
4.6	2.3	4.8	1.0

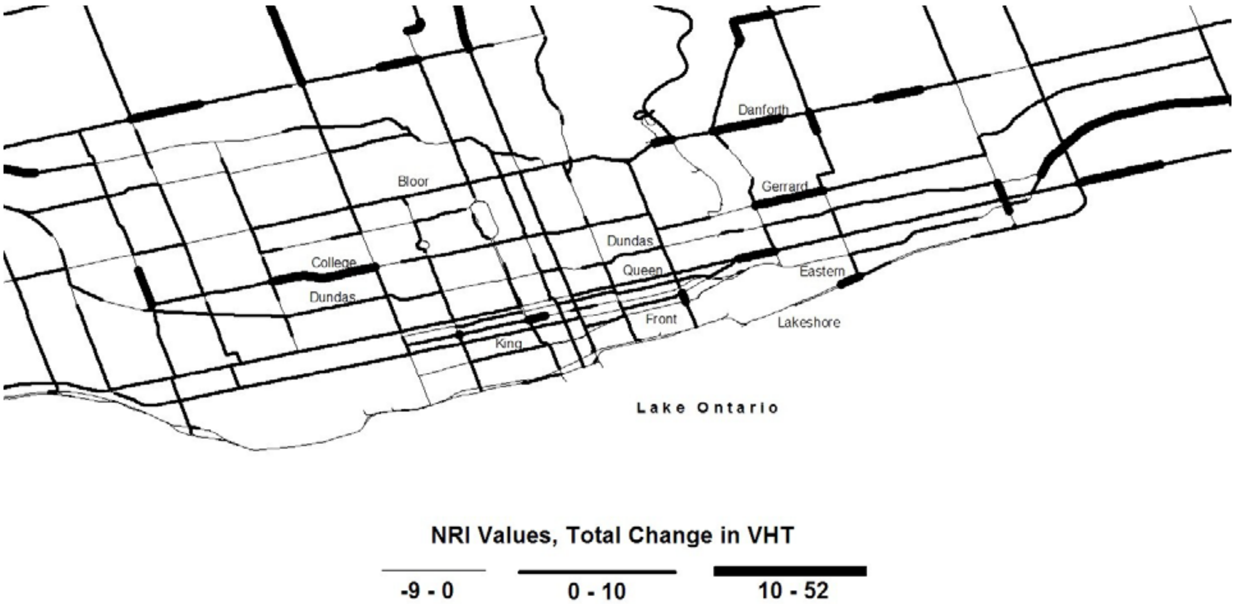

Figure 4. Map of NRI values across the core of the Toronto road network.

From the results above, the most disruptive location on average is Queen Street. A 25% reduction of capacity on this road increases VHT on average by 4.8 total network hours. Close behind however is the Bloor-Danforth corridor with an average increase in VHT of 4.6 hours. The lowest average increase after a 25% road capacity loss is Lakeshore Boulevard at just 1 hour. However much of Lakeshore actually runs closely parallel to an off-street trail along the waterfront, making much of the value of adding an on-road separated lane redundant within the overall cycling network. The best option for a separated bike lane appears to be Dundas Street. Dundas Street runs east-west directly through the middle of Toronto's downtown core and crosses major North-South corridors along the way including Yonge and University. On average a separated bike lane that requires 25% of Dundas Street from Dufferin to Woodbine only increases network VHT by an average of 2.3 hours. Just half the increase of the Bloor-Danforth corridor. By the strict definition of a 'sensible location' for a separated bike lane, Dundas Street makes the most sense.

Conclusion

Building bike lanes in Toronto has always been a challenge because the city's top priority has always been and will remain improving traffic congestion throughout the city. Given the magnitude of the problem across the Greater Toronto Area, this approach is certainly warranted. However as a byproduct the focus on cars has led to a limited cycling network in the city, as 'sensible locations' for bike lanes are necessarily tied to their impact on level of service for cars and transit.

The Network Robustness Index is an applied transportation geography method that uses traffic simulations to measure the impact of reduced road capacity on network travel time for cars. Since bike lanes require road capacity the method can be used to estimate the impact of a bike lane prior to implementation.

The Bloor-Danforth corridor is one potential location for a separated bike lane in Toronto. This location has gained support recently and a pilot project that adds a separated bike lane to a small segment of the corridor has been planned for summer 2016. We use this project's momentum as motivation to evaluate that corridor and several other alternatives. We find Dundas Street and not the Bloor-Danforth arterial to be the corridor that on average impacts travel time the least, and thus may be the most 'sensible location' for a separated bike lane across Toronto's downtown core.

Once again it is the authors' hope this type of modelled evaluation only prevents the potential removal of trial lanes from the network after they have been implemented, and is not the authors' intention to derail any hard fought progress towards that has already been made.

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