THE ‘BIG LIFT’ PROJECT OF MACDONALD BRIDGE RE-DECKING, HALIFAX, CANADA: A DYNAMIC TRAFFIC ASSIGNMENT MODEL

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1. Introduction

The Angus L. Macdonald Bridge is one of the two suspension bridges linking twin cities Halifax and Dartmouth in NS, Canada. The Macdonald Bridge has been a vital link of the Halifax transportation network for its continuous 24/7 access across the Halifax Harbour. The bridge remains very busy in peak periods during the day due to its proximity to Downtown Halifax and Dartmouth. Only light vehicles are permitted to cross the bridge, while truck and other heavy vehicles use the wider Mackay Bridge. The analysis of the bridge traffic volume data collected by the Halifax Harbour Bridge Commission in September, 2014, reveals that up to 40,050 vehicles cross the Macdonald Bridge every day. The congested time periods include 6:00 am- 8:00 am and 3:00 pm- 5:00 pm, which primarily accommodates the commuting traffic flow (30.5% of total daily traffic).

The bridge not only accommodates a large commuter traffic volume, but also facilitates pedestrian and bicyclist that cross the Halifax harbour. In addition to the traffic operational services, the Macdonald Bridge is also contributing to the economy with its annual revenue from toll collection worth $7,204 CAD for 2012/2013 (Halifax Harbour Bridge, n.d.). This 1.3 km long Cable Bridge is considered as a Critical Infrastructure (CI) as it is an essential link for passenger transportation and goods movement for the Halifax Regional Municipality (HRM).

However, after being operational about 60 years, the time has come to replace the entire deck slab of the Macdonald Bridge for an extended service life and a minimum frequency of maintenance. At the beginning of 2015, the Halifax Harbour Bridge Commission launched the “Big Lift” project in order to replace 46 deck segments within 18 months, a total worth of $150 million. Activities such as replacement of the floor beams, stiffening the trusses and suspended ropes, and raising the shipping clearance are also included in the project. The construction activities are scheduled to take place at night, commencing from 7:00 pm and concluding at 5:30 am the following morning. The night time closure includes 10 and ½ hours on weekdays, with frequent weekend closures throughout the 18 month period. This is the second time in the history, after the Lions’ Gate Bridge re-decking in Vancouver (September 2000 to September 2001), a suspended cable bridge is being replaced at night and in use during the day.

Although this is undoubtedly a necessary transportation infrastructure development in Halifax Regional Municipality (HRM), it will likely affect the vicinity of the bridge, traffic flow on Mackay Bridge, daily travel activity and traffic operation, transit routes and schedules. For instance, pedestrian and bicycle users were affected, as the bicycle and walking paths were removed from the bridge for the duration of the project. Transit users who use the Macdonald Bridge at night also needed to take the shuttle. These impacts were conveyed to the road users before the project had been launched and road users have already started to adapt the new routes and schedules.

Cable Bridge re-decking is itself a rare activity. The day use of the bridge during the construction makes it even more critically vulnerable. Any unforeseen issues that arise during night re-decking have the potential to delay the completion of scheduled activities in the allotted time period. Alam et al. (2016) developed a model to assess the construction related bridge opening delay risk and concluded that probability of delayed opening of the bridge is fairly high and traffic impacts on surrounding network is significant. Surprisingly, on the first day of the Big Lift project, after the replacement of the first deck segment, the bridge opening had been delayed for 3.5 hours due to unfinished deck lifting work (CBC, 2015, October 19). In addition, a bump between the new and old decking on the bridge became an issue. Given the magnitude of the impact predicted by earlier model and the observed consequences during the first week of construction, it became clear further understanding of the traffic impact is necessary. Alam et al. (2016) developed a static traffic simulation model for traffic impact study that cannot capture the effects of congestion spillback. Therefore, this study extends the study with a Dynamic Traffic Assignment (DTA) modeling framework to evaluate the traffic impacts on Mackay Bridge as well as on major connectors in surrounding area.

The Dynamic Traffic Assignment model (DTA) has been evolving since last two decades and is now being used in traffic planning and operation sectors. Currently, the DTA model is replacing the static model for many traditional applications. The static model is suitable for long-range planning, but is not always appropriate to analyze traffic condition in congested network at a fine-grained time-based level (Ziliaskopoulos et al. 2004). DTA models are generally classified as analytical and simulation-based DTA models. An extensive literature review on this can be found in Peeta & Ziliaskopoulos (2002). This study focuses on the latter simulation-based DTA modeling approach. Generally, simulation-based DTA modeling technique estimate the time varying link flow in the network and evaluate the time varying network performance with aid of traffic dynamic simulation (Florian et al. 2001). It utilizes the relationship between the demand side (link flow estimation) and supply side (performance measures) of the model to replicate the realistic driver behavior in a congested transport network. Different types of simulation-based DTA modeling approach have been used in many real life networks, for example, VISTA (Ziliaskopoulos et al. 2004), AIMSUN (Barcelo & Casas, 2006), Dynameq (Florian et al. 2006), among others. DTA application in other real world project includes the uses of DynaMIT-P in Beijing for evaluation of a short term benefits of a strategy to reduce pollution and relieve traffic (Ben-Akiva et al. 2012), Dynameq in estimation of traffic diversion and evaluation of traffic impacts during the closure of the Stony Plain Road Bridge at Edmonton, Alberta (Xin et al., 2014).

2. Methodology

2.1 Network Model and Data Used

Figure 1 presents the study area, a mixed urban road network, including Halifax and Dartmouth linked by the two CI, the Macdonald and Mackay Bridge. The Macdonald Bridge experiences traffic congestion on a regular basis due to its proximity to downtown Halifax and Dartmouth. Narrow width also contributes to the congestion propagation as almost 9,500 vehicles use the bridge daily to cross the Harbour in the morning peak period.

A dynamic traffic simulation network model has been developed using VISSIM 6.0 platform which includes all the arterial roads, few important collector roads, two bridges, and Highway 111 within the study area. The network model consists of 613 links and connectors, 18 major intersections equipped with signal controllers, 13 zones with 1275 origin-destination (OD) paths, 894 resolved conflicts areas and other important road network features (i.e. priority rules, reduced speed area). Road geometry information such as number of lanes, grades, direction and turning movements are collected from Google Earth image, Google Street View, and Halifax Regional Municipality (HRM) Geodatabase 2012. Signal time has been obtained from the Public Work Traffic Study of Halifax Regional Municipality (HRM), October 2014. Moreover, the network demand for the morning commuting period (5:30 am – 9:30 am) has been obtained from the Halifax Network Model (Mahbubur & Habib, 2015) and adjusted during the simulation.

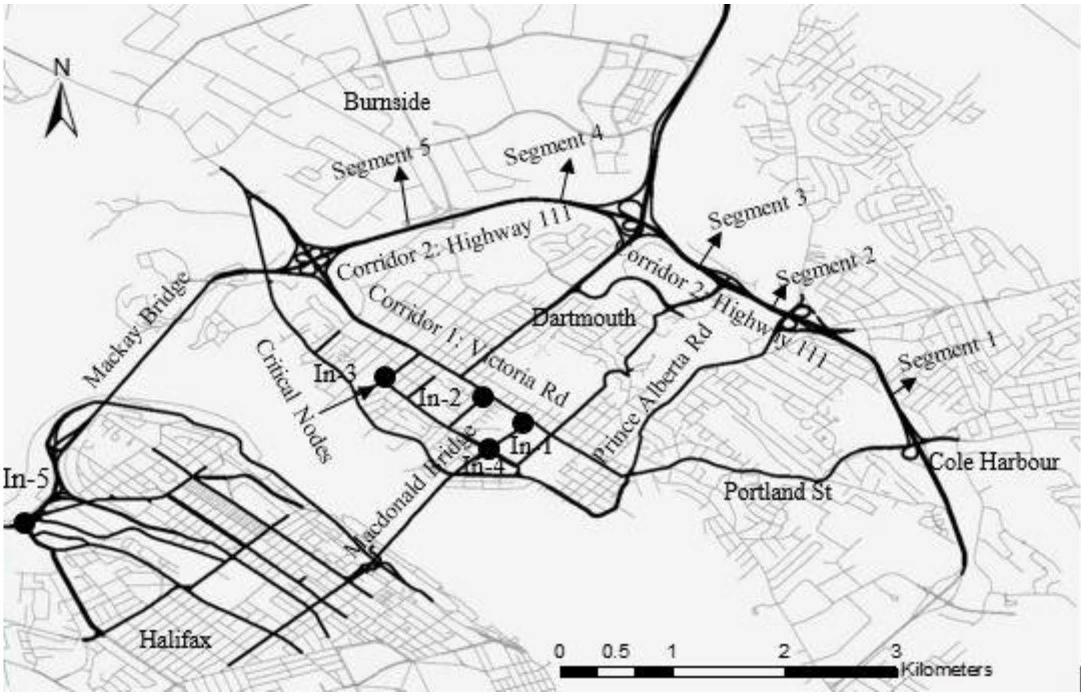

Figure 1: Study Network, Corridor 1 (Victoria Rd), Corridor 2 (Highway 111 with five Segments) and Critical Nodes (In-1 to In-5)

2.2 Calibration of the DTA Model

Calibration is the most critical and time consuming stage of micro simulation modeling. In general, calibration includes the individual model calibration and general parameter calibration. In the absence of disaggregate data, only calibration of critical parameters has been conducted using the aggregate data. Simulation has been conducted for four hours starting at 5:30 am using the time of the day distribution of the morning commute traffic flow based on the "Arrival and Departure Times" distribution (Megenbir et al. 2014) rather than following a 'Flat Demand Profile'.

2.2.1 OD Calibration

The purpose of calibrating the DTA model is to minimize the deviation between the simulated traffic counts and the observed traffic counts as far as possible. A multiple iteration process in this kind of traffic volume-based calibration enables OD matrix to be adjusted to fit the actual traffic data. Necessary OD adjustment is performed and the correlation between the demand matrices and the actual traffic counts has been improved through the iteration process. The further improvement of the model has been done by the calibration of the driving behavior parameters.

2.2.2 Calibration of Driving Behavior Parameters

This study adopted the Wiedemann 74 car-following model that has three car following parameters which are average standstill distance (ax_average), additive part of safety distance (bx_add), and multiplicative part of safety distance (bx_mult) (Wiedemann, 1974; and Olstam & Tapani, 2004). An experimental judgment on the ranges of the values of the parameters has been obtained from the literature. For example, standard average standstill distance is 1-3m (Park & Schneeberger, 2003), and range of additive part of safety distance, and multiplicative part of safety distance used in Cobb Parkway model calibration is 0-3 (Miller, 2005). In total, five candidate parameter sets are considered for iteration process as shown in Table 1. The value of each parameter is lowered by 20% from set 1 to set 5 subsequently until the value of any of the parameters falls out of their respective range obtained from the literature. Afterwards, multiple iteration has been conducted for each parameter set and traffic flows are measured at screen line locations, including few other intersections and compared to the field traffic count.

Table 1: Driving Behavior Parameter Calibration

Parameters	Average Standstill Distance	Additive part of safety distance	Multiplicative part of safety distance
Set 1	2.4	1.5	1.7
Set 2	1.9	1.2	1.4
Set 3	1.5	0.96	1.1
Set 4	1.2	0.80	0.9
Set 5	1.0	0.60	0.7

2.2.3 Evaluation

The network performance after the calibration has been evaluated in terms of the minimum deviation between the simulated and observed traffic count. Screen line and a few strategic locations have been selected for validation purpose. Figure 1 shows that the correlation between the observed traffic count and simulated traffic count which suggests the R^2 value 70% for the morning peak hour calibration. Further calibration effort didn't make any significant improvement of the model and set 5 (Table 1) has been found as the most successful set with the R^2 value 70%.

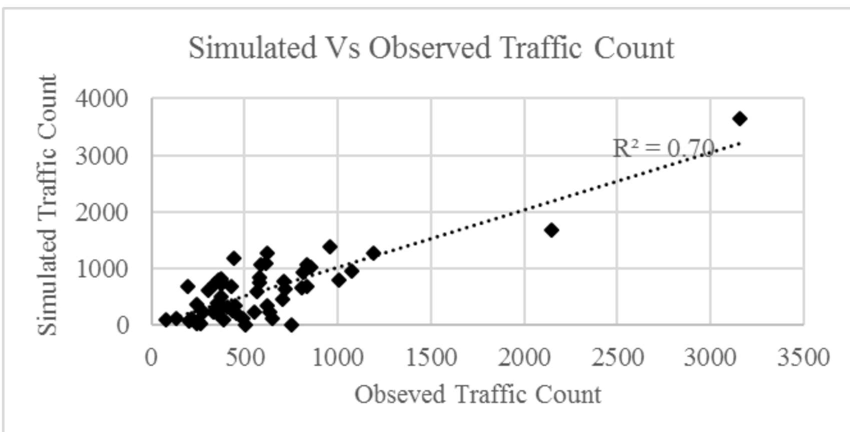

Figure 1: Traffic Assignment Calibration

3. Case Study

A four hour bridge closure scenario has been experimented utilizing the calibrated DTA model in this study and traffic impacts are evaluated on link level as well as on network level in terms of changes in Measures of Effectiveness (MOEs) such as traffic flow indicators, node performance, and highway performance. Traffic flow towards downtown is the main traffic stream in the morning peak period. The analysis performed in this study mainly focuses on the analysis of traffic impact at Dartmouth due to the traffic flow towards Downtown Halifax. Two main corridors (Mackay Bridge, and Highway 111) and five critical nodes (In1-In5) as shown in Figure 1 are found potential to be sensitive to the traffic impacts.

3.1 Network Performance

The traffic analysis results in Table 2 shows that the Macdonald Bridge Closure scenario increases the total network delay with respect to the base case scenario. This is evident as 25% vehicle couldn't reach the destination as that of the base case and remains operational in the network. As a result, network operates under a saturated congestion and average delay increases about 7 minutes with respect to base case. A reduction in average speed from 19.15 km/hr. (base) to 15.78 km/hr. (bridge close) is also advocating the increase of traffic volume in the network.

Table 2: Network Performance

Performance Measures	Base Case	Bridge Close
Average speed (km/hr.)	19.15	15.78
Total Delay (hr.)	7625	9488
Average Delay (min)	10.8	16.5
Arrived Vehicle #	34015	25673

Moreover, in parallel to overall network impacts, simulation model also reveals a significant local traffic impacts in the network.

3.2 Local Traffic Impact Analysis

3.2.1 Impacts on Mackay Bridge

Being one of the two most important CI of the Halifax transportation network, linking Downtown Halifax and Dartmouth, the Mackay Bridge might be a major source of bottleneck during the closure of the Macdonald Bridge in the morning peak period. Figure 2 suggests a gradual cumulative traffic volume increase at 15 minutes interval (Dartmouth to Halifax) across the Mackay Bridge in contrast to base case during the bridge closure. The analysis of the results reveals that almost 2111 vehicles (among a total traffic volume 6491 that use the Macdonald Bridge within the same time interval) cross the Harbour using the Mackay Bridge taking a detour from the Macdonald Bridge within 5:30 am -8:00 am and contributes about 46% of the total traffic volume on Mackay Bridge. The rest of the 6491 vehicles couldn't enter the Mackay Bridge yet due to congestion spillback. Figure 2 suggests a yield point at 8:00 am which indicates the propagation of congestion spillback. As a result, after 8:00 am, simulation model shows a lockstep movement of vehicles across the Mackay Bridge resulting in a lower traffic volume pass across the Harbour with respect to base case scenario. This congestion spillback can be justified in terms of Level of Service (LOS) of the busiest node of Halifax, Windsor Street Exchange (In-5), located at downstream of the Mackay Bridge as shown in Figure 1. The results in Table 3 shows that LOS of the intersection, In-5 degrades from LOS, E to LOS, F. There might have many reasons for the In-5 exceeding the capacity, including the additional 46% traffic volume across the Mackay Bridge.

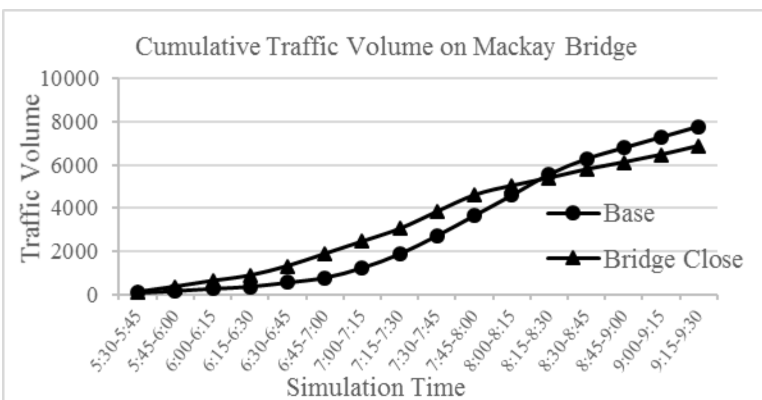

Figure 2: Impacts on Mackay Bridge

3.2.2 Impacts on Corridor 1 in terms of Performance of Critical Nodes

Table 3 shows the performance measures of critical nodes at Halifax and Dartmouth and presents a comparison for both base and bridge closure scenarios. The intersections, including Nantucket and Victoria

Table 3: Performance of Critical Nodes

Area	Intersection #	Name of Intersections	Base Case		Bridge Closure	
			Delay (sec)	LOS	Delay (sec)	LOS
Dartmouth	In-1	Nantucket+ Victoria Rd	42.8	D	133.71	F
	In-2	Boland+Victoria Rd	42.62	D	85.06	F
	In-3	Albro Lake+ Wyse Rd	13.2	B	70.09	E
	In-4	Nantucket+Wyse Rd	54.36	D	23.92	C
Halifax	In-5	Windsor Street Exchange	58.45	E	90.76	F

Rd (In-1), Boland and Victoria Rd (In-2), and Albro Lake and Wyse Rd (In-3) along and adjacent to the corridor 1 due to their proximity to the Macdonald Bridge experience a greater shifted traffic volume during the bridge closure scenario. The results in Table 3 suggest that surrounding key intersections, In-1, In-2, and In-3 at Dartmouth during the closure of the Macdonald Bridge operate with a high intersection delay compared to the base case and LOS of these nodes lies in between E, and F. In-1, and In-2 have a LOS, F during the closure which means the demand through these intersections exceeds the intersection capacity. In summary, as an important link, Victoria road attracts a larger detoured traffic volume which degrades the performance of critical nodes in the network.

3.2.3 Impacts on Corridor 2 (Highway 111)

Simulation model suggests that Highway 111 could significantly be affected during the closure of the Macdonald Bridge. Five segments (Figure 1), including between exit 2W & 3 (segment 5), exit 3 & 4S (segment 4), exit 4 & 5 (segment 3), exit 5 & 6 (segment 2), and exit 6 & 7 (segment 1) are considered for evaluating the potential traffic impacts on highway 111.The further the segment considered (Figure 3 to Figure 7) from Mackay Bridge, the less the variation in traffic flow between the two scenarios. In the case of segment 1 and 2 (Figure 3 & 4) near the Cole Harbour (Figure 1), there is almost no variation in traffic flow. On the other hand, traffic from surrounding area of exit 6 takes detour via Highway 111 rather than taking their usual link, Prince Alberta Rd resulting in 42% increase in traffic volume through the segment 3 (Figure 5). This increased traffic volume approaches to the segment 4 and 5 (Figure 6 & 7) which yields at 8:00 am due to congestion spillback from downstream Mackay Bridge.

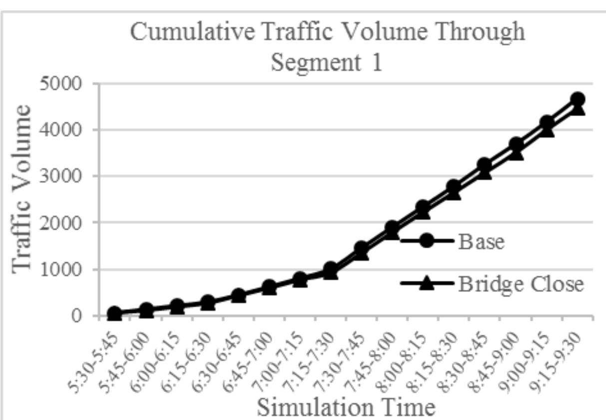

Figure 3:Traffic Volume through Segment 1

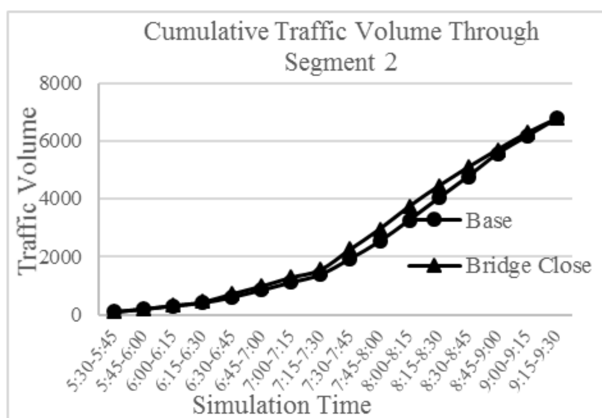

Figure 4:Traffic Volume through Segment 1

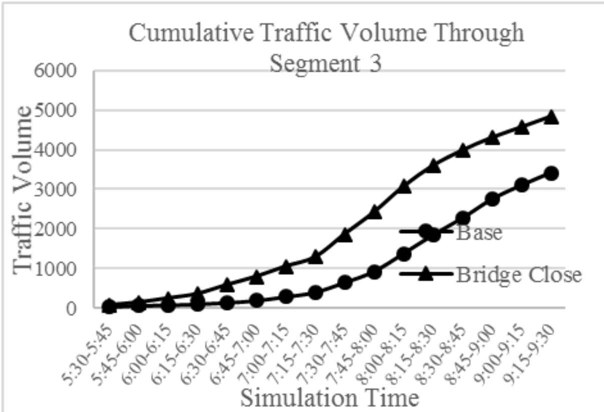

Figure 5:Traffic Volume through Segment 1

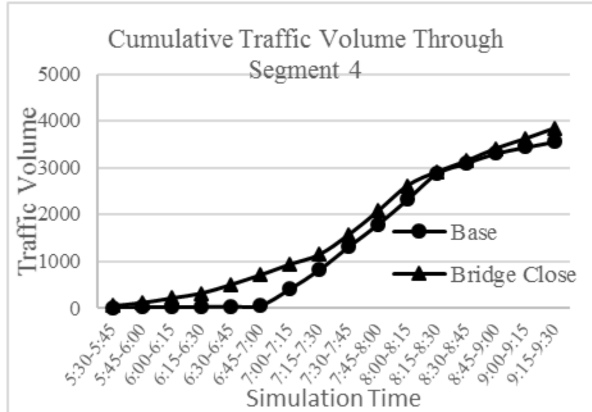

Figure 6:Traffic Volume through Segment 2

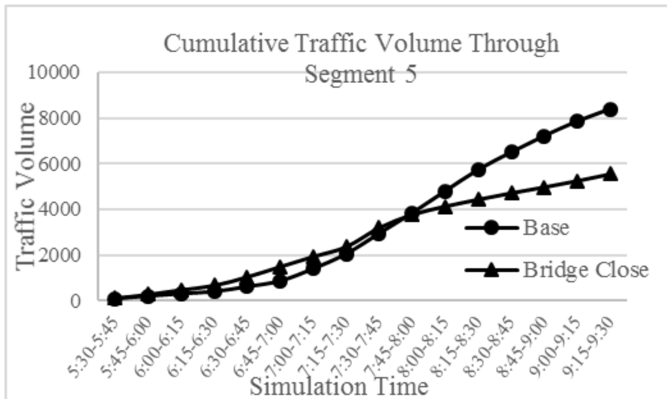

Figure 7:Traffic Volume through Segment 5

4. Conclusions

This study has presented the results of the bridge closure scenario for the entire morning peak period. The micro simulation of the Macdonald Bridge closure scenario within a Dynamic Traffic Assignment (DTA) modeling framework yields considerable impact on network level as well as on local level. Overall network traffic volume increases by 25% and average travel time delay by 7 minutes in the case of bridge closure scenario. In respect to the local traffic impacts, the Mackay Bridge anticipates a high re-routed traffic volume during the closure of the Macdonald Bridge. The yield point at 8:00 am (Figure 7) has been resulted from a significant downstream congestion spillback in the network. The congestion spillback can be justified in terms of the Level of Service (LOS) of Windsor Street Exchange (In-5). Among many reasons, additional 46% detoured traffic volume across the Mackay Bridge before 8:00 am contributes to exceeding the capacity of In-5 that exhibits a LOS, F in the case of bridge closure. Afterwards, the resulting lockstep vehicle movements on MacKay Bridge greatly influences the surrounding links and critical nodes as evident in Table 2 that In-1, and In-2 on Victoria Rd exceeds the capacity. Moreover, congestion on Mackay Bridge affects the upstream traffic flow on the Highway 111 resulting in same traffic condition as that of the Mackay Bridge (Figure 6 and 7). The closure of the Macdonald Bridge shifts a high traffic volume across the Mackay Bridge which could lead the bridge to a congested condition and create critical transportation challenges. Therefore, a traffic diversion plan at strategic locations could be effective to guide the affected road users during the closure of the Macdonald Bridge. Traffic diversion plan could be relayed using social media, including Twitter, Facebook, among others which will enable the road users to be informed upfront about the current traffic condition ahead and available options. Moreover, an access management strategy for Mackay Bridge could also be considered for instance, removal of toll protocol of Mackay Bridge during the closure of the Macdonald Bridge.

Nevertheless, this research contributes by analyzing the effects of congestion spillback on the Mackay Bridge and surrounding network during the closure of the Macdonald Bridge within a DTA modeling framework. Since the re-decking will continue for the next 12 months, this study could be a useful guide for discussions on traffic management and warning procedure to minimize the potential impacts on daily lives and the economy.

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