NACOE
NATIONAL ASSET CENTRE OF EXCELLENCE

FINAL REPORT

Project Title: R47: Review and Update of the Methodology for Measuring Excessive Congestion (2017/18)

ARRB Project No: PRJ16283

Author/s: Dr Clarissa Han, Dr Reza Mahajerpoor and Kevin Wu

Client: Queensland Department of Transport and Main Roads

Date: 28/11/2018

AN INITIATIVE BY:
arrb Queensland Government

SUMMARY

Stage 1 of NACoE project R47 (Review and update of the methodology for measuring excessive congestion) identified two alternative methods for defining thresholds for measuring excessive delay along arterial roads as follows:

- reference speed method, where a ratio of the free-flow speed or posted speed limit is used to calculate travel time threshold values (i.e. $Threshold_{RS}$) for the estimation of excessive delay
- reference intersection delay method, where a range of controlled delays at intersections are used to calculate travel time threshold values (i.e. $Threshold_{RID}$) for the estimation of excessive delay.

The following list of reference values for both methods following the level of service (LOS) concept are suggested:

LOS	Reference intersection delay	Reference speed
B	15 s/veh (> 10–20)	0.75 posted speed limit (PSL) (> 67–80%)
C	28 s/veh (> 20–35)	0.60 PSL (> 50–67%)
D	43 s/veh (> 35–55)	0.45 PSL (> 40–50%)
Current TMR-ARRB method	n.a.	0.55 PSL

A case study using data collected on Gympie Road in 2016 was undertaken to test these two methods. In Stage 2 of the project conducted in 2017–18, further case studies using 2017 data from five Southeast Queensland (SEQ) arterial corridors was undertaken to: (1) validate the findings from the first stage to a broader arterial network, and (2) identify an optimal method and threshold for arterial corridors and side-streets.

The following analysis was conducted for these case studies:

- test if the current reference speed threshold (i.e. 0.55 PSL) is appropriate, by using the speed-flow relationship curves obtained from selected main corridor links
- investigate the travel time variability and test the fitness of different thresholds by considering the TMR operational experience and video footage of selected intersections
- test the sensitivity of the total corridor excessive delay against the change of the two thresholds at different LOS for each corridor, and identify the impacts of side-streets configured with a short NPI link length on total excessive delay.

This report summarises all case study results and learnings to improve the implementation of cost-of-congestion (CoC) for arterial roads. By consolidating the key findings from both Stage 1 and Stage 2, it is concluded that:

1. Based on all test and validation results for these case study sites, for all lengths of main corridor links and side-street links longer than 200 m, the current 0.55 PSL is still the best-fit threshold.
2. For side-streets shorter than 200 m, the 43 seconds intersection delay as the threshold for excessive delay estimation should be considered. However, the overall impact of this improvement is generally small, e.g. for the five SEQ corridors, side-street links shorter than

200 m generally have a small share (0–6%) on the total excessive delays for the whole site when using the current reference speed threshold (i.e. 55% of PSL). This impact would be even smaller (0–4%) if the intersection delay method LOS D (i.e. 43 seconds) is used. Therefore, the effort involved in modifying the current systems to accommodate a secondary threshold should be considered.

3. It was also found that the short NPI link length configured for side-streets tended to present a problematic profile when investigating travel time variability. For future NPI link establishment, it would be preferred to define the minimum link length as 200 m to enable the excessive delay on side-streets to be estimated with a higher degree of confidence.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the NACoE program for providing sustainable funding to support this research project. We also appreciate the great team work and dedicated effort and contribution from the TMR R47 project management team, they are Dr Merle Wood, Frans Dekker, Amanda Breeze, and Ethen Young.

This page is intentionally left blank

CONTENTS

TABLES

FIGURES

1 INTRODUCTION

1.1 Background

Queensland Department of Transport and Main Roads (TMR) has been working collaboratively with the Australian Road Research Board (ARRB) in recent years to develop a cost-of-congestion (CoC) methodology that is suitable for urban areas in Queensland.

A previous research project (NACoE project R22) developed a framework for determining the multi-modal CoC (Luk, Han and Byrne 2016, Han & Byrne 2016a and 2016b). In R22, a series of case studies were also undertaken to validate and enhance the methodology by using multi-modal travel data and multiple data sources.

NACoE project R47 (Review and update of the methodology for measuring excessive congestion) focussed on a review and validation of the definition and methodology of measuring excessive delay. In the current TMR CoC reporting methodology (Dekker et al. 2015), excessive delay is reported when the observed speed on a link drops below a threshold with reference to the posted speed limit (PSL). TMR adopts a reference speed ratio of 0.7 PSL for freeways and 0.55 PSL for urban arterial roads. Due to the limited research available on determining congestion thresholds on lower-order side-streets in urban areas, it is often assumed that the reference speed threshold for urban arterials is applicable to side-streets. As the application of CoC reporting extended to different types of roads, traffic engineering practitioners began to observe some discrepancies in the results for lower-order side-streets. For example, for those links with very short link lengths and poor traffic signal progression, the average link speed can drop below 0.55 PSL quite easily because of very small green time, causing a false impression of excessive delay. As the link length assigned to lower-order side-streets can be arbitrary, adopting this method could potentially produce erroneous results.

Stage 1 of Project R47 (Han and Mahajerpoor 2017) reviewed and identified alternative methods for defining thresholds for measuring excessive delay for arterial roads. A case study using Gympie Road data in 2016 was also undertaken to test these methods.

Work in Stage 2 in 2017–18 has involved the undertaking of further case studies using 2017 data from five Southeast Queensland (SEQ) arterial corridors to validate the findings from the first stage to a broader arterial network, and to identify an optimal method and threshold for arterial corridors and side-streets.

This report is the final report for Stage 2 of this project. It summarises all the case study results and learnings to improve the implementation of CoC for arterial roads.

1.2 Key Findings from Stage 1 of R47

In Stage 1 of the project (Han and Mahajerpoor 2017), two methods of measuring excessive delay were investigated for the estimation of excessive delay:

- reference speed method, where a ratio of the free-flow speed or posted speed limit is used to calculate travel time threshold values (i.e. $Threshold_{RS}$)
- reference intersection delay method, where a range of controlled delays at intersections is used to calculate travel time threshold values (i.e. $Threshold_{RID}$).

A list of reference values for both methods following the level of service (LOS) concept was suggested and tested as presented in Table 1.1.

Table 1.1: Reference values at LOS B-D for both methods

LOS	Reference intersection delay	Reference speed
B	15 s/veh (> 10–20)	0.75 posted speed limit (PSL) (> 67–80%)
C	28 s/veh (> 20–35)	0.60 PSL (> 50–67%)
D	43 s/veh (> 35–55)	0.45 PSL (> 40–50%)
Current TMR-ARRB method	n. a.	0.55 PSL

The Gympie Road case study in Stage 1 found that:

- For main corridor links, the current reference speed method using 0.55 PSL appeared to be appropriate.
- For the six small side-streets, the intersection delay method was feasible and LOS D (using 43 seconds as the reference intersection delay) appeared to be an acceptable threshold for estimating excessive delay. The current reference speed method using 0.55 PSL could have over-estimated the excessive delay at side-streets. However, the total excessive delay of the six lower-order side-streets was very small given their lower volumes and this type of side-street involved only a small number of links.

It was suggested that these findings should be further validated by using more data from SEQ arterial roads before any robust conclusion could be achieved.

1.3 Scope and Contents of Current Report

Five arterial corridors were selected and investigated in Stage 2 of the project. The objective was to validate and generalise the findings from the Gympie Road study in Stage 1 to the whole arterial road network.

Terminology defined in Stage 1 (Han and Mahajerpoor 2017, also in Appendix A) were adopted consistently in Stage 2. The analysis methodology developed in Stage 1 was also re-applied, including the threshold validation using speed-flow curves and sensitivity analysis of the total excessive delay against different thresholds. Furthermore, video footage of selected sites was also used in the threshold validation and selection phase of the project.

The contents of the report are as follows:

- Section 1 – Introduction
- Section 2 – Case study objectives, study sites and data compilation
- Section 3 – Reference speed threshold validation
- Section 4 – Travel time variability and video footage validation
- Section 5 – Sensitivity of total excessive delays to threshold levels
- Section 6 – Main findings and recommendations
- Appendix A – Terminology
- Appendix B – Study sites and data gaps
- Appendix C – Analysis of speed-flow curves
- Appendix D – List of links at camera sites used for video validation
- Appendix E – Examples of Whisker charts for travel time variability
- Appendix F – Sensitivity analysis charts.

2 CASE STUDY OBJECTIVES, METHODS, STUDY SITES AND DATA COMPILATION

2.1 Objectives

The aim of the case studies in Stage 2 was to expand the number of study sites and test if the findings from the Gympie Road case study, using 2016 data, could be generalised and applied into the broader arterial network in Queensland.

The following five arterial corridors in SEQ, as shown in Figure 2.1, and their side-streets, were selected for investigation. These corridors were deemed to represent the broader arterial network in Queensland:

1. Beaudesert Road – a 10.1 km long section between Riawena Road and Algester Road
2. Gold Coast Highway – a 4.3 km long section between Olsen Avenue and North Street
3. Gympie Road – a section between Graham Road and Lutwyche Road, 7.3 km northbound and 6.9 km southbound
4. Olsen Avenue – a 3.1 km long section between Gold Coast Highway and Parklands Drive
5. Stafford Road – a section between South Pine Road and Gympie Road, 4.3 km eastbound and 3.7 km westbound.

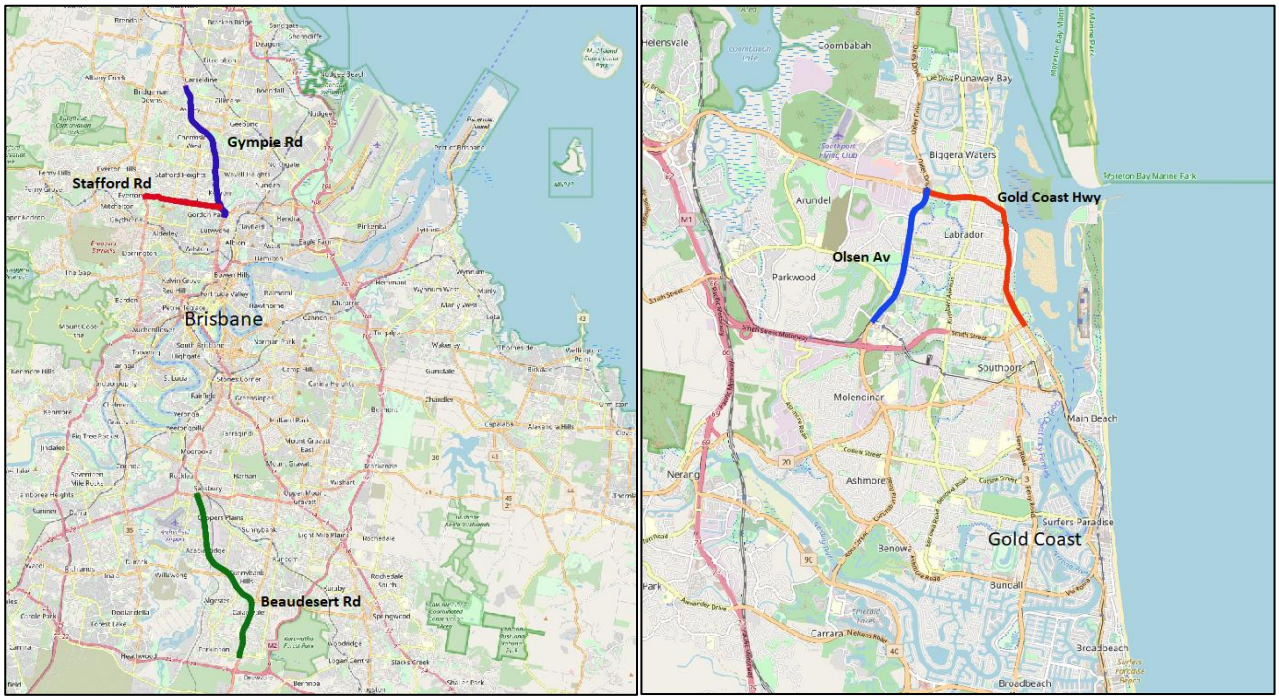
Appendix B lists all National Performance Indicator (NPI) links (defined in Appendix A) including both carriageway links and all associated side-street links for the five corridors respectively. The details of the links, including their lengths, posted speed limits, and assigned IDs for each of the study sites are also given in Appendix B. Note that these link IDs are used in this report only; they are different from the STREAMS NPI IDs.

2.2 Analysis Methodology

The following analysis was conducted for the five study sites:

- Test if the current reference speed threshold (i.e. 0.55 PSL) is appropriate, by using the speed-flow relationship curves obtained from selected main corridor links (Section 3).
- Investigate the travel time variability and test the fitness of different thresholds by considering the TMR operational experience and video footage collected at selected intersections (Section 4).
- Test the sensitivity of the total corridor excessive delay against the change of the two thresholds at different LOS for each corridor and identify the influential factors (Section 5).

Figure 2.1: Location of the five study sites in Brisbane and Gold Coast



Source: OpenStreetMap Contributors 2018.

2.3 Data Compilation and Data Gap Checking

A typical four-week period from 13 February to 12 March 2017 was used as the case study time period. Data quality was measured by the data gaps for both the main corridor links and the side-street links. 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, where data gaps were observed. Table 2.1 and Table 2.2 show the percentage of data gaps for the main corridor links and side-street links respectively. Various time intervals for both average weekday and weekend were investigated, including 24 hours, AM peak, PM peak, and inter-peak. The percentage of data gaps higher than 20% was regarded as relatively poor quality and are shaded in the tables by red, whilst gaps less than 20% were regarded as relatively good/acceptable quality and are shaded by green.

Table 2.1 shows that the main corridors generally had good data quality with the percentage of data gaps all less than or equal to 10% for the 24-hour period, peak and inter-peak periods.

Table 2.1: Proportion of NPI data gaps for the studies sites – main corridors

Corridor	Number of links	Day of week	Percentage of data gap (24 hours)	Percentage of gap data AM peak time (6:00–10:00 am)	Percentage of gap data PM peak time (3:00–7:00 pm)	Percentage of gap data inter-peak time (10:00 am – 2:00 pm)
Beaudesert Road	30	Weekday	5	4	1	1
		Weekend	5	4	2	2
Gold Coast Highway	22	Weekday	9	6	2	4
		Weekend	8	6	3	3
Gympie Road	36	Weekday	6	3	0	0

		Weekend	4	2	0	0
Olsen Road	8	Weekday	3	3	0	0
		Weekend	9	8	8	8
Stafford Road	19	Weekday	10	3	0	0
		Weekend	9	2	0	0

Table 2.2 shows that the quality of data on the side-streets was acceptable during the day, with the percentage of data gaps less than or equal to 20%.

Table 2.2: Proportion of NPI data gaps for the studies sites – side-streets

Corridor	Number of links	Day of week	Percentage of data gap (24 hours)	Percentage of gap data AM peak time (6:00–10:00 am)	Percentage of gap data PM peak time (3:00–7:00 pm)	Percentage of gap data inter-peak time (10:00 am – 2:00 pm)
Beaudesert Road	26	Weekday	25	19	12	14
		Weekend	26	20	12	11
Gold Coast Highway	16	Weekday	31	16	11	12
		Weekend	30	18	11	10
Gympie Road	26	Weekday	18	4	1	1
		Weekend	17	7	2	1
Olsen Road	8	Weekday	22	12	9	8
		Weekend	27	20	18	16
Stafford Road	12	Weekday	16	3	0	0
		Weekend	13	3	1	0

Figure 2.2 and Figure 2.3 show examples of the daily data gaps for each time period using data from the Beaudesert Road main corridor and the side-streets respectively. These two charts show that the data quality of the main corridor and side-streets was generally good or acceptable; however, a larger gap was identified during the morning peak (6:00–10:00 am) and 24-hour period on 15 February 2017. The daily data gaps for other corridors were also plotted and they are presented in Figure B 3 to Figure B 10 in Appendix B. It was found that the data gaps for both the main corridor and the side-streets during the morning peak on the 15 February were consistent in all corridors.

Given that the data gaps were generally small, their impacts on the analysis were negligible.

The extraordinary high percentage of data gaps on 15 February 2017 during the morning peak indicates that the excessive congestion delay could have been underestimated on that day as all the missing data were not filled. However, the omission of data on that day was considered acceptable as the purpose was to compare the impacts of different thresholds on excessive delay estimation, rather than report the absolute values of CoC.

Figure 2.2: Weekday data gap per time period – Beaudesert Road main corridor

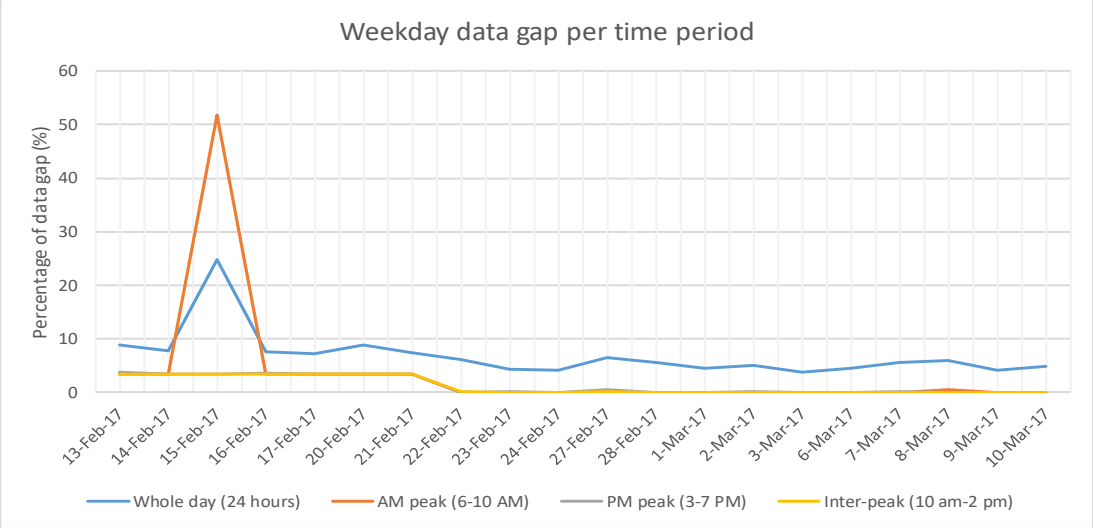
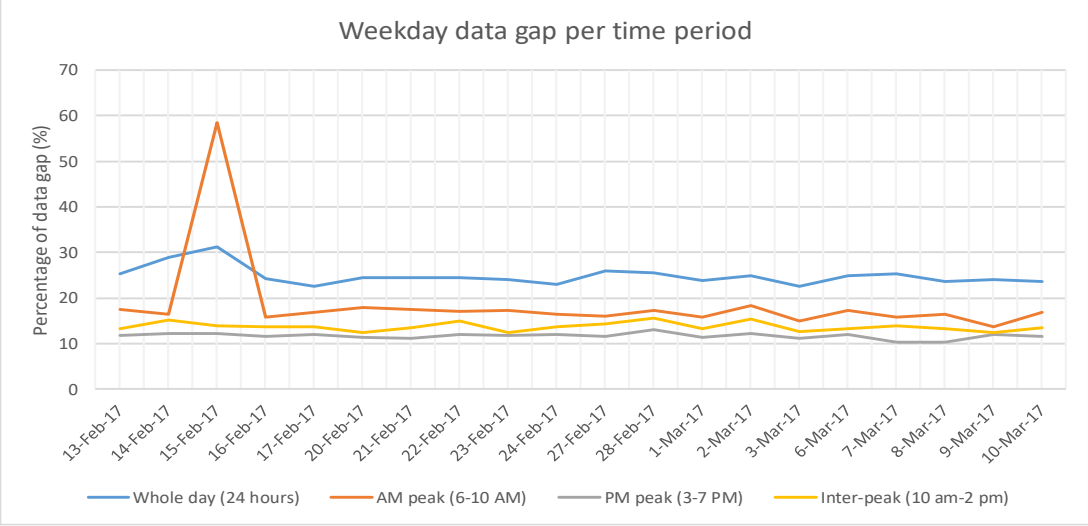


Figure 2.3: Weekday data gap per time period – Beaudesert Road side-streets



3 REFERENCE SPEED THRESHOLD VALIDATION

3.1 Normalised Speed-flow Curve

It was suggested in Austroads (2009a) that the speed before flow breakdown in the harmonised speed-flow curve be used as the reference speed when measuring excessive delay. The reference speeds were identified as the average speed levels at the volume to capacity ratio (v/c ratio) of 0.85–0.95 as used in Luk et al. (2006).

To develop harmonised speed-flow curves as described in Luk et al. (2006) requires a complex process and the available NPI data did not provide sufficient information. A simplified plotting process, developed by Han, Tadros and Wu (2017) was used to identify the speed range before flow breakdown; this involved using the NPI speed and flow data from selected links on Gympie Road. In this process, a normalised speed-flow chart was plotted for NPI links where the y-axis represents the reference speed ratio (i.e. the ratio of NPI speed to the PSL), and the x-axis represents the v/c ratios or the degree of saturation (DOS) for arterials. A theoretical normalised speed-flow chart is shown in Figure 3.1.

In the chart three phases are illustrated:

- under-saturation phase – generally high speed with low DOS (below a critical DOS), noting that the speed may start to drop gradually when the DOS is approaching a critical value
- transition phase – speed starts to drop quite significantly after a critical DOS, traffic flow is becoming more unstable
- over-saturation phase - low speed with high DOS (usually higher than 1.0), traffic flow is congested.

Further investigation of NPI data patterns and consultation with TMR experts suggested that the reference speeds or a speed range can be identified at the turning point of the transition phase as highlighted in Figure 3.1. The DOS at the turning point has been defined as the ‘critical DOS’ in the TMR STREAMS parameters as discussed in Luk (2008) and TMR (2014). For different links, the critical DOS could be slightly different. As a general guidance based on historic data, the critical DOS generally lies between 0.75 and 0.8.

In Han and Mahajerpoor (2017), the v/c ratio was used in the normalised speed-flow curves. The capacity was defined as the maximum NPI volume at each peak and the v/c ratio was therefore capped at 1.0. In this case, because of the wide spreading of data points, the identification of curve turning points and speed range at the turning point is quite challenging. Very often, the data points in the over-saturation phase can be mixed up with the tradition phase. On the other hand, using DOS to build speed-flow relationship provides a curve that could extend beyond a DOS value of 1.0, and this will separate the over-saturation phase from the transition phase more clearly. The DOS data used in this report appears to provide a more practical indicator to identify speed ranges before the flow breakdown.

An example of a normalised speed-flow curve of a typical NPI link along Gympie Road is shown in Figure 3.2. The southbound link between the Sparkes Street pedestrian crossing and Wallace Street (GRSB14) shows clearly that the critical DOS was 0.8 and the link speed varied between 0.66 PSL and 0.8 PSL (average 0.7 PSL) at the critical DOS.

Figure 3.1: Theoretical normalised speed-flow curve

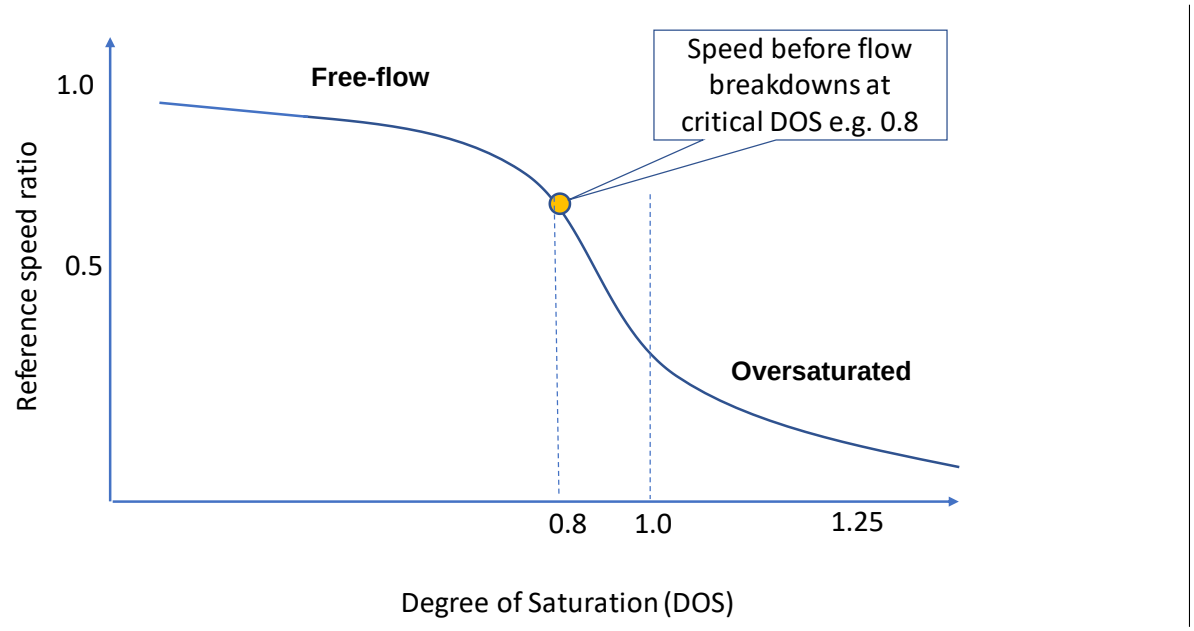
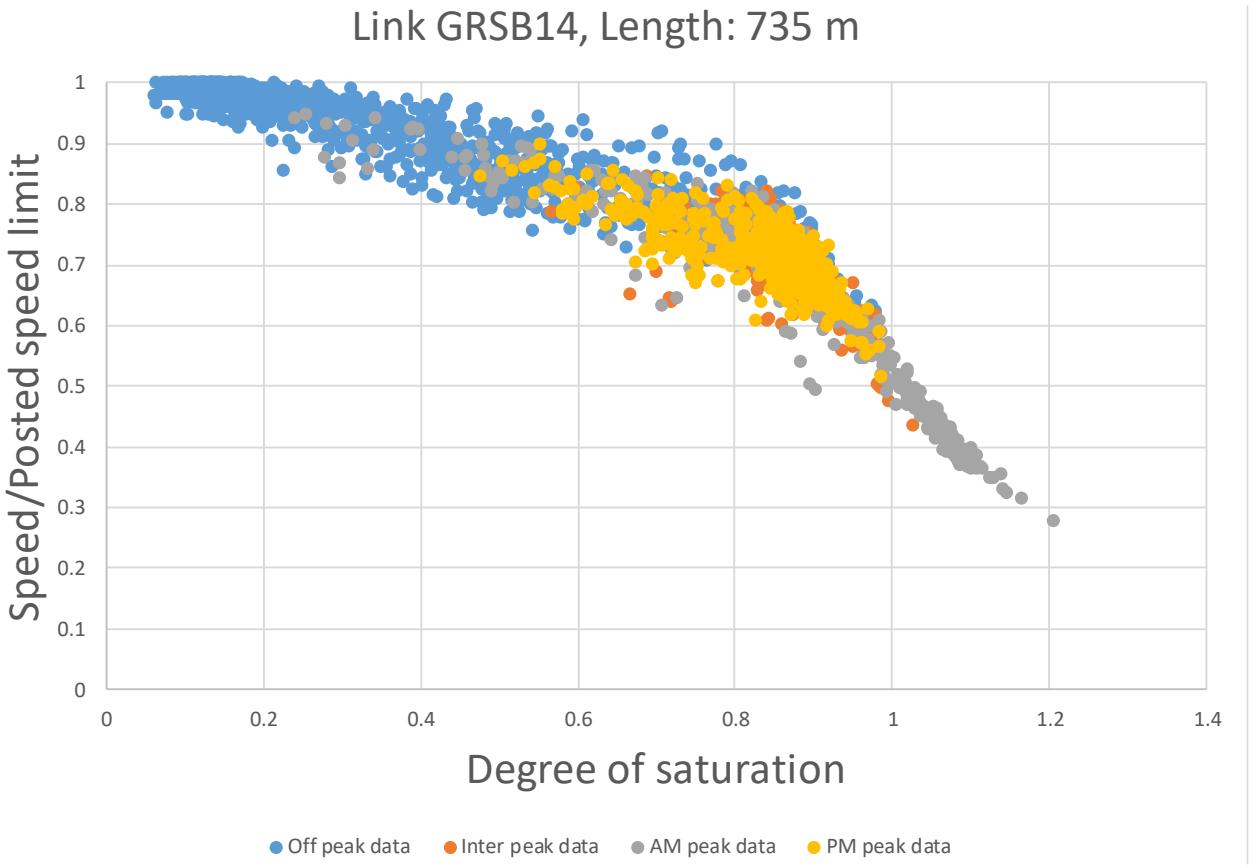


Figure 3.2: Normalised speed-flow diagram using NPI data for Gympie Road link GRSB 14, 2018 data



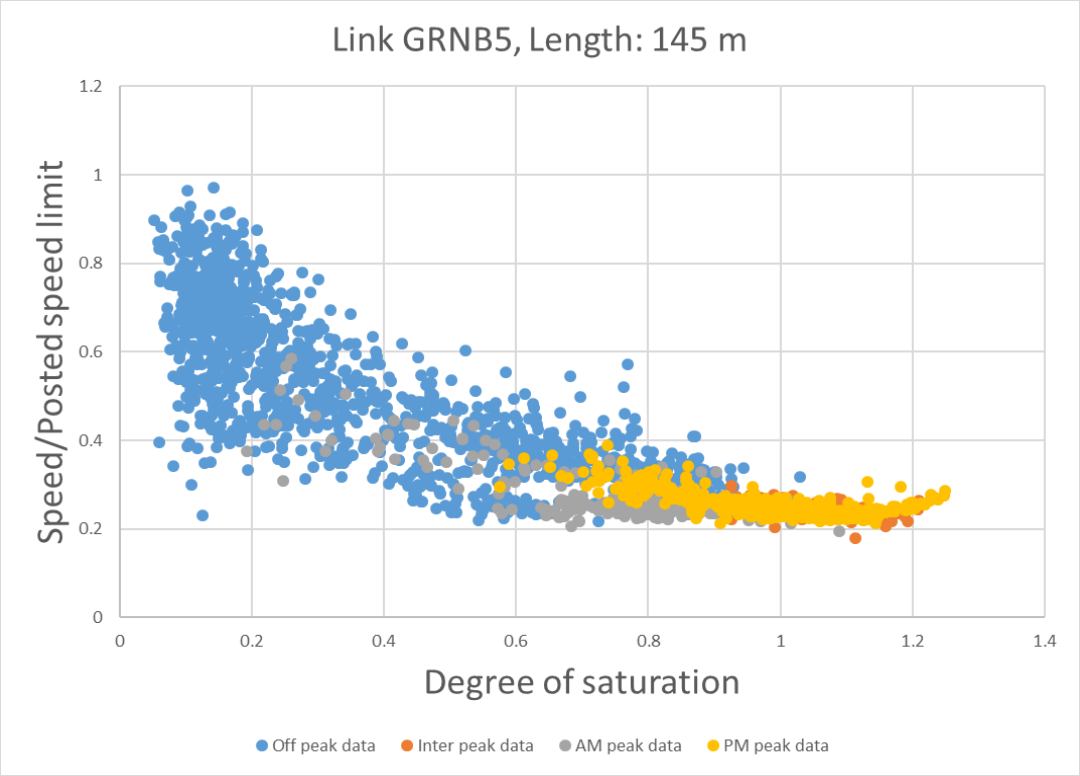
3.2 Observations of Speed Range before Flow Breakdown

The normalised speed-flow curves were then developed for all main corridor links located within the five corridor sites. After an initial review of the normalised speed-flow curves, some unexpected patterns were observed. In order to identify the speed range before flow breakdown, the following

filtering rules were developed and applied to avoid extreme scenarios that could not be generalised:

- Links shorter than 200 m usually demonstrated unexpected patterns of the speed-flow relationships; for example, Figure 3.3 shows a normalised speed-flow curve for link GRNB5 which is 145 m long. It shows that, during peak periods, the link speed was always low whether the DOS was low or high, and no turning point could be observed from the curve. Therefore, these links were excluded from further investigation.

Figure 3.3: Example of normalised speed-flow diagram for a short link (no clear pattern)



- The links which included pedestrian crossings were also excluded due to the infrequent pedestrian phases observed on these study corridors.
- Off-peak (12:00–5:00 am) speed data tended to be on the free-flow end. As the speed drops were most likely occurring during the peaks, different colours were used in these normalised speed-flow curves to differentiate data points in different peaks. The curve plotting should always focus on peak time data.

Both the speed range and average speed at the critical DOS were identified and used for validating the reference speed threshold. Details of the link ID, link length, critical DOS and the mean and range of speed at the critical DOS of all valid links on the five study sites can be found in Appendix C. The main findings are summarised in Table 3.1.

.

Table 3.1: Observations of speed range before flow breakdown for main corridor links greater than 200 m

Study site	Number of valid links (> 200m, with clear pattern)	Average NPI link length [m]	Average critical DOS	Speed range at critical DOS (as a ratio to PSL)	Mean speed at critical DOS (as a ratio to PSL)	Standard deviation of mean speed at critical DOS (as ratio to PSL)
Gympie Rd	24	502	0.80	0.60–0.76	0.68	0.10
Beaudesert Rd	29	660	0.82	0.55–0.68	0.62	0.16
Olsen Rd	8	783	0.78	0.52–0.61	0.56	0.15
Stafford Rd	15	431	0.82	0.57–0.73	0.65	0.16
Gold Coast Hwy	22	394	0.79	0.44–0.62	0.53	0.10
Valid links for all five sites	98	537	0.80	0.54–0.70	0.62	0.14

Table 3.1 and supplementary information in Appendix C, show that:

1. For the five study sites, a total of 98 links were longer than 200 m and there were clear patterns on the normalised speed-flow curves. The average link lengths were between 394 m and 783 m.
2. For those valid 98 links, the critical DOS was 0.8 for most links, with a range between 0.7 and 0.9.
3. The speed (as a ratio to PSL) varied between 0.54 and 0.70 (average 0.62) at the critical DOS. The speed ranges at the critical DOS were different for the five sites: the Gympie Road links had the highest speed (0.60–0.76), and the Gold Coast Highway links had the lowest speed (0.44–0.62).
4. The average speed (as a ratio to the PSL) at critical DOS for all 98 links was relatively consistent, with a mean of 0.62 and a standard deviation of 0.14.
5. The identified average speed at the critical DOS was very close to the LOS C of reference speed threshold (0.60 PSL); it was also relatively consistent with the current TMR reference speed threshold, i.e. 0.55 PSL.

4 TRAVEL TIME VARIABILITY AND VALIDATION

The purpose of this section of the report is to further assess and validate the feasibility of using both reference speed and intersection delay thresholds to measure excessive congestion. It also aims to identify which LOS for each method presents the best fit thresholds for the main corridors and side-streets (if they are deemed to be different).

The assessment involved travel time variability analysis using box and whisker plots, followed by the validation of threshold fitness by observing the CCTV footage and carrying out site inspections. TMR operators specifically selected intersections within the study sites that had functioning CCTV cameras and a clear, unrestricted view of all intersecting roads and side-streets.

A total of 17 intersections which had a CCTV camera were selected; the CCTV footage collected over four typical weeks in February – March were retrieved and observed. Data collected at 32 main corridor links and 25 side-street links was analysed and investigated. For each intersection, vehicle arrival and queuing from all approaches was observed and compared with the travel time variability charts. Details of the selected NPI links – including corridor name, intersection name, link description, NPI link ID, link length, posted speed limit (km/h), corridor/side-street – are showed in Appendix D (Table D 1).

4.1 Travel Time and Green Time Ratio Variability Charts

The variability of link travel times and green time ratios between different weekdays for each 15-minute interval was determined using the box and Whiskers charts. These charts show the minimum, maximum, mean, and three quantiles (25%, 50% and 75%) of the data values for each 15-minute interval across the whole day. It needs to be noted that, in the Whiskers charts, the average values for every 15-minute intervals are connected via a solid black line as shown in Figure 4.1. In order to assess the alignment of the congestion levels and the different thresholds, two sets of travel time variability charts were plotted for each selected link, one for the comparison of the reference speed thresholds in LOS B-D, and another for the comparison of the intersection delay thresholds in LOS B-D. An additional set of charts for the green time ratio variability was also plotted for each link as supporting operational information.

The southbound link of Gympie Road approaching Sadlier Street was selected as an example camera site. Table 4.1 lists the three links that intersect at the camera site; a total of 9 Whiskers charts were plotted for these three links. Figure 4.1 to Figure 4.3 are the three Whiskers' charts for link GRSB16; the other six charts are shown in Appendix E.

Table 4.1: NPI link information for Gympie Road and Sadlier Street intersection

Link description	NPI link ID	NPI link length (m)	Posted speed limit (km/h)	Corridor/side-street
Gympie Rd SB between Castle St Strathmore St & Sadlier St	GRSB16	335	60	Corridor
Gympie Rd NB between Broughton Rd Gympie Rd Off Ramp & Sadlier St	GRNB17	682	65	Corridor
Sadlier St WB between Leckie Rd & Gympie Rd	GRSS23	222	50	Side-street

Figure 4.1: Travel time variability and comparison of Thresholds$_{RID}$ at LOS B-D for corridor link GRSB16

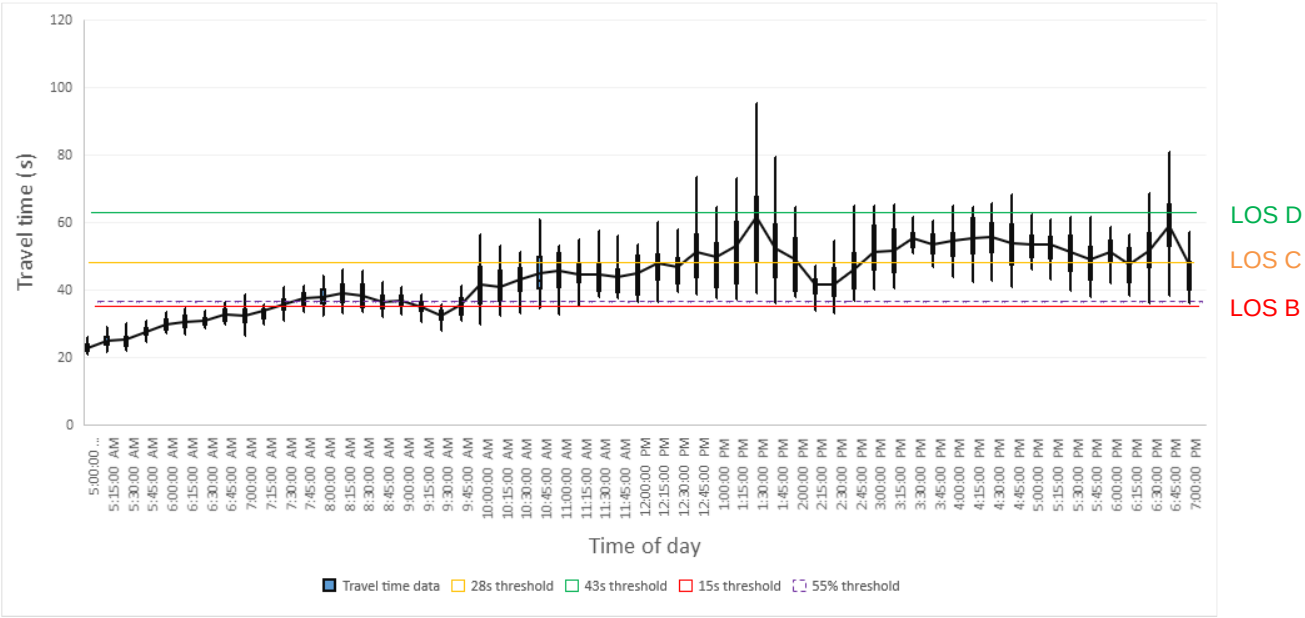


Figure 4.2: Travel time variability and comparison of Thresholds$_{RS}$ at LOS B-D for corridor link GRSB16

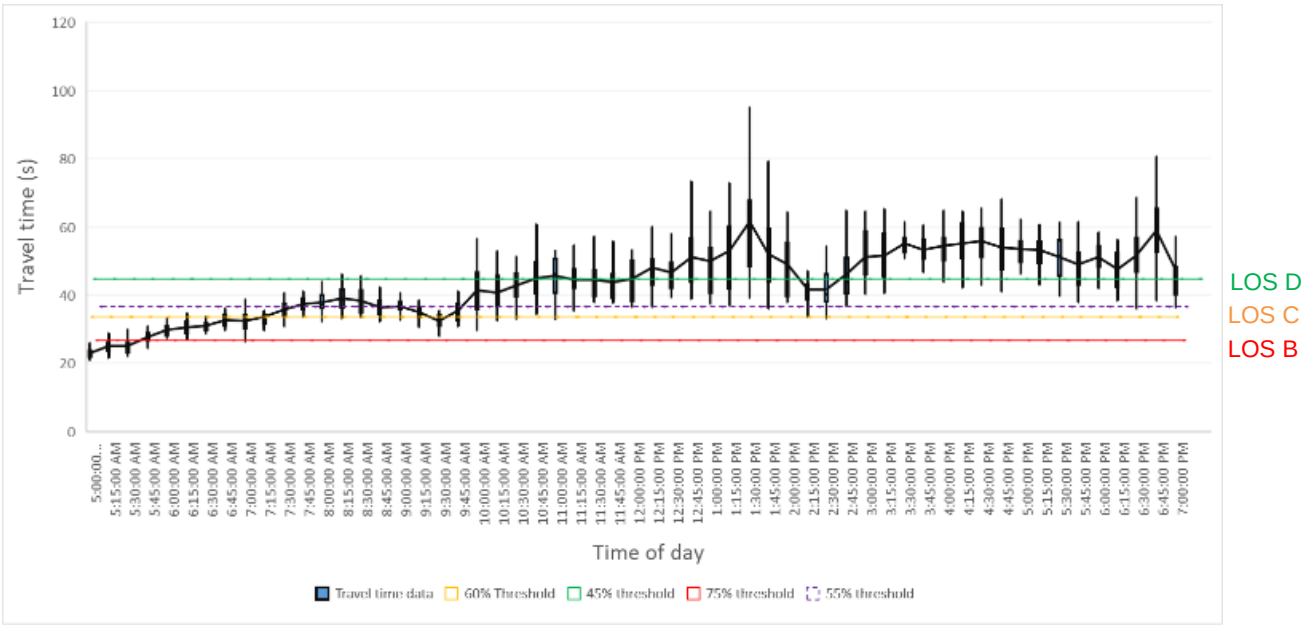


Figure 4.3: Green time ratio variability for corridor link GRSB16

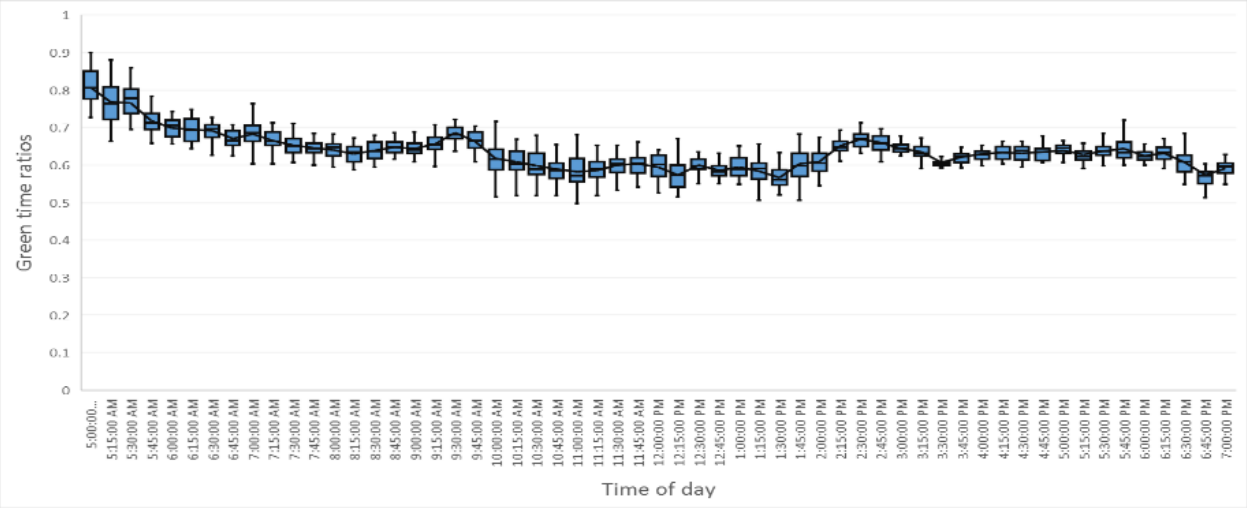


Figure 4.1 shows that for link GRSB16, if adopting the reference intersection delay at LOS D (i.e. 43 seconds), indicates negligible excessive congestion throughout the daytime, as all median travel times are below the green threshold line with occasional upper quartile or maximum values above the line. LOS C (i.e. 28 seconds) suggests minor excessive congestion in the afternoon, while LOS B (i.e. 15 seconds) suggests that most of the daytime periods (from 10:00 am – 7:00 pm) would observe some level of congestion.

Figure 4.2 shows that, for the same link GRSB16, the current reference speed threshold (i.e. 55% PSL) or LOS C (i.e. 60% PSL) has a similar threshold value to LOS B in the reference intersection delay method. There are indications of some level of congestion between 10:00 am and 7:00 pm. LOS D suggests that only minor congestion was observed, mainly in the afternoon, while LOS B suggests that congestion was observed over almost the entire daylight period (6:00 am – 7:00 pm).

Figure 4.3 shows that link GRSB 16, as the main corridor link, generally had a higher percentage of green time, e.g. about 60–65% on average, but their green time ratios drop to 55–60% during the inter-peak (10:00 am – 2:00 pm).

By reviewing all the travel time variability and threshold comparison data for all camera sites, some general observations are made as follows:

- The green time ratios are plotted as a variable that may influence the link's congestion level. Side-streets usually have a low percentage of green time throughout the day, e.g. below 25% on average. The main corridors, on the other hand, have a higher percentage of green time, e.g. around 55% on average, but their green time ratios drop to 40% to 50% during the inter-peak (10:00 am – 2:00 pm).
- The average travel time and the travel time variability for the main corridors during the inter-peak period (10:00 am – 2:00 pm) appears to be high compared with the AM and PM peaks, which indicates a higher congestion level. This could be caused by the reduction in green time ratio for the main corridors and a reduction in cycle time to service the side-streets. Side-streets, on the other hand, showed a reduction in travel time during the inter-peak period.

Note that these findings are based on observation and could be arbitrary. These charts were further used for video validations as discussed in Section 4.2.

4.2 Validation of Threshold Based on Operators' Knowledge

The suitability of LOS B-D thresholds was further validated by applying expert judgement. Traffic conditions were observed using video footage or site visits. The aim was to identify one threshold that could be applicable for both the main corridor and the side-street links.

A rating scale system, known as fitness score as shown in Table 4.2, was developed to indicate which threshold lines are the best fit for each approach, with '0' being the best fit threshold value. That means the threshold lines were able to reflect the level of excessive congestion (expressed as delay in seconds) and the duration of congestion with a high level of confidence. The polarity gives enough detail to indicate how far the other suboptimal values differ from the '0' (best fit).

Based on the observation and consistent validation of the video footage captured using the cameras against the travel time variability Whisker charts for those 57 selected NPI links, a fitness score was assigned for each of the LOS B-D thresholds for both the reference speed method and the reference intersection delay method for each link. Table 4.3 and Table 4.4 were then populated to record these scores for each link. The colour codes defined in Table 4.2 were also applied in Table 4.3 and Table 4.4 consistently, where the green cells indicate the best fit threshold for each link. As the impacts of some threshold values are very similar, the best fit thresholds could be more than one value.

Table 4.2: Fitness score definition

Rating	Definition	Comments
2	Underestimate	Above the best fit line
1	Slightly underestimate	Slightly above the best fit line
0	Best fit	The optimal threshold, provides the best estimates of excessive congestion
–1	Slightly overestimate	Slightly under the best fit line
–2	Overestimate	Under the best fit line

Table 4.3: Fitness score for each threshold – main corridor sites

NPI link ID	NPI link length (m)	LOS B (0.75 PSL)	LOS C (0.60 PSL)	Current (0.55 PSL)	LOS D (0.45 PSL)	LOS B (15 s/veh)	LOS C (28 s/veh)	LOS D (43 s/veh)
GRSB12	194	–1	0	0	1	–1	1	2
GCHWB9	210	–1	0	1	2	1	2	2
SREB8	235	–1	0	0	1	0	1	2
BRSB5	269	–1	0	0	1	1	1	2
ORSB2	297	–1	0	0	1	–1	0	1
ORNB4	297	–1	0	0	1	0	1	2
GRNB9	305	–1	0	0	1	0	1	2
BRNB6	312	–1	0	0	2	0	1	2
GCHWB3	333	–1	0	0	1	0	1	2
GRSB16	335	–1	0	0	1	0	1	2
SRWB4	348	–1	0	0	1	0	1	2
GRNB13	408	–1	0	0	1	0	1	2
GCHEB8	431	0	1	1	2	0	1	2
GCHWB6	436	–1	0	1	2	0	1	2

NPI link ID	NPI link length (m)	LOS B (0.75 PSL)	LOS C (0.60 PSL)	Current (0.55 PSL)	LOS D (0.45 PSL)	LOS B (15 s/veh)	LOS C (28 s/veh)	LOS D (43 s/veh)
GCHEB6	436	–2	–1	0	1	–1	1	2
GRNB15	439	–1	0	0	1	–1	0	1
GCHWB7	441	–2	–1	0	2	–1	1	2
BRNB13	445	–1	0	0	1	0	1	2
GCHEB2	456	–2	–1	0	1	–1	0	1
SREB9	460	–1	0	0	1	–1	0	1
SRWB9	460	–1	0	0	1	–1	0	1
ORNB3	504	–1	0	0	1	–1	0	1
ORSB3	504	–1	0	0	1	–1	0	1
BRNB2	511	–1	0	0	1	0	1	2
GRNB17	682	–1	0	0	1	–1	0	1
GRSB14	735	–1	0	0	1	–2	–1	0
GRSB8	869	–2	–1	0	2	–2	–1	0
ORNB2	911	–2	–1	0	1	–2	–1	0
SREB3	967	–1	0	0	1	–1	0	1
BRSB12	1000	0	1	1	2	0	1	2
BRSB1	1154	–1	0	0	1	–1	0	1
ORSB1	1422	–1	0	0	1	–2	–1	0
Count of “0”		2	25	28	0	13	10	4

Table 4.4: Fitness score for each threshold – side street sites

NPI link ID	NPI link length (m)	LOS B (0.75 PSL)	LOS C (0.60 PSL)	Current (0.55 PSL)	LOS D (0.45 PSL)	LOS B (15 s/veh)	LOS C (28 s/veh)	LOS D (43 s/veh)
ORSS3	87	–2	–2	–2	–2	–2	–1	0
GCHSS10	115	–2	–2	–2	–2	–2	–1	0
GCHSS8	123	–2	–2	–2	–2	–2	–1	0
ORSS6	138	–2	–2	–2	–2	–1	0	1
GCHSS11	174	–2	–2	–2	–2	–2	–1	0
GRSS23	222	–1	0	0	1	0	1	2
GRSS16	245	–1	0	0	1	0	1	2
BRSS20	284	–1	–1	–1	0	–1	0	1
GRSS10	300	–2	–1	–1	–1	–2	–1	0
GRSS20	360	–1	0	0	1	0	1	2
GCHEB5	375	–1	0	1	2	0	1	2
GCHSS5	405	–1	0	0	1	–2	–1	0
SSS6	433	–2	–1	–1	0	–2	–1	0
ORSS5	471	–1	0	0	1	–1	0	1
BRSS3	501	–1	0	0	1	–1	0	1
GRSS15	591	–1	0	0	1	–2	–1	0
BRSS4	710	–2	–1	–1	0	–2	–1	0

NPI link ID	NPI link length (m)	LOS B (0.75 PSL)	LOS C (0.60 PSL)	Current (0.55 PSL)	LOS D (0.45 PSL)	LOS B (15 s/veh)	LOS C (28 s/veh)	LOS D (43 s/veh)
ORSS4	714	–2	–1	0	2	–1	0	1
SSS10	810	–1	0	0	1	–2	–1	0
GCHSS4	824	–2	–1	–1	0	–1	0	1
BRSS10	833	–1	0	0	1	–1	–1	0
SSS9	1127	–1	0	0	1	–2	–1	–1
GRSS19	1218	0	1	1	2	0	0	1
SSS5	1449	0	1	1	2	–1	0	1
GCHSS9	1457	–1	0	1	2	–2	–1	–1
Count of "0"		2	12	11	4	5	8	11

Note: The fitness scores are obtained based on expert judgement and could be arbitrary.

Observation of the fitness scores in Table 4.3 and Table 4.4 shows the following:

1. For the main corridor links, the current threshold of 0.55 PSL is still the best fit threshold to measure the excessive congestion delay for 28 out of 32 links. For the other four links, the 0.55 PSL is just slightly above the best fit line. In this case it is suggested that the current 0.55 PSL for main corridor analysis be retained.

2. For side-street links, the results seem to be divided. For links that are longer than 200 metres, both 0.6 PSL and 0.55 PSL seem to be a good fit for the majority of the links. While the difference in threshold values resulting from the two ratios are very minor, it would be logical to use 0.55 PSL so that a consistent ratio can be applied to all road links.

3. For side-street links configured to be less than 200 m in length, the best fit threshold appears to be the intersection delay method at LOS D (43 seconds), as four out of the five short links has a '0' assigned. As shown in Figure 4.4, the reference speed method was not able to measure the level of congestion properly. The short NPI link length for the Central Street Eastbound link (ORSS3) resulted in a travel time threshold value ranging from 8 to 14 seconds. This suggests that this link had excessive congestion throughout the day. However, while the side-streets tend to receive a lower priority in green signals, especially during peak hours for better coordination, it is unrealistic to define any travel time beyond 8–14 seconds as excessive congestion. Even outside peak hours, the minimum inter-green time is 7 seconds. Therefore the reference speed method tends to overestimate the excessive congestion in this case. On the other hand, the intersection delay method at LOS D appears to be more appropriate to capture the excessive delay as shown in Table 4.4 and Figure 4.5.

4. In addition to point 3 above, it was also discovered that the short NPI link length for side-streets has the tendency to present a problematic profile for site validation. In NPI configuration, the minimum travel speed for arterial roads has been set up as 7 km/h. Using ORSS3 as an example, a minimum travel speed of 7 km/h on an 87 metre long link equates to a maximum travel time of 45 seconds. That limits any periods with a link travel time exceeding 45 seconds to be reported accurately. As shown in Figure 4.4, it potentially disregards the variations during the day. Although the 7 km/h cap applies to all NPI links, it is applied more often for these lower-order side-streets due to their lower priority and green ratios. It may lead to a need to review and reconsider the minimum link length when setting up NPI links for side-streets.

Figure 4.4: Travel time variability and comparison of Thresholds$_{RS}$ at LOS B-D for side-street link ORSS3

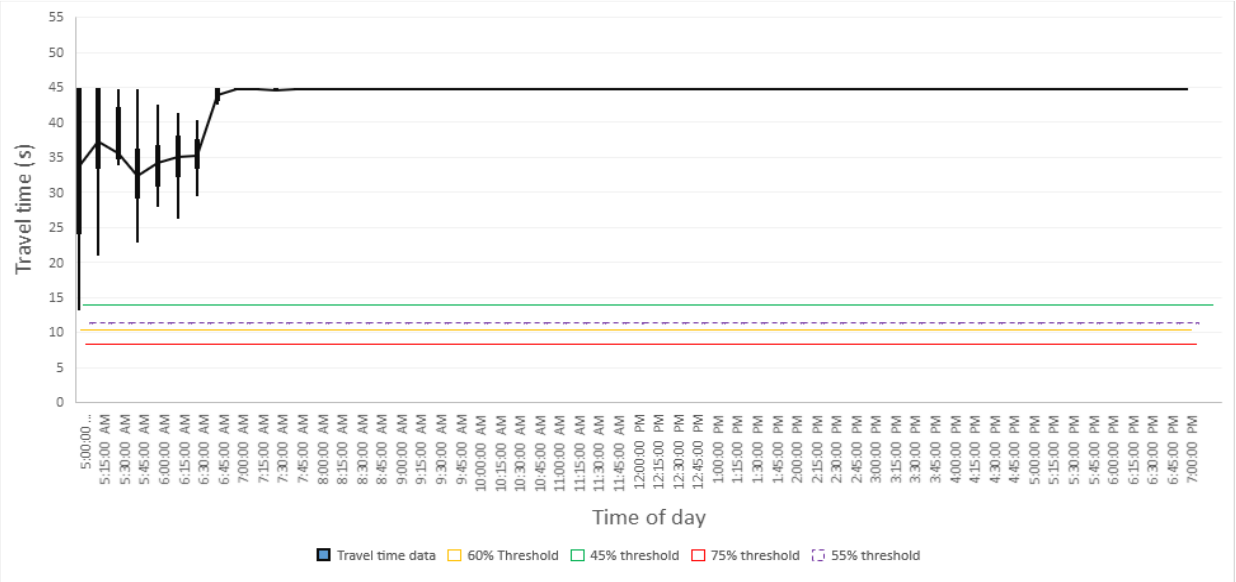
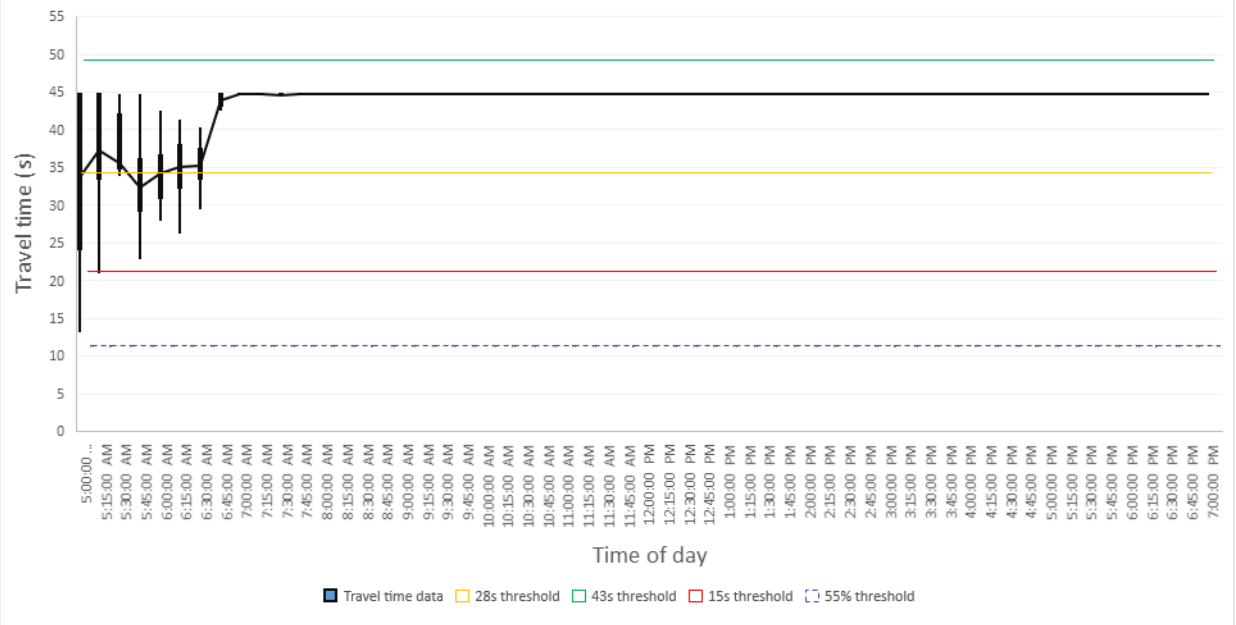


Figure 4.5: Travel time variability and comparison of Thresholds$_{RID}$ at LOS B-D for side-street link ORSS3



4.3 Impacts Check (ANOVA)

To understand if the road link attributes – including link length, peak-hour cycle time, green ratio and traffic volume – have any impacts on the fitness of different thresholds, particularly side-street links, further analysis was conducted using a statistical model – the analysis of variance (ANOVA).

ANOVA was applied to assess the differences between groups of side-street samples by using F-tests. Two models were set up for ANOVA analysis, one for reference speed ratio fitness and one for intersection delay fitness.

The model then picks up the best-fit threshold values of each side-street link in Table 4.3 or Table 4.4 (i.e. having a value of '0'). The threshold value of the two reference methods such as 0.45, 0.55, 0.6, 0.75 and 15, 28 and 43 seconds are treated as the dependent variables, while the

link length, peak-hour cycle time, green ratio and traffic volume are treated as independent variables. For each model, the sample data points are categorised by the four independent variables into four groups for comparison.

Table 4.5 shows the results for the reference speed method. Cycle length and peak green ratio do not have significant impact on threshold changes, while link length and peak volume appears to have significant impact on the threshold change. The positive F-value suggested that, the longer the link length, the higher the PSL ratio deemed appropriate. Similar to link length, the peak-hour volume seemed to correlate better with a higher PSL ratio.

Table 4.6 shows the results for the intersection delay method. None of the four independent variables have significant impact on the threshold fitness, suggesting that correlations could not be established between these independent variables and the threshold values.

This finding is supplementary evidence that, when applying the reference speed method, the link length could be an influential factor for threshold selection and excessive delay estimation. On the other hand, intersection delay thresholds are more independent from the link length.

Note that the results for the intersection delay method were generated from 22 valid samples whilst the results for the reference speed method were generated from 17 valid samples. In order to draw a valid conclusion, this exercise should be repeated with a much larger sample.

Table 4.5: ANOVA best-fit output from SPSS – Reference speed method

		Sum of Squares		df	Mean Square	F	Sig.
Link length (metres)	Between groups	1059171		3	353057	4.805	0.018
	Within groups	955274		13	73483		
	Total	2014446		16			
Peak hour average cycle time (seconds)	Between groups	2072		3	691	0.781	0.525
	Within groups	11498		13	884		
	Total	13571		16			
Peak hour green ratio (%)	Between groups	210		3	70	1.414	0.283
	Within groups	645		13	50		
	Total	855		16			
Peak hour volume (15-minute interval)	Between groups	81470		3	27157	5.413	0.012
	Within groups	65220		13	5017		
	Total	146690		16			

Table 4.6: ANOVA best-fit output from SPSS – Intersection delay method

		Sum of Squares	df	Mean Square	F	Sig.
Link length (m)	Between groups	547353	2	273676	2.321	0.125
	Within groups	2240076	19	117899		
	Total	2787429	21			
	Between groups	251	2	125	0.164	0.850

		Sum of Squares	df	Mean Square	F	Sig.
Peak hour average cycle time (s)	Within groups	14547	19	766		
	Total	14798	21			
Peak hour green ratio (%)	Between groups	9	2	5	0.080	0.924
	Within groups	1077	19	57		
	Total	1086	21			
Peak hour volume (15-minute interval)	Between groups	5308	2	2654	0.309	0.738
	Within groups	163119	19	8585		
	Total	168426	21			

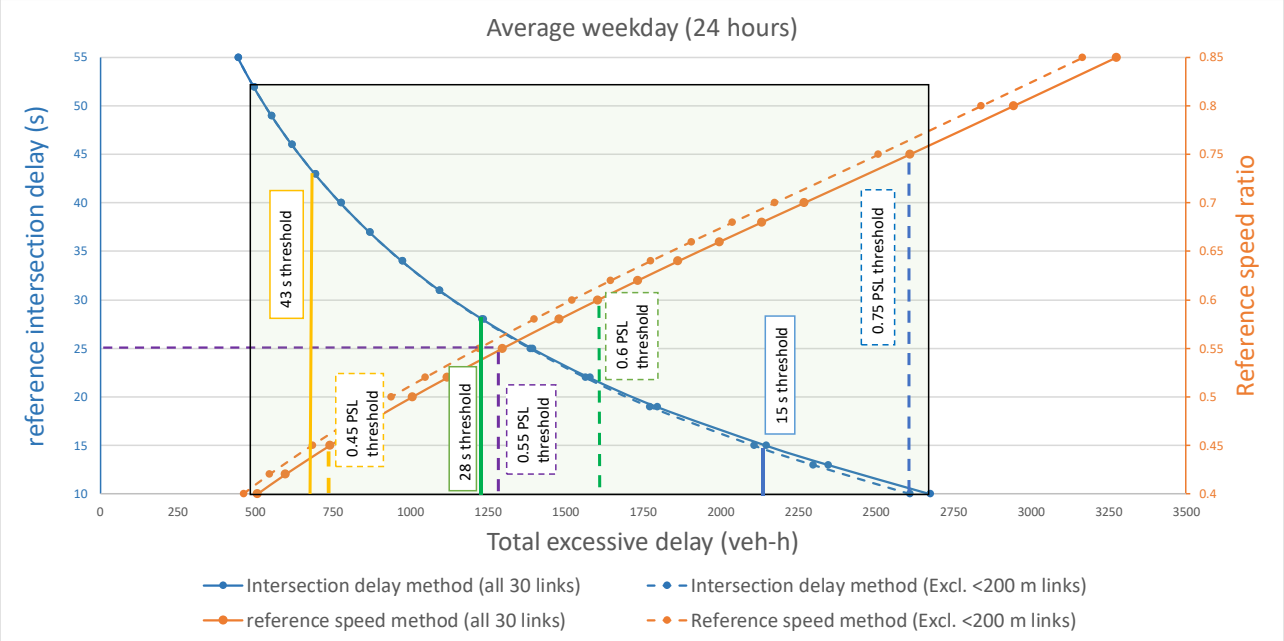
5 SENSITIVITY OF TOTAL EXCESSIVE DELAYS AGAINST THRESHOLD LEVELS

In this section, total excessive delays refer to the total excessive delays of all main corridor and/or side-street links within the study site for an average weekday during the study time period (i.e. 13 February 2017 to 12 March 2017).

The aim was to test the impacts on total excessive delays when the threshold is changing from LOS B-D, and between the reference speed method and intersection delay method. The analysis in this section follows the same methodology defined in the Stage 1 report (Han and Mahajerpoor 2017). The NPI excessive delays were calculated using $Threshold_{RS}$ and $Threshold_{RID}$ by adopting the LOS B, C and D criteria respectively. The analysis also attempted to identify the impact of side-street links that were shorter than 200 m.

Figure 5.1 shows an example of a sensitivity analysis chart of total excessive delay for the Beaudesert Road main corridor links against the different threshold values. The thresholds from both the intersection delay method and the reference delay method at LOS B-D were applied and they are displayed in the chart.

Figure 5.1: Total excessive delay of the main corridor links vs two references – Beaudesert Road



The sensitivity analysis of the Beaudesert Road main corridor links in Figure 5.1 shows that:

- The change of reference speeds and reference intersection delays from LOS B-D had a significant impact on the estimation of total excessive delay. The total excessive delays were more sensitive to the change in reference speeds than to the change in reference intersection delays, as the total excessive delay between LOS B and D decreased by 1826 veh-h per weekday based on the reference speed method while the decrease based on the intersection delay method was 1414 veh-h per weekday.
- The total excessive delay obtained by using the current reference speed ratio (0.55) was 1219 veh-h per weekday, which was equivalent to the total excessive delay estimated by using the 27 seconds reference intersection delay (approximately LOS C). The point is indicated in Figure 5.1 by the purple dashed horizontal line.

- The total excessive delay obtained by using the LOS D reference speed ratio (0.45) was 682 veh-h per weekday, which was very close to the total excessive delay estimated by using the 43 seconds reference intersection delay (approximately LOS D).
- There is only one main corridor link that is shorter than 200 m. It contributes to 3% of the total excessive delay for the whole site if the current threshold is used.
- There are three side-street links that are shorter than 200 m; however, the total estimated excessive delays are negligible for any of the thresholds considered.

For each study site, one sensitivity analysis chart was developed for the main corridor links and another for the side-street links. A further nine charts for all five study sites are attached in Appendix F.

The key values of total excessive delay estimation at different levels of threshold using the two methods for all five study sites are presented in Table 5.1. The total excessive delay for the main corridor links, side-street links and links shorter than 200 m are also given separately in the Table.

Table 5.1: Summary of total excessive delays in veh-h at LOS B-D using two methods

Corridor	Total excessive delay (veh-h) by link type	Reference speed method				Intersection delay method		
		LOS B 0.75 PSL	LOS C 0.6 PSL	LOS D 0.45 PSL	Current 0.55 PSL	LOS B 15 s	LOS C 28 s	LOS D 43 s
Beaudesert Road	All 56 links	4322	3033	1792	2614	3849	2633	1728
	Main corridor 30 links	2508	1519	682	1219	2106	1229	692
	Main corridor links < 200 m, 1 link	100	84	57	76	40	4	0
		2% of whole site	3% of whole site	3% of whole site	3% of whole site	1% of whole site	0% of whole site	0% of whole site
	Side-street, 26 links	1814	1514	1110	1395	1743	1404	1036
	Side-street links < 200 m, 3 links	9	9	8	8	7	5	2
		0% of whole site	0% of whole site	0% of whole site	0% of whole site	0% of whole site	0% of whole site	0% of whole site
Gold Coast Hwy	All 38 links	1792	1236	737	1057	1406	892	524
	Main corridor, 22 links	1045	649	336	532	699	362	174
	Main corridor links < 200 m, 0 link	0	0	0	0	0	0	0
	Side-street, 16 links	747	587	401	525	707	530	350
	Side-street links < 200 m, 6 links	56	54	48	52	42	26	10
		3% of whole site	4% of whole site	7% of whole site	5% of whole site	3% of whole site	3% of whole site	2% of whole site

Corridor	Total excessive delay (veh-h) by link type	Reference speed method				Intersection delay method		
		LOS B 0.75 PSL	LOS C 0.6 PSL	LOS D 0.45 PSL	Current 0.55 PSL	LOS B 15 s	LOS C 28 s	LOS D 43 s
Gympie Road	All 48 links	8720	6480	4055	5684	6413	3997	2445
	Main corridor 36 links	7037	5084	3020	4400	4878	2831	1636
	Main corridor links < 200 m, 12 links	1637	1334	892	1207	459	66	2
		19% of whole site	21% of whole site	22% of whole site	21% of whole site	7% of whole site	2% of whole site	0% of whole site
	Side-street, 26 links	1683	1396	1035	1284	1535	1166	809
	Side-street links < 200 m, 8 links	383	360	320	349	291	193	94
		4% of whole site	6% of whole site	8% of whole site	6% of whole site	5% of whole site	5% of whole site	4% of whole site
Olsen Avenue	All 16 links	1136	790	464	676	1019	657	402
	Main corridor, 8 links	683	396	163	309	618	350	192
	Corridor links < 200 m, 0 link	0	0	0	0	0	0	0
	Side-street, 8 links	453	394	301	367	401	307	210
	Side-street links < 200 m, 2 links	41	38	33	36	27	14	1
		4% of whole site	5% of whole site	7% of whole site	5% of whole site	3% of whole site	3% of whole site	0% of whole site
Stafford Road	All 31 links	2792	2179	1413	1949	2573	1873	1211
	Main corridor, 19 links	954	729	471	648	850	610	400
	Main corridor links < 200 m, 4 links	29	21	16	19	11	3	0
		1% of whole site	1% of whole site	1% of whole site	1% of whole site	0% of whole site	0% of whole site	0% of whole site
	Side-street, 12 links	1838	1450	942	1301	1723	1263	811
	Side-street links < 200 m, 0 links	0	0	0	0	0	0	0

Note: Main corridor refers to main corridor links only, whereas the whole site refers to both main corridor and side-street links.

The key findings identified from Table 5.1 are as follows:

- The change in reference speeds and reference intersection delays from LOS B-D had a significant impact on the estimation of total excessive delay. The total excessive delays were more sensitive to the change in reference speeds than to the change in reference intersection delays.
- The total excessive delay obtained by using the current reference speed ratio (0.55) for most study sites (both main corridor and side-streets) was equivalent to the total excessive delay estimated using the LOS C reference intersection delay (around 28 seconds). The point is indicated in all sensitivity analysis charts (i.e. Figure 5.1 and all charts in Appendix F by the purple dashed horizontal lines.

- The total excessive delay obtained by using LOS D of reference speed ratio (0.45) for most study sites (both main corridor and side-streets) was significantly different from the total excessive delay estimated using the LOS D reference intersection delay (around 43 seconds).
- Side-street links shorter than 200 m generally had a small impact (0–6%) on the total excessive delay for the whole site when the current reference speed threshold (i.e. 0.55 PSL) was used. This impact would be even smaller (0–4%) if the intersection delay method LOS D 43 seconds) was used. It is therefore obvious that the overall impact of changing the methodology for short side-streets (from 0.55 PSL) to using an intersection delay of 43 seconds is small. However, in certain cases, and when only considering the impact on side-streets of a corridor, it can be significant. Also, when considering the excessive delay caused by incidents, the improvement in methodology could have a significant impact.

6 MAIN FINDINGS AND RECOMMENDATIONS

Stage 2 of project R47 involved an evaluation of the feasibility of measuring excessive delay using the reference speed and intersection delay methods. Various tests and validation using data from five SEQ arterial corridors found that:

1. In the reference speed validation, a total of 98 main corridor links were identified where link lengths were greater than 200 m and with clear patterns in terms of speed-flow curves. The observation of these normalised speed-flow curves showed that the speed dropped significantly after a critical DOS, which is about 0.8. The speed range for the five study sites at the critical DOS was between 0.54–0.70 PSL. The average speeds at critical DOS for all 98 links showed a quite consistent pattern, with a mean of 0.62 PSL and standard deviation of 0.14 PSL. This average speed is very close to the LOS C of reference speed threshold (0.60 PSL), and it is also relatively consistent with the current TMR reference speed threshold, i.e. 0.55 PSL.
2. In the travel time variability analysis and validation based on road operators' knowledge, a total of 57 links were selected to investigate travel time variability and to compare it with historic video data. It was identified that for main corridor links, the current threshold 0.55 PSL is still the best fit threshold to measure the excessive congestion delay. For side-street links that are longer than 200 m, 0.55 PSL still seems to be a reasonably good fit for the majority of the links. For side-street links shorter than 200 m, the best fit threshold appears to be the intersection delay method at LOS D (43 seconds). Further ANOVA testing showed that, when applying the reference speed method, the link length and peak volume could be influential factors for threshold selection and excessive delay estimation. On the other hand, intersection delay thresholds are more independent from link length, peak volume, cycle length and green ratio.
3. From the sensitivity analysis, total excessive delay for all the main corridor links and side-street links were plotted against different levels of thresholds for both methods. The total excessive delays were more sensitive to the change of reference speeds than to the change of reference intersection delays. The total excessive delay obtained using the current reference speed ratio (0.55) for most study sites (both main corridor and side-streets) was equivalent to the total excessive delay estimated using the LOS C reference intersection delay (around 28 seconds). However, the total excessive delay obtained by using the LOS D of the reference speed ratio (0.45) for most study sites (both main corridor and side-streets) was significantly different from the total excessive delay estimated by using LOS D of reference intersection delay (around 43 seconds). Side-street links shorter than 200 m generally had a small impact (0–6%) on the total excessive delays for the whole site when using the current reference speed threshold (i.e. 55% of PSL). This impact would be even smaller (0–4%) if using the intersection delay method LOS D (i.e. 43 seconds).

By consolidating the key findings from this report and the Stage 1 report, it is suggested that:

1. For all lengths of main corridor links and side-streets links longer than 200 m, the current 0.55 PSL is still the best-fit threshold.
2. For side streets shorter than 200 m, the use of the 43 second intersection delay as the reference for excessive delay estimation should be considered. However, since the overall impact of this improvement is small, the effort involved in modifying the current systems to accommodate a secondary threshold should be considered.
3. For future NPI link establishment, it would be preferable to define the minimum link length as 200 m to enable the excessive delay on side-streets to be estimated with a higher degree of accuracy and confidence.

REFERENCES

Austroads 2007, *National performance indicators for network operations*, by RJ Troutbeck, M Su & J Luk, AP-R305-07, Austroads, Sydney, NSW.

Austroads 2009a, *Estimating road network congestion and associated costs*, by J Luk, G Kazantzidis & C Han, AP-R345-09, Austroads, Sydney, NSW.

Austroads 2009b, *Implementation of national network performance indicators: first round results*, by J Luk & G Kazantzidis, AP-T122-09, Austroads, Sydney, NSW.

Austroads 2017, *Guide to traffic management: part 3: traffic studies and analysis*, 3rd edn, by C Han, I Espada, G Gers & R Mahajerpoor AGTM03-17, Austroads, Sydney, NSW.

Bennett, P, Luk, J & Marsh, B 2008, 'Real-time estimation of travel times on arterial roads: the ARRB travel time model'*, Conference of Australian Institutes of Transport Research (CAITR), 30th, 2008, Perth, Western Australia*, University of Western Australia, Crawley, WA.

Dekker, F, Dhanjee, A, Johnston, D, Blogg, M & Johnston, K 2015, 'Analysing the cost of excessive congestion on state-controlled roads in Brisbane', *Australian Institute of Traffic Planning and Management (AITPM) national conference, 2015, Brisbane, Queensland, Australia*, AITPM, Toombul, Qld.

Han, C & Byrne, M 2016a, 'Measuring the cost of congestion on a multi-modal basis: case study 2', contract report 000580-3, ARRB Group, Vermont South, Vic.

Han, C & Byrne, M 2016b, 'Measuring the cost of congestion on a multi-modal basis: case study 1', contract report 000580-2, ARRB Group, Vermont South, Vic.

Han, C & Mahajerpoor, R 2017, 'Review and update the methodology of measuring excessive congestion'*,* contract report PRJ16077-2, ARRB Group, Vermont South, Vic.

Han, C, Tadros, M & Wu, K 2017, 'Measuring excessive congestion costs for freeways and arterials by using multiple data sources, Bruce Highway case study'*,* contract report PRJ16077-1, ARRB Group, Vermont South, Vic.

Luk, J 2008, 'Support information for implementing online NPIs in STREAMS', contract report prepared forTMR, VC74151-3, ARRB Group, Vermont South, Vic.

Luk, J, Han, C & Byrne, M 2016, 'Measuring the cost of congestion on a multi-modal basis: methodology report', contract report 000580-1, ARRB Group, Vermont South, Vic.

Luk, J, Karl, CA, Su, M & Bennett, P 2006, 'Real-time estimation of travel times on arterial roads in Melbourne, *ARRB conference, 22nd, 2006, Canberra, ACT, Australia*, ARRB Group, Vermont South, Vic, 14 pp.

OpenStreetMap Contributors 2018, 'Queensland', map data, OpenStreetMap Foundation.

Queensland Department of Transport and Main Roads 2014, 'Memorandum to SEQ Road Operations on intersection performance tool', developed by M Blogg and F Dekker, ref 0S20R001973.C.1, TMR, Brisbane, Qld.

APPENDIX A TERMINOLOGY

This section lists the terminology and the definitions used in the report:

- **ARRB travel time model (ATTM)**: ARRB Group (ARRB) developed this model to calculate real-time travel time estimations on arterial roads at the link level (refer to the definition of NPI links) using real-time data from traffic control systems such as SCATS and STREAMS (Luk et al. 2006; Bennett, Luk & Marsh 2008). The ATTM calculates travel time of through traffic as the sum of cruise time[1], uniform delay[2] and overflow delay[3].
- **ARRB congestion model (ACM)**: ARRB Group (ARRB) developed this model (Austroads 2009a) to calculate congestion and associated costs using speed and volume data from freeways and arterials. In ACM, the congestion cost consists of excessive delay costs, extra pollutant costs and extra fuel costs due to congestion delays.
- **Arterials**: Arterials refer to typical urban arterial roads (divided) such as Gympie Road.
- **Excessive delay**: also known as excessive congestion delay, the excessive delay was defined in the ACM (Austroads 2009a) to estimate congestion delay cost. It is the *extra delay* or *excessive delay* with reference to an optimal (spatial) speed for a road user group (spatial speed is the inverse of travel time), rather than the free-flow speed (FFS) or the posted speed limit (PSL). The traffic flow at this optimal speed leads to maximum overall road user benefit and is closely linked to the speed before flow breakdown in a traffic facility.
- **Excessive delay threshold (Threshold)**: The benchmark or threshold travel time value (in seconds) above which the travel time is considered as excessive delay.
- **Excessive delay threshold using reference speed (*Threshold$_{RS}$*)**: In the TMR-ARRB cost-of-congestion reporting process, the threshold is the link travel time value (in seconds) at the reference speed.

$$Threshold_{RS} = \frac{NPI\ link\ length}{Reference\ speed\ ratio\ \times PSL} \quad (1)$$

where

Reference speed ratio = 0.55 for urban arterials and 0.7 for freeways in the TMR application of ACM

[1] Cruise time – This is the travel time less stopped delay (control delay) on a link. It is dependent on traffic and road geometric conditions. Cruise times should be calibrated for each link. A link cruise time increases with congestion due to more vehicle-to-vehicle interactions. In this report, cruise time is assumed to be unaffected by traffic along the link and road geometry; therefore it is assumed to be travel time at the posted speed limit (as used in the TMR adopted ATTM). The implication is that the only delay on the link is assumed to be caused by the signalised intersection at which the link ends, which is the sum of uniform delay and overflow delay, as described below.

[2] Uniform Delay – The delay due to through traffic arriving at a traffic signal with a uniform distribution. This delay is due to the red phase at a traffic signal. Proper signal coordination improves traffic progression and hence reduces uniform delay.

[3] Overflow delay – Traffic seldom arrives uniformly at a traffic signal, so it is necessary to consider an extra delay due to random arrivals and oversaturation due to arrival through traffic exceeding the capacity (degree of saturation > 1).

- **Excessive delay threshold using reference intersection delay (*$Threshold_{RID}$*)**: The benchmark or threshold travel time value (in seconds) above which the travel time is considered as excessive delay. If using a reference intersection delay to estimate the excessive delay, the threshold would be calculated as follows:

$$Threshold_{RID} = \frac{NPI\ link\ length}{PSL} + Reference\ intersection\ delay \quad (2)$$

- **National performance indicator (NPI)**: Austroads has established the National Performance Indicator (NPI) program since 1995 to measure and report performance indicators for the road system (Austroads 2007, 2009b). The indicators used to be published yearly and focussed on monitoring road safety, environmental effects, the traffic system and other areas of importance. To determine their road operations NPIs, TMR is using STREAMS together with their STREAMS NPI reporting system.
- **NPI delay:** TMR adopted ATTM to estimate the NPI delay and NPI travel time. The NPI delay is the control delay (the sum of uniform delay and overflow delay) for the downstream signalised intersection of each arterial NPI link as defined in ATTM.
- **NPI excessive delay**: The excessive delay for arterial NPI links estimated by using NPI data.

$$NPI\ excessive\ delay = NPI\ travel\ time - Threshold \quad (3)$$

for NPI travel time > Threshold

= 0 for NPI travel time ≤ Threshold

where

Threshold = $Threshold_{RS}, or\ Threshold_{RID}$

- **NPI link**: An arterial NPI link (used for arterial roads and their side-streets) is either one or a sequence of contiguous surface street transport network links that terminate at a signalised intersection and, where possible, also commence at a signalised intersection. Where it consists of two or more transport network links, its length cannot exceed a prescribed threshold value (set to 1500 m). Subsequently there are two scenarios when an NPI link can commence at an **un**signalised intersection: (1) due to the above threshold, or (2) when no contiguous transport network link is available (which occurs more on side-streets). The NPI link is used as the basic unit by TMR for the calculation of NPIs, excessive delay and the cost of congestion.
- **NPI travel time**: TMR adopted ATTM to estimate the NPI delay and NPI travel time. NPI travel time is the estimated travel time of each NPI link. In the TMR application of ATTM, it is assumed that all delays are due to the intersection control delay; therefore, the cruise travel time is assumed to be the travel time at the PSL. NPI travel time is therefore defined by Equation 4 as follows:

$$NPI\ travel\ time = NPI\ delay\ +\ Cruise\ time \quad (4)$$

where

NPI delay = the sum of uniform delay and overflow delay at intersections, which is calculated via ATTM (as control delay)

Cruise time = free-flow travel time (assumed to be the link travel time at PSL)

In the TMR application, Equation 4 can be rewritten as follows:

$$NPI\ travel\ time = NPI\ delay + \frac{NPI\ link\ length}{PSL} \quad (5)$$

- **NPI speed**: The estimated average link speed of each NPI link. In TMR NPI speed is estimated using the NPI travel time and link length.

$$NPI\ speed = \frac{NPI\ link\ length}{NPI\ travel\ time} \quad (6)$$

- **Reference intersection delay**: Following the LOS definition in the Highway Capacity Manual (HCM) (Transportation Research Board (TRB) 2016) and the Guide to Traffic Management (ATM) Part 3 (Austroads 2017), it is proposed to use a reference intersection delay (control delay) as the benchmark to estimate the excessive delay for arterial roads. Reference intersection delay is a constant time value in seconds.
- **Reference speed**: the optimal speed which is used for estimating the excessive delay as recommended in ACM.
- **Reference speed ratio:** the ratio of reference speed to the PSL, which is used to measure the excessive delay. In current TMR practice, the reference speed ratios are 70% for freeways and 55% for arterials.
- **Side-streets**: Side-streets refer to lower-order roads (usually two-way, two-lane roads) that end at arterial roads, but do not belong to any arterial road corridors. In the Gympie Road study, these side-streets usually have less than 150 veh/h/lane during the peak period and receive less than 20% of the cycle time as the effective green time. There are other types of side-streets that have more lanes or belong to other arterial corridors, which are not addressed in this report.

APPENDIX B STUDY SITES AND DATA GAPS

B.1 Beaudesert Road Case Study Site

Table B 1: List of Beaudesert Road main corridor NPI link details

Link description	NPI link ID	NPI link length (m)	Posted Speed Limit (km/h)
Northbound			
Beaudesert Rd, northbound between Boyland Ave & Beaudesert Rd (refer to the section between Boundary Rd & Riawena Rd)	BRNB1	1154	70
Beaudesert Rd, northbound between Kerry Rd & Boundary Rd	BRNB2	511	70
Beaudesert Rd, northbound between Mortimer Rd & Kerry Rd	BRNB3	771	70
Beaudesert Rd northbound between Acacia Ridge & Mortimer Rd	BRNB4	184	70
Beaudesert Rd, northbound between Oconnel St & Acacia Ridge	BRNB5	659	70
Beaudesert Rd, northbound between Elizabeth St & Oconnel St	BRNB6	269	70
Beaudesert Rd, north-westbound between Paradise Rd & Elizabeth St	BRNB7	312	70
Beaudesert Rd, north-westbound between Bradman St & Paradise Rd	BRNB8	792	70
Beaudesert Rd, north-westbound between Hellawell Rd & Bradman St	BRNB9	504	80
Beaudesert Rd, north-westbound between Algester Rd & Hellawell Rd	BRNB10	679	80
Beaudesert Rd, north-westbound between Highlands Dve & Algester Road	BRNB11	688	80
Beaudesert Rd, north-westbound between Compton Road & Highlands Dve	BRNB12	408	80
Beaudesert Rd, north-westbound between Ormskirk St & Compton Rd	BRNB13	1000	80
Link MVT on Beaudesert Rd, north-eastbound between Kameruka St & Ormskirk St	BRNB14	445	80
Beaudesert Rd, northbound between Nottingham R Honeysuckle & Beaudesert R Kameruka St Muirhead St	BRNB15	795	80
Beaudesert Rd, northbound between Algester Rd & Honeysuckle	BRNB16	918	80
Northbound total	16 links	10089	
Southbound			
Beaudesert Rd, southbound between Boyland Ave & Boundary Road (refer to the section between Riawena Road & Boundary Rd)	BRSB1	1154	70
Beaudesert Rd southbound between Boundary Rd & Kerry Rd	BRSB2	511	70
Beaudesert Rd southbound between Kerry Rd & Mortimer Rd	BRSB3	771	70
Beaudesert Rd, southbound between Mortimer Rd & Acacia Ridge	BRSB4	184	70
Beaudesert Rd southbound between Acacia Ridge & Oconnel St	BRSB5	659	70
Beaudesert Rd, southbound between Oconnel St & Elizabeth St	BRSB6	269	70
Beaudesert Rd, south-eastbound between Elizabeth St & Paradise Rd	BRSB7	312	70
Beaudesert Rd, south-eastbound between Paradise Rd & Bradman St	BRSB8	792	70
Beaudesert Rd, south-eastbound Bound between Bradman St & Hellawell Rd	BRSB9	504	80
Beaudesert Rd, south-eastbound between Hellawell Rd & Algester Rd	BRSB10	679	80
Beaudesert Rd, south-eastbound between Algester Road & Highlands Dve	BRSB11	688	80
Beaudesert Rd, south-eastbound between Highlands Dve & Compton Road	BRSB12	408	80
Beaudesert Rd, southbound between Compton Rd & Ormskirk St	BRSB13	1000	80

Link description	NPI link ID	NPI link length (m)	Posted Speed Limit (km/h)
Link MVT on Beaudesert Road south-westbound between Ormskirk St & Kameruka St	BRSB14	445	80
Beaudesert Rd, southbound between Beaudesert R Kameruka St Muirhead St & Nottingham Rd Honeysuckle	BRSB15	795	80
Beaudesert Rd, southbound between Nottingham R Honeysuckle & Illaweena St Algester Rd	BRSB16	918	80
Southbound total	16 links	10,089	

Note: Link descriptions are sourced from TMR StreamBI System.

Figure B 1: Weekday data gap per time period – Beaudesert Road main corridor

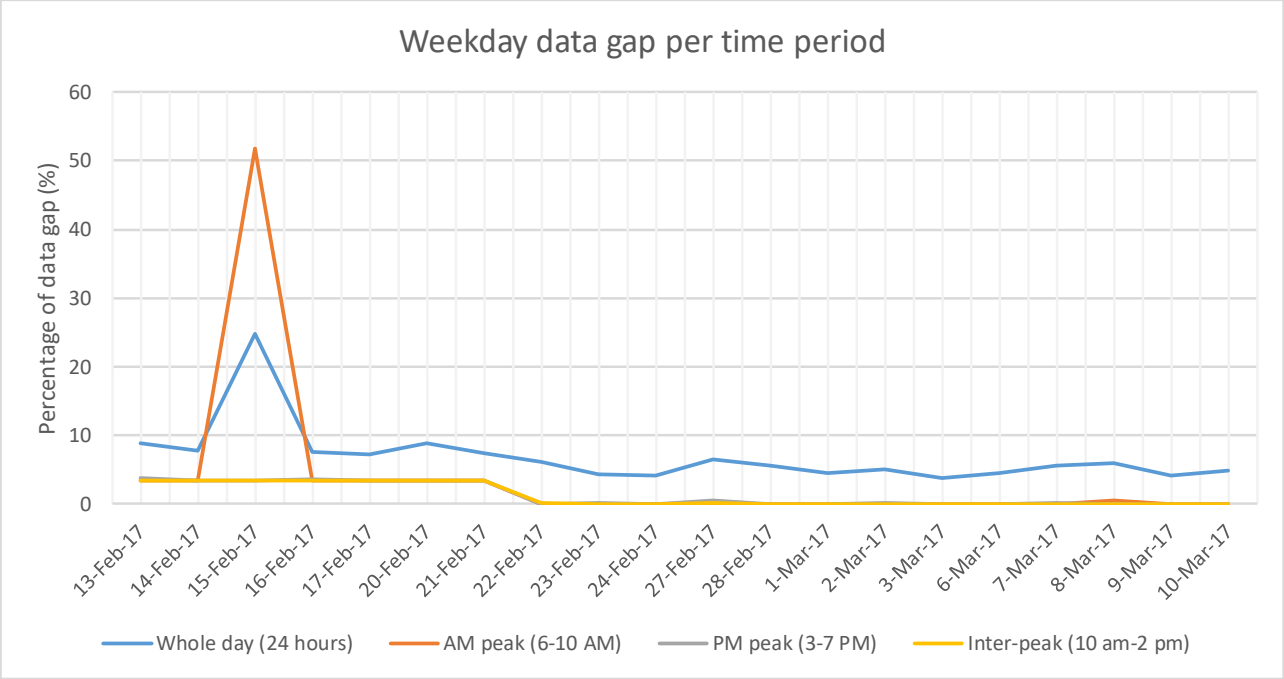


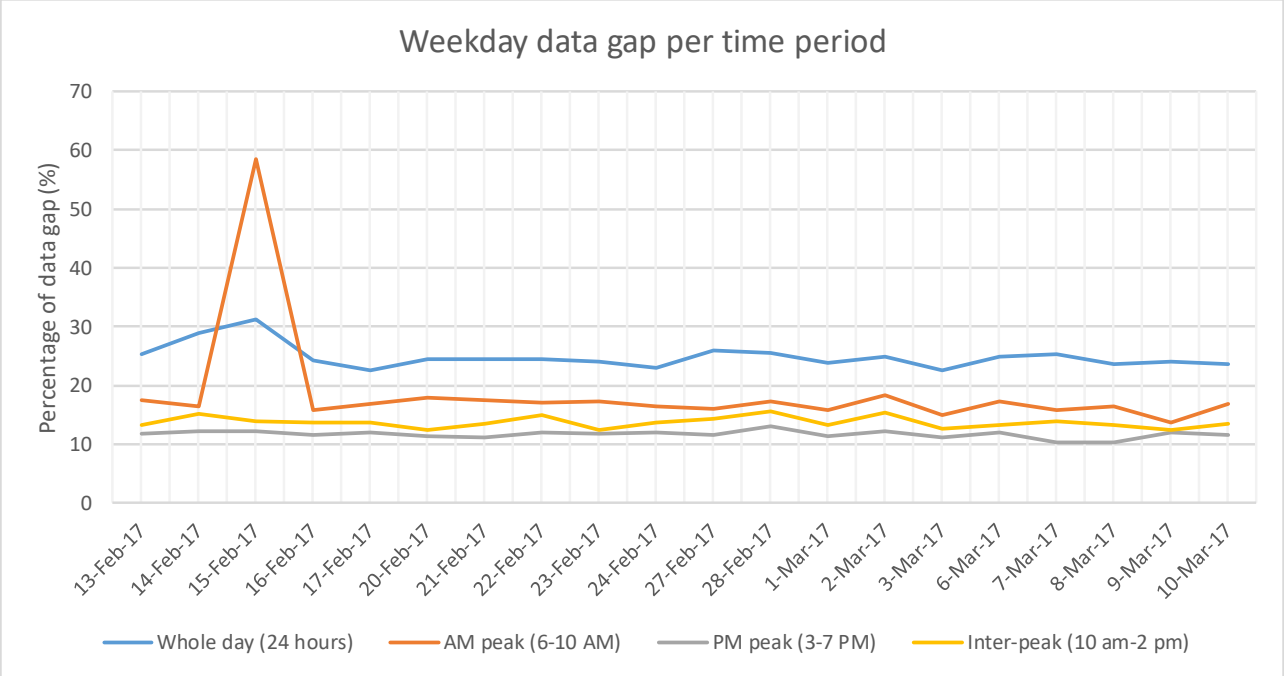
Table B 2: List of Beaudesert Road side-street NPI links details

Link description	NPI link ID	NPI link length (m)	Posted Speed Limit (km/h)
Granard Rd, eastbound between Short St & Beaudesert R	BRSS1	401	60
Riawena Rd, westbound between Perrin Place & Beaudesert R	BRSS2	1013	76
Boundary Rd, eastbound between Boniface St Woomera Pl & Beaudesert Rd	BRSS3	501	60
Boundary Rd, westbound between Postle St & Beaudesert Rd	BRSS4	710	60
Kerry Rd, eastbound between Desgrand St & Beaudesert Rd	BRSS5	1050	60
Kerry Rd, westbound between Postle St & Beaudesert Rd	BRSS6	406	60
Mortimer Rd, eastbound between Foote St & Beaudesert Rd	BRSS7	443	60
Aquatic Centre, eastbound between Aquatic End & Beaudesert Rd	BRSS8	137	50
Oconnel St, westbound between Wellington S & Beaudesert Rd	BRSS9	135	50
Elizabeth St, eastbound between Mitchell St & Beaudesert Rd	BRSS10	833	50
Paradise Rd, northbound between Iris Pl & Beaudesert Rd	BRSS11	668	50

Link description	NPI link ID	NPI link length (m)	Posted Speed Limit (km/h)
Beaudesert Rd, Paradise Rd, Fox St End, south-westbound between Fox St end & Beaudesert Rd Paradise Rd	BRSS12	111	50
Bradman Street northbound between Learoyd Rd & Beaudesert R	BRSS13	257	60
Bradman St, southbound between Overlord Pla & Beaudesert Rd	BRSS14	1353	60
Learoyd Rd, eastbound between Rnd Bradman St, Mccotter St, Learoyd Rd & Beaudesert Rd Hellawell Rd	BRSS15	406	60
Hellawell Rd, westbound between Acacia Place & Beaudesert Rd	BRSS16	453	60
Algester Rd, northbound between Woodland St & Beaudesert Rd	BRSS17	1086	52
Highlands Dve, north-eastbound between Highlands Dve End & Beaudesert Rd	BRSS18	316	50
Compton Rd, westbound between Calam Rd & Beaudesert Rd	BRSS19	319	60
Ormskirk St, eastbound between Riley St & Beaudesert Rd	BRSS20	284	60
Muirhead St, eastbound between Hamish St & Beaudesert Rd	BRSS21	386	60
Kameruka St, westbound between Golden Ave & Beaudesert Rd	BRSS22	1112	54
Nottingham Rd, eastbound between Lakewood Ave & Honeysuckle Rd	BRSS23	720	54
Honeysuckle Rd, westbound between Sunflower Crescent & Nottingham Rd	BRSS24	1206	53
Algester Rd, eastbound between Algester Rd end & Beaudesert Rd	BRSS25	1343	50
Illaweena Beaudesert Algester Rd Tamarisk, westbound between Illaweena St Tamarisk Wy & Illaweena St Beaudesert	BRSS26	1205	56

Note: Link descriptions are sourced from TMR StreamBI System.

Figure B 2: Weekday data gap per time period – Beaudesert Road side-street



B.2 Gold Coast Highway Case Study Site

Table B 3: List of Gold Coast Highway main corridor NPI links details

Link description	NPI link ID	NPI link length (m)	Posted Speed Limit (km/h)
Westbound			
Gold Coast Hwy, Olsen Ave, Oxley Dr, Babbidge St WB between Gold Coast Hwy Babbidge St & Gold Coast Hwy Ol	GCHWB1	601	70
Gold Coast Hwy, westbound between Government R & Babbidge St	GCHWB2	456	60
Gold Coast Hwy, Government R, Hollywell Rd, Brisbane Rd And Turpin Rd westbound between Brisbane Rd & Turpi	GCHWB3	333	60
Brisbane Rd & Turpin Rd, Marine Pde, Brisbane Rd, north-westbound between Marine Pde Brisbane Rd & Brisbane Rd	GCHWB4	376	60
Marine Pde, northbound between Frank St Broad St & Brisbane Rd	GCHWB5	375	60
Frank St, northbound between Whiting St & Marine Pde Broad St	GCHWB6	436	60
Frank St, northbound between Central St & Whiting St	GCHWB7	441	60
Frank St, Central St, Gold Coast Hwy, Robert St northbound between Gold Coast Hwy Robert St & Frank St Central St	GCHWB8	431	60
Frank St, northbound between Gold Coast Hwy/Frank St ped Xing Robert St & Robert St	GCHWB9	210	60
Marine Pde, north-westbound between Stevens St & Robert St	GCHWB10	337	60
Gold Coast Hwy/Marine Pde, north-westbound between North St & Stevens St	GCHWB11	339	60
Westbound total	11 links	4335	
Eastbound			
Gold Coast Hwy, Olsen Ave, Oxley Dr, Babbidge St, eastbound between Gold Coast Hwy Olsen Ave Oxley Dr & Gold Coast	GCHEB1	601	70
Gold Coast Hwy, eastbound between Babbidge St & Government Rd	GCHEB2	456	60
Gold Coast Hwy, Government Rd, Hollywell Rd, Brisbane Rd & Turpin Rd, eastbound between Gold Coast Hwy Government Rd	GCHEB3	333	60
Brisbane Rd & Turpin Rd, Marine Pde, Brisbane Rd, south-eastbound between Brisbane Rd & Turpin Rd & Marine Pde	GCHEB4	376	60
Marine Pde, southbound between Brisbane Rd & Frank St Broad St	GCHEB5	375	60
Frank St, southbound between Marine Pde Broad St & Whiting St	GCHEB6	436	60
Frank St, southbound between Whiting St & Central St	GCHEB7	441	60
Frank St, Central St, Gold Coast Hwy, Robert St, southbound between Frank St Central St & Gold Coast Hwy Robert St	GCHEB8	431	60
Frank St, southbound between Robert St & Gold Coast Hwy/frank St Ped Xing Robert St	GCHEB9	210	60
Frank St, south-eastbound between Ped Xing Robert St & Stevens St	GCHEB10	337	60
Gold Coast Hwy/Marine Pde, south-eastbound between Stevens St & North St	GCHEB11	339	60
Eastbound total	11 links	4335	

Note: Link descriptions are sourced from TMR StreamBI System.

Figure B 3: Weekday data gap per time period – Gold Coast Hwy main corridor

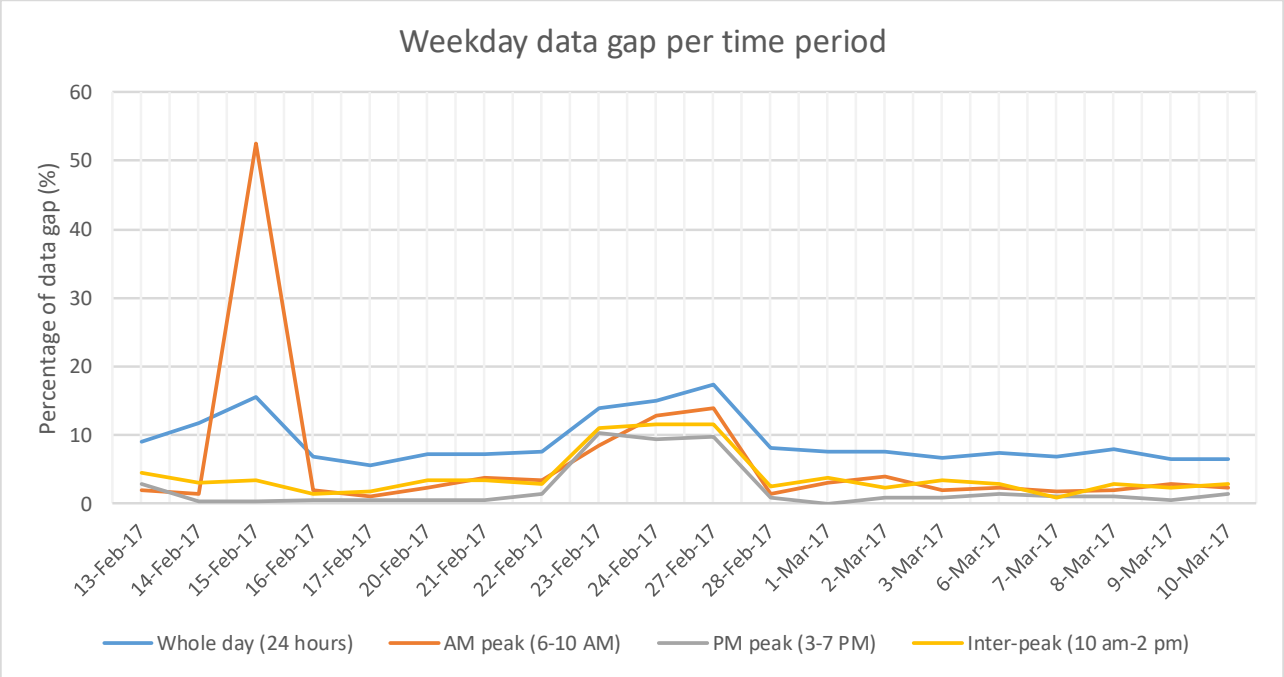


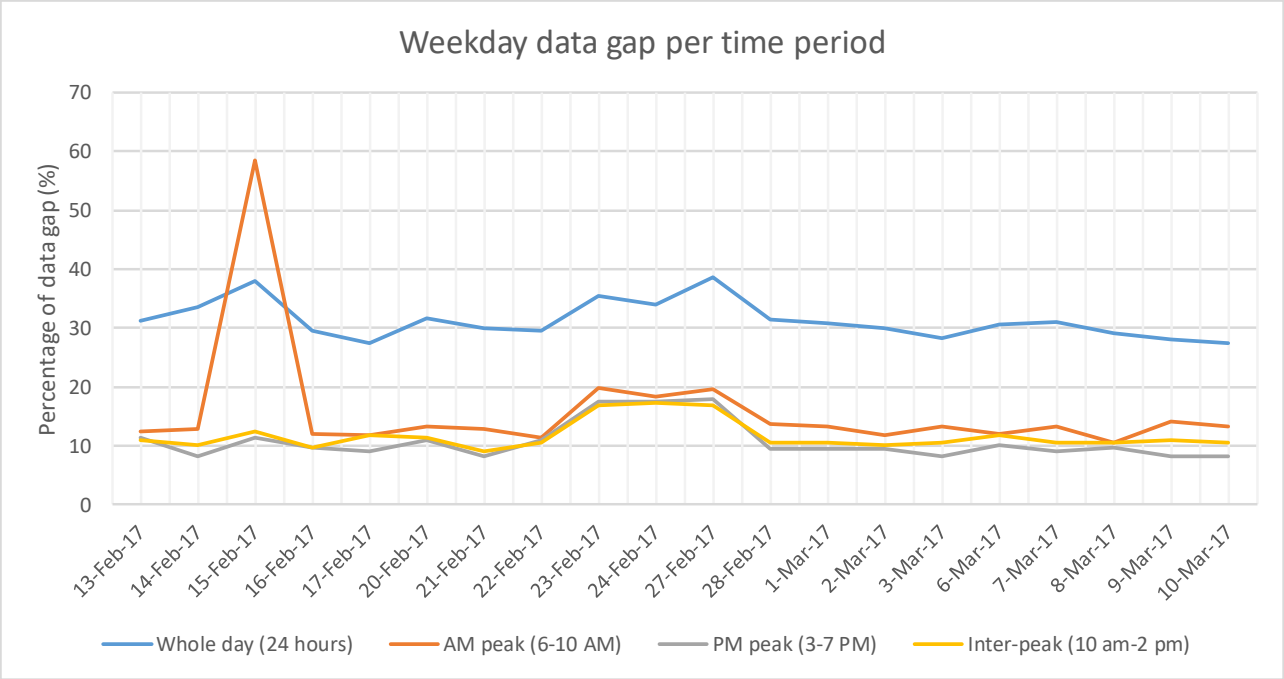
Table B 4: List of Gold Coast Highway side street NPI links details

Link description	NPI link ID	NPI link length (m)	Posted Speed Limit (km/h)
Olsen Ave N, northbound between Barnard St & Gold Coast Hwy	GCHSS1	1422	70
Oxley Drive, southbound between Harbour Town Sth Access & Gold Coast Hwy	GCHSS2	259	70
Babbidge St, northbound between Ashton Street & Gold Coast Hwy	GCHSS3	93	50
Government Rd, northbound between Imperial Pde & Gold Coast Hwy Government R Hollywell Rd	GCHSS4	824	60
Hollywell Rd, south-eastbound between Burrows St & Gold Coast Hwy	GCHSS5	405	60
Brisbane Rd & Turpin Rd, Turpin Rd, Teresa Easement, northbound between Turpin Rd Teresa Easement & Brisbane	GCHSS6	777	52
Marine Pde, southbound between Marine Parad Clark St & Brisbane Rd	GCHSS7	729	60
Broad St, eastbound between Muir St & Marine Pde Frank St	GCHSS8	123	50
Marine Pde, north-westbound between Imperial Pde & Frank St Broad St	GCHSS9	1457	50
Frank St, Whiting St, Proud St, eastbound between Whiting St Proud St & Frank St Whiting St	GCHSS10	115	50
Frank St, Whiting St, Marine Pde, westbound between Marine Pde Whiting St & Frank St Whiting St	GCHSS11	174	50
Central St, eastbound between Ahern St & Frank St	GCHSS12	625	50
Central St, westbound between Marine Pde & Frank St	GCHSS13	99	50

Link description	NPI link ID	NPI link length (m)	Posted Speed Limit (km/h)
Gold Coast Hwy, Marine Pde, Robert St, southbound between Marine Pde Robert St & Gold Coast Hwy Marine Pde	GCHSS14	1208	50
Stevens St, High St, Gold Coast Hwy/Marine Pde, Caravan Park, eastbound between Stevens St High St & Gold Coast Hwy	GCHSS15	148	60
North St North, eastbound between Scarborough & Gold Coast Hwy/Marine Pde	GCHSS16	237	60

Note: link descriptions are sourced from TMR StreamBI System.

Figure B 4: Weekday data gap per time period – Gold Coast Hwy side-street



B.3 Gympie Road Case Study Site

Table B 5: List of Gympie Road main corridor NPI links details

Link description	NPI link ID	NPI link length (m)	Posted Speed Limit (km/h)
Northbound			
Gympie Rd, north-westbound between Zillmere Rd & Graham Rd	GRNB1	134	70
Gympie Rd, northbound between Gayford St Nth & Zillmere Rd	GRNB2	469	70
Gympie Rd, northbound between Windrest Ave & Gayford St Sth	GRNB3	23	70
Gympie Rd, northbound between Aspley Shopping Centre Ped Xing & Windrest Ave	GRNB4	142	70
Gympie Rd, northbound between Albany Creek & Aspley Shopp	GRNB5	135	70
Gympie Rd, northbound between Albany Creek & Robinson Road	GRNB6	145	70
Gympie Rd, northbound between Nevin St & Albany Creek Rd	GRNB7	480	70
Gympie Rd, north-westbound between Webster/Ellison Rd & Darwin St	GRNB8	689	70
Gympie Rd, north-westbound between Monserrat St & Webster/Ellison Rds	GRNB9	869	64

Link description	NPI link ID	NPI link length (m)	Posted Speed Limit (km/h)
Northbound			
Gympie Rd, northbound between Banfield St & Murphy Rd	GRNB10	305	60
Gympie Rd, northbound between Bouchard St & Banfield St	GRNB11	320	60
Gympie Rd, northbound between Hamilton Rd & Bouchard St	GRNB12	156	60
Gympie Rd, northbound between Sparkes St P & Hamilton Rd	GRNB13	240	60
Gympie Rd, northbound between Wallace St & Sparkes St P	GRNB14	194	60
Gympie Rd, northbound between Rode Rd & Wallace St	GRNB15	408	60
Gympie Rd, northbound between Kitchener Rd & Rode Rd	GRNB16	735	60
Gympie Rd, northbound between Edinburgh Ca & Kitchener Rd	GRNB17	439	60
Gympie Rd, northbound between Sadlier St & Castle St Strathmore St	GRNB18	335	60
Gympie Rd, northbound between Broughton Rd Gympie Rd Off-ramp & Sadlier St	GRNB19	682	65
Gympie Rd north-westbound between Gympie Rd & Lutwyche Rd & Stafford Rd	GRNB20	411	55
Northbound total	20 links	7311	
Southbound			
Gympie Rd, south-eastbound between Graham Road & Zillmere Road	GRSB1	134	70
Gympie Rd, southbound between Gayford St Nth & Gayford St Sth	GRSB2	82	70
Gympie Rd, southbound between Gayford St Sth & Windrest Ave	GRSB3	23	70
Gympie Rd, southbound between Windrest Ave & Aspley Shopping Centre ped Xing	GRSB4	142	70
Gympie Rd, southbound between Aspley Shopp & Albany Creek	GRSB5	135	70
Gympie Rd, southbound between Robinson Rd & Albany Creek	GRSB6	145	70
Gympie Rd, south-eastbound between Nevin St & Darwin St	GRSB7	480	70
Gympie Rd, south-eastbound between Darwin St & Webster / Ellison Rds	GRSB8	689	70
Gympie Rd, south-eastbound between Gympie Rd & Murphy Rd	GRSB9	869	64
Gympie Rd, southbound between Murphy Rd & Banfield St	GRSB10	305	60
Gympie Rd, southbound between Banfield St & Bouchard St	GRSB11	320	60
Gympie Rd, southbound between Bouchard St & Hamilton Rd	GRSB12	156	60
Gympie Rd, southbound between Hamilton Rd & Sparkes St P	GRSB13	240	60
Gympie Rd, southbound between Sparkes St P & Wallace St	GRSB14	194	60
Gympie Rd, southbound between Wallace St & Rode Rd	GRSB15	408	60
Gympie Rd, southbound between Rode Rd & Kitchener Rd	GRSB16	735	60
Gympie Rd, southbound between Edinburgh Ca & Castle St	GRSB17	439	60
Gympie Rd, southbound between Castle St Strathmore St & Sadlier St	GRSB18	335	60
Gympie Rd, inbound between Leckie Rd & Stafford Rd	GRSB19	686	60
Lutwyche Rd, north-eastbound between Gympie Rd & Lutwyche Rd & Gympie Rd Kedron Pk Rd	GRSB20	410	50
Southbound total	20 links	6927	

Note: Link descriptions are sourced from TMR StreamBI System.

Figure B 5: Weekday data gap per time period – Gympie Road main corridor

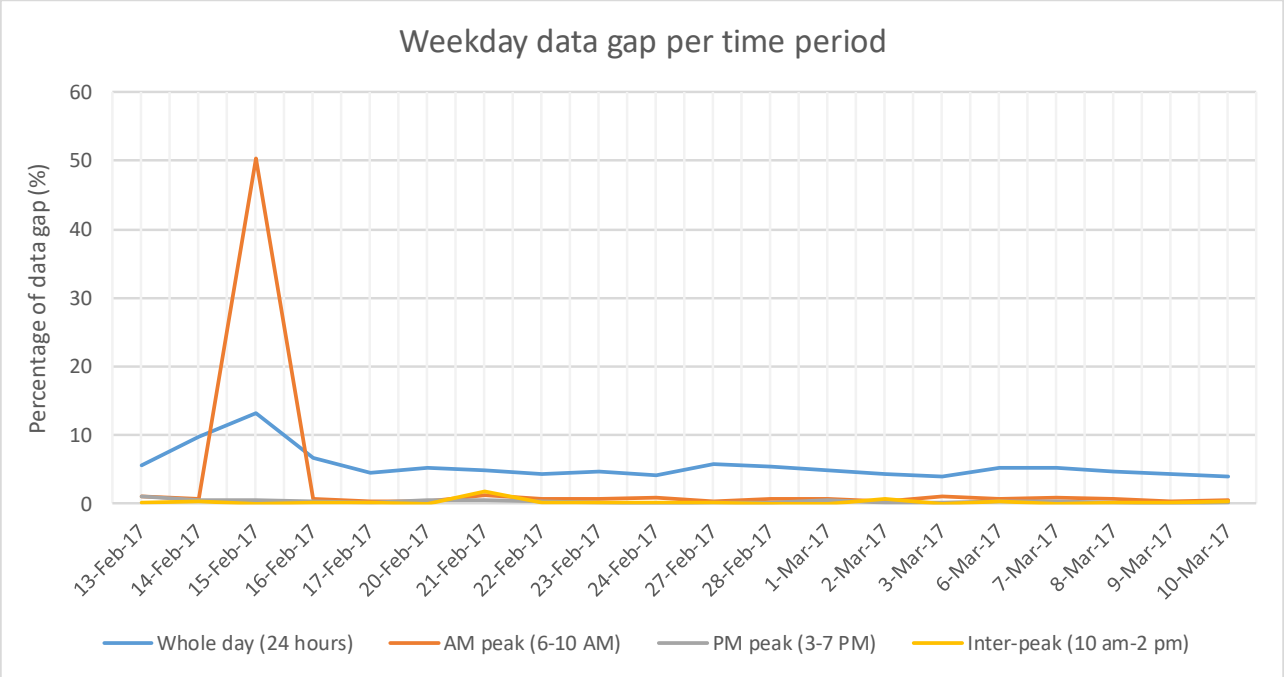


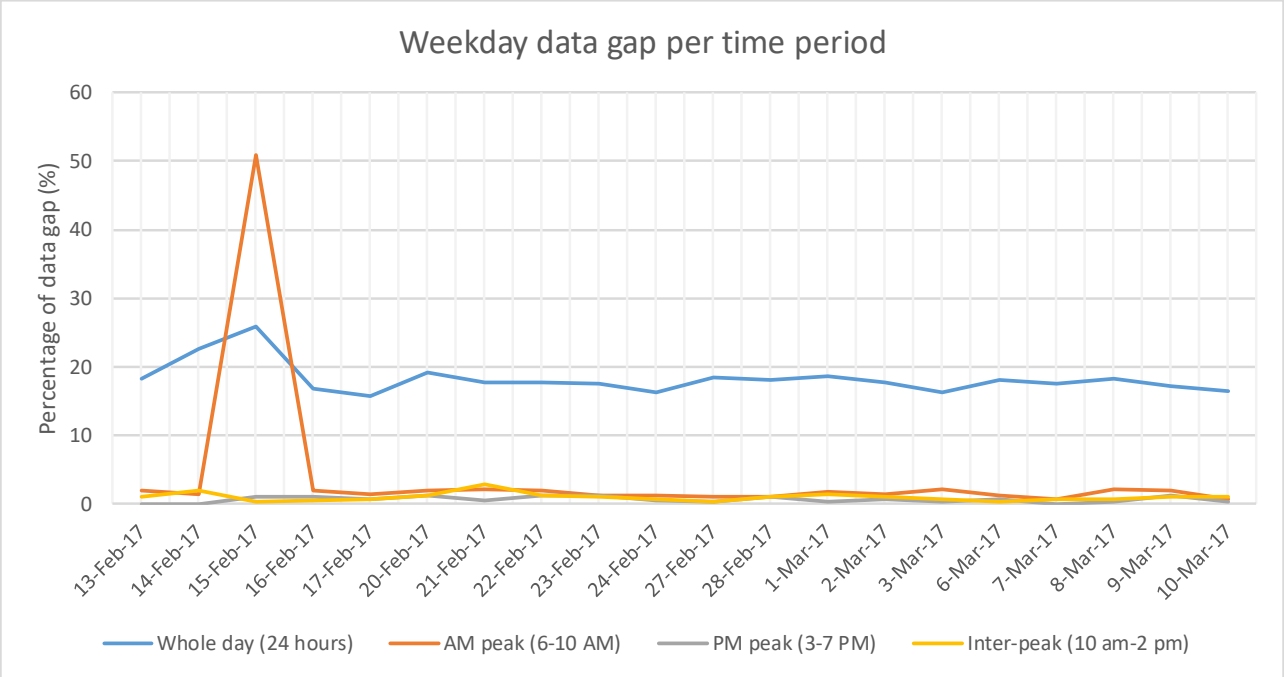
Table B 6: List of Gympie Road side-street NPI links details

Link description	NPI link ID	NPI link length (m)	Posted Speed Limit (km/h)
Graham Rd, eastbound between Hawbridge St & Gympie Rd	GRSS1	1210	60
Zillmere Rd, westbound between Brickfield R & Zillmere Road	GRSS2	389	60
Gayford St, northbound between Gayfiord Split & Gympie Rd	GRSS3	196	60
Albany Creek Conn Rd, eastbound between Albany Creek & Gympie Rd	GRSS4	142	50
Robinson Rd West, westbound between Navua Ave & Robinson Rd Gympie Rd Albany Conne	GRSS5	652	60
Albany Creek, eastbound between Maundrell Tce & Gympie Rd	GRSS6	92	60
Darwin St, eastbound between Maundrell Tce & Gympie Rd	GRSS7	277	50
Webster Rd, northbound between Webster and Pie & To Ellison Rd	GRSS8	264	60
To Ellison Rd, southbound between Ellison Rd & Webster Rd	GRSS9	129	60
Murphy Rd, westbound between Ellison Rd & Gympie Rd	GRSS10	300	50
Banfield & Banfield St Gympie Rd, westbound between Banfield & Chermside & Banfield St Gympie Rd	GRSS11	161	50
Bouchard St, Gympie Rd, Myers Entran, Ch, westbound between Chermside Bus Station 5 & Bouchard St Gympie Rd M	GRSS12	88	50
Hamilton Rd, eastbound between Farnell St Kelso St & Gympie Rd	GRSS13	831	60
Hamilton Rd, westbound between Thomas St & Gympie Road	GRSS14	124	60
Wallace St eastbound between Farnell St & Gympie Rd Kuran St	GRSS15	591	50
Kuran St, westbound between Buruda St & Gympie Rd	GRSS16	245	50
Rode Rd, eastbound between Parkdale St & Gympie Rd	GRSS17	1049	60
Rode Rd, westbound between Bristol Rd & Gympie Rd	GRSS18	1055	60

Link description	NPI link ID	NPI link length (m)	Posted Speed Limit (km/h)
Kitchener Rd, eastbound between Turner Rd & Gympie Rd Sport St	GRSS19	1218	50
Sport St, westbound between Colac St & Gympie Rd	GRSS20	360	60
Strathmore St, eastbound between Caithness St & Gympie Rd	GRSS21	555	60
Castle St, westbound between Seabrook St & Gympie Rd	GRSS22	338	60
Sadlier St, westbound between Leckie Rd & Gympie Rd	GRSS23	222	50
Suez St, Swan St, Gympie Rd, Stafford Rd, northbound between Suez St Swan St & Gympie Rd Stafford Rd	GRSS24	154	50
Stafford Rd, eastbound between Rose Ln & Gympie Rd	GRSS25	636	60
Kedron Pk Rd, westbound between Park Rd & Lutwyche Rd	GRSS26	247	60

Note: Link descriptions are sourced from TMR StreamBI System.

Figure B 6: Weekday data gap per time period – Gympie Road side-street



B.4 Olsen Road Case Study Site

Table B 7: List of Olsen Road main corridor NPI links details

Link description	NPI link ID	NPI link length (m)	Posted Speed Limit (km/h)
Northbound			
Olsen Ave, northbound between Barnard St & Gold Coast Hwy	ORNB1	1422	70
Olsen Ave, northbound between Musgrave Ave & Central St	ORNB2	911	70
Olsen Ave, Musgrave Ave, Napper Rd, Hospital Dr, north-eastbound between Hospital Dr & Olsen Ave Musgrave Ave Nap	ORNB3	504	60
Olsen Ave, Parklands Dr, Wintergreen Dr, Hospital Dr, north-eastbound between Olsen Ave Parklands Dr Wintergreen	ORNB4	297	60
Northbound total	4 links	3134	

Link description	NPI link ID	NPI link length (m)	Posted Speed Limit (km/h)
Northbound			
Southbound			
Olsen Avenue, southbound between Barnard St & Central St	ORSB1	1422	70
Olsen Ave, southbound between Central Street & Musgrave Ave	ORSB2	911	70
Olsen Ave, Musgrave Ave, Napper Rd, Hospital Dr, south-westbound between Olsen Ave Musgrave Ave Napper Rd & Hospital	ORSB3	504	60
Olsen Ave, Parklands Dr, Wintergreen Dr, Hospital Dr, south-westbound between Hospital Dr & Olsen Ave Parklands Dr	ORSB4	297	60
Southbound total	4 links	3134	

Note: Link descriptions are sourced from TMR StreamBI System.

Figure B 7: Weekday data gap per time period – Olsen Road main corridor

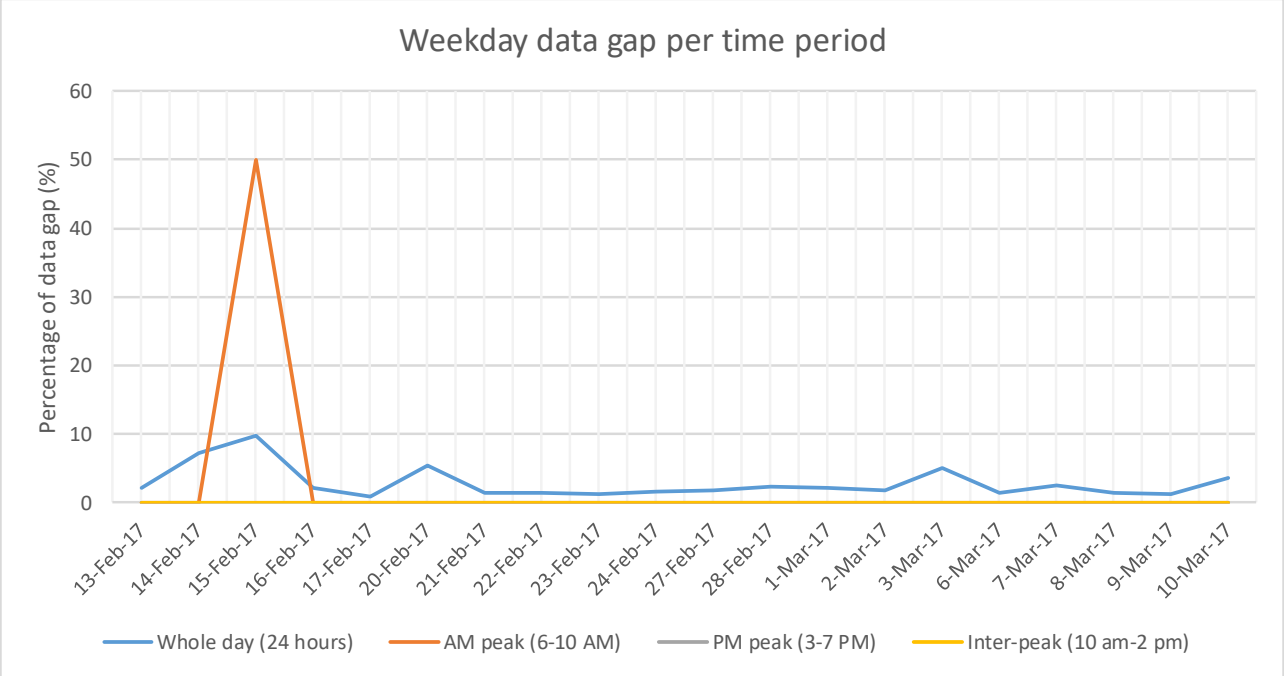


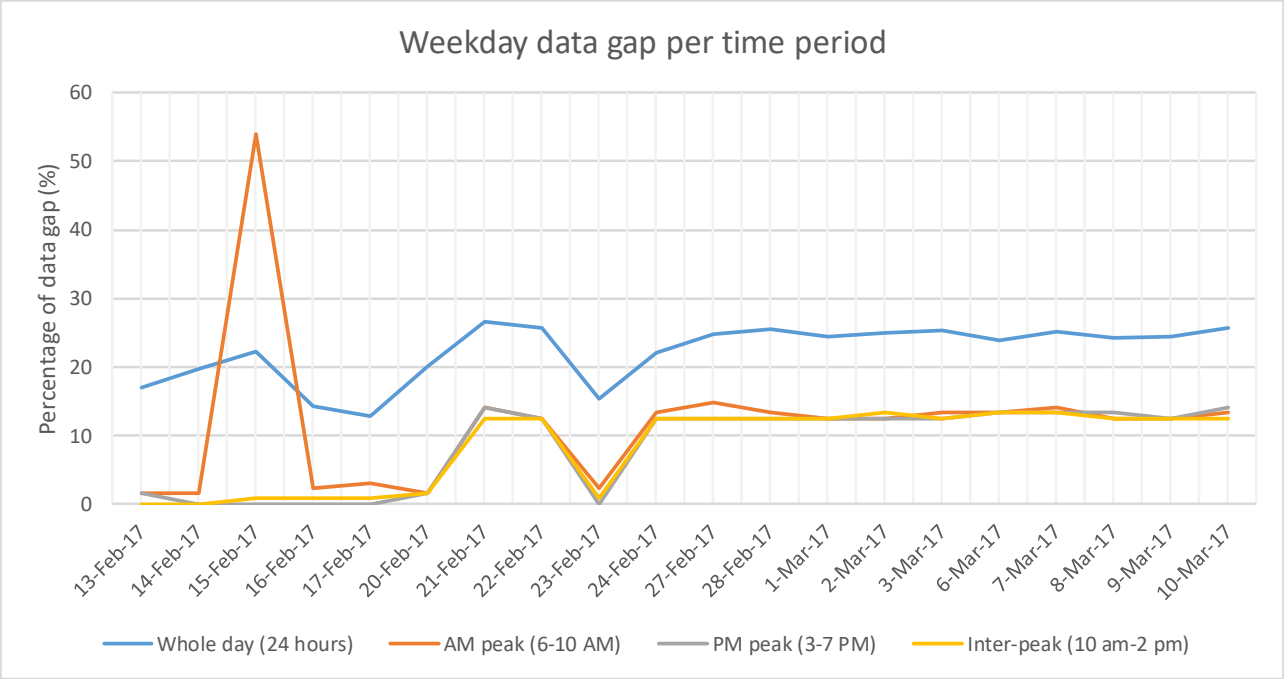
Table B 8: List of Olsen Road side-street NPI links details

Link description	NPI link ID	NPI link length (m)	Posted Speed Limit (km/h)
Gold Coast Hwy, eastbound between Bus Access H & Olsen Ave	ORSS1	272	70
Gold Coast Hwy, Olsen Ave, Oxley Dr, Babbidge St, westbound between Gold Coast Hwy Babbidge St & Gold Coast Hwy Ol	ORSS2	601	70
Central St, eastbound between Melbourne Rd & Olsen Ave	ORSS3	87	50
Napper Rd, south-eastbound between Nina Pde & Olsen Ave	ORSS4	714	67
Musgrave Ave, westbound between Private Rd & Olsen Ave Napper Rd	ORSS5	471	50
Hospital Dr, Hospital Blvd, Hollows Wy, north-westbound between Hospital Blvd Hollows Wy & Hospital Dr	ORSS6	138	50
Wintergreen, eastbound between Henry Cotton & Parklands Dr	ORSS7	400	50

Link description	NPI link ID	NPI link length (m)	Posted Speed Limit (km/h)
Parklands Dr, north-westbound between University Dve & Olsen Ave	ORSS8	223	50

Note: Link descriptions are sourced from TMR StreamBI System.

Figure B 8: Weekday data gap per time period – Olsen Road side-street



B.5 Stafford Road Case Study Site

Table B 9: List of Stafford Road main corridor NPI links details

Link description	NPI link ID	NPI link length (m)	Posted Speed Limit (km/h)
Westbound			
Stafford Rd, westbound between Cutbush Rd & South Pine Rd	SRWB1	254	50
Stafford Rd, westbound between Mountridge St & Cutbush Rd	SRWB2	364	56
Stafford Rd, westbound between Trouts Rd & Everton Pk SH Ped	SRWB3	141	60
Stafford Rd, north-westbound between Kidgell St & Trouts Rd	SRWB4	967	60
Stafford Rd, westbound between Windorah St & Appleby Rd Shand St	SRWB5	348	60
Windorah St Stafford Rd/Stafford Rd, westbound between Stafford Rd/Stafford City S/c carpark & Stafford Rd	SRWB6	188	60
Hayward St to Stafford City Shops3, Staf, westbound between Hayward St To Stafford City Shops3 & Stafford Rd	SRWB7	369	60
Stafford Rd, westbound between Stafford Pri & Webster Rd	SRWB8	154	60
Stafford Rd, westbound between Crawford Ave & Stafford Primary School ped Xing	SRWB9	205	50
Stafford Rd, westbound between Lennon St & Clifford St	SRWB10	235	60
Stafford Rd, westbound between Bradley Ave & Lennon St	SRWB11	460	50
Westbound total	11 links	3685	

Link description	NPI link ID	NPI link length (m)	Posted Speed Limit (km/h)
Westbound			
Eastbound			
Stafford Rd, eastbound between South Pine Rd & Cutbush Rd	SREB1	254	50
Stafford Rd, eastbound between Mountridge St & Everton Pk SH Ped	SREB2	364	56
Stafford Rd, eastbound between Everton Pk SH Ped & Trouts Rd	SREB3	141	60
Stafford Rd, eastbound between Cockle St & Stafford Road	SREB4	967	60
Stafford Rd, eastbound between Appleby Rd Shand St & Windorah St	SREB5	348	60
Windorah St Stafford Rd/Stafford Rd, eastbound between Stafford Rd Windorah St & Stafford Rd/Stafford City	SREB6	188	60
Stafford Rd, eastbound Between Stafford City Shops & Webster Rd	SREB7	369	60
Stafford Rd, eastbound between Webster Rd & Stafford Pri	SREB8	154	60
Stafford Rd, eastbound between Crawford Ave & Clifford St	SREB9	205	54
Stafford Rd, eastbound between Clifford St & Lennon St	SREB10	235	60
Stafford Rd, eastbound between Bradley Ave & Richmond St	SREB11	460	50
Stafford Rd, eastbound between Rose Ln & Gympie Rd	SREB12	636	60
Eastbound total	12 links	4321	

Note: Link descriptions are sourced from TMR StreamBI System.

Figure B 9: Weekday data gap per time period – Stafford Road main corridor

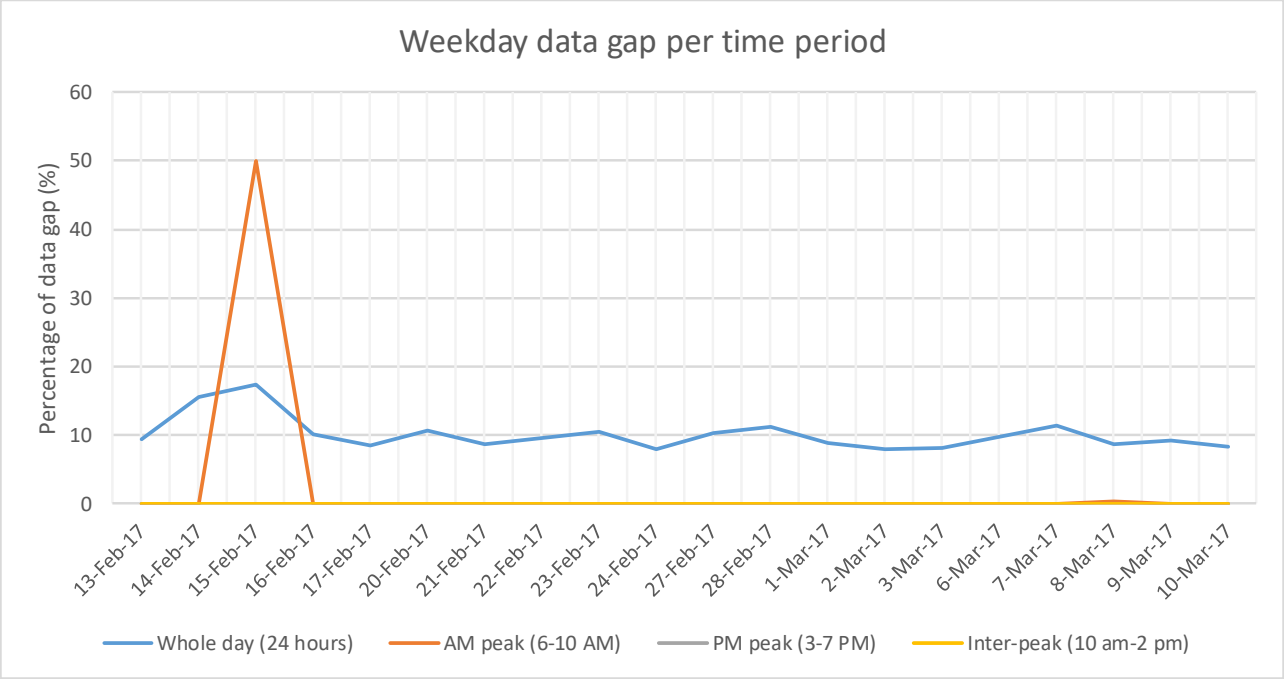


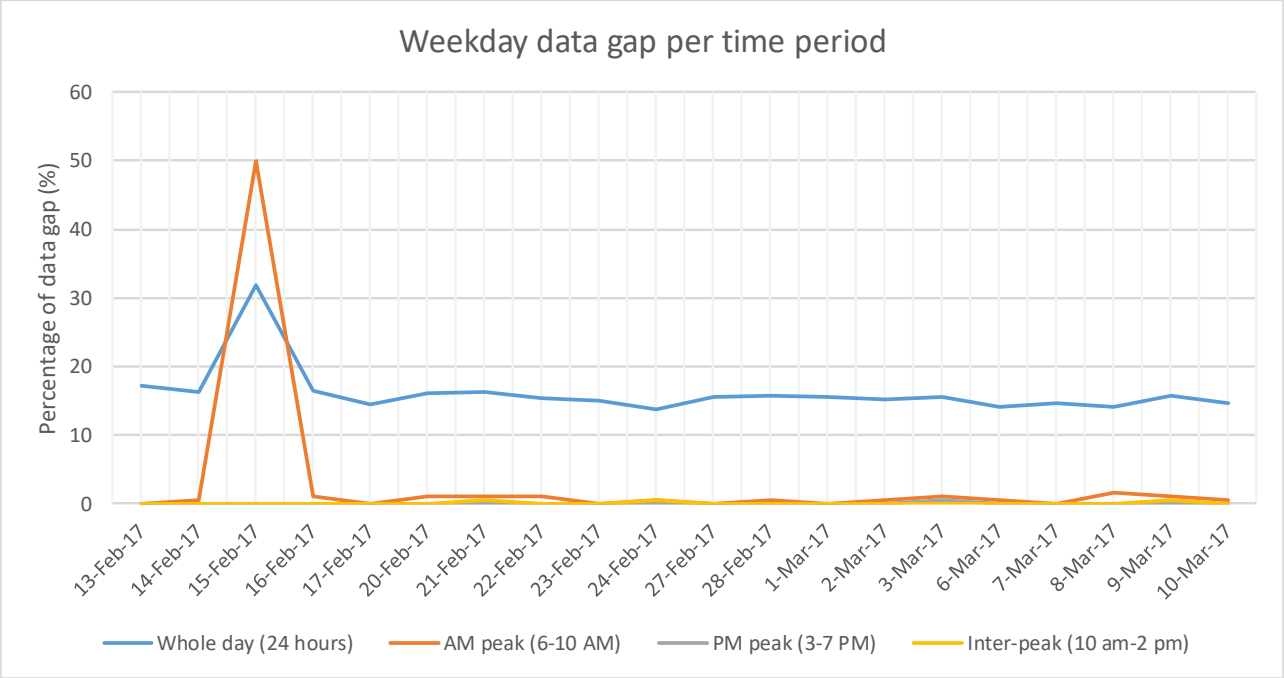
Table B 10: List of Stafford road side-street NPI links details

Link description	NPI link ID	NPI link length (m)	Posted Speed Limit (km/h)
South Pine Rd, northbound between Newhaven St & Stafford Rd	SRSS1	273	60

South Pine Rd, south-eastbound between White St & Stafford Rd	SRSS2	653	60
Stafford Development, Stafford Rd, Cutbush, northbound between Everton Ave & Stafford Rd Cutbush Rd	SRSS3	247	50
Trouts Rd, southbound between Page St & Stafford Rd	SRSS4	695	60
Shand St, northbound between Brennan St & Appleby Rd	SRSS5	1449	60
Appleby Rd, southbound between Quandeine St & Stafford Rd	SRSS6	433	60
Webster Rd, northbound between Lindley St & Webster Rd	SRSS7	568	60
Webster Rd, southbound between School Rd & Stafford Rd	SRSS8	441	53
Clifford St, southbound between Collier St & Stafford Rd	SRSS9	1127	50
Richmond St, northbound between Haig St & Stafford Rd	SRSS10	810	50
Gympie Rd, north-westbound between Gympie Rd And Lutwyche Rd & Stafford Rd	SRSS11	411	55
Gympie Rd, inbound between Leckie Rd & Stafford Rd	SRSS12	686	60

Note: Link descriptions are sourced from TMR StreamBI System.

Figure B 10: Weekday data gap per time period – Stafford Road side-street



APPENDIX C ANAYSIS OF SPEED-FLOW CURVES

C.1 Beaudesert Road Case Study Site

Table C 1: Observations of speed range before flow breakdown from Beaudesert Road main corridor links

LinkID	NPI Link Length [m]	Critical DOS	Speed range at critical DOS (as a % of PSL)	Mean speed at critical DOS (as a % of PSL)	Comments
BRNB1	1154	0.8	55–64	59.5	
BRNB2	511	0.8	49–62	55.5	
BRNB3	771	0.8	70–81	75.5	
BRNB4	184				Exclude link < 200 m, low speed at low volume conditions
BRNB5	269				No clear pattern
BRNB6	312				No clear pattern
BRNB7	792				No breakdown
BRNB8	504	0.8	50–57	53.5	No clear pattern for pm peak
BRNB9	679	0.8	55–65	60	
BRNB10	688	0.8	37–69	53	
BRNB11	408	0.8	57–73	65	
BRNB12	1000	0.8	66–79	72.5	
BRNB13	445				No clear pattern
BRNB14	795	0.85	53–77	65	
BRNB15	918	0.9	44–64	54	
BRSB1	1154	0.8	56–69	62.5	
BRSB2	511	0.8	51–66	58.5	
BRSB3	771	0.8	71–79	75	
BRSB4	659	0.8	72–84	78	
BRSB5	269				No breakdown
BRSB6	312				No clear pattern
BRSB7	792				No clear pattern
BRSB8	504	0.9	22–37	29.5	Low speed at low volume conditions
BRSB9	679	0.8	80–86	83	
BRSB10	688	0.8	84–92	88	
BRSB11	408	0.85	18–32	25	Low speed at low volume conditions
BRSB12	1000	0.9	74–89	81.5	
BRSB13	445	0.85	37–51	44	
BRSB14	795	0.85	57–62	59.5	
BRSB15	918	0.8	51–68	59.5	
Average estimation	660 (for all links > 200 m)	82%	55–68	62	Standard deviation of the samples is 15.85

C.2 Gold Coast Highway Case Study Site

Table C 2: Observations of speed range before flow breakdown from Gold Coast Highway main corridor links

LinkID	NPI Link Length [m]	Critical DOS	Speed range at critical DOS (as a % of PSL)	Mean speed at critical DOS (as a % of PSL)	Comments
GCHWB1	601	0.80	25–45	35	Low speed at low volume condition
GCHWB2	456	0.80	43–62	53	
GCHWB3	333	0.80	30–44	37	
GCHWB4	376				No clear pattern, max DOS 65%
GCHWB5	375	0.80	35–48	42	
GCHWB6	436	0.80	48–65	57	
GCHWB7	441	0.75	52–74	63	
GCHWB8	431	0.80	53–66	60	
GCHWB9	210	0.80	38–71	55	
GCHWB10	337				No breakdown
GCHWB11	339	0.80	34–55	45	
GCHEB1	601	0.80	53–68	61	
GCHEB2	456	0.80	37–51	44	
GCHEB3	333				No breakdown
GCHEB4	376				No clear pattern
GCHEB5	375				No clear pattern
GCHEB6	436	0.80	49–68	59	
GCHEB7	441	0.80	56–66	61	
GCHEB8	431	0.80	52–80	66	
GCHEB9	210				No breakdown
GCHEB10	337	0.70	49–68	59	
GCHEB11	339	0.80	42–61	52	
Average estimation	394 (for all links > 200 m)	79%	44–62	53	Standard deviation of the samples is 9.57

C.3 Gympie Road Case Study Site

Table C 3: Observations of speed range before flow breakdown from Gympie Road main corridor links

LinkID	NPI Link Length [m]	Critical DOS	Speed range at critical DOS (as a % of PSL)	Mean speed at critical DOS (as a % of PSL)	Comments
GRNB1	134				Exclude link < 200 m, no clear pattern
GRNB2	469	0.95	70–82	76	
GRNB3	23				Exclude link < 200 m, low speed at low volume conditions
GRNB4	142				Exclude link < 200 m, low speed at low volume conditions

LinkID	NPI Link Length [m]	Critical DOS	Speed range at critical DOS (as a % of PSL)	Mean speed at critical DOS (as a % of PSL)	Comments
GRNB5	145				Exclude link < 200 m, low speed at low volume conditions
GRNB6	480	0.90	73–82	78	
GRNB7	689	0.85	67–87	77	
GRNB8	869	0.80	55–70	63	
GRNB9	305	0.75	72–89	81	No congestion
GRNB10	320	0.75	77–89	83	No congestion
GRNB11	156				Exclude link < 200 m, low speed at low volume conditions
GRNB12	240	0.80	36–41	39	Am peak showed strange pattern
GRNB13	408	0.80	58–71	65	
GRNB14	735	0.80	61–69	65	
GRNB15	439	0.80	50–66	58	
GRNB16	335	0.80	50–72	61	
GRNB17	682	0.80	75–95	85	
GRNB18	411	0.80	43–57	50	Pm peak high DOS
GRSB1	134				Exclude link < 200 m, low speed at low volume conditions
GRSB2	82				Exclude link < 200 m, low speed at low volume conditions
GRSB3	23				Exclude link < 200 m, no clear pattern
GRSB4	135				Exclude link < 200 m, low speed at low volume conditions
GRSB5	145				Exclude link < 200 m, no clear pattern
GRSB6	480	0.75	70–89	80	
GRSB7	689	0.90	49–64	57	
GRSB8	869	0.80	61–80	71	
GRSB9	305				No clear pattern
GRSB10	320				No clear pattern
GRSB11	156				Exclude link < 200 m, low speed at low volume conditions
GRSB12	194				Exclude link < 200 m, no clear pattern
GRSB13	408	0.85	44–63	54	
GRSB14	735	0.80	68–83	76	
GRSB15	439	0.70	59–79	69	
GRSB16	335	0.70	56–86	71	
GRSB17	686	0.70	70–86	78	
GRSB18	410	0.70	60–77	69	
Average estimation	502 (for all links > 200 m)	80%	60–76	68.2	Standard deviation of the samples is 9.569

C.4 Olsen Avenue Case Study Site

Table C 4: Observations of speed range before flow breakdown from Olsen Avenue main corridor links

LinkID	NPI Link Length [m]	Critical DOS	Speed range at critical DOS (as a % of PSL)	Mean speed at critical DOS (as a % of PSL)	Comments
ORNB1	1422	0.80	52–62	57	
ORNB2	911	0.80	62–71	67	
ORNB3	504	0.80	42–51	47	
ORNB4	297	0.75	48–57	53	
ORSB1	1422	0.70	67–77	72	Almost no congestion
ORSB2	911	0.70	57–64	61	
ORSB3	504	0.75	63–76	70	
ORSB4	297	0.90	24–30	27	Low speed during low volume conditions
Average estimation	783 (for all links > 200 m)	78%	52–61	56	Standard deviation of the sample is 14.67

C.5 Stafford Road Case Study Site

Table C 5: Observations of speed range before flow breakdown from Stafford Road main corridor links

LinkID	NPI Link Length [m]	Critical DOS	Speed range at critical DOS (as a % of PSL)	Mean speed at critical DOS (as a % of PSL)	Comments
SRWB1	254				Low speed at low volume conditions
SRWB2	364	0.80	38–67	53	
SRWB3	967	0.90	68–83	76	
SRWB4	348				Low speed at low volume conditions
SRWB5	188				Exclude link < 200 m, no clear pattern
SRWB6	369	0.85	43–56	50	
SRWB7	154				Exclude link < 200 m, low speed at low volume conditions
SRWB8	235				No breakdown
SRWB9	460	0.90	67–82	75	
SREB1	254				No breakdown
SREB2	141				Exclude link < 200 m, low speed at low volume conditions
SREB3	967	0.80	47–62	55	
SREB4	348				No breakdowns
SREB5	188				Exclude link < 200 m, no breakdown
SREB6	369	0.85	29–42	36	Critical DOS not clear
SREB7	205	0.80	72–82	77	
SREB8	235	0.80	67–89	78	
SREB9	460	0.80	77–89	83	

LinkID	NPI Link Length [m]	Critical DOS	Speed range at critical DOS (as a % of PSL)	Mean speed at critical DOS (as a % of PSL)	Comments
SREB10	636	0.65	61–73	67	Critical DOS not clear
Average estimation	431 (for all links > 200 m)	82%	57–73	65	Standard deviation of the samples is 15.70

APPENDIX D LIST OF LINKS SELECTED FOR THRESHOLD VALIDATION

Table D 1: List of camera sites

Corridor name	Intersection name	Link description	NPI link ID	NPI link length (m)	Posted speed limit (km/h)	Corridor /side-street
Beaudesert Road	Beaudesert Rd and Boundary Rd	Beaudesert Rd, northbound between Kerry Rd & Boundary Rd	BRNB2	511	70	Corridor
		Beaudesert Rd, southbound between Boyland Ave & Boundary Rd	BRSB1	1154	70	Corridor
		Boundary Rd, eastbound between Boniface St Woomera Pl & Beaudesert Rd	BRSS3	501	60	Side St
		Boundary Rd, westbound between Postle St & Beaudesert Rd	BRSS4	710	60	Side St
	Beaudesert Rd and Elizabeth St	Beaudesert Rd, southbound between Oconnel St & Elizabeth St	BRSB5	269	70	Corridor
		Beaudesert Rd, north-eastbound between Paradise Rd & Elizabeth St	BRNB6	312	70	Corridor
		Elizabeth St, eastbound between Mitchell St & Beaudesert Rd	BRSS10	833	50	Side St
	Beaudesert Rd and Ormskirk St	Beaudesert Rd, southbound between Compton Rd & Ormskirk St	BRSB12	1000	80	Corridor
		Link MVT on Beaudesert Rd. north-eastbound between Kameruka St & Ormskirk St	BRNB13	445	80	Corridor
		Ormskirk St. eastbound between Riley St & Beaudesert Rd	BRSS20	284	60	Side St
Gympie Road	Gympie Road and Murphy Road	Gympie Rd. northbound between Banfield St & Murphy Rd	GRNB9	305	60	Corridor
		Gympie Rd south-eastbound between Gympie Rd & Murphy Rd	GRSB8	869	65	Corridor
		Murphy Rd. westbound between Ellison Rd & Gympie Rd	GRSS10	300	50	Side St
	Gympie Rd and Sadlier St	Gympie Rd, southbound between Castle St Strathmore St & Sadlier St	GRSB16	335.0	60	Corridor
		Gympie Rd, northbound between Broughton Rd Gympie Rd off-ramp & Sadlier St	GRNB17	682.0	65.41	Corridor
		Sadlier St, westbound between Leckie Rd & Gympie Rd	GRSS23	222	50	Side St
	Gympie Rd, Kitchener Rd, and Sport street	Gympie Rd, northbound between Edinburgh Ca & Kitchener Rd	GRNB15	439	60	Corridor
		Gympie Rd, southbound between Rode Rd & Kitchener Rd	GRSB14	735	60	Corridor
		Kitchener Rd, eastbound between Turner Rd & Gympie Rd Sport St	GRSS19	1218	50	Side St
		Sport St, westbound between Colac St & Gympie Rd	GRSS20	360	60	Side St
	Gympie Rd, Wallace St and Kuran St	Gympie Rd, southbound between Sparkes St P & Wallace St	GRSB12	194.0	60	Corridor
		Gympie Rd, northbound between Rode Rd & Wallace St	GRNB13	408.0	60	Corridor
		Kuran St, westbound between Buruda St & Gympie Rd	GRSS16	245	50	Side St
		Wallace St, eastbound between Farnell St & Gympie Rd Kuran St	GRSS15	591	50	Side St

Corridor name	Intersection name	Link description	NPI link ID	NPI link length (m)	Posted speed limit (km/h)	Corridor /side-street
Gold Coast Highway	Frank St and Robert St	Frank St, Central St, Gold Coast Hwy, Robert St, southbound between Frank St Central St & Gold Coast Hwy Robert St	GCHEB8	431	60	Corridor
		Frank St, northbound between Gold Coast Hwy/Frank St ped Xing Robert St & Robert St	GCHWB9	210	60	Corridor
	Gold Coast Hwy and Whiting St	Frank St, southbound between Marine Pde Broad St & Whiting St	GCHEB6	436	60	Corridor
		Frank St, northbound between Central St & Whiting St	GCHWB7	441	60	Corridor
		Frank St, Whiting St, Proud St, eastbound between Whiting St Proud St & Frank St Whiting St	GCHSS10	115	50	Side St
		Frank St, Whiting St, Marine Pde, westbound between Marine Pde Whiting St & Frank St Whiting St	GCHSS11	174	50	Side St
	Gold Coast Hwy, Government Rd and Hollywell Rd	Gold Coast Hwy, eastbound between Babbidge St & Government Rd	GCHEB2	456	60	Corridor
		Gold Coast Hwy, Government Rd, Hollywell Rd, Brisbane Rd & Turpin Rd, westbound between Brisbane Rd And Turpin Rd	GCHWB3	333	60	Corridor
		Government Rd, northbound between Imperial Pde & Gold Coast Hwy Government Rd Hollywell Rd	GCHSS4	824	60	Side St
		Hollywell Rd, south-eastbound between Burrows St & Gold Coast Hwy	GCHSS5	405	60	Side St
	Marine Pde and Broad St	Marine Pde, southbound between Brisbane Rd & Frank St Broad St	GCHEB5	375	60	Corridor
		Frank St, northbound between Whiting St & Marine Pde Broad St	GCHWB6	436	60	Corridor
		Broad St, eastbound between Muir St & Marine Pde Frank St	GCHSS8	123	50	Side St
		Marine Pde, north-westbound between Imperial Pde & Frank St Broad St	GCHSS9	1457	50	Side St
Olsen Road	Olsen Ave and Central St	Olsen Ave, northbound between Musgrave Ave & Central Street	ORNB2	911	70	Corridor
		Olsen Avenue, southbound between Barnard St & Central St	ORSB1	1422	70	Corridor
		Napper Rd, south-eastbound between Nina Pde & Olsen Ave	ORSS4	714	67	Side St
		Central St, eastbound between Melbourne Rd & Olsen Ave	ORSS3	87	50	Side St
	Olsen Ave and Hospital Dr	Olsen Ave, Musgrave Ave, Napper Rd, Hospital Dr, south-westbound between Olsen Ave Musgrave Ave Napper Rd & Hospital	ORSB3	504	60	Corridor
		Olsen Ave, Parklands Dr, Wintergreen Dr, Hospital Dr, north-eastbound between Olsen Ave Parklands Dr Wintergreen	ORNB4	297	60	Corridor
		Hospital Dr, Hospital Blvd, Hollows Wy, north-westbound between Hospital Blvd Hollows Wy & Hospital Dr	ORSS6	138	50	Side St
	Olsen Ave and Musgrave Ave	Olsen Ave, Musgrave Ave, Napper Rd, Hospital Dr, north-eastbound between Hospital Dr & Olsen Ave Musgrave Ave Nap	ORNB3	504	60	Corridor
		Olsen Ave, southbound between Central Street & Musgrave Ave	ORSB2	297	60	Corridor
		Musgrave Ave, westbound between Private Rd & Olsen Ave Napper Rd	ORSS5	471	50	Side St

Corridor name	Intersection name	Link description	NPI link ID	NPI link length (m)	Posted speed limit (km/h)	Corridor /side-street
Stafford Road	Stafford Rd and Clifford St	Stafford Rd, eastbound between Clifford St & Lennon St	SREB8	235	60	Corridor
		Clifford St, southbound between Collier St & Stafford Rd	SSS9	1127	50	Side St
	Stafford Rd and Richmond St	Stafford Rd eastbound between Bradley Ave & Richmond St	SREB9	460	50	Corridor
		Stafford Rd, westbound between Bradley Ave & Lennon St	SRWB9	460	50	Corridor
		Richmond St, northbound between Haig St & Stafford Rd	SSS10	810	50	Side St
	Stafford Rd, Shand St and Appleby Rd	Stafford Rd, westbound between Windorah St & Appleby Rd Shand St	SRWB4	348	60	Corridor
		Stafford Rd, eastbound between Cockle St & Stafford Road	SREB3	967	60	Corridor
		Appleby Rd, southbound between Quandeine St & Stafford Rd	SSS6	433	60	Side St
		Shand St, northbound between Brennan St & Appleby Road	SSS5	1449	60	Side St

Note: As the process of requesting relevant CCTV footage consumed longer time than expected, the project delivery would be jeopardised if NPI was not extracted and analysed in advance. As a result, the NPI data was extracted for the period from 13 February to 12 March 2017 and the video footage was recorded for the period from 12 February to 2 March 2018.

APPENDIX E EXAMPLES OF WHISKER CHARTS FOR TRAVEL TIME VARIABILITY

Figure E 1: Travel time variability and comparison of Thresholds$_{RS}$ at LOS B-D for corridor link GRNB17

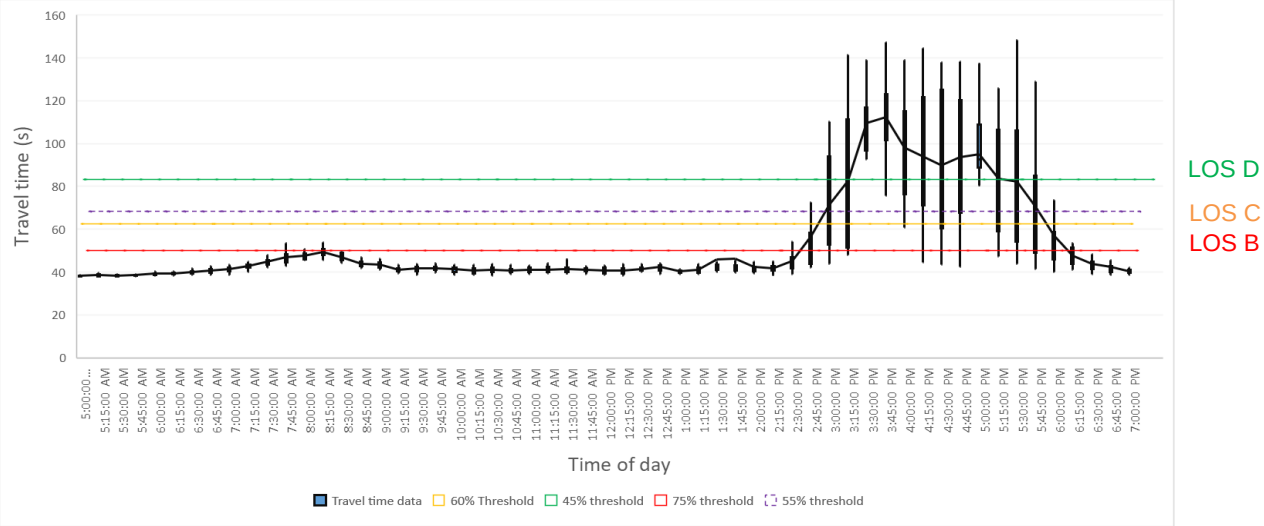


Figure E 2: Travel time variability and comparison of Thresholds$_{RID}$ at LOS B-D for corridor link GRNB17

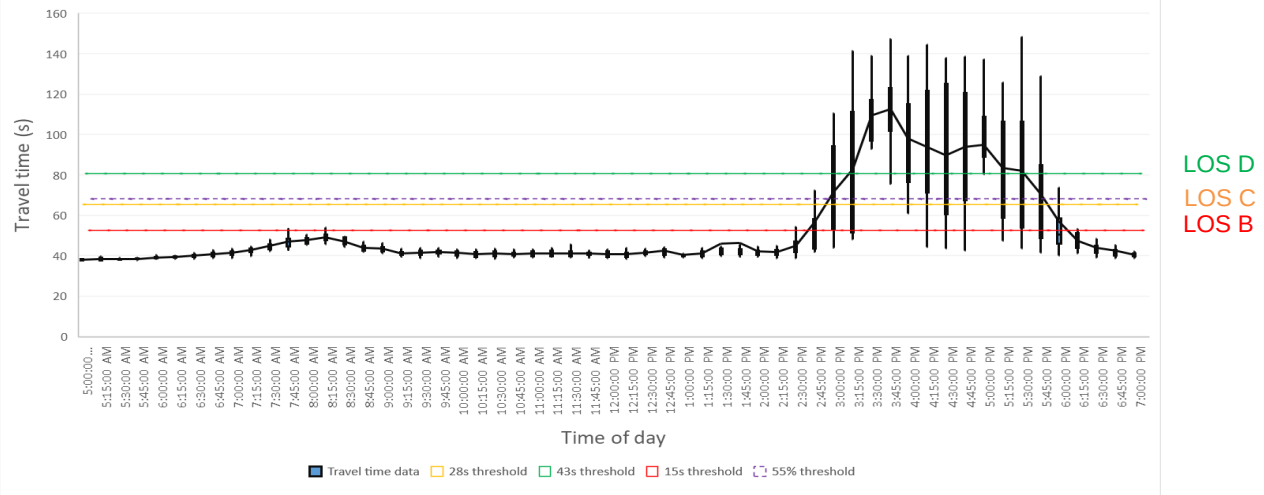


Figure E 3: Green time ratio variability for corridor link GRNB17

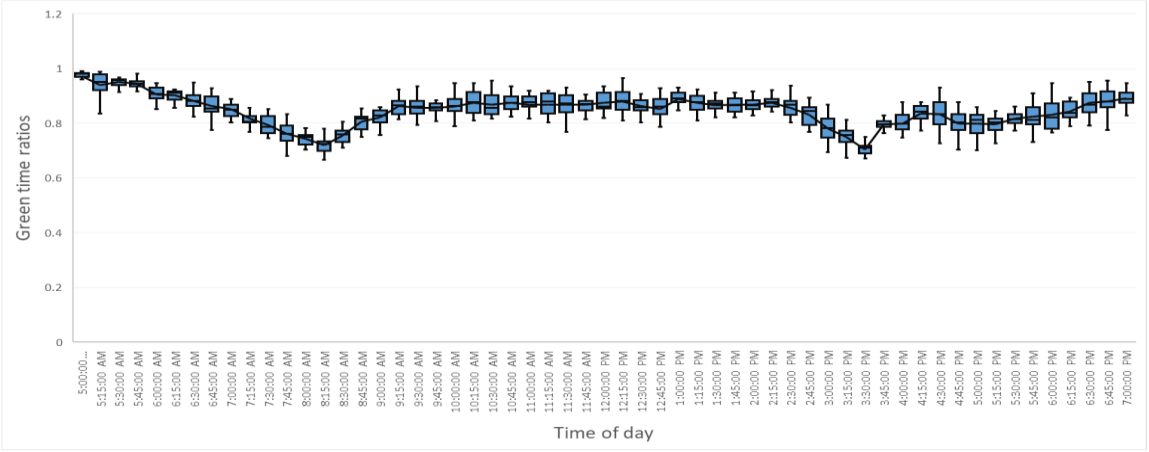


Figure E 4: Travel time variability and comparison of Thresholds$_{RS}$ at LOS B-D for side street link GRSS23

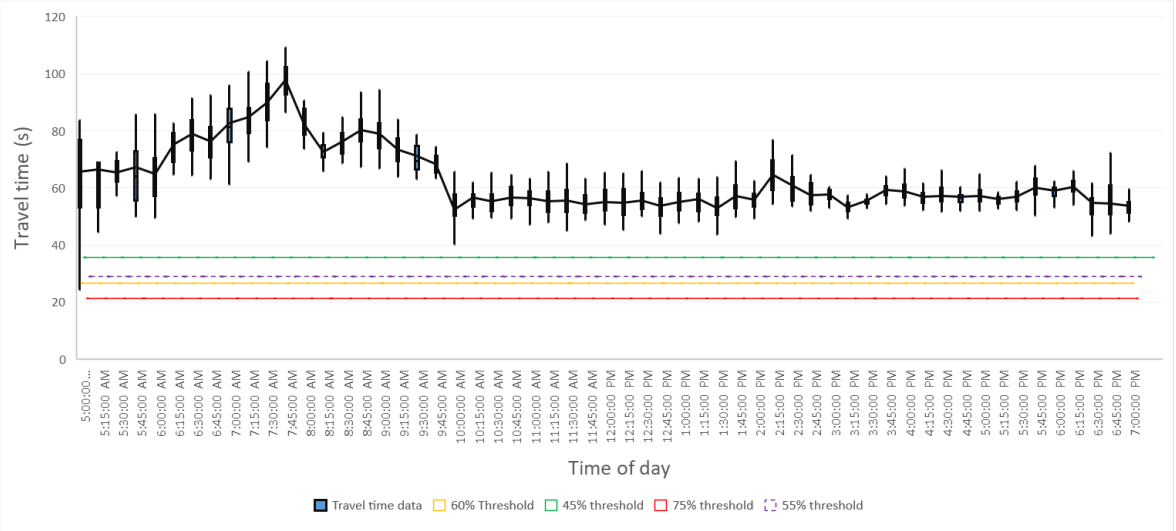


Figure E 5: Travel time variability and comparison of Thresholds$_{RID}$ at LOS B-D for side street link GRSS23

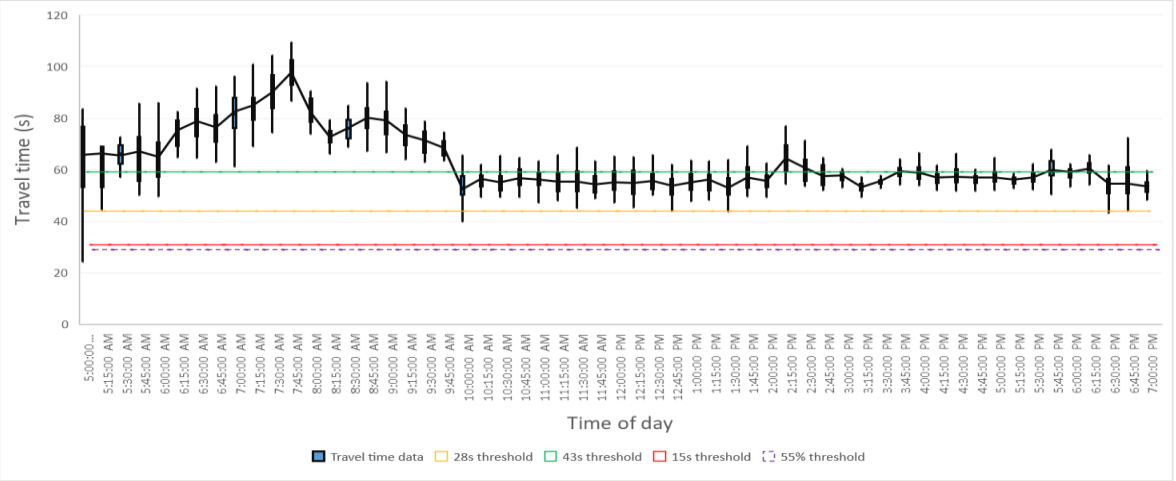
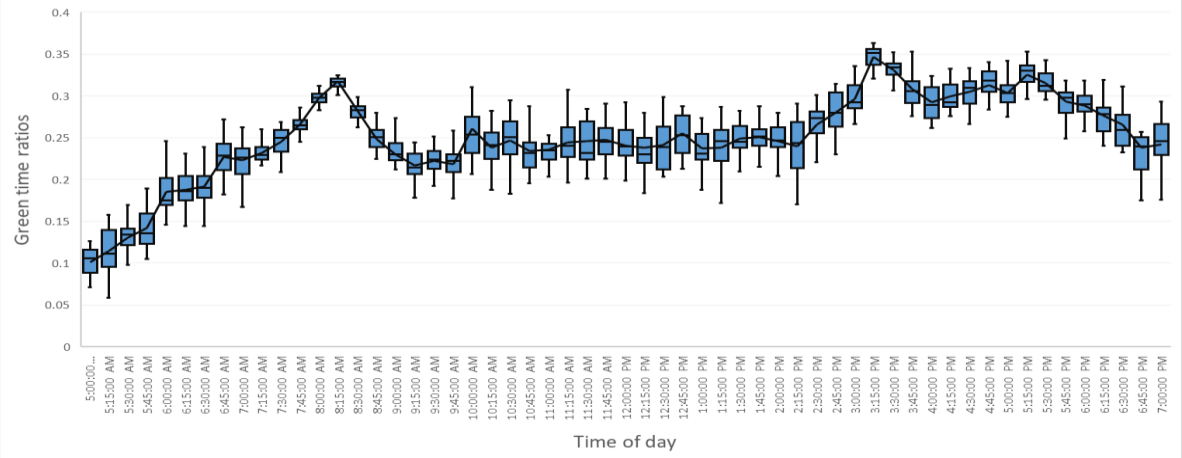


Figure E 6: Green time ratio variability for side street link GRSS23



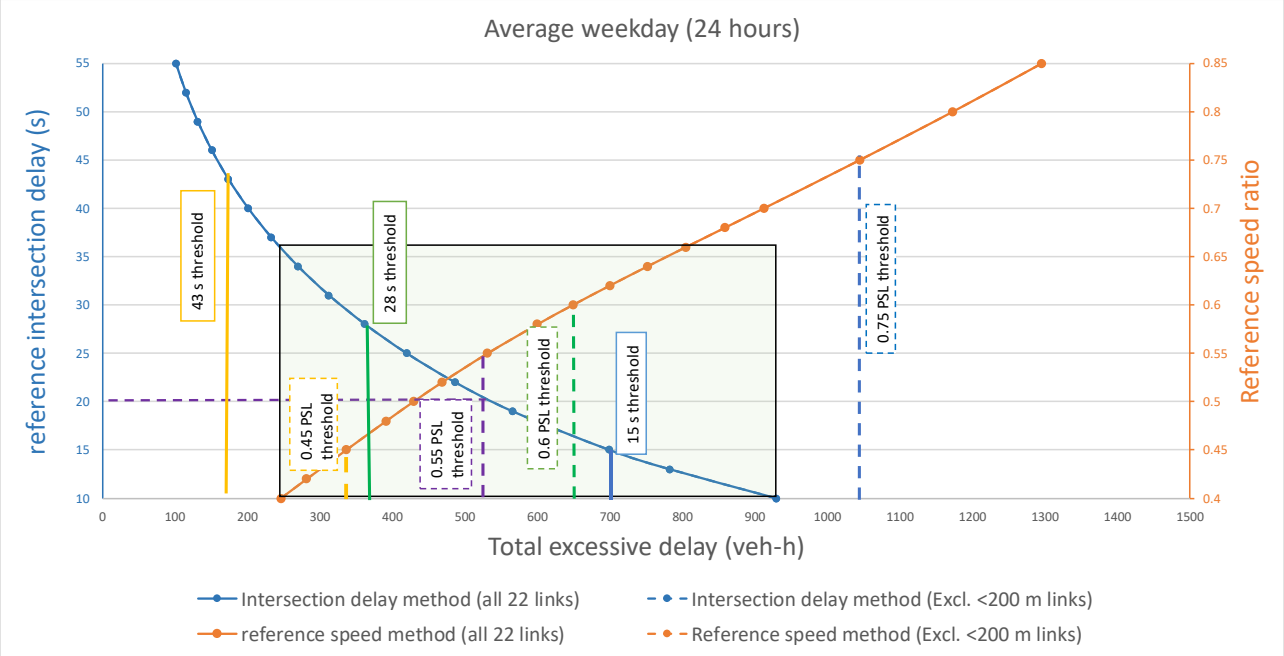
APPENDIX F SENSITIVITY ANALYSIS CHARTS

F.1 Main Corridor

This section shows four sensitivity analysis charts for four study sites as follows:

- Gold Coast Highway, main corridor (Figure F 1)
- Gympie Road, main corridor (Figure F 2)
- Olsen Road, main corridor (Figure F 3)
- Stafford Road, main corridor (Figure F 4).

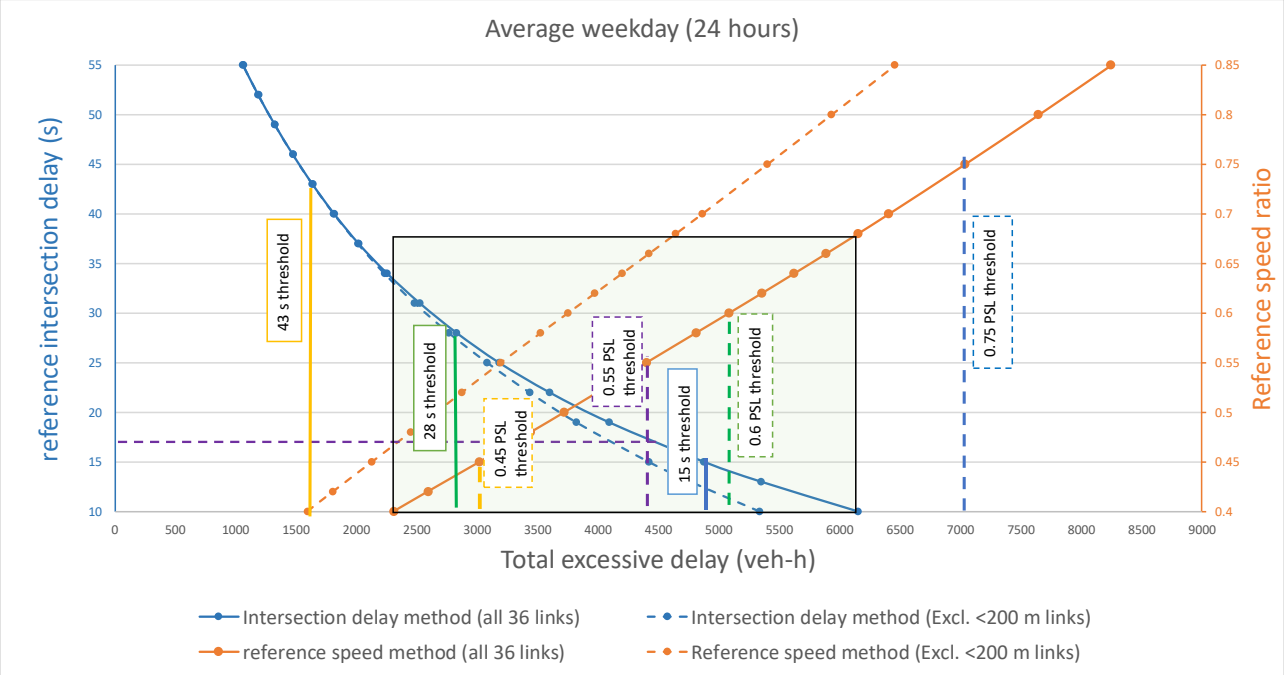
Figure F 1: Total excessive delay of the main corridor links vs two references – Gold Coast Hwy



The sensitivity analysis of the Gold Coast Highway main corridor links in Figure F 1 shows that:

- The change of reference speeds and reference intersection delays from LOS B-D had significant impact on the estimation of total excessive delay. The total excessive delays were more sensitive to the change in reference speed rather than to the change in reference intersection delay.
- The total excessive delay obtained by using the current reference speed ratio (0.55) was 532 veh-h per weekday, which was equivalent to the total excessive delay estimated by using 20 seconds reference intersection delay (between LOS B and C). The point is indicated in Figure F 1 by the purple dashed horizontal line.
- The total excessive delay obtained by using the LOS D reference speed ratio (0.45) was 336 veh-h per weekday, which was significantly higher than the total excessive delay estimated by using 43 seconds reference intersection delay (approximately LOS D) at 174 veh-h.
- There is no main corridor link that is shorter than 200 m.

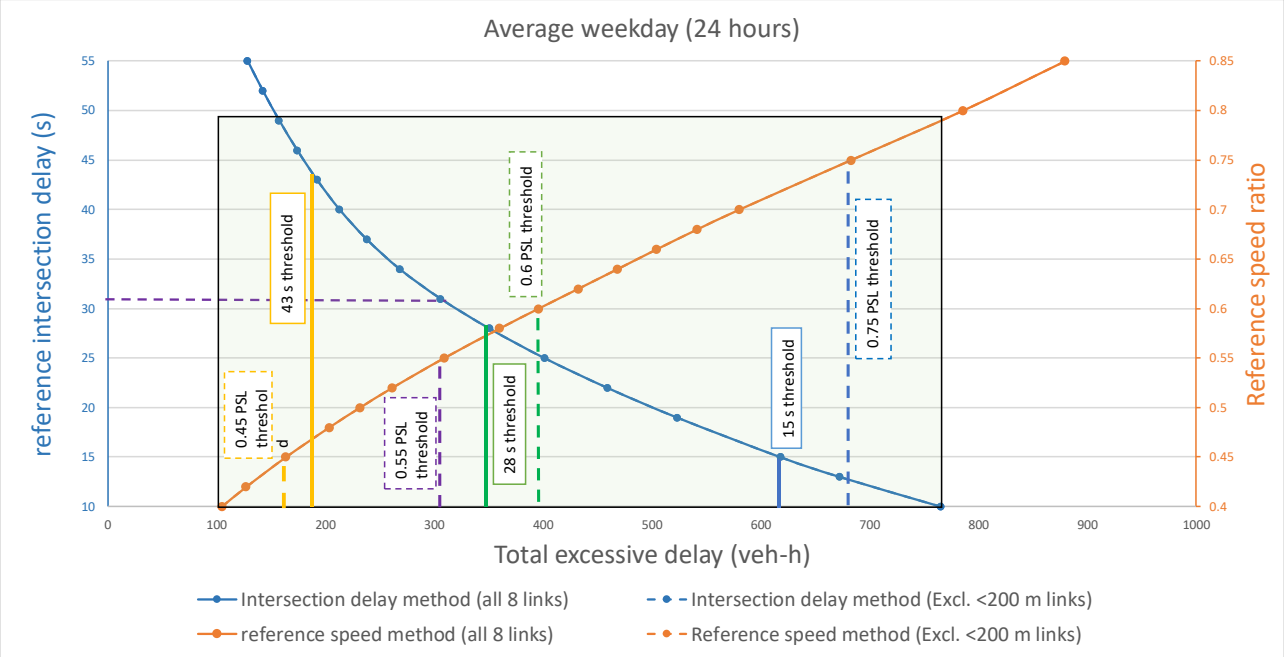
Figure F 2: Total excessive delay of the main corridor links vs two references – Gympie Road



The sensitivity analysis of Gympie Road main corridor links in Figure F 2 shows that:

- The change of reference speeds and reference intersection delays from LOS B-D had significant impact on the estimation of total excessive delay. The total excessive delays were more sensitive to the change in reference speed than to the change in reference intersection delay.
- The total excessive delay obtained by using the current reference speed ratio (0.55) was 4400 veh-h per weekday, which was equivalent to the total excessive delay estimated by using 17 seconds reference intersection delay (approximately LOS B). The point is indicated in Figure F 2 by the purple dashed horizontal line.
- The total excessive delay obtained by using the LOS D reference speed ratio (0.45) was 3020 veh-h per weekday, which was significantly higher than the excessive delay estimated by using 43 seconds reference intersection delay (approximately LOS D) at 1636 veh-h.
- There are 12 main corridor links that are shorter than 200 m. They contribute to the excessive delays by 21% for main corridor links and 6% for whole site if using the current threshold, where whole site refers to the all main corridor and side-street links.

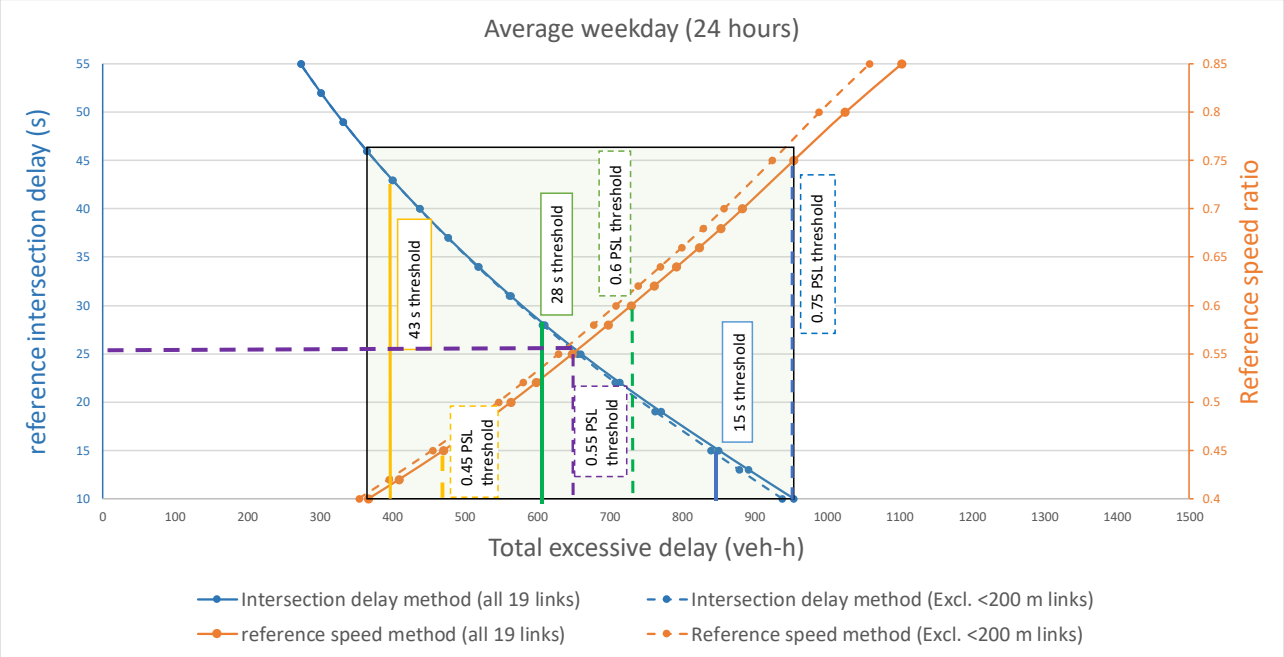
Figure F 3: Total excessive delay of the main corridor links vs two references – Olsen Road



The sensitivity analysis of Olsen Road main corridor links in Figure F 3 shows that:

- The change of reference speeds and reference intersection delays from LOS B-D had significant impact on the estimation of total excessive delay. The total excessive delays were more sensitive to the change of reference speeds than to the change of reference intersection delays.
- The total excessive delay obtained by using the current reference speed ratio (0.55) was 309 veh-h per weekday, which was equivalent to the total excessive delay estimated by using 31 seconds reference intersection delay (approximately LOS C). The point is indicated in Figure F 3 by the purple dashed horizontal line.
- The total excessive delay obtained by using the LOS D reference speed ratio (0.45) was 163 veh-h per weekday, which was relatively close to the total excessive delay estimated by using 43 seconds reference intersection delay (approximately LOS D) was 192.
- There is no main corridor link that is shorter than 200 m.

Figure F 4: Total excessive delay of the main corridor links vs two references – Stafford Road



The sensitivity analysis of Stafford Road main corridor links in Figure F 4 shows that:

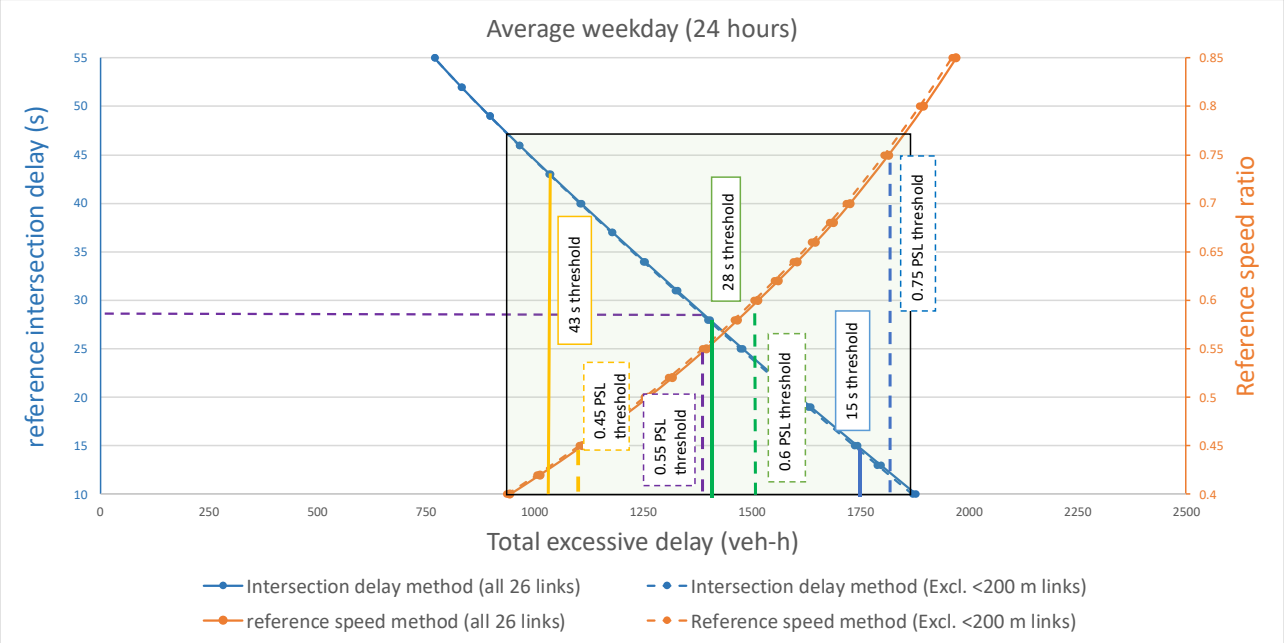
- The change of reference speeds and reference intersection delays from LOS B-D had significant impact on the estimation of total excessive delay. The total excessive delays were slightly more sensitive to the change of reference speeds than to the change of reference intersection delays.
- The total excessive delay obtained by using the current reference speed ratio (0.55) was 648 veh-h per weekday, which was equivalent to the total excessive delay estimated by using 26 seconds reference intersection delay (approximately LOS C). The point is indicated in Figure F 4 by the purple dashed horizontal line.
- The total excessive delay obtained by using the LOS D reference speed ratio (0.45) was 471 veh-h per weekday, where the total excessive delay estimated by using 43 seconds reference intersection delay (approximately LOS D) was 400.
- There are only four main corridor links that are shorter than 200 m. They contribute marginal to the total excessive delays by 3% for main corridor links and 1% for whole site, where whole site refers to all main corridor and side-street links.

F.2 Side-Streets

This section shows five sensitivity analysis charts of five study sites as follows:

- Beaudesert Road side-street links (Figure F 5)
- Gold Coast Hwy side-street links (Figure F 6)
- Gympie Road side-street links (Figure F 7)
- Olsen Road side-street links (Figure F 8)
- Stafford Road side-street links (Figure F 9).

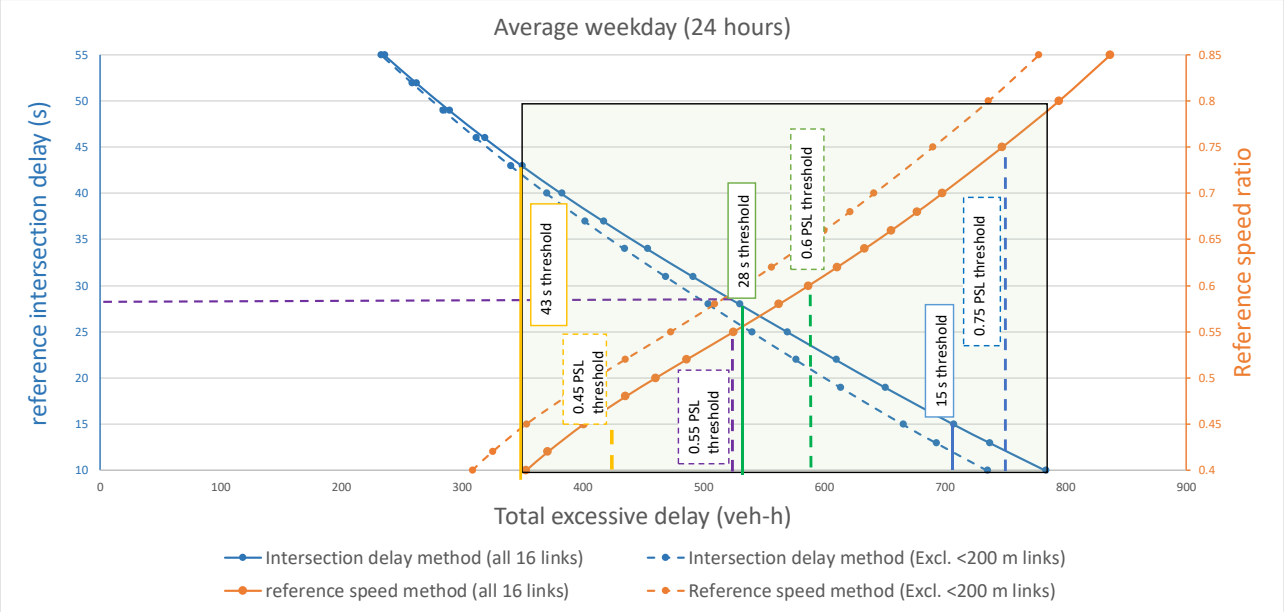
Figure F 5: Total excessive delay of the side-street links vs two references – Beaudesert Road



The sensitivity analysis of Beaudesert Road side-street links in Figure F 5 shows that:

- The change of reference speeds and reference intersection delays from LOS B-D had significant impact on the estimation of total excessive delay. The total excessive delays responded similarly to the change of reference speeds or reference intersection delays.
- The total excessive delay obtained by using the current reference speed ratio (0.55) was 1395 veh-h per weekday, which was equivalent to the total excessive delay estimated by using 28 seconds reference intersection delay (approximately LOS C). The point is indicated in Figure F 5 by the purple dashed horizontal line.
- The total excessive delay obtained by using the LOS D reference speed ratio (0.45) was 1110 veh-h per weekday, which was similar to the total excessive delay estimated by using 43 seconds reference intersection delay (approximately LOS D) at 1036 veh-h.
- There are three side-street links that are shorter than 200 m; however, they do not contribute to the excessive delays of the corridor.

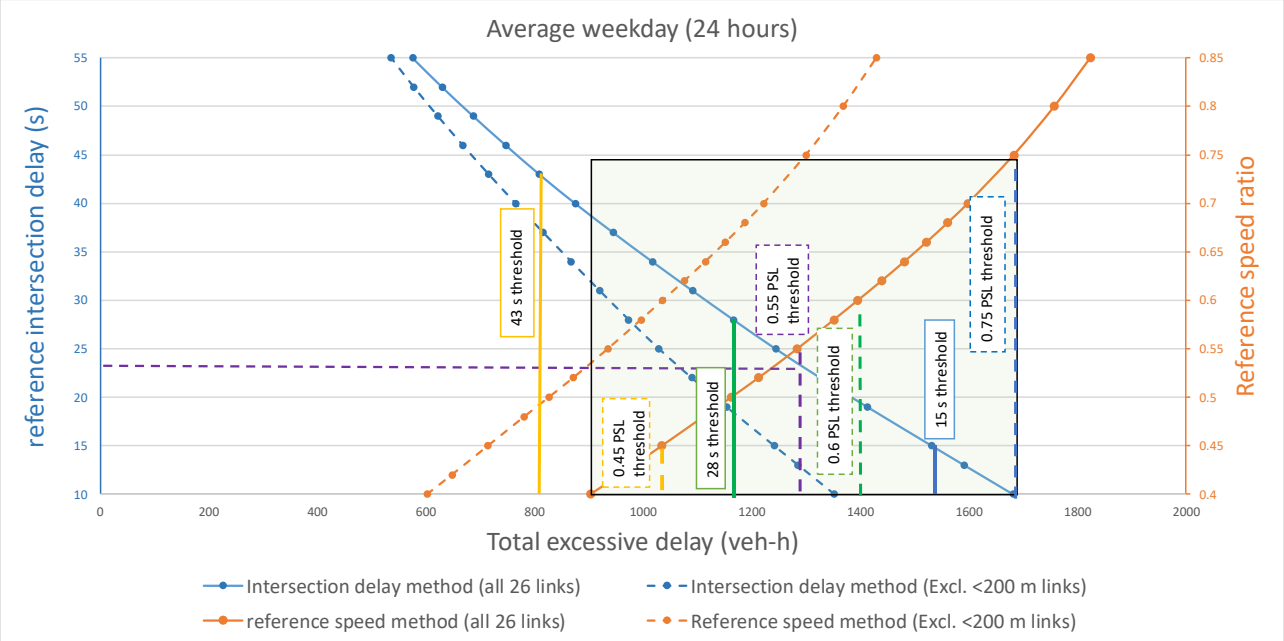
Figure F 6: Total excessive delay of the side-street links vs two references – Gold Coast Hwy



The sensitivity analysis of Gold Coast Highway side-street links in Figure F 6 shows that:

- The change of reference speeds and reference intersection delays from LOS B-D had significant impact on the estimation of total excessive delay. The total excessive delays were more sensitive to the change of reference speeds than to the change of reference intersection delays.
- The total excessive delay obtained by using the current reference speed ratio (0.55) was 525 veh-h per weekday, which was equivalent to the total excessive delay estimated by using 29 seconds reference intersection delay (approximately LOS C). The point is indicated in Figure F 6 by the purple dashed horizontal line.
- The total excessive delay obtained by using the LOS D reference speed ratio (0.45) was 401 veh-h per weekday, which was marginal difference to the total excessive delay estimated by using 43 seconds reference intersection delay (approximately LOS D) at 350 veh-h.
- There are six side-street links that are shorter than 200 m. They contribute to the excessive delays by 12% for side-street links and 7% for whole site, where whole site refers to all main corridor and side-street links.

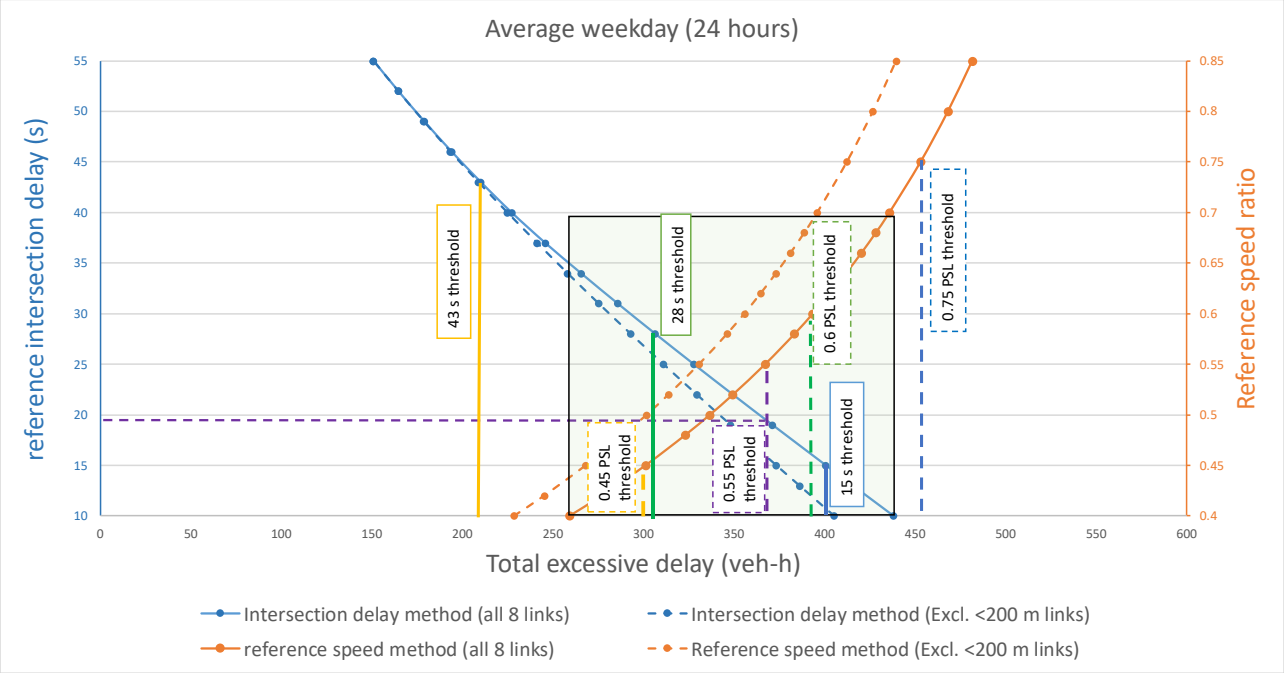
Figure F 7: Total excessive delay of the side-street links vs two references – Gympie Road



The sensitivity analysis of Gympie Road side-street links in Figure F 7 shows that:

- The change of reference speeds and reference intersection delays from LOS B-D had significant impact on the estimation of total excessive delay. The total excessive delays were slightly more sensitive to the change of reference intersection delays than to the change of reference speeds.
- The total excessive delay obtained by using the current reference speed ratio (0.55) was 1284 veh-h per weekday, which was equivalent to the total excessive delay estimated by using 24 seconds reference intersection delay (quite close to LOS C). The point is indicated in Figure F 7 by the purple dashed horizontal line.
- The total excessive delay obtained by using the LOS D reference speed ratio (0.45) was 1035 veh-h per weekday, where the total excessive delay estimated by using 43 seconds reference intersection delay (approximately LOS D) was 809 veh-h.
- There are eight side-street links that are shorter than 200 m. They contribute to the total excessive delays by 27% for side-street links and 6% for whole site, where whole site refers to all main corridor and side-street links.

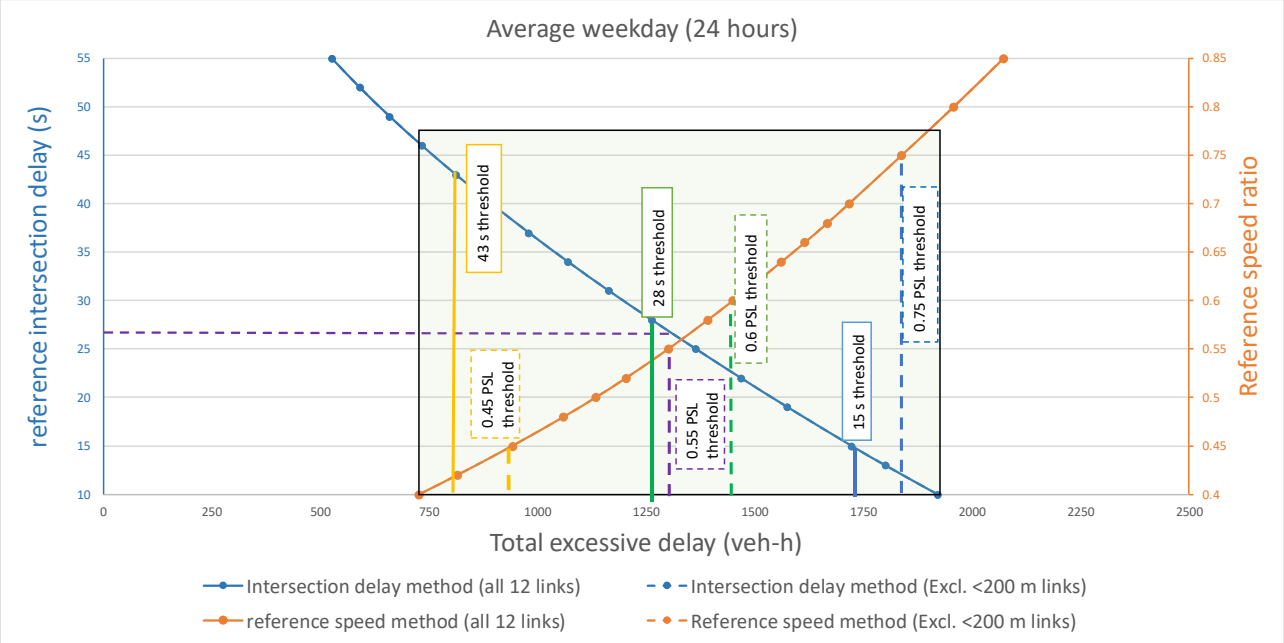
Figure F 8: Total excessive delay of the side-street links vs two references – Olsen Road



The sensitivity analysis of Olsen Road side-street links in Figure F 8 shows that:

- The change of reference speeds and reference intersection delays from LOS B-D had significant impact on the estimation of total excessive delay. The total excessive delays were more sensitive to the change of reference intersection delays than to the change of reference speeds.
- The total excessive delay obtained by using the current reference speed ratio (0.55) was 367 veh-h per weekday, which was equivalent to the total excessive delay estimated by using 19 seconds reference intersection delay (approximately LOS B). The point is indicated in Figure F 8 by the purple dashed horizontal line.
- The total excessive delay obtained by using the LOS D reference speed ratio (0.45) was 301 veh-h per weekday, where the total excessive delay estimated by using 43 seconds reference intersection delay (approximately LOS D) was 210 veh-h.
- There are two side-street links that are shorter than 200 m. They contribute to the total excessive delays by 10% for side-street links and 5% for whole site, where whole site refers to all main corridor and side-street links.

Figure F 9: Total excessive delay of the side-street links vs two references – Stafford Road



The sensitivity analysis of Stafford Road side-street links in Figure F 9 shows that:

- The change of reference speeds and reference intersection delays from LOS B-D had significant impact on the estimation of total excessive delay. The total excessive delays responded similarly to the change of reference speeds or reference intersection delays.
- The total excessive delay obtained by using the current reference speed ratio (0.55) was 1301 veh-h per weekday, which was equivalent to the total excessive delay estimated by using 27 seconds reference intersection delay (approximately LOS C). The point is indicated in Figure F 9 by the purple dashed horizontal line.
- The total excessive delay obtained by using the LOS D reference speed ratio (0.45) was 942 veh-h per weekday, where the total excessive delay estimated by using 43 seconds reference intersection delay (approximately LOS D) was 811 veh-h.
- There is no side-street link that is shorter than 200 m.