

TECHNICAL NOTE

Project Title: Addendum to R22 Measuring On-Road Congestion Costs for Multi-modal Travel - Case Study 2: Bruce Highway Managed Motorway Project

Project No: PRJ18088

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SUMMARY

The technical note is prepared to extend the NACoE Project R22: *Measuring On-Road Congestion Costs for Multi-Modal Travel Case Study 2: Before-and-after comparison of congestion cost for the Bruce Highway managed motorway* with two additional After-periods' data from 2017 and 2018. It aims to determine the changes in traffic performance after three managed motorway strategies were implemented along Bruce Highway in the past a few years. The implemented strategies are:

- the coordinated ramp metering, where the impact was observed from the After-period 1 as shown in the R22 report
- the variable speed limits, and automatic queue detection and protection, which were implemented after the After-period 1 and the impact was observed in the two new After-periods.

The technical note presents the analysis and findings from the inclusion of the additional two After periods. It evaluates the impacts of implementing the additional two managed motorway strategies along the Bruce Highway by comparing the freeway excessive congestions cost.

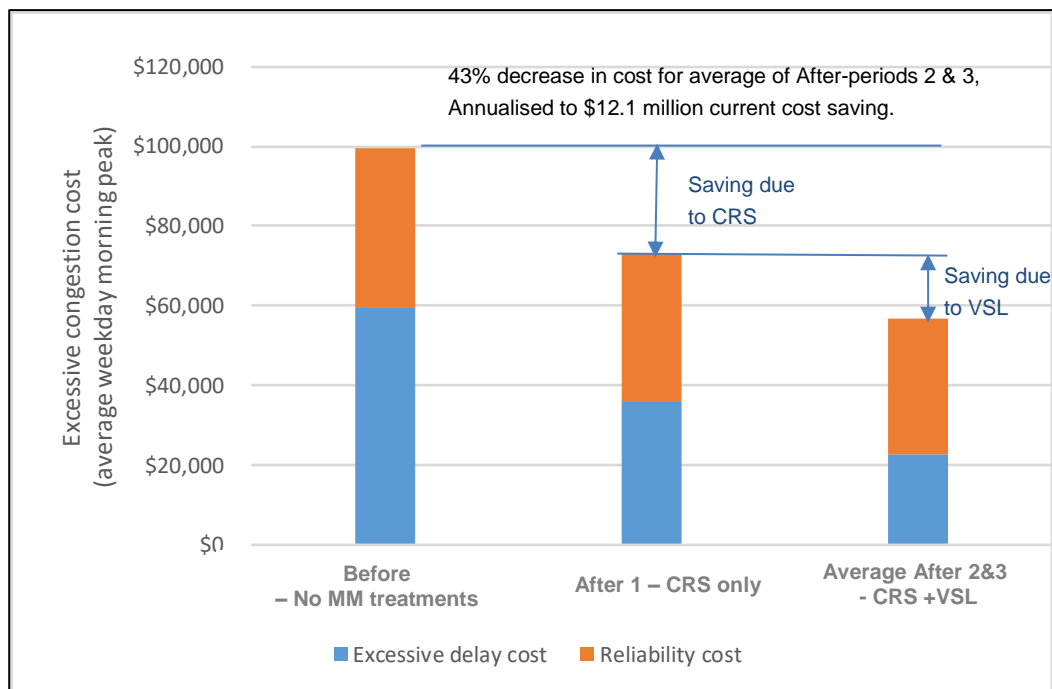
The results of this study are mainly on the weekday morning peak periods, during which the implemented managed motorway strategies are activated. The excessive congestion cost is defined as the sum of excessive delay cost and travel time reliability cost. To be consistent with the original R22 report, the scope of this analysis focuses on the same performance measures (excessive delay cost). It is worth noting, however, the use of delay cost, which compares against the posted speed limit, could probably reveal a higher benefit as a result of the three new strategies.

The analysis in the technical note confirmed that the implemented managed motorway strategies along the Bruce Highway were highly successful in reducing both excessive delay and reliability costs during the morning peak.

The excessive congestion cost reductions identified in the before-and-after comparisons are as follows:

- The average daily vehicle-kilometre-travelled (VKT) during morning peak was increased by 5% between the Before-period and the average of After-periods 2 and 3, indicating the managed motorway strategies have potentially increased the throughput of this constrained section of Bruce Highway. Despite the increase in VKT, the daily morning peak excessive congestion cost was reduced by 43% on a typical weekday. It is equivalent to an annual congestion cost saving of \$12.1 million in 2018-dollar values. By comparing these periods with After-period 1, assume the benefits of the coordinated ramp metering remain constant, it was found that the share between individual benefits of coordinated ramp metering, and VSL and automatic queue detection and protection is 61%/39%.

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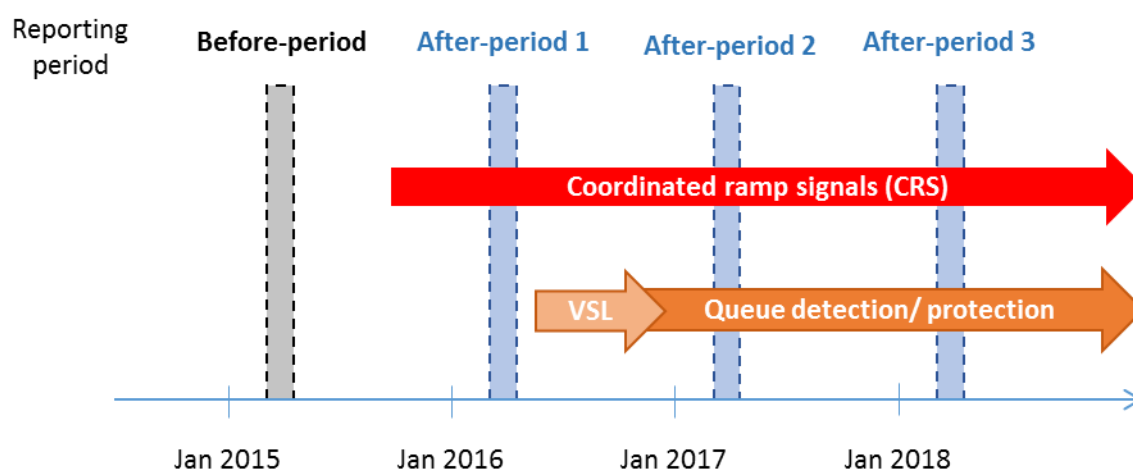
- When normalising by VKT, more significant cost saving of 46% was identified for the average of After-periods 2 and 3 during the morning peak.
- The individual weekday morning peak analysis suggested substantial improvement in excessive delay cost in terms of daily maximum, minimum and variation, with reduction of 51%, 89% and 42% respectively for the average of After-periods 2 and 3.

1 INTRODUCTION

The technical note was prepared to extend the *NACoE Project R22: Measuring On-Road Congestion Costs for Multi-Modal Travel Case Study 2: Before-and-after comparison of congestion cost for the Bruce Highway managed motorway* with two additional After-periods' data from 2017 and 2018. Only additional After-periods' results and additional comparison outcomes are provided in the technical note as an addendum of the R22 report.

The main purpose of the technical note is to present the analysis and findings from the inclusion of the additional two After periods for *Case Study 2: Before-and-after comparison of congestion cost for the Bruce Highway managed motorway project*. The original R22 report examined the impacts before and after the installation of coordinated ramp signals (CRS) in August 2015. The technical note extends the evaluation period by considering the impacts of implementing the variable speed limit (VSL) signs, coupling with the automatic queue detection and protection algorithm (the measures are collectively referred as 'VSL' in the technical note). The evaluation compares the excessive congestion cost of this instrumented section of Bruce Highway on a yearly basis. The timeline of the reporting periods referred in the technical note is illustrated in Figure 1.1.

Figure 1.1: Timeline of managed motorway measures installation and reporting periods



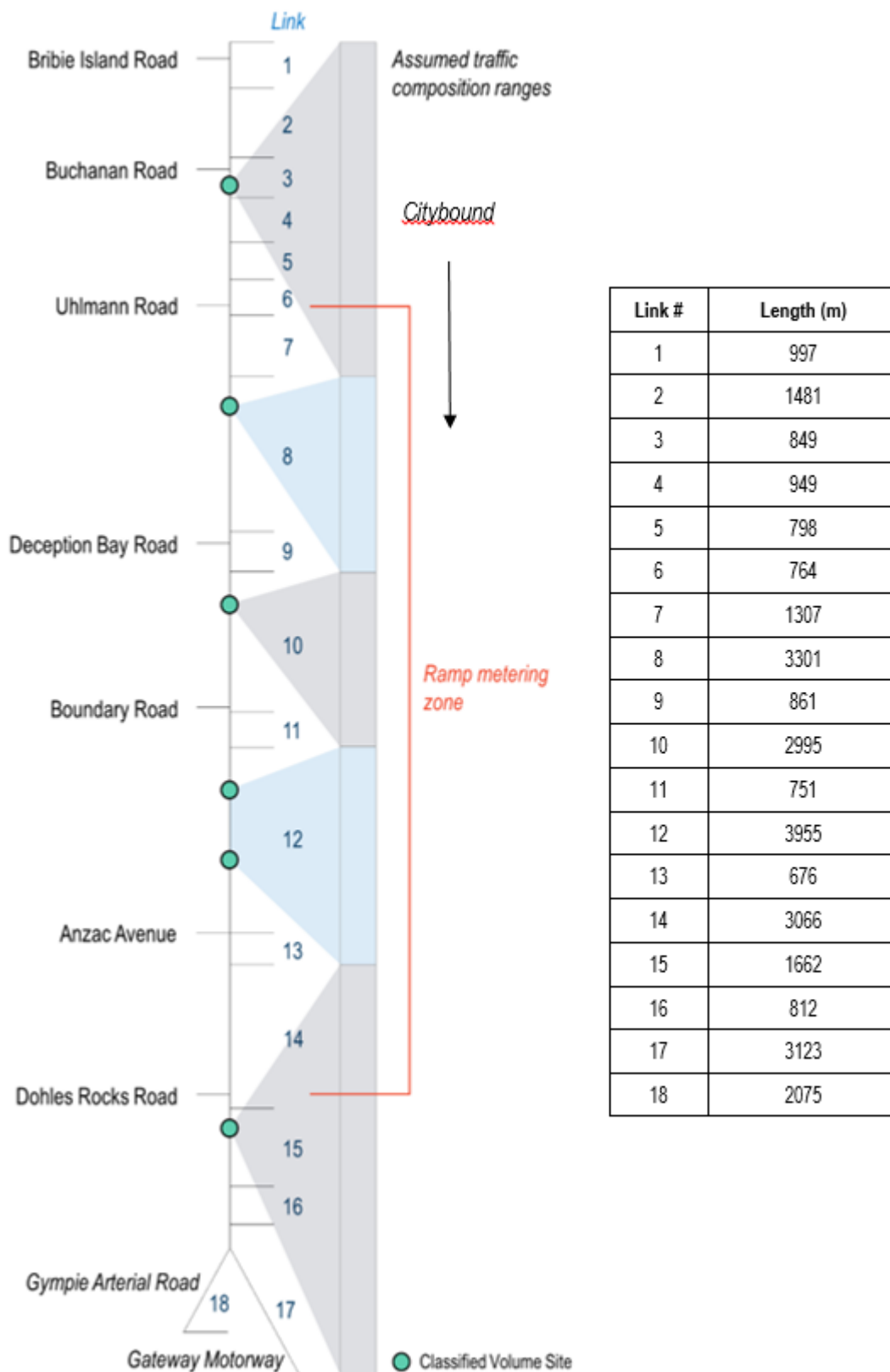
The case study scope, methodology, Before-period (2015) data, After-period 1 (2016) data, and before-and-after comparison results for 2016 remain unchanged as shown in the R22 report. TMR also advised that the following parameters used in After-period 1 data process be re-applied to the additional two After-periods, 2017 and 2018, for consistency purpose:

- business/ private trip split for car travel
- unit time costs (in 2013 Australian dollar values)
- vehicle classification along the Bruce Highway study site.

The managed motorway strategies are mainly activated on typical weekdays between 5 and 10 am, therefore the analysis and reporting focuses on these periods to determine the impacts.

The study site is the inbound section of Bruce Highway between Bribie Island Road and Gateway Motorway/ Gympie Arterial Road. It contains 18 links and Figure 1.2 shows a diagrammatic representation along with the locations of key features referred in the R22 report.

Figure 1.2: Representation of Bruce Highway study site and location of key features



2 DATA CLEANING FOR ADDITIONAL TIME PERIODS

The following time periods were selected for the before-and-after analysis in R22:

- Monday 16 February to Sunday 15 March 2015 (Before-period)
- Monday 15 February to Sunday 13 March 2016 (After-period 1). This is used to measure the impact of the coordinated ramp metering.

Two additional time periods after the implementation of VSL were considered in this technical note:

- Monday 13 February to Sunday 12 March 2017 (After-period 2)
- Monday 12 February to Sunday 11 March 2018 (After-period 3).

Table 2.1 lists the two incident days that were excluded from the analysis in the two additional periods. The criteria for the exclusion of these two days were consistent with the R22 study. As stated in the R22 report, 'Extreme weather conditions and major incidents have a significant impact on traffic volume and speed, particularly travel time reliability. As the technical note is focused on facilitating a robust comparison between the Before-period and After-period to evaluate ramp metering impacts, days in either period that experienced incidents were excluded from the analysis. This was done to ensure that day-to-day variation in travel times did not adversely bias either time period'.

As the managed motorway treatments are potentially mitigating the impact of incidents, the exclusion of the major ones in this study is likely causing the measured benefits to be conservative.

Table 2.1: Incident days excluded from analysis

Incident days	Incident	TMR incident log details
Monday 27 February 2017	Major incident, multi vehicle crash	'T9 Traffic Crash Bruce Hwy SB RH lane after Moreton Rail o/pass Multi vehicle crash RH lane blocked south of north lakes exit - 4 vehicles. Traffic affected. Right hand lanes. Info to gas adv an air bag had been deployed.'
	Major incident, multi vehicle crash	'T9 Traffic Crash Bruce Hwy SB between Buchanan Rd and SB BP servo Multi vehicle crash truck and dog and car - reported debris on road - vehicles on LH shoulder Truck in RH lane.'
Saturday 10 March 2018	Major incident, multi vehicle crash	'Crash, 3 vehicles Bruce Hwy, SB L2/3/4, after Pine Rivers Bridge, Bald Hills Long Delays Injuries Confirmed. FCU attended'

Note: There are three other days with minor incidents: 09/03/2017, 22/02/2018, 06/03/2018. These days are included in the analysis.

The data from STREAMS and the classified counting stations was crosschecked by TMR before being applied to the analysis. The data was of sufficiently good quality for the purpose of this technical note.

After initial filling the gaps for several links as detailed in Appendix A, the percentage of gap data for each period is as follows:

- For Before-period, 0.02% of records (11 out of 48,384).
- For After-period 1, 0.52% of records (253 out of 48,384).
- For After-period 2, 1.56% of records (755 out of 48,384).

- For After-period 3, 1.04% of records (503 out of 48,384).

These few entries were replaced using hot-deck imputation. A flow or speed value from the same 15-minute segment of the day, but from exactly one week after or before was used in its place. Due to the small number of replaced speed and flow values, the impact on the calculation results is deemed to be minimal.

3 ADDITIONAL CASE STUDY RESULTS

The following before-and-after comparison results were obtained:

- vehicle-kilometres travelled (VKT)
- average excessive congestion cost for weekdays
- average excessive congestion cost per VKT for weekdays
- average weekday excessive congestion cost by time-of-day
- excessive congestion cost for all study days.

The above items were calculated for the effective ramp metering time during the weekday morning peak (between 5am to 10am). As mentioned above, this morning peak period is also the time in the week during which the VSL is mostly active. For the sake of completeness, the 24-hour day values are also calculated and are reported within the appendices of this document.

Note that the term congestion (and delay) in the technical note refers to excessive congestion (and excessive delay), as defined in the original R22 report. *Excessive congestion cost* is the extra delay cost with reference to a threshold (spatial) speed, rather than the free-flow speed or the posted speed limit. For freeways in Queensland, 70% of posted speed limit is considered adequate as the threshold. *Route reliability cost* is the cost associated with route buffer time (the difference between 95th percentile travel time and 50th percentile travel time).

All cost values in and unit time costs in this technical note are in 2013 Australian dollar values (\$2013) for consistency. In the conclusion section of the technical note, the annualised figure is converted to 2018 Australian dollar values (\$2018).

3.1 Before-and-After Comparison of VKT

VKT provides a standard metric for determining the total amount of traffic that passed through the study site for the Before-period and After-periods. This was calculated using the flow data from STREAMS and the link lengths provided by TMR for each 15-minute time slice. Table 3.1 shows the average VKT for each day of the week for all time periods across the whole study site, including the percentage difference.

Table 3.1: Day-of-week average VKT comparison (5 – 10 am morning peak only)

Day	VKT (millions)				Percentage difference		
	Before-period	After-period 1	After-period 2	After-period 3	After-period 1	After-period 2	After-period 3
Monday	0.53	0.55	0.54	0.57	4%	2%	8%
Tuesday	0.52	0.56	0.54	0.57	6%	3%	9%
Wednesday	0.53	0.55	0.54	0.57	3%	1%	7%
Thursday	0.53	0.56	0.54	0.57	5%	2%	7%
Friday	0.52	0.55	0.54	0.55	6%	3%	6%
Saturday	0.34	0.35	0.33	0.34	2%	-3%	0%
Sunday	0.23	0.25	0.24	0.24	7%	3%	4%
Average weekdays	0.53	0.55	0.54	0.57	5%	2%	7%

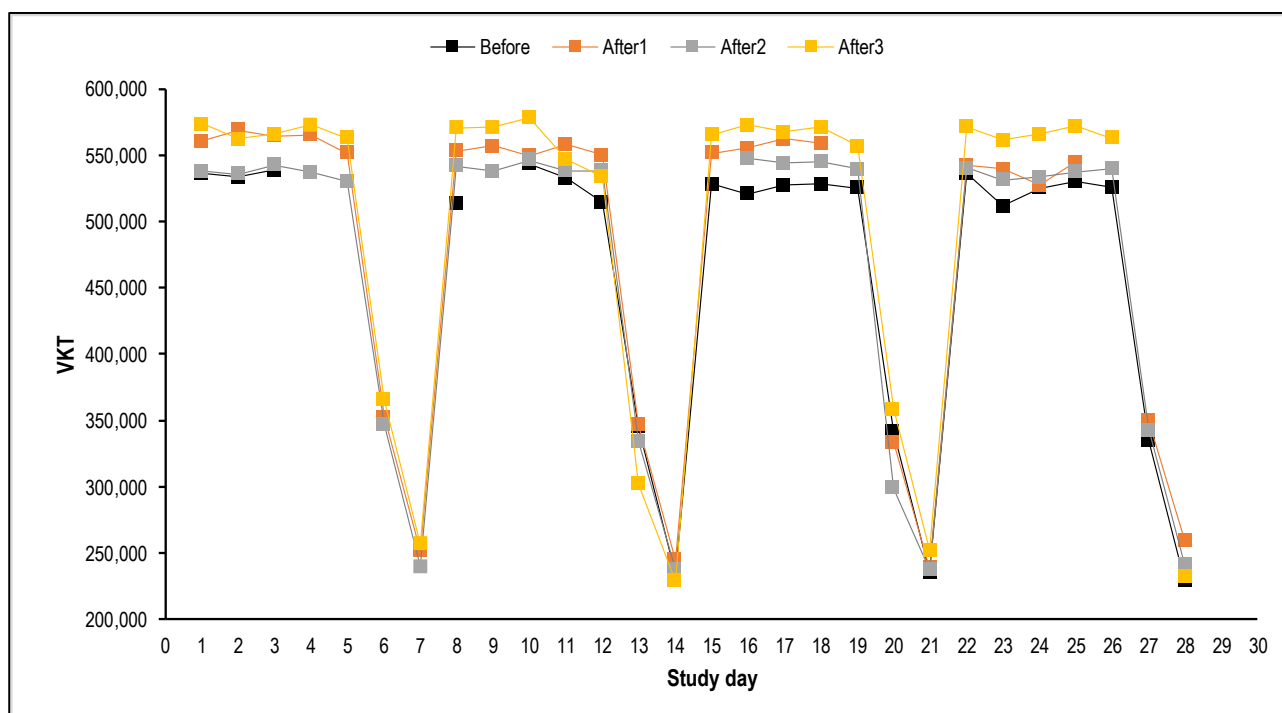
As major incident days had been excluded from the analysis, the number of each weekday may not be the same between the Before-period and the After-periods. To ensure that average VKT

values were not biased, weighted averaging for each of the weekdays was used to ensure that fair comparison was made between the Before-period and After-periods.

Overall, VKT increased by an average of 5%, 2% and 7% for weekdays morning peak from the Before-period to After period 1, After period 2, and After period 3 respectively. The increase in VKT can be an indication of enhanced roadway capacity since the introduction of the managed motorway strategies and the natural traffic growth. The VKT growths for the year of 2016 and 2018 are generally consistent with expected traffic growth for the Bruce Highway, while the VKT growth for 2017 appears to be lower than expected. Indicative reasons for the VKT drop may include the opening of Redcliffe Peninsula Rail Line in October 2016 and the faulty detectors observed on some road links in 2017. However, this had not impacted the ability of the implemented managed motorway strategies to improve the performance of Bruce Highway.

Figure 3.1 shows the daily variation in the VKT over the four weeks (28 days) of the Before-period and After-periods 1 to 3. Gaps in the chart are the days removed due to incidents.

Figure 3.1: Bruce Highway study site daily VKT for the Before-period and After-periods comparison (\$2013, 5am – 10 am weekday morning peak only)



3.2 Before-and-After Comparison of Average Congestion Cost per Weekday

Average congestion cost per weekday between 5 and 10 am was calculated through aggregation of total congestion cost across all relevant days of the analysis period. Weekends were therefore not included in the comparison (nevertheless, the sample size was too small to produce statistically meaningful values). In addition, the congestion costs due to excessive delay were generally very small over the weekend.

Table 3.2 summarises the before-and-after comparison results of the average daily congestion cost. The congestion cost saving is evident in each of the first three years after the installation of the managed motorway initiatives.

Table 3.2: Average daily congestion cost comparison (\$2013, 5am – 10 am weekday morning peak only)

Congestion cost	Cost (\$)					Percentage difference			
	Before-period	After-period 1	After-period 2	After-period 3	Average of After-periods 2&3	After-period 1	After-period 2	After-period 3	Average of After-periods 2&3
Excessive delay cost	59,408	36,014	18,398	26,960	22,679	-39%	-69%	-55%	-62%
Reliability cost	40,021	37,102	32,699	35,166	33,933	-7%	-18%	-12%	-15%
Total cost	99,429	73,115	51,097	62,126	56,612	-26%	-49%	-38%	-43%

Main findings in Table 3.2 show that:

- Before-period and After-period 1 (2015 vs 2016)

Despite the 5% increase in the average VKT on weekdays, the cost of congestion following the installation of ramp metering was reduced significantly. During managed motorway operation hours, the average congestion cost was reduced from \$99,429 to \$73,115, representing a 26% cost reduction. Most significant cost saving originates from excessive delay cost, which was decreased from \$59,408 to \$36,014, indicating a 39% reduction. The travel time reliability cost was also reduced by 7% from \$40,021 to \$37,102. Those cost reductions were deemed to be the benefits of the coordinated ramp metering.

- Before-period and average of After-periods 2 and 3 (2015 vs 2017&18)

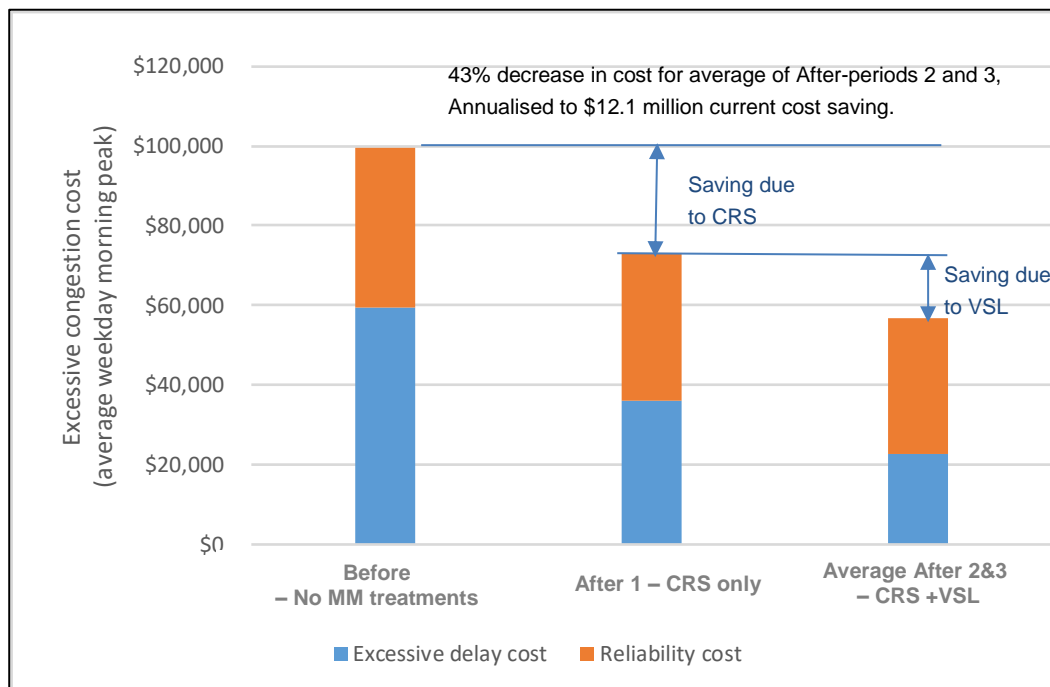
The underlying assumption in this comparison is that the average of After-periods 2 and 3 represents the new normal (and therefore that After-period 1 should not be used in the average to determine the eventual total benefit of all three managed motorway treatments). Despite the 5% increase in the average VKT, the cost of congestion following the installation of ramp metering and VSL was reduced significantly. During managed motorway operation hours, the average congestion cost was reduced from \$99,429 to \$56,612, representing a 43% cost reduction. Most significant cost saving originates from excessive delay cost, which was decreased from \$59,408 to \$22,679, indicating a 62% reduction. The travel time reliability cost was also reduced by 15% from \$40,021 to \$33,933.

- After-period 1 and average of After-periods 2 and 3 (2016 vs 2017&18)

Assuming the benefits of the ramp metering system remain constant, the additional cost saving for the average of After-periods 2 and 3 in comparison to After-period 1 can be treated as the benefits for the VSL and automatic queue detection and protection. By comparing these periods, it is found that the share between individual benefits of ramp metering, and VSL and automatic queue detection and protection is 61%/39%.

Note that since the three After-periods are a year apart, there could be other factors that contributing to performance changes (between After-periods 1, 2 and 3), including road works and the 'settlement period' in regard to road users getting accustomed to the treatments. A more comprehensive and targeted analyses using longer Before and After-periods relating to the VSL and automatic queue detection and protection implementation could more accurately reveal the specific benefits of each of the three treatments.

Figure 3.2: Average daily excessive congestion cost comparison (\$2013, 5 – 10 am weekday only)



Note: the annualised value was based on the daily cost saving (weekday morning peak only) multiply by 250 working days, and then converted into 2018-dollar value based on 2.5% per year increase.

In summary, the operation of the managed motorway has shown a significant benefit in congestion cost saving for the first three years after the installation, as shown in Figure 3.2. For After-periods 2 and 3, it has shown on average a reduction in average weekday morning peak congestion cost by 43%, which is equivalent to an annual congestion cost saving of \$12.1 million (in \$2018) with an average increase of 5% in total VKT during morning peak. This congestion cost reduction was attributed by the resultant benefit of ramp signals, VSL and automatic queue detection and protection initiatives.

3.3 Before-and-After Comparison of Average Congestion cost per 1000 VKT for Weekdays

In addition to average congestion cost, average congestion cost per 1000 VKT was also calculated. This indicator normalises congestion cost by VKT and it mitigates the effects of increased traffic volumes between the Before-period and After-periods. Table 3.3 summarises these results. Recall that all cost values in Project R22 are in 2013-dollar values for consistency. The congestion cost saving is evident in each of the first three year after the installation of the managed motorway initiatives.

Table 3.3: Average daily congestion cost per 1000 VKT (\$2013, 5 – 10 am weekday only)

Congestion cost	Cost (\$)					Percentage difference			
	Before-period	After-period 1	After-period 2	After-period 3	Average of After-periods 2&3	After-period 1	After-period 2	After-period 3	Average of After-periods 2&3
Excessive delay cost	113	65	34	48	41	-42%	-70%	-58%	-64%
Reliability cost	76	67	61	62	61	-12%	-20%	-18%	-19%

Congestion cost	Cost (\$)					Percentage difference			
	Before-period	After-period 1	After-period 2	After-period 3	Average of After-periods 2&3	After-period 1	After-period 2	After-period 3	Average of After-periods 2&3
Total cost	189	132	95	110	102	-30%	-50%	-42%	-46%

The key findings in Table 3.3 are as follows:

- Before-period and After-period 1 (2015 vs 2016)

After normalising by VKT, total congestion cost was reduced by 30% during managed motorway operation hours, from \$189 per 1000 VKT in the Before-period to \$132 per 1000 VKT in the After-period. Excessive delay cost per 1000 VKT was reduced by 42% from \$113 to \$65. Reliability cost per 1000 VKT was also reduced by 12% from \$76 to \$67.

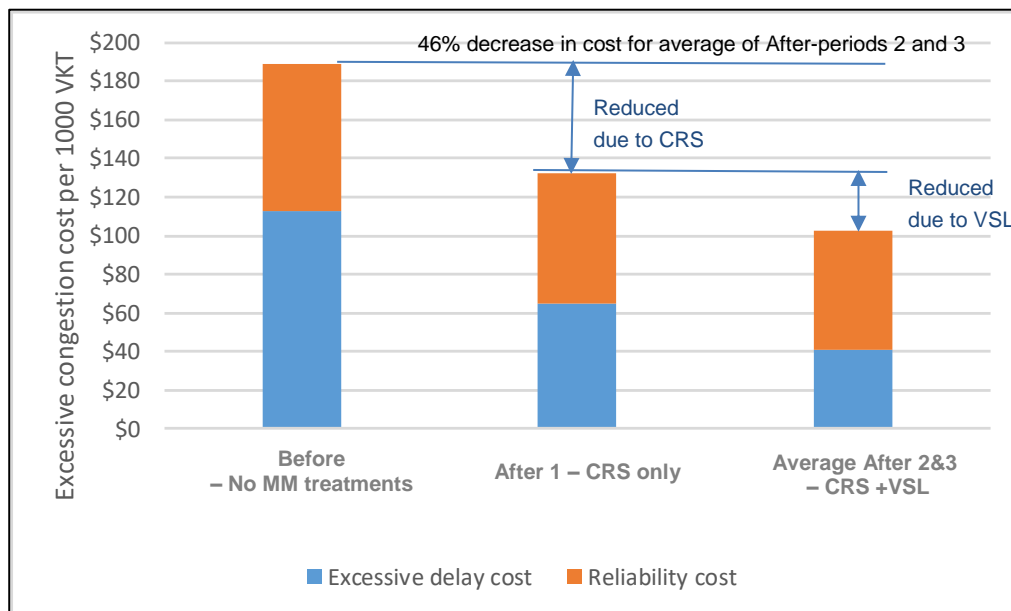
- Before-period and average of After-periods 2 and 3 (2015 vs 2017&18)

After normalising by VKT, total congestion cost was reduced by 46% during managed motorway operation hours, from \$189 per 1000 VKT in the Before-period to \$102 per 1000 VKT in the After-periods. Excessive delay cost per 1000 VKT was reduced by 64% from \$113 to \$41. Reliability cost per 1000 VKT was also reduced by 19% from \$76 to \$61.

- After-period 1 and average of After-periods 2 and 3 (2016 vs 2017&18)

By comparing these periods in the congestion cost per 1000 VKT point of view, assume the benefits of the ramp metering system remain constant, it can be concluded that the share between individual benefits of ramp metering, and VSL and automatic queue detection and protection is 66%/34%.

Figure 3.3: Average daily congestion cost per 1000 VKT comparison (\$2013, 5am – 10 am weekday morning peak only)



In summary, if normalising by VKT, more significant cost savings are demonstrated for the managed motorway strategies as shown in Figure 3.3. The average of After-periods 2 and 3 shows a significant reduction of 46% in total daily morning peak congestion cost.

3.4 Before-and-After Comparison of Average Weekday Congestion Cost by Time-of-Day

Figure 3.4 to Figure 3.6 show the average congestion costs by time-of-day for weekdays for the Before-period and After-periods 1 to 3. As expected, a clear spike in congestion cost was experienced during the morning peak as commuters travel inbound, with little congestion encountered at any other time of the day.

Figure 3.4: Average weekday total costs by time-of-day (\$2013)

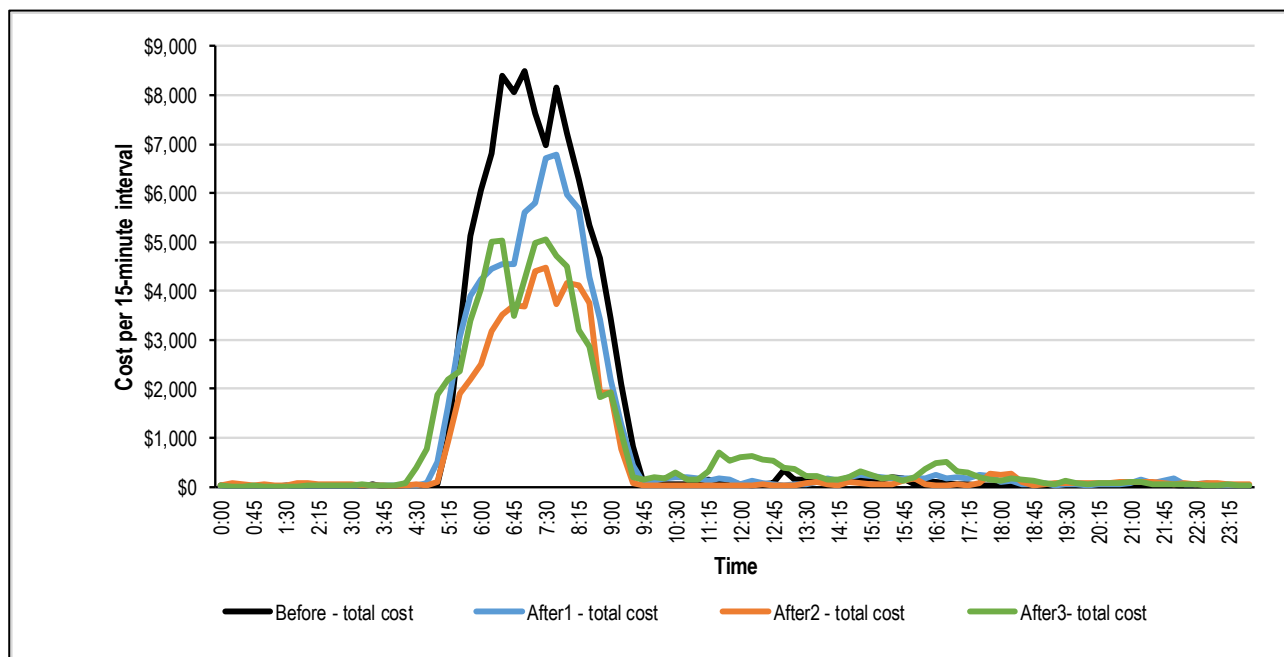


Figure 3.4 shows a significant reduction in total congestion cost for After-periods 1 to 3 in comparison to the Before-period during managed motorways operation hours (5 – 10 am). Amongst the After-periods, After-period 1 still shows a spike between 7am and 8:30am, while after periods 2 and 3 show much flat pattern during the morning peak.

For outside of the managed motorways operation hours, After-period 3 in general has higher total congestion cost compared to the Before-period in particular between 11:15 am and 1 pm. This amount of increase in congestion cost, and for the other time of the day is relatively small in comparison to the amount of reduction during managed motorways operation hours. After-periods 1 and 2 have similar total congestion costs compared to the Before-period outside of the managed motorways operation hours.

Figure 3.5: Average weekday excessive delay costs by time-of-day (\$2013)

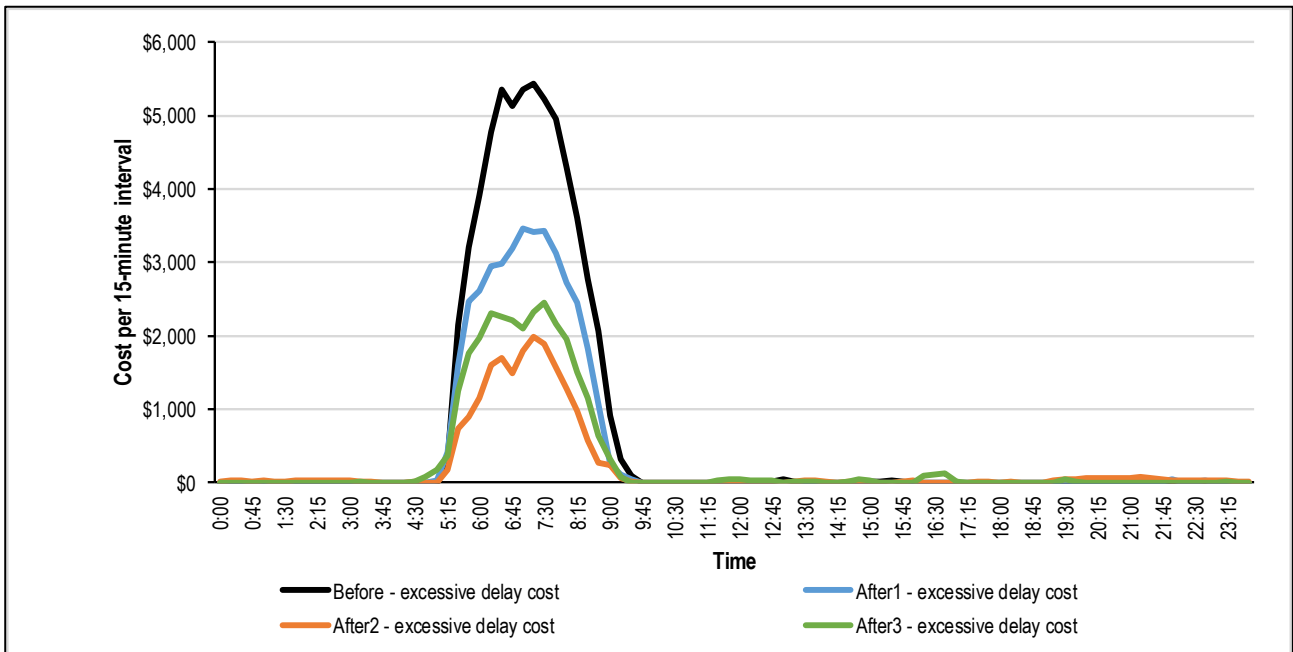


Figure 3.5 shows a clear reduction in excessive delay cost for After-periods 1 to 3 in compared to the Before-period during managed motorways operation hours. After-period 2 (2017) outperformed other two After-periods and recorded most significant reduction in excessive delay cost. For outside of the managed motorways operation hours, the changes in excessive delay cost among those three After-periods were relatively small.

Figure 3.6: Average weekday reliability costs by time-of-day (\$2013)

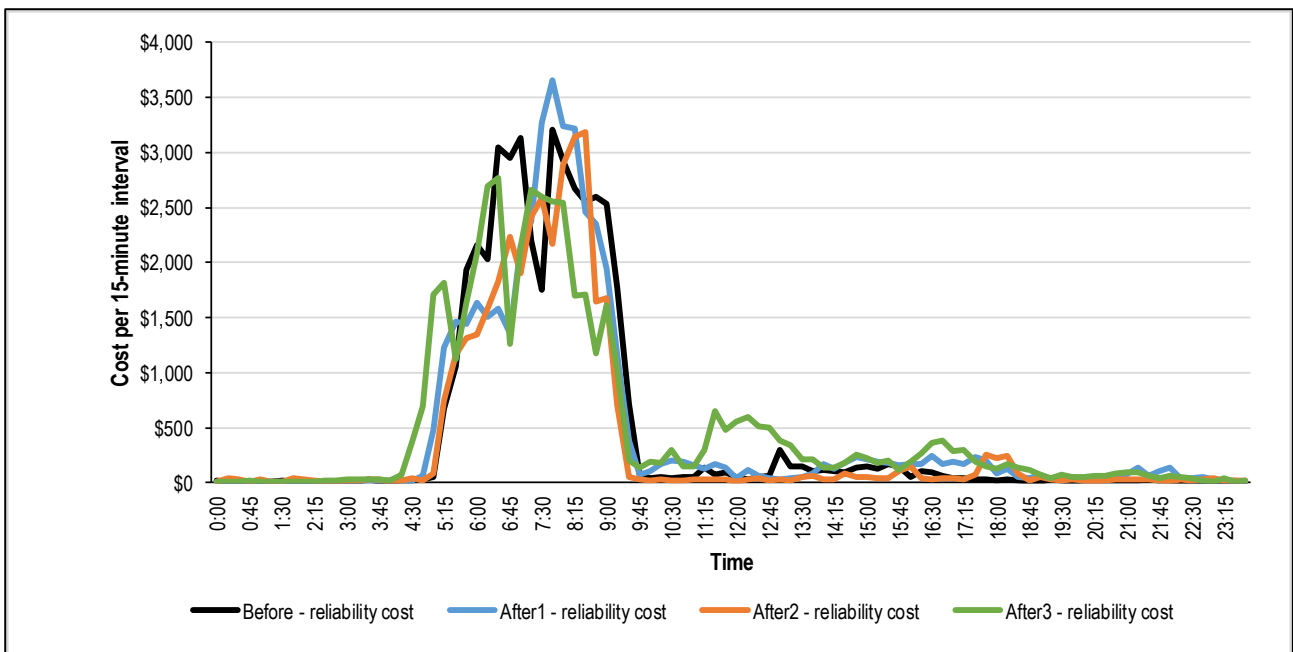


Figure 3.6 shows a mixture of results in the change of reliability costs by time-of-day. Recall that from Table 3.2, it can be observed that the average daily reliability cost is reduced. Outside of the managed motorways operation hours the costs are all relatively lower. Since this falls outside the period of impact of the managed motorway initiatives introduced during the After-periods, it has no bearing on its effectiveness.

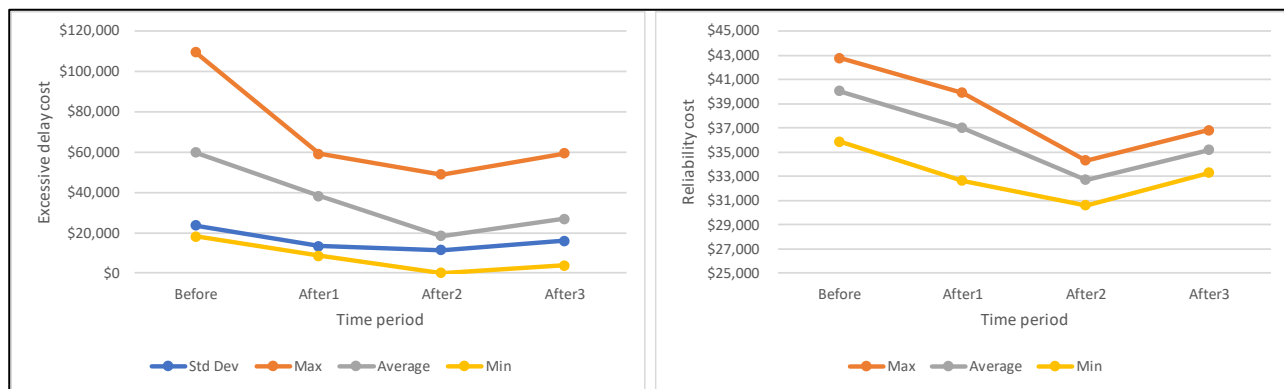
To further examine the variability of congestion cost for each individual day, Appendix B contains a full breakdown of the congestion cost for each day of the Before-period and After-periods.

The evidence for the benefits of the managed motorways based on the results of the study is compelling. The following was found when evaluating the individual weekdays days (for the period 5-10 am):

- Between the Before-period and the average of After-periods 2 and 3, the daily maximum, minimum and variation of excessive delay cost between weekdays improved substantially (reduced by 51%, 89% and 42% respectively)
- The excessive delay cost for most weekdays (over 80%) in After-periods 2 and 3, were less than the Before-period.
- In order to determine the impact of implementing the additional two managed motorway strategies along the Bruce Highway on the freeway excessive congestions cost (being VSL, and automatic queue detection and protection), a comparison is also done of After-periods 2 and 3 with After-period 1. The excessive delay cost for most weekdays (over 70%) in After-periods 2 and 3 were less than that in the Before-period.

Figure 3.7 further depicts the range of the morning peak (5 – 10 am) congestion cost per weekday. The operation of the managed motorway clearly improved the traffic operation and decreased the total congestion cost during managed motorways operation hours. It can also be noted that the standard deviation (indicating the variation between days), maximum and minimum weekday morning peak excessive delay and reliability costs for all After-periods are improved, in comparison to those of the Before-period. Note that the standard deviation for reliability is not shown since reliability as such is a function of the day-to-day variation of congestion (based on comparing the same 15-minute intervals between days).

Figure 3.7: Weekday morning peak (5 – 10 am) congestion cost comparison.



4 CONCLUSIONS

The findings from this study further confirmed the benefits of the implemented managed motorway strategies along Bruce Highway. It significantly reduced congestion cost that road users experience during the morning peak commute (5 – 10 am). Within the three years following the implementation of managed motorway strategies, the VKT was observed to have increased, indicating these strategies have increased the throughput of Bruce Highway. While the scope of the technical note was to use travel time reliability and excessive delay cost (to be consistent with the original R22 report), the use of delay cost (instead of only excessive delay cost) would potentially reveal a higher benefit as the result of the three new strategies.

The comparison of congestion cost before installation ramp metering system and the first year after installation yield encouraging results. Although the average VKT of the After-period 1 was 5% higher compared to the Before-period during morning peak, the average daily morning peak congestion costs of the After-period 1 was 26% lower compared to the Before-period. The saving was predominantly due to the sharp decline of 39% in excessive delay cost. The reliability cost during the operation of the ramp metering also demonstrated an improvement of 7% reduction. The congestion cost savings for After-period 1 were deemed to be the benefits of the coordinated ramp metering.

Since the VSL and automatic queue detection and protection strategies were installed at the end of the After-period 1 before After-period 2, the congestion cost savings from the average of After-periods 2 and 3 were deemed to be the combined benefits of the coordinated ramp metering, VSL and automatic queue detection and protection. Similarly, the average daily VKT during morning peak increase by 5% between the Before-period and the average of After-periods 2 and 3, the average weekday daily morning peak congestion cost was reduced by 43%. To break down the congestion cost further, the average reductions for average After-periods 2 and 3 were 62% for excessive delay cost and 15% for reliability cost. Those savings are equivalent to an annual congestion cost saving of \$12.1 million in 2018-dollar values.

When normalising by VKT, more significant cost savings were identified during the morning peak when the managed motorway strategies were active. Reductions of total congestion, excessive delay and reliability costs per 1000 VKT during morning peak were 30%, 42% and 12% respectively for After-period 1; 46%, 64% and 19% respectively for average of After-periods 2 and 3.

In conclusion, the analysis in the technical note further confirms the positive changes that can mostly be attributed to the installation of the managed motorways strategies, namely the coordinated ramp metering, VSL and automatic queue detection and protection. The amount of congestion has been markedly reduced as a result, with improvements seen in both travel time and travel reliability along the Bruce Highway study site during the period when the managed motorways is operating.

APPENDIX A NOTE ON DATA CLEANING

During certain time periods, flow and speed data were missing due to electronic disturbances and other errors in communication of data between the vehicle detectors and the STREAMS system. Data gap filling was conducted by TMR for link 16 at the year of 2018. Details of the gap filling are as follow:

- For link 16 (*Bruce Hwy SB between Pine River Sb - North Coast District/metro District Boundary & Pine Rivers Brid*) in 2018, there were no volume data available. Since it should have the same volumes as link 15 due to having no access in-between, the link 15 (*Bruce Hwy SB between Bruce Hwy On Ramp 7 & Pine River Sb - North Coast District/metro District Bound*) volumes were used for link 16.
- For link 16 in 2018, there were also no speed data available. The ratios between link 16 and adjacent links 15 and 17 of 2017 speed data were calculated. These ratios were then applied to the link 15 and 17 of 2018 data to populate link 16 speed data.

For 2017 volume data, additional revisions were made to those links' data with low confidence level. The details of the revisions are as follow:

- The 2017 flows on link 11 (*Bruce Hwy SEB between Bruce Hwy Boundary Sb Off Ramp & Bruce Hwy Boundary Sb On Ramp*) were affected by the low level of confidence of the data, the flows were replaced by using the ratio between the volumes of link 11 and link 12 in the year of 2018, and applied to 2017 link 12 volumes to estimate the link 11 volumes. A different factor is used for weekdays vs weekends.
- The 2017 flows on link 16 were affected by the low level of confidence of the data, since it should have the same volumes as link 15 due to having no access in-between, the link 15 volumes were used for link 16.

APPENDIX B DAILY CONGESTION COSTS

Table B 1: Daily congestion cost for the Before-period

Date	Excessive delay Cost	Reliability cost
Monday, 16 February 2015	\$57,682	\$44,459
Tuesday, 17 February 2015	\$67,186	\$44,212
Wednesday, 18 February 2015	\$45,556	\$45,622
Thursday, 19 February 2015	-	-
Friday, 20 February 2015	-	-
Saturday, 21 February 2015	-	-
Sunday, 22 February 2015	-	-
Monday, 23 February 2015	\$89,865	\$39,695
Tuesday, 24 February 2015	-	-
Wednesday, 25 February 2015	\$37,218	\$46,353
Thursday, 26 February 2015	\$58,378	\$43,937
Friday, 27 February 2015	\$63,884	\$42,777
Saturday, 28 February 2015	\$0	\$828
Sunday, 1 March 2015	\$11,568	\$11,859
Monday, 2 March 2015	\$72,830	\$43,659
Tuesday, 3 March 2015	\$79,229	\$42,613
Wednesday, 4 March 2015	\$81,396	\$43,385
Thursday, 5 March 2015	\$66,762	\$43,720
Friday, 6 March 2015	\$20,499	\$46,704
Saturday, 7 March 2015	\$0	\$825
Sunday, 8 March 2015	\$0	\$14,041
Monday, 9 March 2015	\$62,587	\$44,517
Tuesday, 10 March 2015	\$109,507	\$39,449
Wednesday, 11 March 2015	\$59,985	\$42,666
Thursday, 12 March 2015	\$29,212	\$44,802
Friday, 13 March 2015	\$18,115	\$44,946
Saturday, 14 March 2015	\$0	\$802
Sunday, 15 March 2015	\$0	\$12,969

Table B 2: Daily congestion cost for After-period 1

Date	Excessive delay Cost	Reliability cost
Monday, 15 February 2016	\$54,592	\$44,122
Tuesday, 16 February 2016	\$22,046	\$46,152
Wednesday, 17 February 2016	\$33,087	\$45,310
Thursday, 18 February 2016	\$41,979	\$45,252
Friday, 19 February 2016	\$25,066	\$45,590
Saturday, 20 February 2016	\$7,762	\$8,661
Sunday, 21 February 2016	\$335	\$7,319
Monday, 22 February 2016	\$51,852	\$42,374
Tuesday, 23 February 2016	\$35,847	\$44,095
Wednesday, 24 February 2016	\$31,151	\$43,993
Thursday, 25 February 2016	\$37,783	\$44,052
Friday, 26 February 2016	\$8,588	\$45,086
Saturday, 27 February 2016	\$0	\$9,779
Sunday, 28 February 2016	\$1,275	\$7,394
Monday, 29 February 2016	\$50,554	\$41,155
Tuesday, 1 March 2016	\$34,507	\$43,470
Wednesday, 2 March 2016	\$32,667	\$44,466
Thursday, 3 March 2016	\$24,316	\$44,129
Friday, 4 March 2016	-	-
Saturday, 5 March 2016	\$0	\$10,142
Sunday, 6 March 2016	\$1,932	\$6,373
Monday, 7 March 2016	\$59,037	\$38,764
Tuesday, 8 March 2016	\$51,131	\$40,924
Wednesday, 9 March 2016	\$57,642	\$40,428
Thursday, 10 March 2016	\$37,327	\$43,146
Friday, 11 March 2016	-	-
Saturday, 12 March 2016	\$0	\$9,919
Sunday, 13 March 2016	\$40	\$7,002

Table B 3: Daily congestion cost for After-period 2

Date	Excessive delay Cost	Reliability cost
Monday, 13 February 2017	\$20,923	\$35,125
Tuesday, 14 February 2017	\$9,983	\$35,944
Wednesday, 15 February 2017	\$17,495	\$35,657
Thursday, 16 February 2017	\$24,006	\$35,559
Friday, 17 February 2017	\$452	\$36,539
Saturday, 18 February 2017	\$2	\$1,505
Sunday, 19 February 2017	\$3,288	\$10,125
Monday, 20 February 2017	\$12,906	\$35,659
Tuesday, 21 February 2017	\$32,430	\$35,557
Wednesday, 22 February 2017	\$8,101	\$36,693
Thursday, 23 February 2017	\$30,403	\$35,801
Friday, 24 February 2017	\$5,420	\$36,818
Saturday, 25 February 2017	\$43	\$1,630
Sunday, 26 February 2017	\$1,785	\$10,944
Monday, 27 February 2017	-	-
Tuesday, 28 February 2017	\$24,958	\$36,480
Wednesday, 1 March 2017	\$22,470	\$35,953
Thursday, 2 March 2017	\$16,324	\$36,490
Friday, 3 March 2017	\$8,555	\$37,897
Saturday, 4 March 2017	\$42	\$1,538
Sunday, 5 March 2017	\$2,493	\$10,606
Monday, 6 March 2017	\$25,099	\$35,243
Tuesday, 7 March 2017	\$50,750	\$33,607
Wednesday, 8 March 2017	\$30,956	\$34,805
Thursday, 9 March 2017	\$26,203	\$35,456
Friday, 10 March 2017	\$7,691	\$37,010
Saturday, 11 March 2017	\$0	\$1,538
Sunday, 12 March 2017	\$16,665	\$11,042

Table B 4: Daily congestion cost for After-period 3

Date	Excessive delay Cost	Reliability cost
Monday, 12 February 2018	\$47,394	\$46,476
Tuesday, 13 February 2018	\$59,743	\$45,279
Wednesday, 14 February 2018	\$23,953	\$47,801
Thursday, 15 February 2018	\$35,684	\$47,782
Friday, 16 February 2018	\$5,137	\$49,198
Saturday, 17 February 2018	\$50	\$1,082
Sunday, 18 February 2018	\$1,370	\$11,412
Monday, 19 February 2018	\$40,942	\$47,005
Tuesday, 20 February 2018	\$49,593	\$45,891
Wednesday, 21 February 2018	\$11,961	\$48,471
Thursday, 22 February 2018	\$45,923	\$47,096
Friday, 23 February 2018	\$15,957	\$46,215
Saturday, 24 February 2018	\$0	\$919
Sunday, 25 February 2018	\$3,187	\$9,416
Monday, 26 February 2018	\$36,390	\$46,045
Tuesday, 27 February 2018	\$26,838	\$47,944
Wednesday, 28 February 2018	\$37,624	\$46,775
Thursday, 1 March 2018	\$32,141	\$47,902
Friday, 2 March 2018	\$20,738	\$50,028
Saturday, 3 March 2018	\$2	\$1,097
Sunday, 4 March 2018	\$187	\$11,210
Monday, 5 March 2018	\$8,623	\$47,891
Tuesday, 6 March 2018	\$21,359	\$48,066
Wednesday, 7 March 2018	\$24,073	\$47,240
Thursday, 8 March 2018	\$5,368	\$49,205
Friday, 9 March 2018	\$8,285	\$49,341
Saturday, 10 March 2018	-	-
Sunday, 11 March 2018	\$364	\$10,718

Table B 5: Daily congestion cost for the Before-period (5am – 10 am weekday morning peak only)

Date	Excessive delay Cost	Reliability cost
Monday, 16 February 2015	\$57,674	\$41,039
Tuesday, 17 February 2015	\$67,186	\$40,697
Wednesday, 18 February 2015	\$44,088	\$42,003
Thursday, 19 February 2015	-	-
Friday, 20 February 2015	-	-
Saturday, 21 February 2015	-	-
Sunday, 22 February 2015	-	-
Monday, 23 February 2015	\$89,862	\$36,281
Tuesday, 24 February 2015	-	-
Wednesday, 25 February 2015	\$37,185	\$42,762
Thursday, 26 February 2015	\$58,378	\$40,231
Friday, 27 February 2015	\$63,817	\$38,658
Saturday, 28 February 2015	-	-
Sunday, 1 March 2015	-	-
Monday, 2 March 2015	\$72,813	\$40,164
Tuesday, 3 March 2015	\$79,229	\$39,080
Wednesday, 4 March 2015	\$81,346	\$39,719
Thursday, 5 March 2015	\$66,727	\$39,819
Friday, 6 March 2015	\$20,485	\$42,491
Saturday, 7 March 2015	-	-
Sunday, 8 March 2015	-	-
Monday, 9 March 2015	\$61,680	\$41,075
Tuesday, 10 March 2015	\$109,507	\$35,869
Wednesday, 11 March 2015	\$59,975	\$38,953
Thursday, 12 March 2015	\$29,212	\$41,090
Friday, 13 March 2015	\$18,115	\$40,887
Saturday, 14 March 2015	-	-
Sunday, 15 March 2015	-	-

Table B 6: Daily congestion cost for After-period 1 (5am – 10 am weekday morning peak only)

Date	Excessive delay Cost	Reliability cost
Monday, 15 February 2016	\$54,592	\$37,968
Tuesday, 16 February 2016	\$22,046	\$39,890
Wednesday, 17 February 2016	\$32,500	\$38,907
Thursday, 18 February 2016	\$41,882	\$38,510
Friday, 19 February 2016	\$25,065	\$38,271
Saturday, 20 February 2016	-	-
Sunday, 21 February 2016	-	-
Monday, 22 February 2016	\$51,852	\$35,994
Tuesday, 23 February 2016	\$35,847	\$37,676
Wednesday, 24 February 2016	\$30,895	\$37,282
Thursday, 25 February 2016	\$37,752	\$37,158
Friday, 26 February 2016	\$8,582	\$37,918
Saturday, 27 February 2016	-	-
Sunday, 28 February 2016	-	-
Monday, 29 February 2016	\$49,053	\$35,091
Tuesday, 1 March 2016	\$34,507	\$37,535
Wednesday, 2 March 2016	\$32,639	\$38,459
Thursday, 3 March 2016	\$24,311	\$37,764
Friday, 4 March 2016	-	-
Saturday, 5 March 2016	-	-
Sunday, 6 March 2016	-	-
Monday, 7 March 2016	\$59,037	\$32,623
Tuesday, 8 March 2016	\$51,131	\$34,732
Wednesday, 9 March 2016	\$57,618	\$33,850
Thursday, 10 March 2016	\$37,324	\$36,215
Friday, 11 March 2016	-	-
Saturday, 12 March 2016	-	-
Sunday, 13 March 2016	-	-

Table B 7: Daily congestion cost for After-period 2 (5am – 10 am weekday morning peak only)

Date	Excessive delay Cost	Reliability cost
Monday, 13 February 2017	\$20,067	\$32,357
Tuesday, 14 February 2017	\$8,621	\$32,801
Wednesday, 15 February 2017	\$14,681	\$32,526
Thursday, 16 February 2017	\$21,682	\$32,233
Friday, 17 February 2017	\$149	\$32,997
Saturday, 18 February 2017	-	-
Sunday, 19 February 2017	-	-
Monday, 20 February 2017	\$11,624	\$32,677
Tuesday, 21 February 2017	\$30,943	\$32,524
Wednesday, 22 February 2017	\$6,645	\$33,555
Thursday, 23 February 2017	\$28,719	\$32,564
Friday, 24 February 2017	\$4,841	\$33,141
Saturday, 25 February 2017	-	-
Sunday, 26 February 2017	-	-
Monday, 27 February 2017	-	-
Tuesday, 28 February 2017	\$23,296	\$33,482
Wednesday, 1 March 2017	\$21,180	\$32,872
Thursday, 2 March 2017	\$14,877	\$33,271
Friday, 3 March 2017	\$8,282	\$34,310
Saturday, 4 March 2017	-	-
Sunday, 5 March 2017	-	-
Monday, 6 March 2017	\$23,594	\$32,367
Tuesday, 7 March 2017	\$48,985	\$30,593
Wednesday, 8 March 2017	\$29,557	\$31,677
Thursday, 9 March 2017	\$24,774	\$32,196
Friday, 10 March 2017	\$7,013	\$33,377
Saturday, 11 March 2017	-	-
Sunday, 12 March 2017	-	-

Table B 8: Daily congestion cost for After-period 3 (5am – 10 am weekday morning peak only)

Date	Excessive delay Cost	Reliability cost
Monday, 12 February 2018	\$47,288	\$34,241
Tuesday, 13 February 2018	\$59,407	\$33,285
Wednesday, 14 February 2018	\$23,782	\$35,313
Thursday, 15 February 2018	\$35,562	\$34,994
Friday, 16 February 2018	\$5,130	\$35,667
Saturday, 17 February 2018	-	-
Sunday, 18 February 2018	-	-
Monday, 19 February 2018	\$40,299	\$34,650
Tuesday, 20 February 2018	\$49,421	\$33,670
Wednesday, 21 February 2018	\$11,896	\$36,114
Thursday, 22 February 2018	\$42,625	\$35,045
Friday, 23 February 2018	\$15,891	\$33,775
Saturday, 24 February 2018	-	-
Sunday, 25 February 2018	-	-
Monday, 26 February 2018	\$36,170	\$34,112
Tuesday, 27 February 2018	\$26,763	\$35,760
Wednesday, 28 February 2018	\$37,556	\$34,164
Thursday, 1 March 2018	\$32,066	\$34,919
Friday, 2 March 2018	\$20,224	\$36,274
Saturday, 3 March 2018	-	-
Sunday, 4 March 2018	-	-
Monday, 5 March 2018	\$8,563	\$36,017
Tuesday, 6 March 2018	\$13,435	\$36,802
Wednesday, 7 March 2018	\$24,020	\$35,475
Thursday, 8 March 2018	\$5,296	\$36,831
Friday, 9 March 2018	\$3,801	\$36,213
Saturday, 10 March 2018	-	-
Sunday, 11 March 2018	-	-

Table B 9: Daily congestion cost for the Before-period (outside morning peak on weekdays)

Date	Excessive delay Cost	Reliability cost
Monday, 16 February 2015	\$8	\$3,420
Tuesday, 17 February 2015	\$0	\$3,514
Wednesday, 18 February 2015	\$1,468	\$3,620
Thursday, 19 February 2015	-	-
Friday, 20 February 2015	-	-
Saturday, 21 February 2015	-	-
Sunday, 22 February 2015	-	-
Monday, 23 February 2015	\$3	\$3,414
Tuesday, 24 February 2015	-	-
Wednesday, 25 February 2015	\$33	\$3,591
Thursday, 26 February 2015	\$0	\$3,706
Friday, 27 February 2015	\$67	\$4,119
Saturday, 28 February 2015	-	-
Sunday, 1 March 2015	-	-
Monday, 2 March 2015	\$17	\$3,495
Tuesday, 3 March 2015	\$0	\$3,533
Wednesday, 4 March 2015	\$50	\$3,666
Thursday, 5 March 2015	\$35	\$3,902
Friday, 6 March 2015	\$15	\$4,213
Saturday, 7 March 2015	-	-
Sunday, 8 March 2015	-	-
Monday, 9 March 2015	\$908	\$3,442
Tuesday, 10 March 2015	\$0	\$3,580
Wednesday, 11 March 2015	\$10	\$3,712
Thursday, 12 March 2015	\$0	\$3,712
Friday, 13 March 2015	\$0	\$4,059
Saturday, 14 March 2015	-	-
Sunday, 15 March 2015	-	-

Table B 10: Daily congestion cost for After-period 1 (outside morning peak on weekdays)

Date	Excessive delay Cost	Reliability cost
Monday, 15 February 2016	\$0	\$6,154
Tuesday, 16 February 2016	\$0	\$6,263
Wednesday, 17 February 2016	\$586	\$6,404
Thursday, 18 February 2016	\$97	\$6,741
Friday, 19 February 2016	\$0	\$7,318
Saturday, 20 February 2016	-	-
Sunday, 21 February 2016	-	-
Monday, 22 February 2016	\$0	\$6,380
Tuesday, 23 February 2016	\$0	\$6,419
Wednesday, 24 February 2016	\$256	\$6,710
Thursday, 25 February 2016	\$31	\$6,893
Friday, 26 February 2016	\$6	\$7,169
Saturday, 27 February 2016	-	-
Sunday, 28 February 2016	-	-
Monday, 29 February 2016	\$1,502	\$6,064
Tuesday, 1 March 2016	\$0	\$5,936
Wednesday, 2 March 2016	\$27	\$6,007
Thursday, 3 March 2016	\$4	\$6,365
Friday, 4 March 2016	-	-
Saturday, 5 March 2016	-	-
Sunday, 6 March 2016	-	-
Monday, 7 March 2016	\$0	\$6,141
Tuesday, 8 March 2016	\$0	\$6,193
Wednesday, 9 March 2016	\$25	\$6,578
Thursday, 10 March 2016	\$3	\$6,932
Friday, 11 March 2016	-	-
Saturday, 12 March 2016	-	-
Sunday, 13 March 2016	-	-

Table B 11: Daily congestion cost for After-period 2 (outside morning peak on weekdays)

Date	Excessive delay Cost	Reliability cost
Monday, 13 February 2017	\$856	\$2,768
Tuesday, 14 February 2017	\$1,363	\$3,143
Wednesday, 15 February 2017	\$2,814	\$3,131
Thursday, 16 February 2017	\$2,324	\$3,326
Friday, 17 February 2017	\$303	\$3,542
Saturday, 18 February 2017	-	-
Sunday, 19 February 2017	-	-
Monday, 20 February 2017	\$1,282	\$2,982
Tuesday, 21 February 2017	\$1,487	\$3,033
Wednesday, 22 February 2017	\$1,456	\$3,138
Thursday, 23 February 2017	\$1,684	\$3,237
Friday, 24 February 2017	\$578	\$3,677
Saturday, 25 February 2017	-	-
Sunday, 26 February 2017	-	-
Monday, 27 February 2017	-	-
Tuesday, 28 February 2017	\$1,662	\$2,999
Wednesday, 1 March 2017	\$1,290	\$3,081
Thursday, 2 March 2017	\$1,447	\$3,219
Friday, 3 March 2017	\$273	\$3,587
Saturday, 4 March 2017	-	-
Sunday, 5 March 2017	-	-
Monday, 6 March 2017	\$1,506	\$2,876
Tuesday, 7 March 2017	\$1,765	\$3,014
Wednesday, 8 March 2017	\$1,399	\$3,128
Thursday, 9 March 2017	\$1,429	\$3,259
Friday, 10 March 2017	\$678	\$3,632
Saturday, 11 March 2017	-	-
Sunday, 12 March 2017	-	-

Table B 12: Daily congestion cost for After-period 3 (outside morning peak on weekdays)

Date	Excessive delay Cost	Reliability cost
Monday, 12 February 2018	\$106	\$12,235
Tuesday, 13 February 2018	\$337	\$11,995
Wednesday, 14 February 2018	\$171	\$12,488
Thursday, 15 February 2018	\$122	\$12,788
Friday, 16 February 2018	\$7	\$13,532
Saturday, 17 February 2018	-	-
Sunday, 18 February 2018	-	-
Monday, 19 February 2018	\$642	\$12,355
Tuesday, 20 February 2018	\$171	\$12,221
Wednesday, 21 February 2018	\$65	\$12,358
Thursday, 22 February 2018	\$3,299	\$12,051
Friday, 23 February 2018	\$66	\$12,440
Saturday, 24 February 2018	-	-
Sunday, 25 February 2018	-	-
Monday, 26 February 2018	\$220	\$11,934
Tuesday, 27 February 2018	\$75	\$12,183
Wednesday, 28 February 2018	\$67	\$12,611
Thursday, 1 March 2018	\$74	\$12,983
Friday, 2 March 2018	\$515	\$13,754
Saturday, 3 March 2018	-	-
Sunday, 4 March 2018	-	-
Monday, 5 March 2018	\$60	\$11,874
Tuesday, 6 March 2018	\$7,924	\$11,265
Wednesday, 7 March 2018	\$53	\$11,764
Thursday, 8 March 2018	\$71	\$12,374
Friday, 9 March 2018	\$4,485	\$13,128
Saturday, 10 March 2018	-	-
Sunday, 11 March 2018	-	-