Arterial Road Lane Closure Impacts and Costs Estimation

Rita Yaxin Hu, Yannis Stogios, Andre Filippetti

ABSTRACT

Arterial road lane closures due to construction and other scheduled events reduce traffic capacity and cause delays for road users. The economic losses to the general public caused by the lane closures could be significant if the lane closures are not managed well. The City of Toronto initiated this study of lane closure policy review with the purpose of developing a methodology and quick analysis tool to establish a fee structure for lane closures / rentals that would more realistically reflect the impacts of lane closures relative to the existing pricing scheme. Consequently, the monetary value of the permit required to close one or multiple lanes for a specific period could be estimated based on the anticipated impacts.

This paper provides a brief review of 1) the arterial road lane closure policies that have been implemented in some large urban centers in North America and Western Europe focusing on the lane closure permit fee policies, and 2) the studies that have been conducted for estimating the impacts of lane closures. As well, the paper presents 3) a methodology that was proposed to address the City of Toronto's needs for estimating lane closure permit fees that better reflect the varying impacts of lane closures, and 4) a "Quick Analysis Tool" that was developed in Excel and VBA to facilitate the estimation of impacts and costs associated with planned lane closures on arterial roads.

The methodology was developed based on the Highway Capacity Manual (HCM 2010) with limited data resources and utilizing engineering judgment so that the results could better reflect local conditions. Different scenarios were tested and the results were compared to actual lane closure cases. The test and comparison results demonstrate that the proposed methodology and tool provide reasonable and practical results (i.e. estimation of arterial road lane closure impacts and associated costs) in an easy and quick way.

INTRODUCTION

Traffic congestion is the resultant direct impact of arterial road lane closures, and the road user costs resulting from the lane closures manifest themselves in many ways, including travel delay costs, vehicle operating costs, collision costs, emission costs and so on (Maleta and Sadasivam, 2011). The economic losses to the general public could be significant if the lane closures are not managed well. The City of Toronto initiated this study of lane closure policy review with the purpose of developing a methodology and quick analysis tool to assess the fees for lane closures/rentals that would more realistically reflect the impacts of lane closures relative to the existing pricing scheme. Consequently, the monetary value of the permit required to close one or multiple lanes for a specific period could be estimated based on the anticipated impacts. It is expected that a permit fee scheme that would better reflect the impacts of lane closures could help in the management of lane closures, such as when and how (how long) the lanes can be closed (or cannot be closed) for a given segment of arterial road.

LITERATURE REVIEW

A quick scan of the lane closure permit fees policies was conducted focusing on the policies that have been implemented in some large urban centers in North America and Western Europe (e.g. London, Dublin, New York City, San Francisco, Los Angeles, Houston, Ottawa, Montreal, Vancouver, and Toronto) through an internet search and direct contact with the cities' relative departments. The purpose of this scan is to identify the cities that have practices of interest to the City of Toronto with respect to the lane closure policies. Through the quick scan, it was found that the lane closure permit fees typically include two components: a fixed fee (e.g. one time administration fee) and a variable fee (e.g. a fee that depends on the duration of the work and the length of the closed road). For example, the "Temporary Road Closures and Traffic Orders" in the City of London (City of London web, access at 2015) indicates that the permit fees consist of two elements: (1) administration fee (including advertising and cost of notification to Transport for London); (2) on-going inspection fee (for continuous road closures lasting longer than one month), e.g. £1,750 for a duration between one and three months, £2,550 for each three month thereafter. New York City (New York City web, access at 2015) issues a "Construction-Related Permits for Work on a Street", the permit fees are varied with different types of work, e.g. Street Opening (work in a street that may cause damage to the street surface), Building Operations/Construction, Sidewalk Construction etc., but the permit fee associated with each type of work is fixed for a specific duration, e.g. $50 for a duration of 90 days. Through communications with staffs of the City of Vancouver, and review of the provided city's "Street and Traffic By-law", it was found that there are different fee structures for use of street (transitory), occupancy of street (short term for structures on street), licenses and encroachments (for long term). The fees mainly include: a fee varying by location and time on rate of $/day, $/week on a case by case basis; a fee sufficient to reimburse the City for the full cost of labor and materials incurred in erecting the necessary signs or makers placed on the street; and an annual fee for some cases. The City of Toronto currently issues a "Street Occupation Permit" (City of Toronto web, access at 2015), the permit fees are based upon the type of permit required and the duration of the work, e.g. Hoisting, $46.27 per day + HST plus lineal & daily enclosure fee, and $111.99 + HST for each additional lane closure. In general, the impacts of the lane closure to the general public, especially the variation of the impacts based on the lane closure characteristics (e.g. number of closed lanes, number of opening lanes), closure time (e.g. day or night, winter or summer), and road closure area (e.g. downtown or suburbs, major street or minor street) are seldom reflected on the closure permit fee scheme, which is the interest of the City of Toronto.

Studies on the impacts of lane closures can be found in various literature sources. However most of these studies have been conducted for freeways and most of the study results have not yet been implemented in practice (Bonneson and Ngugen, 2012). Moreover, the primary objective of these studies was to better schedule the lane closures to minimize the impact of lane closures on the public and reduce the road users' costs in relation to the lane closures rather than estimate the costs to support the lane closure policy implementation. The Maryland State Highway Administration (SHA) provided guidance on the evaluation of work zone mobility impacts to assist in the work zone lane closure management. In this guidance, thresholds for freeways and arterials were suggested to determine whether or not the lane closure impacts are acceptable (Maryland SHA, 2006 & 2008). Some tools were suggested in the literature in order to estimate the expected impacts of lane closures, (Maryland SHA, 2008; Maleta and Sadasivam, 2011). For example, the spreadsheet-based tools; QUEWZ-98 and Quick Zone which were developed on the basis of the Sketch-Planning and HCM methodologies; the HCS and Synchro those are the HCM traffic analysis tools; and the traffic simulation models such as CORSIM, VISSIM, PARAMICS or SimTraffic. These existing tools that help practitioners to understand and estimate the impacts of work zone prior to construction are either tailored for specific agency's needs (e.g. Spreadsheet-based tools), or are too complicated to be implemented quickly (e.g. Syhcro or Traffic simulation models), or are designed for freeways rather than arterials (QuickZone or Quewz-98).

In conclusion, there are few current practices which can be practically applied to the City of Toronto. Therefore, it needs a methodology for assessing the impacts of lane closures and costs to society associated with lane closures that would be practical to address the City's specific needs. The impacts and costs related to travel delay are the focus of this study.

METHODOLOGY

The proposed methodology shown in Figure 1 consists of two steps: Lane Closure Impact Analysis and Cost Estimation. The curve chart shown in Step 1 is developed based on the regression analysis (i.e. fitting curves to data points), in which the utilized data points are measures representing the traffic performance differences between the "Before Lane Closure" (BLC) and the "During Lane Closure" (DLC). The y axis of the curve chart is the "Impact Index" which is defined in the following section, and the x axis of the curve chart is volume to capacity (v/c) ratio. There would be multiple charts representing different areas (i.e. Downtown vs. Suburban) and in each chart there would be multiple curves representing existing number of lanes (e.g. two) before lane closure and number of closed lanes (e.g. one) during lane closure. In Step 2, the cost associated with a specific lane closure is a function of the impact index, affected traffic demand (in persons) and the duration of lane closure.

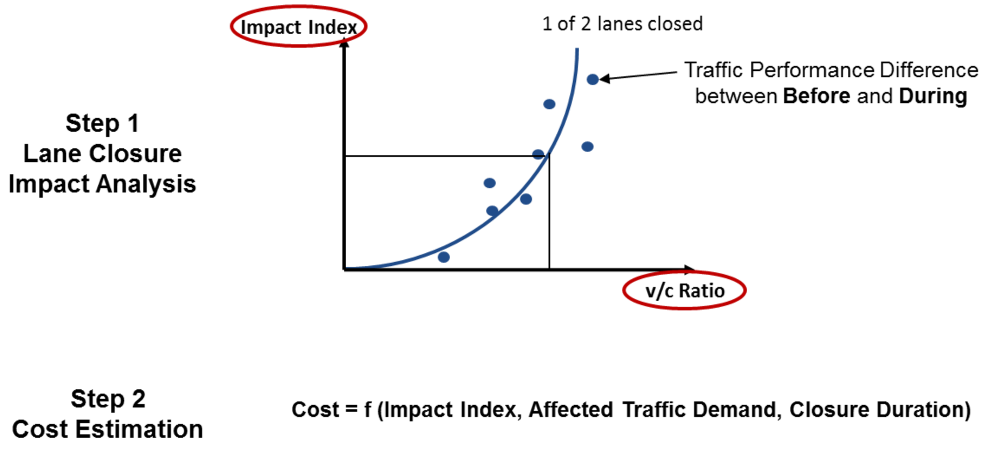


Figure 1: Illustration of the Conceptual Methodology

Lane Closure Impact Analysis

There are three candidate solutions for lane closure impact analysis: (1) Field Measurements (e.g., TomTom Data); (2) Traffic Simulation; (3) 2010 HCM (Highway Capacity Manual) Analytical Method. The first solution is expected to provide a relatively accurate result, while the data are generally costly. The second solution requires a significant modeling and calibration effort which is time consuming. As a result, the third solution is adopted since it is more efficient in comparison to the previous two solutions in terms of cost and time.

The HCM 2010 urban street segment analysis method is utilized to analyze the traffic impact difference between the “BLC” and the “DLC”. The overall segment performance is determined by the level of service (LOS) which is established on the basis of the travel speed and the volume to capacity ratio. The difference between the “LOS Before” and “LOS During” is considered as the traffic impact caused by the lane closure at a specific segment. In order to quantify the LOS difference, following method is proposed:

Step a: Set LOS (A,B,C,D,E,F)=LOS(1,2,3,4,5,6);

Step b: Compute LOS reduction at segment i, R_{LOS,Seg_i}

$$R_{LOS,Seg_i} = LOS_{During,Seg_i} - LOS_{Before,Seg_i}$$

Where, LOS_{During,Seg_i} is the LOS at segment i during lane closure; and LOS_{Before,Seg_i} is the LOS at segment i before lane closure.

Step c: LOS reduction adjustment to reflecting severity

$$R_{A,LOS,Seg_i} = \omega_i R_{LOS,Seg_i}$$

Where, R_{A,LOS,Seg_i} is the adjusted LOS reduction at segment i; and ω_i is a weight factor reflecting the severity of LOS reduction. The method used to determine the weight factor is illustrated in Table 1.

Table 1: Weight factor used to reflect the severity of LOS reduction

LOS Before Lane Closure	LOS During Lane Closure	Weight Factor ω_i
A	B	1
B	C	2
C	D	4
D	E	7
E	F	11
F	F+	16
F+	F++	22

The weight factor ω_i for LOS from A to C is a sum of A to B and B to C (i.e. 1+2=3), and the LOS from A to D is a sum of A to B, B to C and C to D (i.e. 1+2+4=7), and the remainder can be deduced in the same manner. It is noteworthy that two additional levels of service (F+ and F++) are proposed. This is because the change of LOS is difficult to be represented when the LOS before lane closure is already F, and in order to solve this problem the spectrums of LOS in HCM are modified as shown in Table 2.

Table 2: Updated LOS Thresholds

Travel Speed as a Percentage of Base Free-Flow Speed (%)	LOS by Volume-to-Capacity Ratio [a]	
	≤1.0	>1.0
>85	A	F++
>67-85	B	F++
>50-67	C	F++
>40-50	D	F++
>30-40	E	F++
>20-30	F	F++
>10-20	F+	F++
≤10	F++	F++

Note: [a] Volume-to-capacity ratio of through movement at downstream boundary intersection

The comparison of the LOS reduction before severity adjustment and after severity adjustment is shown in Table 3. Based on the comparison, it can be found that the LOS reductions after the severity adjustment, which is shown in Table 3 (b) can better interpret the lane closure impacts than LOS reductions before the severity adjustment which is shown in Table 3 (a). The method to determine the weight factor ω_i is an arbitrary method based on engineering judgments. It is recommended to be calibrated using field observations when relevant data are available.

Table 3: Comparison of the LOS Reduction before and after Severity Adjustment

(a) Before severity adjustment

		LOS during lane closure							
		A	B	C	D	E	F	F+	F++
LOS before lane closure	A		1	2	3	4	5	6	7
	B			1	2	3	4	5	6
	C				1	2	3	4	5
	D					1	2	3	4
	E						1	2	3
	F							1	2
	F+								1
	F++								

(b) after severity adjustment

		LOS during lane closure							
		A	B	C	D	E	F	F+	F++
LOS before lane closure	A		1	3	7	14	25	41	63
	B			2	6	13	24	40	62
	C				4	11	22	38	60
	D					7	18	34	56
	E						11	27	49
	F							16	38
	F+								22
	F++								

With the quantified LOS, the impact of lane closure for a single segment can be estimated, while the estimation of the traffic impact caused by congestion propagation and traffic divergence is a challenge as well. The congestion propagation and traffic divergence at urban streets are much more complex than that on the freeways, since the impacts of congestion propagation on urban streets are not a linear segment impact, but rather a wide area impact due to the characteristics of urban street networks. In addition, the urban street networks provide more alternative routes for road users which introduces more complexity when estimating traffic divergence.

In this study, the area impact was considered with a method illustrated in Figure 2. It shows that there are at least six segments which are affected as a result of the closure at urban street segment close to intersection (i.e. segment 1). The segments shaded in red are the segments which are affected by queue propagation, and the segments shaded in yellow are the segments which are affected by traffic divergence. The arrows indicate the directions of the impact propagation.

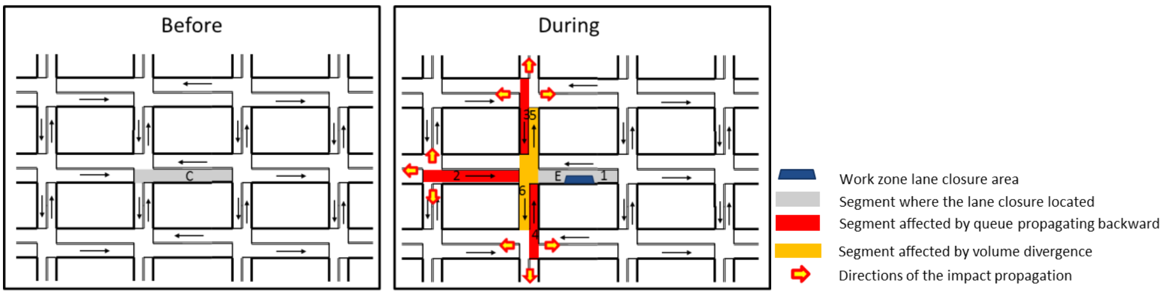


Figure 2: Area Impact of Lane Closure

The following assumptions are made to address the queue propagation and traffic divergence impacts:

- ❑ 25% capacity reduction is applied to the segment where the left or right turn movement is affected by the closure.
- ❑ 10% volume reduction is applied to through inbound volume, in which 5% (i.e. 2.5% per each each) volume diverge to left and right turn, the rest of the 5% is assumed to diverge in upstream intersections.

The below equation is used to obtain the measure of area impact difference between the "DLC" and the "BLC", where the segments LOS reductions are aggregated.

$$Impact\ Index = \sum_{i=1}^{N_{seg}} R_{A,LOS,Seg_i}$$

Where, N_{seg} is the number of segments analyzed for a specific lane closure; and $Impact\ Index$ is defined to represent the area impact because of lane closure.

The proposed method was applied to lane closure sites which were selected within Toronto Downtown area (Figure 3). The selections were intended to reflect different areas with different traffic characteristics to the greatest extend possible, such as CBD vs. Non-CBD areas, one lane vs. multiple lanes, high vs. low pedestrian activities, street car presence vs. street car absence and so on.

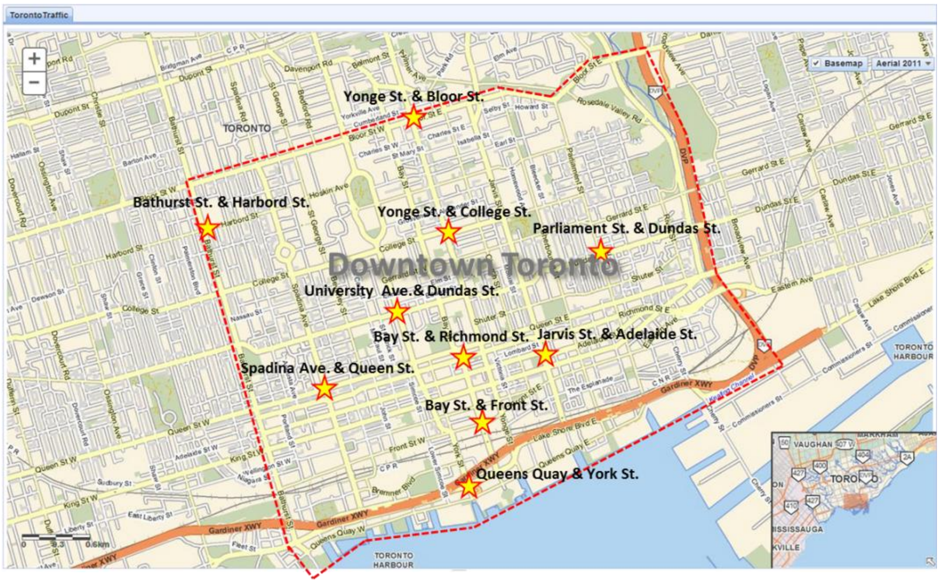


Figure 3: Selected Closure Sites at Downtown Toronto

The lane closure case "one lane is closed out of two lanes" was tested. The resultant impact indexes are shown in Figure 4. These results are considered reasonable based on the local experiences. However, it was not possible to validate them due to the limitation of available data. The variation of the impact index with the combined volume to capacity ratio (i.e. a weighted average of the V/C ratios from affected segments, details are discussed in the full report of the study) is shown in Figure 5. Since the y axis is an index without unit, it is generalized through being divided by ten. According to the trend of the data, a curve is expected to be fitted to the data points, but the standard curve functions (Exponential, Polynomial and Power) do not fit very well. In order to identify the best fit curve, a fitted line is used to determine the thresholds (i.e. maximum impact index and the minimum combined v/c ratio), and based on the determined thresholds (i.e. 10 as the maximum impact index, 0.25 as the minimum combined v/c ratio), a reasonable fitted curve is obtained. The curve function is a step function with two steps. When the combined v/c ratio is equal or less than the minimum threshold, the impact index is zero; otherwise a Polynomial function is applied. The y axis is shifted up to keep the range of the index from 0 to 10.

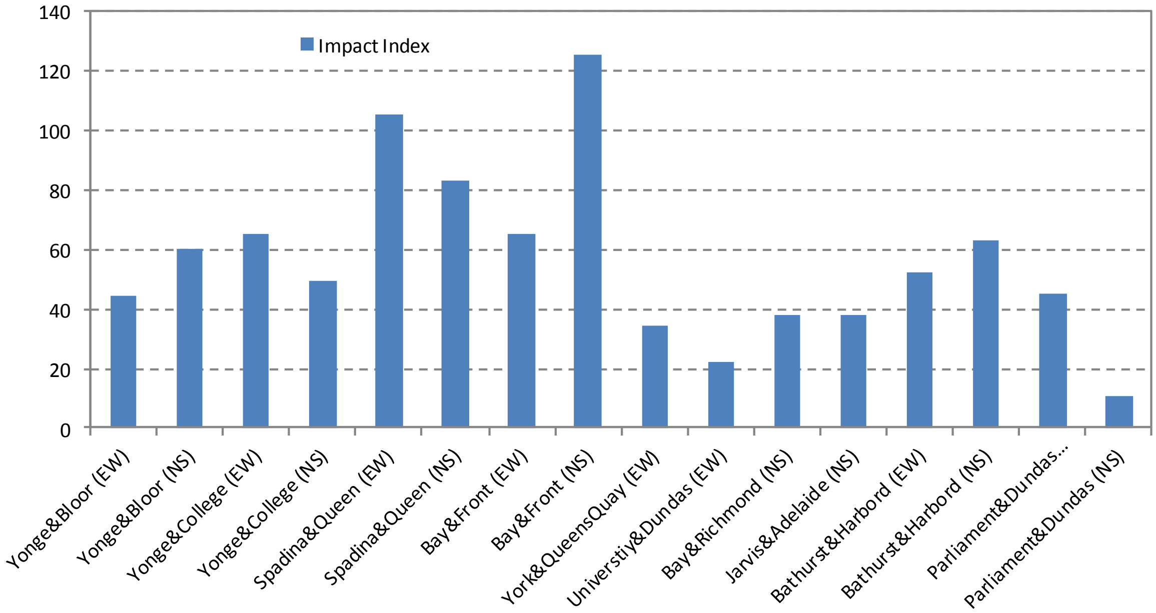


Figure 4: Lane Closure Impact Index Results

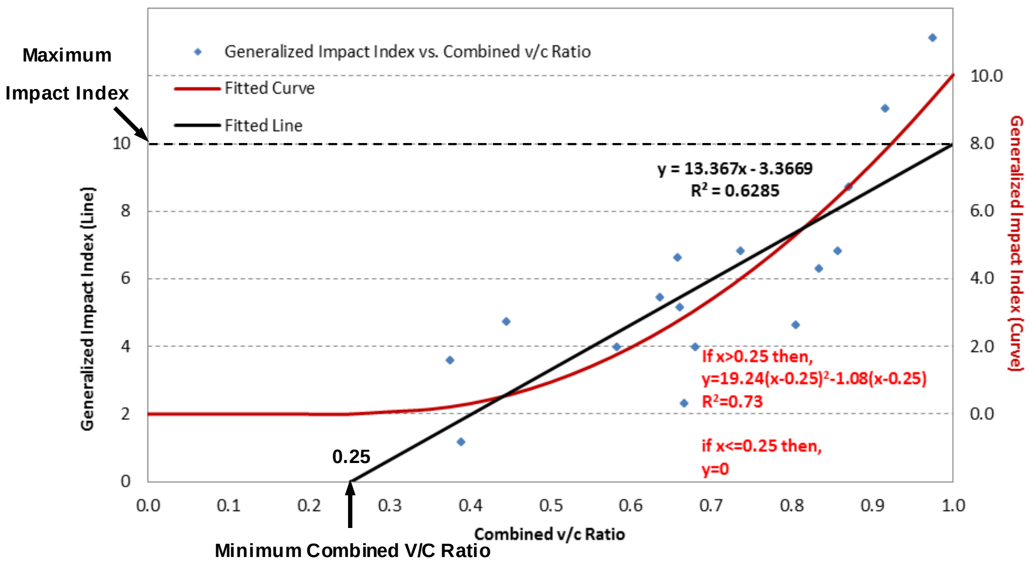


Figure 5: Fitted Curve of the Generalized Impact Index

The curves for other closure cases (e.g. one lane closed out of three lanes, two lanes closed out of three lanes, closure at suburban area etc.) can be estimated based on the above method. In this study, these curves are deduced due to the limitation of data and time, and the method is based on the concept that the curves are determined on the basis of two thresholds, which are the maximum impact index and the minimum combined v/c ratio, in addition following rules are applied:

Rule 1: Maximum impact index is 10, and it is fixed for all the closure cases.

Rationale: we acknowledge that the maximum impacts of different closures are different, however for the purpose of determine monetary cost of a specific closure, it is acceptable and practical to make the above assumption.

Rule 2: Threshold of the minimum v/c ratio during lane closure which is associated with a considerable impact is 0.625.

Rationale: If the v/c ratio of 0.25 identified previously can be explained as volume equals 2.5, capacity equals 10 before the lane closure, and during lane closure, the volume does not change, capacity changes to less than 5 (say 5*0.82≈4), then the v/c ratio becomes 2.5/4≈0.625. This means that when the v/c ratio increases due to lane closure, as long as it is lower than 0.625 during the lane closure, the impact of the closure is small enough to be ignored, only when it increase and exceed 0.625, the impact of lane closure is considerable.

Rule 3: The impact of a lane closure at suburban area is 80% of the impact of a similar lane closure at downtown area.

Rationale: The impact of a lane closure in a suburban area is expected to be lower than the impact of a similar lane closure in a downtown area. An obvious example is that the link distance between two consecutive intersections in a downtown area is typically shorter than that within a suburban area. This makes the impact/congestion caused by the lane closure in a downtown area more easily and quickly propagate to upstream intersection(s) and spread to a large area. The impact of the lane closures in downtown and suburban intersections were compared, and the results show that there was approximately two levels difference between the LOS during a lane closure (e.g. LOS F for the case at downtown area, and LOS D for the case at Suburban area), assuming the LOS before lane closures are same (e.g. LOS C). With this result, we believe the assumption of 80% is proper to reflect the impact difference between lane closure at downtown and lane closure at suburban.

Based on the above discussions, the fitted curves for other closure cases are derived (Figure 6), and the curve functions are summarized in Table 4.

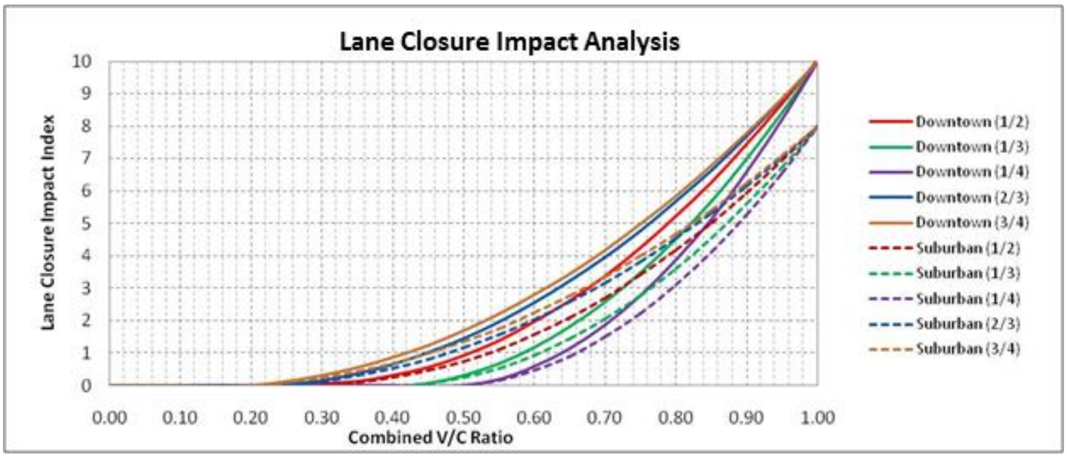


Figure 6: Fitted Curves for Lane Closure Cases

Table 4: Functions of the Fitted Curves

Closure Cases	Curve Function
1 of 2	$y = \begin{cases} 19.24(x-0.25)^2 - 1.08(x-0.25) & x > 0.25 \\ 0 & x \le 0.25 \end{cases}$
1 of 3	$y = \begin{cases} 26.74(x-0.36)^2 - 1.50(x-0.36) & x > 0.36 \\ 0 & x \le 0.36 \end{cases}$
1 of 4	$y = \begin{cases} 35.40(x-0.44)^2 - 1.99(x-0.44) & x > 0.44 \\ 0 & x \le 0.44 \end{cases}$
2 of 3	$y = \begin{cases} 15.20(x-0.16)^2 - 0.85(x-0.16) & x > 0.16 \\ 0 & x \le 0.16 \end{cases}$
2 of 4	same to 1 of 2 as the difference is small enough to be ignored
3 of 4	$y = \begin{cases} 13.85(x-0.12)^2 - 0.78(x-0.12) & x > 0.12 \\ 0 & x \le 0.12 \end{cases}$

Cost Estimation

The time value (in 2006 $) to congestion based on time periods and trip purposes (shown in Table 5) is obtained from the study of Transport Canada (Yanes and Zavergiu, 2011), proportions of trips by category are estimated based on the data from 2011 Transportation Tomorrow Survey (TTS) and the information provided by City of Toronto. A factor of 14.68% (Bank of Canada, 2014) is used to account for the inflation between 2006 and 2014.

Table 5: Time Value to Congestion

	Work Day Peak Hour			Work Day Off-peak Hour			Non-Work Day		
Trip Purpose	Business	Commuter	Leisure	Business	Commuter	Leisure	Business	Commuter	Leisure
Time Value in 2006 $	$23.61	$11.35	$10.22	$23.61	$11.35	$10.22	$23.61	$11.35	$10.22
% of Trips	25%	70%	5%	50%	20%	30%	10%	10%	80%
($/h/person) in 2014 $	$16.47			$19.66			$13.39		

Note: $16.47 = ($23.61*25%+$11.35*70%+$10.22*5%)*(1+14.68%)

To estimate the cost of lane closure by converting the lane closure impact index to the monetary value, an average traffic delay associated with the lane closure traffic impact index is estimated (Table 6) based on the Canadian Capacity Guide for Signalized Intersections (CCG, 2008).

Table 6: Average Delay and Unit Cost Associated with Lane Closure Impact Index

Traffic Impact Index	Average Delay (seconds/person/hour of lane closure)	Unit Cost ($/person/hour of closure)		
		Work Day Peak Hour	Work Day Off-peak Hour	Non-Work Day
10	200	$0.92	$1.09	$0.74
9	180	$0.82	$0.98	$0.67
8	160	$0.73	$0.87	$0.60
7	140	$0.64	$0.76	$0.52
6	120	$0.55	$0.66	$0.45
5	100	$0.46	$0.55	$0.37
4	80	$0.37	$0.44	$0.30
3	60	$0.27	$0.33	$0.22
2	40	$0.18	$0.22	$0.15
1	20	$0.09	$0.11	$0.07

Note: $0.09 = (20/3600)* $16.47

As discussed previously, the threshold v/c ratio during lane closure is 0.625, therefore in order to be conservative, the average delay associated with impact index 1 is estimated as 20 seconds. The average delay associated with higher impact index is calculated using 20 seconds multiplying by the index number. Unit costs associated with impact index by time periods are calculated and listed in Table 6. Total cost can be calculated using the Unit cost multiplying the affected traffic demand (i.e. number of persons per hour that is estimated based on information of the vehicle occupancy, details are discussed in the full report of the study) and closure duration (i.e. number of closure hours).

QUICK ANALYSIS TOOL

To facilitate the estimation of the impacts and the costs associated with planned lane closures on arterial roads, a "Quick Analysis Tool" was developed incorporating the proposed methodology. The flow chart of the tool is shown in Figure 7.

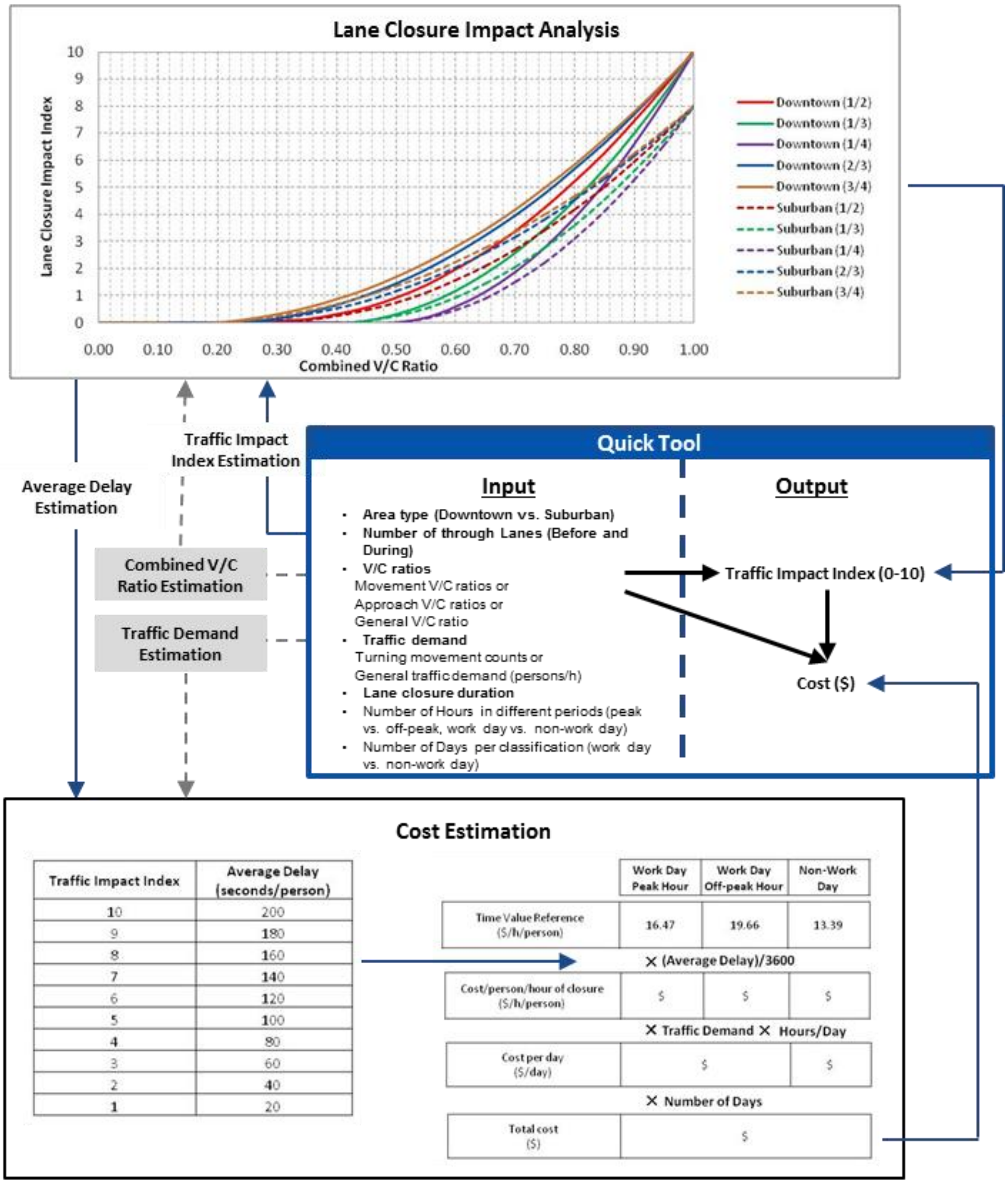


Figure 7: Flow Chart of the "Quick Analysis Tool"

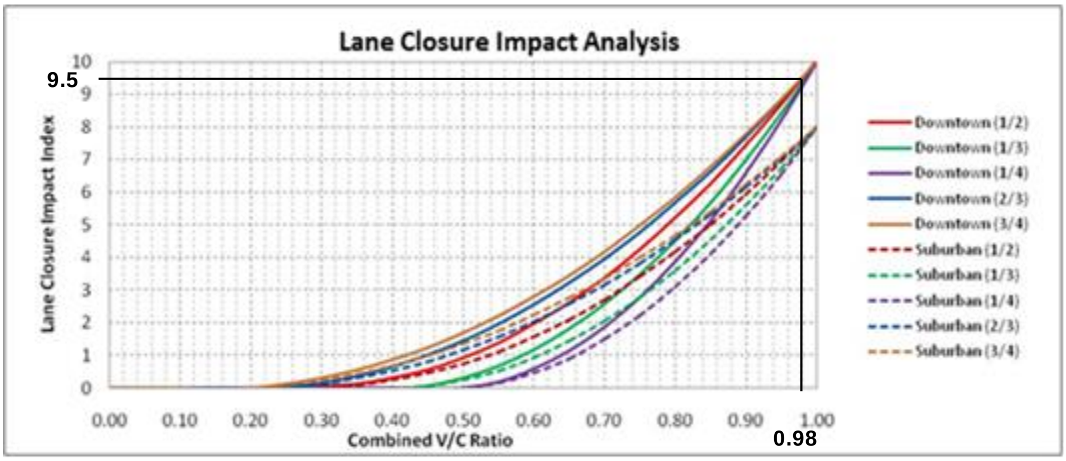
The Traffic Impact Analysis and Cost Estimation are two requisite analysis modules. In addition, the Combined V/C Ratio Estimation and Traffic Demand Estimation are the modules that may be used depending on the inputs. Following the steps shown in the flowchart, cost associated with a specific lane closure can be estimated through looking up charts and tables, and calculation using some simple equations. An example calculation is shown as below:

Example: Intersection at Yonge St and Bloor St (Northbound Closure) Toronto

Area Type:	Downtown
Number of Through Lanes Before Closure:	2
Number of Through Lanes During Closure:	1
Volume to Capacity (V/C) Ratios:	0.98 (combined)
Traffic Demand:	4000 persons/hour
Closure Duration:	1 hour during work day peak period

In this example, the combined V/C ratio and traffic demand in persons/h are assumed to be available.

Step 1: Looking up the “Traffic Impact Analysis Chart” to determine the traffic impact index based on the combined V/C ratio.



As shown in the above chart, the traffic impact index is approximately estimated as 9.5.

Step 2: Looking up the “Average Delay Estimation Table” to estimate the average delay based on the traffic impact index from previous step.

Traffic Impact Index	Average Delay (seconds/person)
10	200
9	180
8	160
7	140
6	120
5	100
4	80
3	60
2	40
1	20

Impact Index=9.5
Average Delay=9.5*20=190 seconds/person

Step 3: Looking up the “Time Value Reference Table”, and calculating the Unit Cost ($/person/hour of closure) based on the average delay from previous step.

	Work Day Peak Hour	Work Day Off-peak Hour	Non-Work Day
Time Value Reference ($/h/person)	16.47	19.66	13.39
Unit Cost ($/person/hour of closure)	16.47*(190/3600)=$0.866	0	0

Step 4: Calculating Daily Cost using the Unit Cost from previous step multiply by Traffic Demand and Hours/Day, then aggregating the costs of Peak Hours and Off-peak Hours for the Work Day.

	Work Day Peak Hour	Work Day Off-peak Hour	Non-Work Day
Time Value Reference ($/h/person)	16.47	19.66	13.39
Unit Cost ($/person/hour of closure)	16.47*(190/3600)=$0.866	0	0
Daily Cost ($/day)	($0.866*4000*1)+0=$3464		0

Step 5: Calculating Total Cost by aggregating Daily Costs of Work Days and Non-Work Days.

	Work Day Peak Hour	Work Day Off-peak Hour	Non-Work Day
Time Value Reference ($/h/person)	16.47	19.66	13.39
Unit Cost ($/person/hour of closure)	16.47*(190/3600)=$0.866	0	0
Daily Cost ($/day)	($0.866*4000*1)+0=$3464		0
Total Cost ($)	$3464+0=$3464		

The outputs are Traffic Impact Index which is 9.5 and Total Cost which is $3464.

As the example shown, the manual calculation can be done easily when the combined V/C ratio and traffic demand in persons/h are available. However, it would be difficult to obtain the results through manual calculation if they are not available. In practical applications, it is more likely to calculate these two values based on the information that is easier to be obtained or to be estimated (e.g. movement V/C ratios or approach V/C ratios, and turning movement counts, etc.). In these cases, the methods used to estimate the combined V/C ratio and traffic demand in persons/h are applicable, and that's the reason that two additional modules "Combined V/C Ratio Estimation" and "Traffic Demand Estimation" are provided in the "Quick Analysis Tool". It is not easy to follow the methods developed for these two modules and calculate the combined V/C ratio and traffic demand manually.

APPLICATIONS AND RESULTS

To facilitate the analysis, an Excel-based application is developed. With this application, the user only needs to input the available information. The process of looking up charts and tables, calculating results including estimating combined V/C ratio and traffic demand, if necessary, are all automatic. This Excel-based Application is developed using Visual Basic Language programming. The Main User Interface is shown in Figure 8, and this user interface is also a template of the analysis report. User can edit and print the Main User Interface once the analysis is complete and the Main User Interface is saved as "Report" in another Excel workbook.

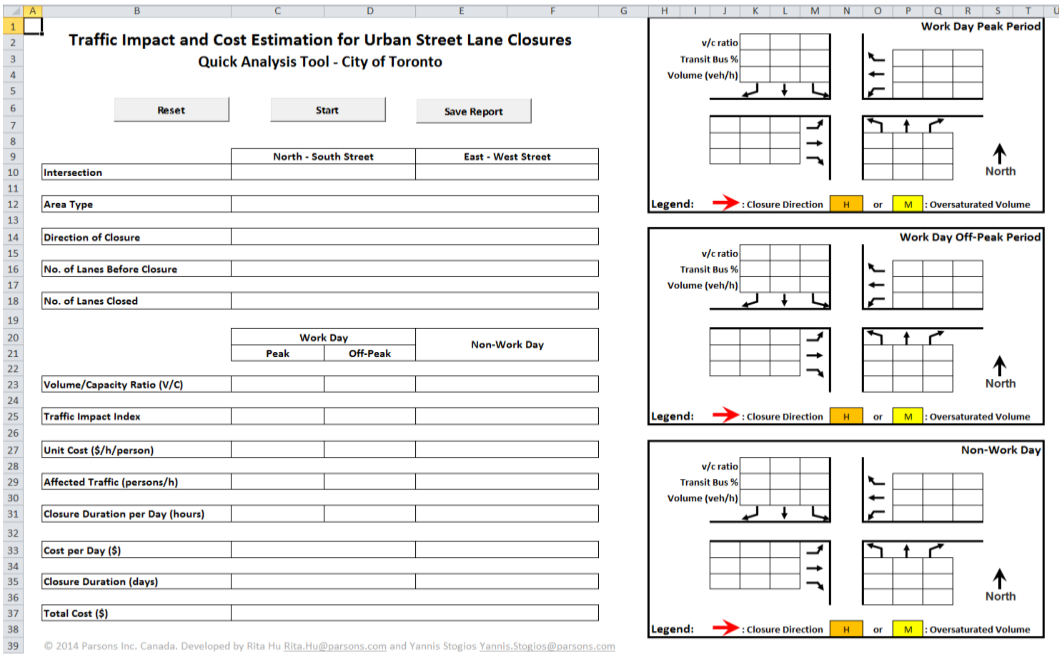


Figure 8: Main User Interface

In the Main User Interface, the left-side text window shows the entered general input information and the analysis results; the right-side graphic window shows the entered traffic information (e.g. Volumes, Transit Bus %, and V/C ratios). In the graphic window, the red arrow (→) is used to indicate the closure direction, and traffic volume cells will be shadded in orange (High Level) or yellow (Moderate Level) if the volumes are considered as oversaturated volumes, and, in this case, the overstaturated volumes would be adjusted for estimating the affected traffic demand (details are discussed in the full report of this study).

Application results and comparsions are summarized in Table 7. Some typical major intersections are selected to test the different secenarios that were compared with the base secenarios (shaded). Based on the comparsion, we can see the variation of the cost with characteristics of lane closure are intuitively reasonable, as to the magnitude of the cost, while it requires further studies to validate.

Table 7: Application Results and Comparisons

Intersection	Area Type	# of Lanes Before Closure	# of Lanes Closed	Combined V/C ratio	Saturation Condition	Affected Traffic Demand at Peak Period (persons/h)	Work Day Peak Hourly Cost	Work Day Off-Peak Hourly Cost	Non-Work Day Hourly Cost
Yonge&Bloor	Downtown	2	1	1	Under	2256	$2,066.71	$1,030.14	$199.25
		2	1	1	Over	4512	$4,133.42	$2,060.27	$398.50
Spadina&Queen	Downtown	2	1	0.9	Under	6020	$4,091.12	$1,968.70	$350.63
Morningside&Ellesmere	Suburban	2	1	0.8	Under	4434	$1,696.28	$776.50	$121.82
Yonge&Sheppard	Downtown	3	1	0.9	Under	4939	$3,158.35	$1,262.52	$131.45
	Suburban	3	1	0.9	Under	4939	$2,526.28	$1,115.17	$105.16
	Downtown	3	2	0.9	Under	9878	$6,952.11	$3,701.67	$824.71
	Suburban	3	2	0.9	Under	9878	$5,561.69	$2,961.33	$659.77
University&Dundas	Downtown	4	1	0.9	Under	1544	$929.34	$299.44	$10.70
	Downtown	4	2	0.9	Under	2317	$1,574.18	$757.51	$134.92
	Downtown	4	3	0.9	Under	4633	$3,315.63	$1,829.94	$437.77

CONCLUSIONS AND RECOMENDATIONS

In conclusion, the methodology proposed in this study was developed based on the HCM 2010 analytical method with limited data resources and the engineering judgment to reflect local conditions. Different scenarios were tested and the results were compared to the actual lane closure cases. The test and comparison results show that the proposed methodology and tool provide reasonable and practical results (i.e. estimation of arterial road lane closure impacts and associated costs) in an efficient manner. Further studies that focus on the validation of the results are recommended if there are sufficient field observations.

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Authors' information:

Rita Yaxin Hu
Transportation Planner
Parsons Inc.
625 Cochrane Drive, Suite 500,
Markham, Ontario, L3R 9R9.
Tel: 905-943-0500,
Email: Rita.Hu@parsons.com

Yannis Stogios
Principle, Transportation Planning & Engineering
Parsons Inc.
625 Cochrane Drive, Suite 500,
Markham, Ontario, L3R 9R9.
Tel: 905-943-0500,
Email: Yannis.Stogios@parsons.com

Andre Filippetti
Manager, Right-of-Way Management
City of Toronto, Toronto–East York District,
55 John Street, Toronto, Ontario, M5V 3C6
Tel: 416-392-1525,
Email: afilipp@toronto.ca