ANNUAL SUMMARY REPORT

R77: Real-time determination of spare capacity of routes for enhanced management of congested road network: literature review (2018/19)

ARRB Project No.: PRJ18054

Author/s: Ian Espada

Prepared for: Queensland Department of Transport and Main Roads

15 July 2019

5

AN INITIATIVE BY:

SUMMARY

A system that can determine real-time spare capacity is an important element next generation traffic management of motorways and arterial roads. The long-term objective of the project is to develop such a system. This report covers the first stage of this project and the focus was on an industry review and an examination of design capacity, i.e. what the road theoretically should be able to carry. Case studies were conducted on the application of real-time capacity estimation on a motorway (Centenary Hwy) and arterial road (Samford Rd).

The review found that assessing capacity in real-time requires determination of the prevailing operational regime of the highway. If the highway is operating in undersaturated conditions then capacity can be estimated as the theoretical capacity (i.e. estimated by models) or the highest recorded historical flow. On the other hand, if the highway is operating in saturated conditions then capacity is equal to the realised flow. Density, speed and queue storage are the indicators of the operational regime of a highway. A methodology to estimate capacity in real time was outlined based on these principles.

Real-time capacity estimation requires good coverage of data. The availability of flow, speed and occupancy data on motorways and arterials in Queensland are at a level wherein coverage can be considered adequate for real-time capacity estimation. There are however limitations, such as a limited number of departure-side detectors and low spatial resolution of Bluetooth speed data. These limitations constrain the accuracy of the estimated real-time capacity of a highway.

Real-time capacity estimation was applied to a motorway and an arterial road, i.e. Centenary Hwy and Samford Rd, respectively. The analysis of Centenary Hwy and Samford Rd also identified potential applications of information of real-time capacity which could yield benefits in road operation. These applications included: (i) bottleneck capacity management; (ii) proactive traffic management measures on motorways to mitigate or manage flow breakdown; and (iii) maximising the use of corridor capacity by diverting traffic to optimise use of available capacity between parallel routes on the same corridor. It was concluded that real-time capacity estimation is feasible and is expected to lead to new traffic management techniques that could lower congestion cost; however, further research and development is needed to ensure that potential risks such as ‘ratruns’ are properly managed.

Key recommendations resulting for this project are as follows:

- develop a system that will incorporate the currently available real-time data to estimate realtime capacity; develop traffic control strategies and tactics to take advantage of the information; and, utilise archived real-time capacity estimates for planning purposes
- review current network of detectors and readers and consider improving the density of detectors and readers where needed; and, to examine the utility of probe data for real-time capacity estimation

ACKNOWLEDGEMENTS

This project was made possible through the significant contributions of Queensland Department of Transport and Main Roads in the provision of data, sharing of lessons learned from related past projects and technical review.

- examine methods for predictive capacity estimation as further extension of real-time capacity estimation to enable proactive traffic management measures
- examine the use of approach-side detector data for use in real-time capacity estimation
- research the impact of random and temporary events (e.g. crashes, roadworks, social events, and severe weather) for incorporation in real-time capacity estimation.
- develop strategies in assigning demand to available spare capacities in the network in consultation with stakeholders.

CONTENTS

TABLES

FIGURES

1 INTRODUCTION

Knowledge of spare capacity in real-time would lead to enhanced traffic management strategies, such as providing more accurate traveller information and more efficient traffic signal control, such as gating and pre-emption. A system that can determine real-time spare capacity is an important element to advance traffic management strategies.

There are three levels of capacity, as follows:

- ‘design capacity’ (what the road theoretically should be able to carry)
- ‘operational capacity’ (what the road is currently able to carry)
- ‘available capacity’ (how much additional traffic can be served without exceeding capacity).

This is a multi-year project that aims to develop the system for determination of real-time spare capacity in four stages as follows:

- stage 1: industry review and design capacity (year 1)
- stage 2: operational capacity and available capacity application (year 2)
- stage 3: stakeholder consultation and system review (year 3)
- stage 4: system development (year 3 and 4).

This year 1 of the project has the following objectives:

- identify key elements of the system
- identify the potential benefits of the system
- develop a methodology to determine design capacity.

The tasks for year 1 include:

- scan of Australian and international practices based on a review of literature
- case study of an arterial road and a motorway corridor.

This report is a draft report which covers the following:

- update of the literature review
- real-time capacity estimation methodology (outline only)
- case study on an arterial road (Samford Rd) and a motorway (Centenary Hwy).

2 LITERATURE REVIEW

This chapter reviews the definition of capacity (Section 2.1.1) and the measurement of capacity (Section 2.2).

2.1 DEFINITION OF CAPACITY

Design capacity is what the road theoretically should be able to carry. Capacity can be defined in a number of ways, including the following:

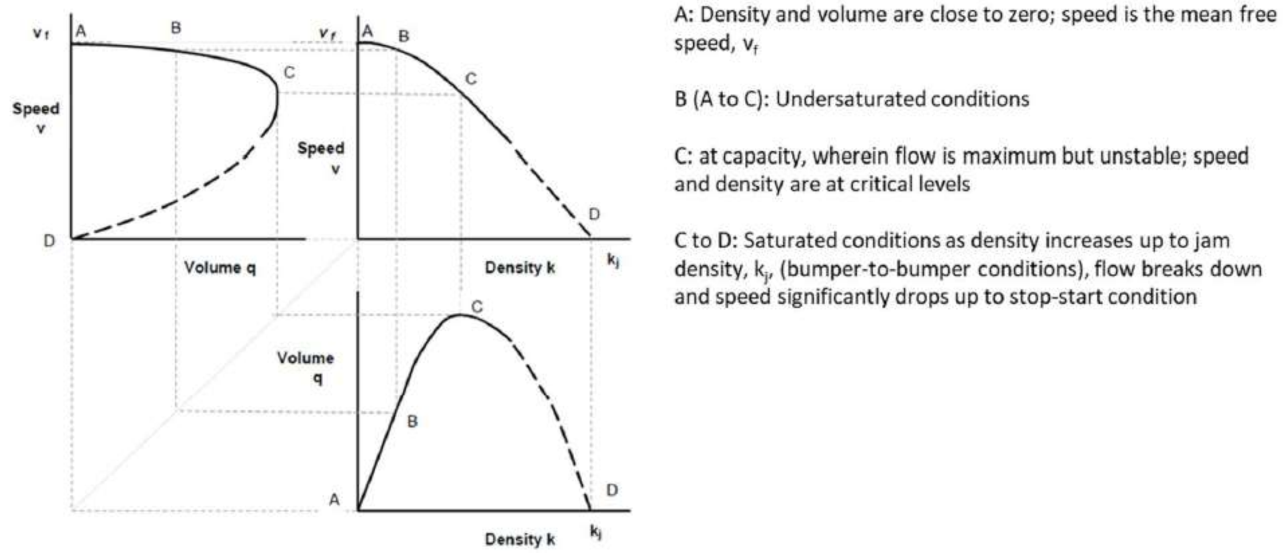
- maximum flow
- density and queue
- speed.

There is a direct inter-relationship between flow, density and speed which is a well-established concept in traffic flow theory (Austroads 2015) with the following fundamental equations (illustrated in Figure 2.1):

- flow is the product of density and speed
- speed is function of density, wherein speed decreases as density increases.

How these variables manifest in motorways and arterials are discussed in Section 2.1.1 and Section 2.1.2, respectively.

Figure 2.1 Theoretical speed, flow (or volume) and density relationship



Source: Austroads Guide to Traffic Management Part 2 (Austroads 2015).

2.1.1 MOTORWAY CAPACITY

The capacity of a motorway expressed in terms of maximum flow rate have been defined as follows:

- flow at critical speed and critical density (TRB 2016)
- maximum sustained 15-min flow (Austroads 2015)
- Highway Capacity Manual (HCM) (TRB 2010) noted of two maximum flow rates:
  - flow just before the formation of a queue at a bottleneck
  - flow after a queue has formed, which is associated with a significant reduction in speed.

Capacity of a motorway can also be expressed in terms of density. Density is the number of vehicles per unit distance. The HCM (TRB 2016) defined critical capacity to be 28 passenger car units (pcu) per lane-km. At this density, there are virtually no usable gaps within the traffic stream, leaving little room to manoeuvre within the traffic stream. Any disruption to the traffic stream, such as vehicles entering from a ramp or an access point or a vehicle changing lanes, can easily cause a flow breakdown. Density of 16 to 22 pcu per lane-km can achieve a more sustainable operational regime and the likelihood of flow breakdown is less likely.

Travel speed can also be used to determine capacity. The motorway is operating at capacity when the speed is just above the critical level. Flow break down occurs when speeds falls below the critical speed. Luk, Han and Byrne (2016) and Han and Mohajerpoor (2017) defined the critical speed on Queensland motorways to be 70% the posted speed limit. HCM (TRB 2016) set the critical speed to be 80% of the posted speed limit.

2.1.2 ARTERIAL CAPACITY

The capacity of an arterial road is typically limited by the capacity at its signalised intersections. An arterial road capacity can therefore be defined in terms in the maximum flow that is allowed by the traffic signals, which is the product of the saturation flow rate and the green split (Austroads 2017). The saturation flow rate is the number of vehicles that can pass across the stop line per unit time when there is a queue (i.e. there is infinite demand) and the signals does not stop the flow (i.e. it stays green). The basic saturation flow rate is around 1,850 pcu/h for through movements. The green split is proportion of the cycle time that is utilised by the movement.

The capacity of an arterial road can also be defined based on travel speed and delay. The HCM (TRB 2016) determines an arterial road to be operating at capacity when travel speed is between 30% to 40% of the free flow speed. Han -et al (2018) defined the critical speed on Queensland arterials to be 55% of the posted speed limit.

Queue storage is an important consideration for arterial road capacity. Luk and Green (2010) noted that arterials roads can be considered as facilities to store vehicular demand such that they do not cause gridlock congestion. Queue spill over happens when queues from a downstream intersection extends towards the upstream intersection. At this stage, the arterial has exceeded its storage capacity. The capacity of the arterial road section is thereby constrained by the number of vehicles that can be stored before the queue storage is fully utilised.

2.2 MEASUREMENT OF DESIGN CAPACITY

This section describes how design capacity can be measured in terms of the following:

- maximum flow
- critical density and queue length
- critical speed.

2.2.1 MAXIMUM FLOW

Maximum flow can be established based on highway configuration. The base capacity of different types of facilities are shown in Table 2.1. The base capacity estimate would then be adjusted based on the following factors using a highway capacity model:

- roadway conditions (e.g. type of facility, lane width, lateral clearance, design speed, horizonal alignment and vertical alignment)
- terrain conditions (e.g. level, rolling or mountainous terrain)
- traffic composition (e.g. heavy vehicle percentage)
- driver population (e.g. commuters or tourists, wherein familiarity of roadway would impact capacity)

- control conditions (e.g. traffic signal settings).

Capacity estimates calculated from models tend to be based on average or typical conditions. They may not necessarily accurately represent site-specific capacity on a given time.

Table 2.1: Capacity of highway facilities

Facility type		Base capacity
Uninterrupted highway	Single lane	1800 pc/h
	Two-lane two-way highway	1700 pc/h for one direction and 3200 pc/h for both directions
	Multi-lane highway	2200 pc/h per lane (100 km/h free flow speed) 2100 pc/h per lane (90 km/h free flow speed) 2000 pc/h per lane (80 km/h free flow speed) 1900 pc/h per lane (70 km/h free flow speed)
Motorway	Segment	2350 pc/h per lane (110 km/h free flow speed) 2300 pc/h per lane (100 km/h free flow speed) 2250 pc/h per lane (90 km/h free flow speed)
	Merge section	2100 pc/h per lane (100 km/h free flow speed, with ramp metering)
Urban arterial	1800 pc/h per lane (100 km/h free flow speed, without ramp metering), note: capacity varies with different ratios of ramp and mainline demand	
	Basic (e.g. limited side traffic)	1800 pc/h per lane
	Median lane (typical)	900 pc/h (undivided) and 1000 pc/h (divided)
	Middle lanes (typical)	1000 pc/h (undivided) and 1000 pc/h (divided)

Source: Austroads Guide to Traffic Management Part 3 (Austroads 2017).

Another method to establish the possible maximum flow on a road is to estimate it through recorded historical traffic flow data from traffic counters. TMR has considered this approach, using data from STREAMS (source: e-mail from TMR, 3 August 2018). Maximum capacity is determined as the highest sustainable recorded flow. The estimate was based on a 15-minute period and it is 'aged', i.e. the estimated maximum capacity is continuously updated wherein older measurements are given less weight. Noted limitations of this approach were as follows:

- Highway sections that do not regularly experience oversaturated conditions would be assigned inaccurately low maximum capacity values, hence capacity is underestimated.
- Highway sections that are experiencing oversaturated conditions would result in low flow values, and the equation would inaccurately estimate high spare capacity.

The SCATS Strategic Performance (SP) framework is also a historical flow-based approach (Chong-White & Mazur 2016). The SCTAS SP defines a Reference Possible Flow as the reference supply capacity and it is measured as the maximum realised flow observed on the previous weekday.

The use of maximum historical flow as an indicator of capacity has its limitations. Key lessons from the TMR pilot on using maximum historical flow to estimate capacity in real-time were as follows:

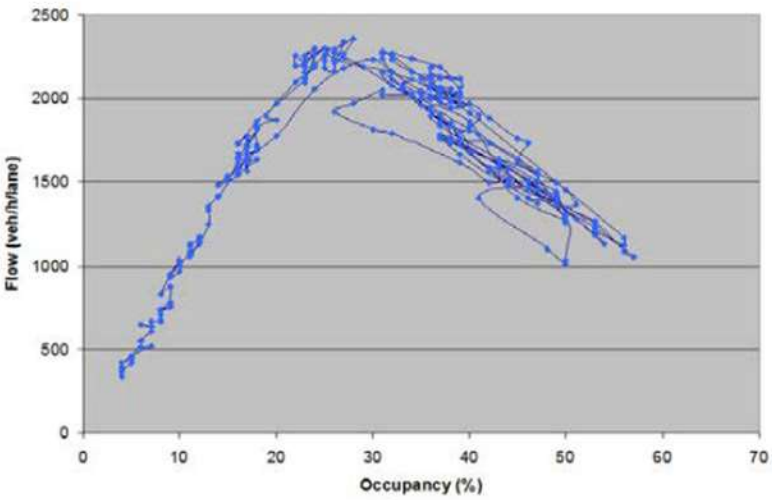
- There is a need for the system to recognise whether the highway segments are undersaturated or oversaturated.
- There appears to be a need to consider additional parameters and data sources, such as travel speed and occupancy during green which are now readily available.
- There is a need to constrain estimated maximum capacity values to theoretical capacity estimates to avoid significantly underestimating capacity.

2.2.2 CRITICAL DENSITY AND QUEUE SPILLBACK

Density is the number of vehicles in a unit distance of highway. Density could not be easily estimated directly as it requires a high vantage point to count the number of vehicles on a unit length of highway. Density can be approximated by occupancy, which is the proportion of time a presence of a vehicle over a detector is recorded. In the case of motorways, managed motorway systems include occupancy detectors at every lane at bottleneck sections and at certain spacing intervals (e.g. 500 m) along the motorway segments (Austroads 2016).

Figure 2.2 illustrate that flow on a motorway breaks down at approximately 25% occupancy. This can be considered as an approximate critical value of occupancy on a motorway wherein the operation transitions from undersaturated to saturated conditions.

Figure 2.2 Flow versus occupancy on a motorway

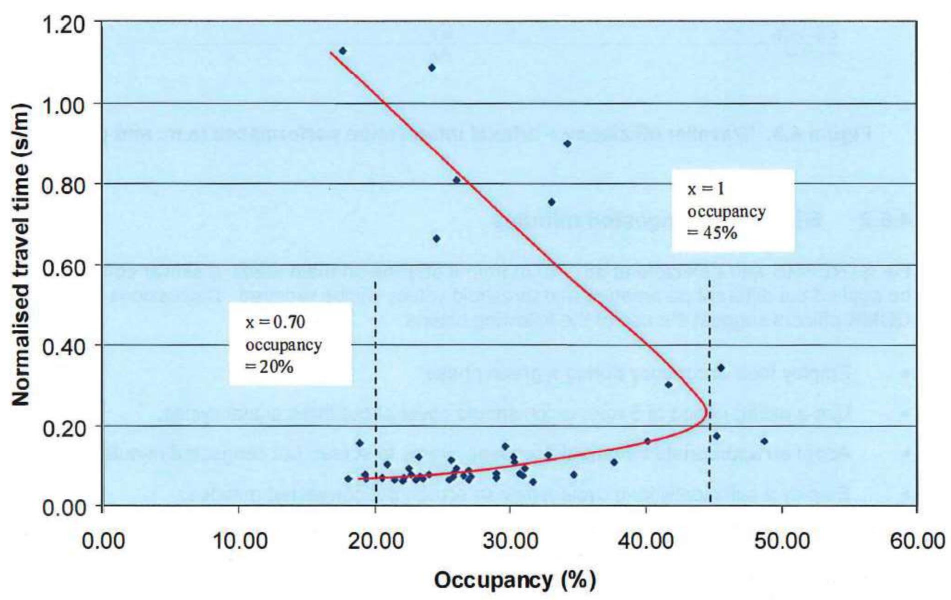


Source: Austroads 2016.

Arterials are also be equipped with occupancy detectors. For arterials, detector loop occupancy can also be utilised as a proxy for density to detect congestion. This has been demonstrated by Chung and Rosalion (1999) in arterial congestion monitoring. It is required that detectors be located at the mid-block and at the departure-side. Stop line detectors were not able to provide a signal to detect congestion due to its location near the head of the queue. Luk (2008) approximated the relationship between loop occupancy and travel time as shown in Figure 2.3.

Luk proposed that a saturated conditions in STREAMS could be defined when occupancy in greater than 35%~45% and that when cycles times are greater than 2 minutes. Travel speeds at these conditions could be 25 km/h or less.

Figure 2.3 Travel time and loop occupancy in STREAMS



Source: *Luk 2008.*

Traffic density and queue formation on arterials can also be estimated by the tracking of inflow and outflow of vehicles on a link. This would require traffic counters at the departure-side and approach-side of the intersection. The availability of a departure-side and approach-side detectors could provide information on traffic inflow and outflow to estimate queue formation (Austroads 2012). Signalised arterials in Queensland have approach-side detectors (35m upstream of the stop line in the case of STREAMS). However, there are only a limited number of arterials that feature departure-side detectors. In the absence of departure-side detectors, Luk (1989) proposed to use a recursive regression technique to estimate the link flow from detector counts of the upstream intersection in a SCATS-controlled network. Obviously, the installation of departure-side or mid-block detectors would be a more direct solution.

An indirect method to detect whether a downstream arterial is experiencing high traffic density and queue spillback is by combining data on flow and degree of saturation on the upstream approach. The SCATS Variation Routine 83 (VR83) is a function in SCATS. VR83 uses a measure of the SCATS DS (degree of saturation) and a consumption factor (known as Vk/Vo or the ratio of the maximum possible throughput volume divided by observed volume) to determine whether there is downstream congestion. Queue blocking or 'spill-over' is detected with a high probability when DS > 1 and the number of flowing vehicles measured is less than expected. That is a situation when there is available demand, however the realised outflow is less than the theoretical capacity, which is indicative that vehicles are being hindered by downstream queues. VR83 is used by SCATS to redistribute green time when it cannot be efficiently utilised by a movement due to downstream congestion blocking progression of that movement (Austroads 2010; Chung & Rosalion 1999). SCATS VR83 is used by various road authorities including VicRoads, Main Roads WA and RMS as follows:

- RMS applies VR83 in the Sydney CBD.
- VicRoads uses VR83 mainly to limit the impact of SCATS during oversaturated conditions (e.g. not to push for more green time if downstream is already oversaturated), especially for closely spaced intersections.
- Main Roads uses VR83 for the purpose of gating traffic.

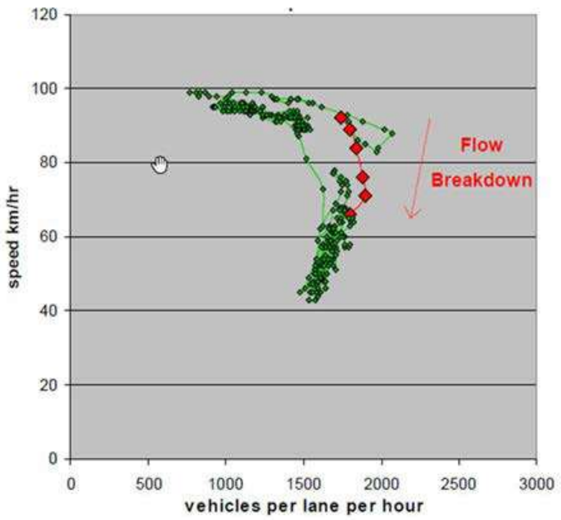
The drawback of VR83 is that it is not practical for arterials with long lengths. VR83 would only be able to detect downstream congestion if the queue spillback is close to the upstream intersection. In arterials with long lengths, VR83 would not be able to detect congestion quickly. Thereby, VR83 is mostly used on highways with relatively short distances between intersections.

For STREAMS detectors, occupancy during green is the input for the calculation of NPI congested minutes on arterial roads. The relationship between occupancy during green and degree of saturation was discussed in Luk (2008).

2.2.3 CRITICAL SPEED

Speed data can be used to determine the operation regime of a highway. Austroads (2016) illustrated the relationship of traffic flow and speed on a motorway as shown as Figure 2.4. Flow breakdown occurs when traffic flows are lower than the peak traffic flow and speeds are low. Flow breakdown typically occurs when speed falls below 80 km/h or 80% the free-flow operating speed.

Figure 2.4 Speed and flow on a motorway during flow breakdown



Source: Austroads 2016.

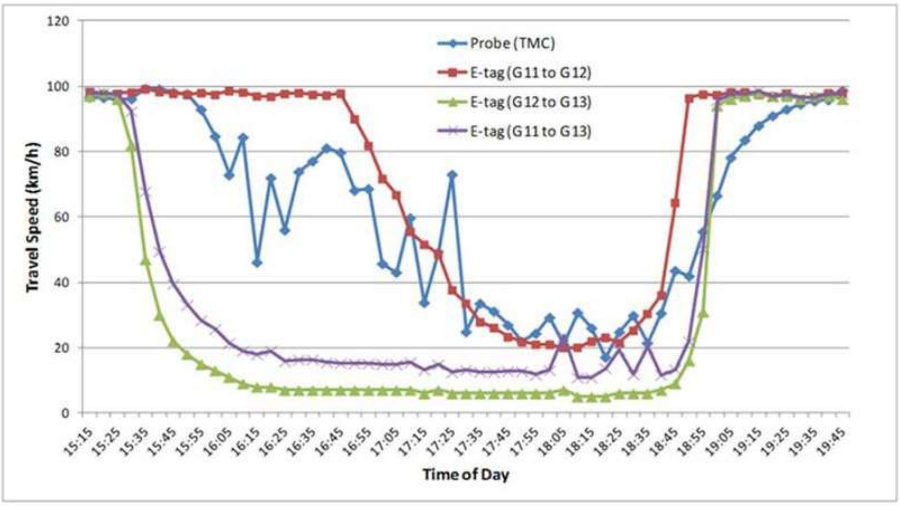
There are a number of ways to measure travel speed on arterials and motorways, including the following sources:

- probe vehicles
- road-based detectors (including inductive loops and radar)
- Bluetooth readers, e-tag readers and automatic number plate recognition (ANPR).

Probes are devices which are either carried by travellers or vehicles and are able to relay their GPS location and any available additional data in real-time and at frequent refresh rates (Espada and Bennett 2015). For example, a case study on the Eastlink (Melbourne) showed that real-time probe data was able to monitor the impacts of a lane closure in real-time as shown in Figure 2.5. In this figure, travel speed data from probes decreased at the same time as travel speed data recorded from toll e-tag readers when a lane closure occurred. Toll e-tag readers records the time a vehicle crosses toll gantries which can be used to determine travel speed between gantries. E-tag readers are highly reliable and accurate.

Probe speed data is relatively accurate, but it is reliant on probes being available in the traffic stream. On high volume highways, it is likely that data points are available at 5-minute intervals, but there is no guarantee that there is sufficient data to derive an accurate estimate. Nonetheless, probe data availability has been increasing since 2012 and it is expected to further improve in the future.

Figure 2.5 Travel speeds during a lane closure (15:15 to 16:45) on the Eastlink: probe data and e-tag data



Note: G11, 12 and G13 are gantries, arranged from upstream to downstream respectively. The probe data TMC spans much of the segment bounded by G11 and G13.

Source: Espada & Bennett 2015

Road-based detectors include loop detectors, video detectors, infrared detectors, and others. Road-based detectors typically measure spot speeds. These detectors can accurately measure spot speeds (Austroads 2015).

Bluetooth readers record unique device identifiers and the time stamp. If the same device is recorded at two roadside Bluetooth readers, the difference in the time stamps and the distance between the readers can be used to estimate travel speed (Austroads 2015; Blogg et al. 2010). E-tag data and automatic number plate recognition (ANPR) data work in the same way. Over 500 Bluetooth readers have been installed on the state-controlled roads in Southeast Queensland. This provides a reasonable coverage to determine travel time and speed of the urban road network. Travel time estimates from Bluetooth data showed similarity to probe speed data (Han et al. 2018). TMR is trialling AddInsight which predominately uses Bluetooth data to determine the traffic state of corridors in real-time.

For arterial travel time estimation using roadside detectors, TMR have adopted and implemented the ARRB Travel Time Model (ATTM) (Luk et al 2008) to estimate delay and travel time. The ATTM is used as the basis for National Performance Indicators (NPI) travel time data (Han & Mohajerpoor 2017). The NPI travel time estimates are based on effective green time, cycle time, effective red time, and degree of saturation (DS) which are sourced from the traffic signal control system.

Roadside detectors, Bluetooth data, and probe vehicle data are all viable methods of travel speed detection and each have their pros and cons. The Intelligent Hybrid Data Model (Wood and Johnston 2018) aimed to fuse data from various sources including roadside sensors (loop), point- to-point sensor data (Bluetooth) and GPS-tracked vehicle data (probe vehicle). The model applies rules to select the best speed data, and the rules are based on traffic conditions as shown in Table 2.2. The model also employs data patching process to fill in missing data based on a set of extrapolation rules applied to fill the gaps.

Table 2.2: Selection of 'best' speed in fusion in the Intelligent Hybrid Data Model

Traffic conditions	Roadside sensor data (e.g. NPI travel time data)	Point-to-point sensor data (e.g. Bluetooth data)	GPS tracked vehicle data (e.g. probe speed data)
No traffic	Best data	No data	No data
Light traffic	Best data	High risk data	High risk data
Medium traffic	Good data	Good data	Good data
Heavy traffic	Good data	Good, but delayed data	Best data
Jammed traffic	Limited data	No data	Best data
Rapidly varying data	Good data	Good, but delayed data	Best data

2.3 DISCUSSION

2.3.1 VARIABLES DEFINING CAPACITY

Capacity is defined by three variables as follows:

- maximum sustainable flow
- critical density and queue spillback
- critical speed.

Summary of the review of approaches to the measurement of capacity are summarised in Table 2.3.

Table 2.3: Measurement of capacity

Variable	Method	Remarks
Maximum sustainable flow	Static capacity estimate, using models, e.g. HCM, SIDRA, etc. *(Note: model estimates tend to be on the higher end of the scale for sustainable operation, and sustainable flow may be around 10% to 15% less than model capacity estimates)*	Model estimates are representative of average conditions and may not account for site-specific factors that affect capacity.
	Highest historical sustainable flow	Flow data is an imperfect measure of congestion as the same flow values occur at both saturated and free-flow conditions. Moreover, Roads that do not regularly cater to high demand will register an underestimated capacity value.
Critical density and queue spillback	Loop occupancy (for motorway and for arterials with departure-side detectors)	Occupancy is an effective method for detecting congestion on motorways and arterials. It is however constrained by the location of detectors. Detectors are best located on bottleneck sections.
	Departure-side and approach-side detectors to count number of vehicles on the link (for arterials) *(Note: It is theoretically possible to use upstream detectors in the absence of departure-side detectors)*	There are only a limited arterials with departure-side and approach- side detectors. The use of upstream detectors in lieu of departure- side detectors is an alternative, but this is not widely applied in practice (if any). There are also limitations in dealing with access/egress lanes that are equipped with detectors (e.g. side roads and slip lanes).
	Detection of downstream queue spill back using occupancy and flow data from loop detectors (e.g. VR83)	Spillback detection through VR83 is effective in detecting presence of downstream queue spillback, although it does not provide an estimate of capacity. VR83 is useful for arterials with short lengths but it is not particularly sensitive for long arterial segments. VR83 is nonetheless useful in traffic control under saturated conditions. STREAMS is able to measure occupancy during green for NPI congested minutes, however it is reported at movement level rather than at lane level . Development of an equivalent function in STREAMS can be considered.
Critical speed	The intelligent hybrid data model which is a fusion of three data types to derive a best estimate of travel speed	Speed is an effective method to detecting congestion.

On both motorway and arterial cases, it is considered best practice to employ all three variables as the basis of measuring capacity. Maximum sustainable flow is an appropriate definition of design capacity when the road is operating in undersaturated conditions. When operating in saturated conditions or near saturated conditions, the maximum sustainable flow is not relevant because capacity of the road is manifested as the observed flow. Hence the observed flow is the best estimate of the capacity of the road under saturated conditions. Incoming traffic greater than the observed flow will increase queues signifying the road capacity is no longer able to cater to demand. Critical density, queue spillback and critical speed are benchmarks that signify that the road if operating either in undersaturated or saturated conditions.

2.3.2 IMPERFECT MEASUREMENT DATA

The issue of imperfect measurement data is a relevant one, which entail errors in the data or gaps in the data. One methodology to address the issue of imperfect data measurement is traffic state estimation techniques. Traffic state estimation was developed in the 1970s (Wang & Papageorgiou 2005) to address the problem of estimating all the traffic variables of a network at the current time instance based on available real-time traffic measurements, particularly limited and imperfect measurements.

Traffic state estimation involves real-time statistical estimation of flow, density and speed of highway segments. Traffic state estimation tracks the inflow and outflow of a highway segment. The inflow and outflow are then used to track the number of vehicles in the segment, which is its traffic density. Based on the traffic density, the speed is estimated using a speed-density model. Traffic flows and speed are measured in real-time. Corrections to the estimated variables are made in real-time (Nathawichit, Suzuki & Nakatsuji 2003). Traffic state estimation techniques have been successfully applied in motorways (Nathawichit, Suzuki & Nakatsuji 2003; Wang & Papageorgiou 2005) and arterials (Bhaskar, Tsubota, Kieu & Chung 2014), which includes incorporation of emerging data sources such as Bluetooth and probe vehicles.

Experience in actual practice however appear to favour installation of instruments and improvement of data quality over traffic state estimation techniques. Traffic state estimation techniques could still play a role in managing data issues and should be considered in future methodology developments.

2.3.3 NETWORK CAPACITY

The review focussed on the capacity of a link. The capacity can also be conceptualised at the area (or network) level. The fundamental traffic variables of flow, density and speed have been shown to also manifest in a large areas (Gerolominis & Daganzo 2008). Empirical data from Yokohama (Japan) showed that vehicular flow across the network is highest at a critical level of density and when network flow degrades when density exceeds this critical level. Chen et al. (2002) defined capacity reliability as the probability that the network can accommodate a certain traffic demand (in terms of origin-destination demand) at a required service level. Empirical studies by Tsubota, Bhaskar and Chung (2014) in Brisbane developed a macroscopic fundamental diagram which identified the critical density to be around 20 veh/lane-km.

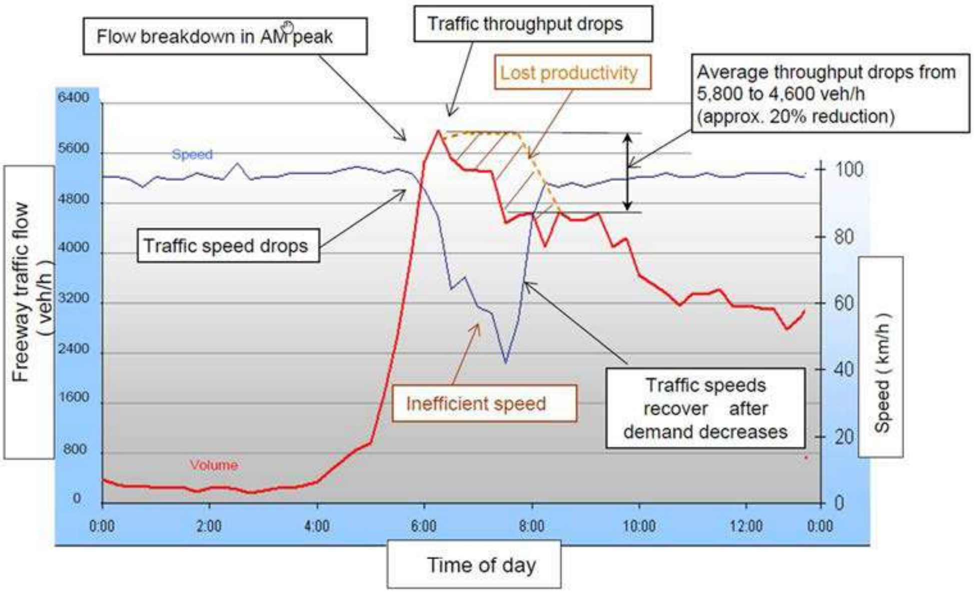
The application of network capacity is a useful concept for strategic area traffic control strategies.

It is suggested that network capacity be further investigated, including development of macroscopic fundamental diagrams.

2.3.4 REAL-TIME CAPACITY AND PREDICTED CAPACITY

This project focused on real-time capacity, which is the capacity of the segment under prevailing conditions. Predicting capacity, say in the next 5 minutes, is not part of this project. However, capacity prediction is an important aspect of real-time control. For example, if flow breakdown occurs on a motorway then the motorway experiences a capacity drop of approximately 20% which incapacitates the motorway to accommodate the high demand at that moment, leading to prolonged periods of inefficient speeds (Figure 2.6). It is therefore important to prevent flow breakdown from occurring in the first place. This requires a proactive approach, which identifies precursors of flow break down and implementing traffic management measures to prevent flow break down. This can be considered by future research work.

Figure 2.6 Typical flow break down impacts on motorway throughput and speed



Source: Austroads 2016.

3 ESTIMATING OPERATIONAL CAPACITY

The proposed methodology for estimating real-time operational capacity is discussed in this section. Operational capacity is estimated based on two principles, as follows:

- If the segment is operating in saturated operation regimes, then the realised flow is the operational capacity of the segment. Otherwise, the operational capacity is equal to the design capacity.
- The operational capacity of an upstream segment is constrained by the operational capacity of the segment adjacent downstream segment.

The design capacity is the capacity estimated by models (Section 2.2.1). It may also be the highest observed historical sustainable flow.

The operation regime of the segment is either undersaturated or saturated. The segment is considered to be saturated based on the following indicators (Sections 2.2.2 and 2.2.3):

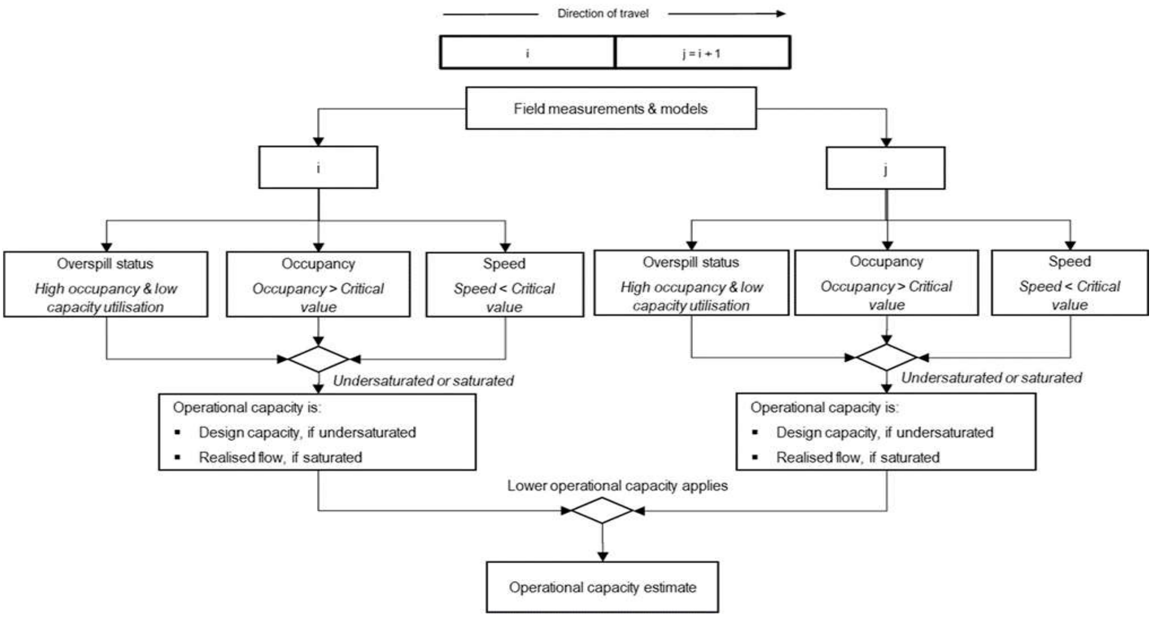
- Occupancy (as a proxy for density) is below the critical occupancy value.
- Speed is above the critical speed value.
- The segment outflow is constrained by queue overspill from the adjacent downstream segment.

For arterial roads, the critical occupancy value is about 35% and the critical speed is approximately 25 km/h. For motorways, the critical occupancy value is about 25% and the critical speed is approximately 80% of the operating speed. These values are approximations and would need to be calibrated when there is available data at selected bottleneck sites.

It is possible that there are cases wherein the above three indicators present conflicting determinations of whether the segment is saturated or not. An arbitration logic would be required to assess the quality of determination from each indicator to arrive at an accurate determination. At this stage, a conservative approach can be assumed, wherein if one indicator determines saturated conditions it would identify the segment as saturated whether the other two indicators indicate otherwise.

Figure 3.1 illustrates the methodology for two adjacent segments. Field measurements of occupancy, speed and overspill determines the operation regime of the segment. This establishes whether the operational capacity of the segment is the design capacity or the realised flow. This is done for the upstream and the downstream segment. The effective operational capacity of the segment is the lower estimate of the upstream and downstream segment's operational capacity.

Figure 3.1 Method of calculating real-time operational capacity



4 ARTERIAL ROAD CASE STUDY: SAMFORD RD

This chapter examines the application of the proposed methodology (Section 3) to determine real- time capacity of an arterial road. Samford Rd was selected as the study area.

4.1 SAMFORD ROAD STUDY AREA

The 7-km study area of Samford Rd is shown in Figure 4.1, which is composed of four sections, as shown in Table 4.1:

Table 4.1: Samford Rd study section

Section	Start	End	Distance (km)	Posted speed limit (km/h)
1	Ferny Way	Settlement Road	2.2	70
2	Settlement Road	Dawson Parade	1.5	60 – 70[1]
3	Dawson Parade	Osborne Road	1.6	60
4	Osborne Road	Wardell Street	1.7	60

1. *Speed limit changes at 500 m west of Dawson Parade.*

Figure 4.1 Samford Rd study section

Source: Google Earth.

Travel speed data from Bluetooth readers and flow and occupancy data from STREAMS departure-side detectors were collected from 12 November 2018 to 16 November 2018 (i.e. Monday to Friday). In addition, STREAMS traffic signal data were also collected for the same period. The attributes of the data sets are in Table 4.2

Table 4.2: Samford Rd datasets

Data	Description
Bluetooth data	The Bluetooth data includes travel speed from end-to-end for each of the four segments at 5-minute intervals.
Departure loop data	The departure loop data includes flow and occupancy data in 1-minute intervals. In total seven detector sites were included in the datasets, as follows: • Section 1: no site available • Section 2: 1 site • Section 3: 4 sites • Section 4: 2 sites. For each site, data is available for each lane on the site. Note that lane detectors are labelled from 1, starting from the kerbside lane to the median lane.
Traffic signal data	The data includes the time allocated for each signal phase at various times of the day. The traffic signal data was utilised to estimate the green split, which was needed to estimate the theoretical capacity of intersections.

4.2 SPEED PLOTS

The travel speed data (from Bluetooth) was plotted as shown in Figure 4.3. It was identified that Samford Rd experiences congested periods during the morning and afternoon peak, in particular the eastbound direction have pronounced congested periods during these periods. Day 1 (i.e. 12 November 2018) was selected for more detailed analysis. On Day 1, the morning peak was from 06:30 to 08:00 and the afternoon peak was from 15:00 to 17:00. Congestion were on Sections 3 and 4, as illustrated in Figure 4.2 with their available detectors sites. Succeeding sub-chapters would examine this period and location in more detail.

Figure 4.2 Samford Rd bottleneck section

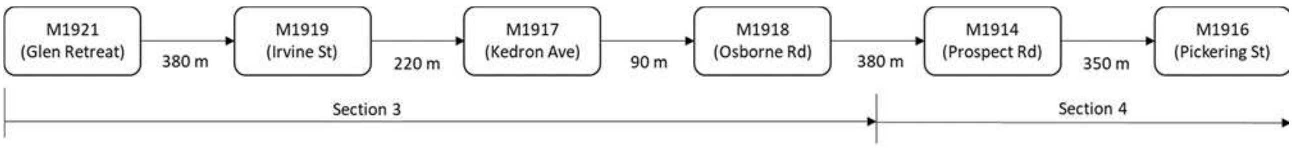
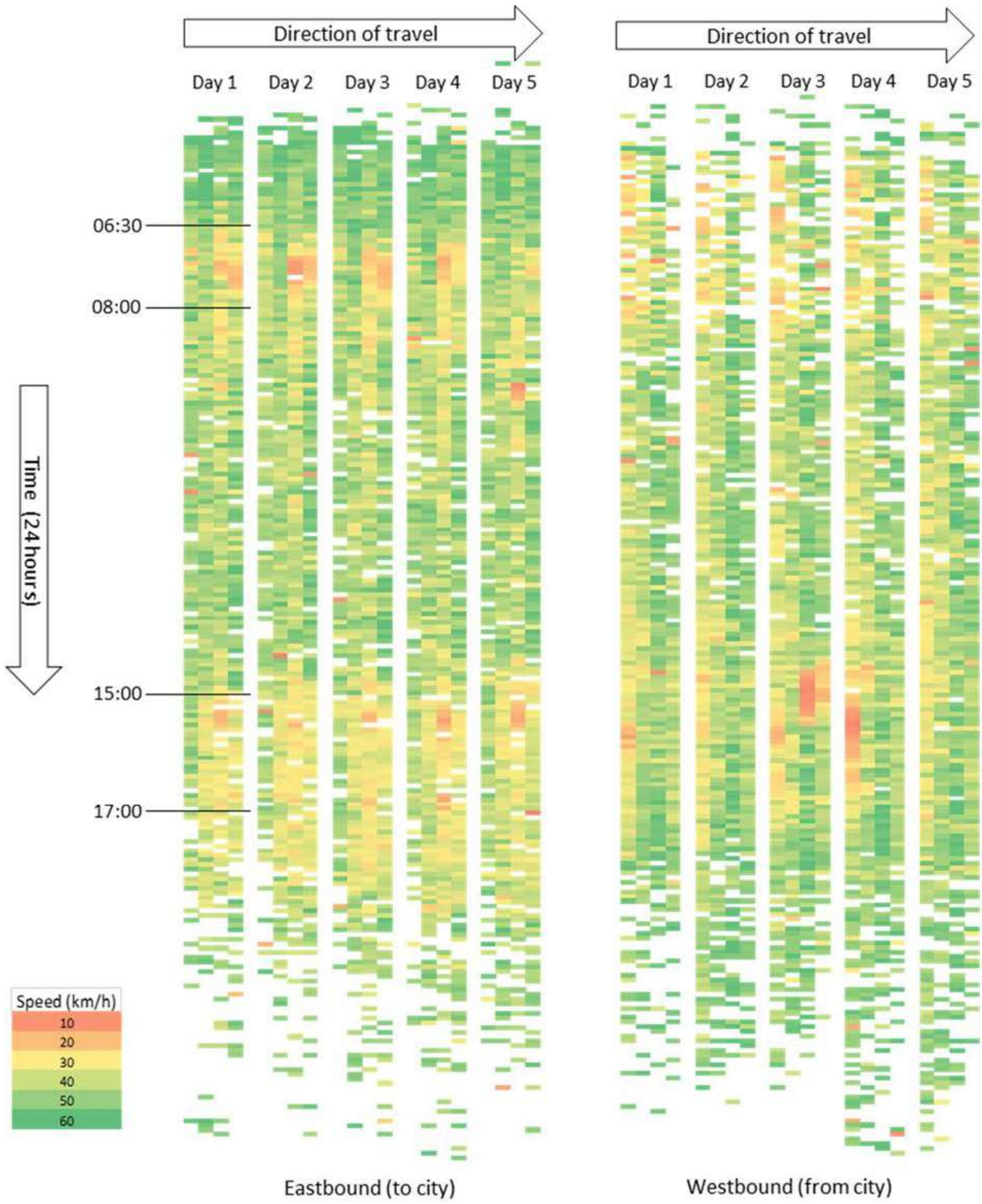


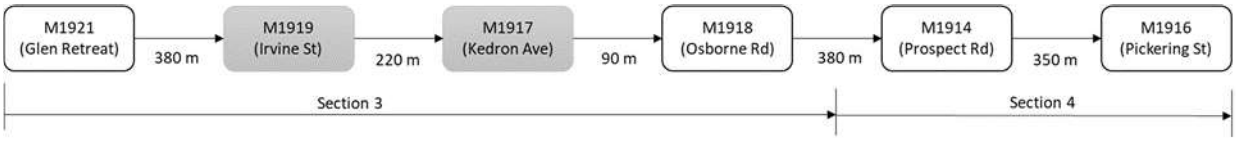
Figure 4.3 Speed plot of Samford Rd study area



4.3 DETAILED ANALYSIS: SAMFORD RD EASTBOUND FROM IRVINE ST (M1919) TO KEDRON AVE (M1917)

This sub-chapter will illustrate the application of the real-time capacity estimation as outlined in Section 3. The segment is bounded by the departure loop detectors at M1919 and M1917 (highlighted in Figure 4.4).

Figure 4.4 M1919 – M1917 segment in Samford Rd

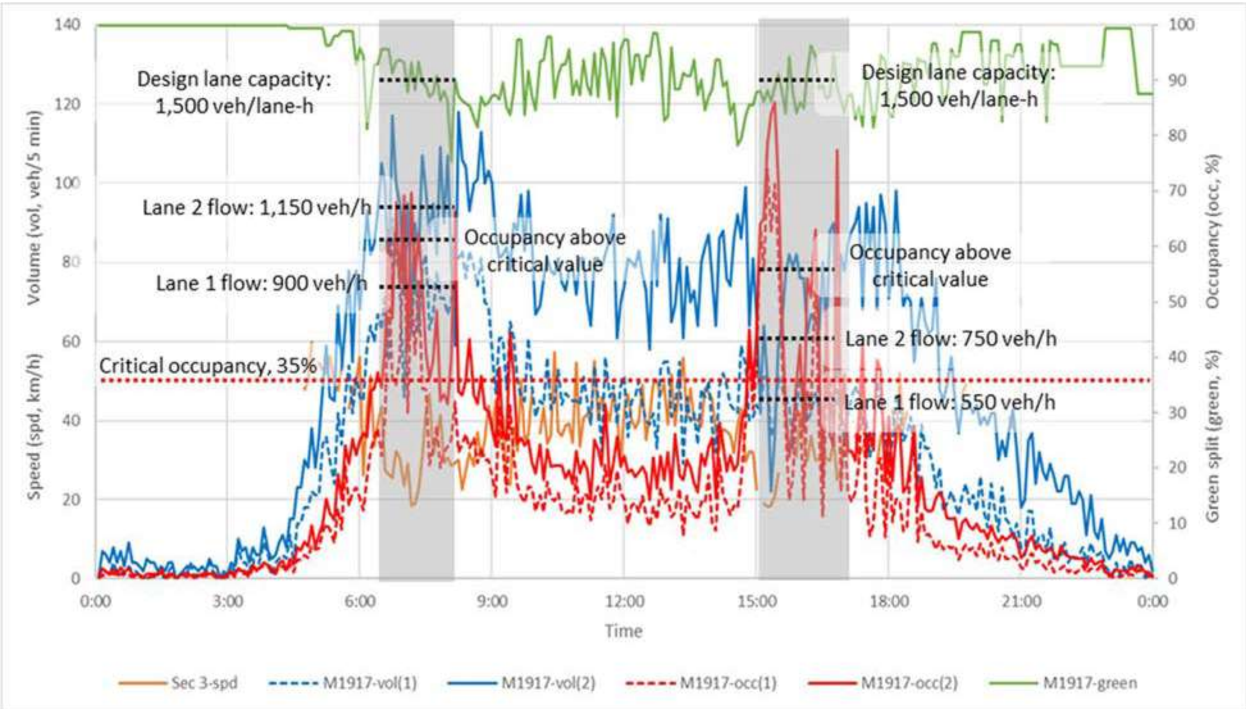


4.3.1 M1917 DAY 1 SPEED, FLOW AND OCCUPANCY

The speed, flow and occupancy data of M1917 are shown in Figure 4.5. The AM and PM peak periods are shaded in the figure. Critical occupancy value was set at 35%. If occupancy is above this value, then M1917 would be determined to be operating at saturated conditions. As shown in Figure 4.5, M1917 is saturated during the AM and PM peak. For other times of the day, its occupancy was below 35%; hence, M1917 was undersaturated during these times.

The critical speed was set at 25 km/h. Note that the speed data spans the whole of Section 3 wherein M1917 is included; thereby, the level of resolution of the speed data is not detailed enough to characterise the operation at M1917. The speed data was used only as supplemental information, and the occupancy data was used as the primary determinant of the saturation level of M1917. Nonetheless, Section 3 speeds during the AM and PM peak was just above 25 km/h, indicating that the section was operating at near saturation levels. This most likely meant that M1917 was operating at saturated conditions, but other parts of Section 3 were operating at undersaturated conditions.

Figure 4.5 M1917 speed, flow and occupancy on Day 1 (Samford Rd eastbound)



It was assumed that the base saturation flow rate of M1917 is 1,700 veh/h per lane. The green split during the AM and PM peak hours was around 90%. The design capacity can therefore be approximated to be around 1,500 veh/h per lane (i.e. 0.9 × 1,700 ~ 1,500).

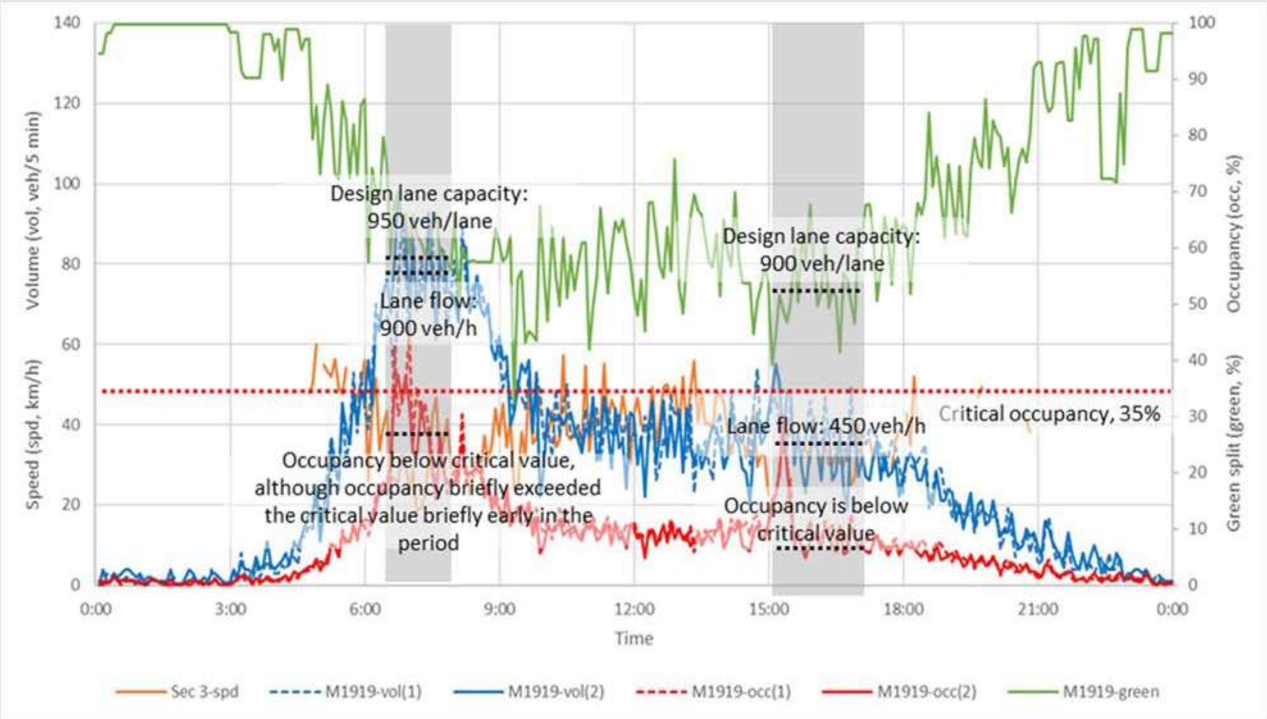
The realised flow was 1,025 veh/h per lane and 650 veh/h per lane during the AM peak and PM peak, respectively (note: estimated flow is the average of the flow of Lane 1 and 2). During the AM and PM peak, the realised flow was significantly below the design capacity. Occupancy levels during this period indicate that the intersection was saturated hence there was sufficient demand. Underutilisation of design capacity while at the same time there was sufficient demand meant that flow through the intersection was constrained and was indicative that M1917 was experiencing spillback from the adjacent downstream intersection (i.e. M1918).

4.3.2 M1919 DAY 1 SPEED, FLOW AND OCCUPANCY

The speed, flow and occupancy data of M1919 is shown in Figure 4.6. The AM and PM peak periods are shaded in the figure. Critical occupancy value was set at 35%. The intersection was operating at undersaturated conditions throughout the day. Although it was noted that during the AM peak, occupancy of M1919 briefly exceeded the critical value early in the AM peak.

As with M1917, the critical speed was set at 25 km/h. The available speed data however spans the entire Section 3, wherein M1919 covers only a portion of the section. The speed data was used only as supplemental information.

Figure 4.6 M1919 speed, flow and occupancy on Day 1 (Samford Rd eastbound)

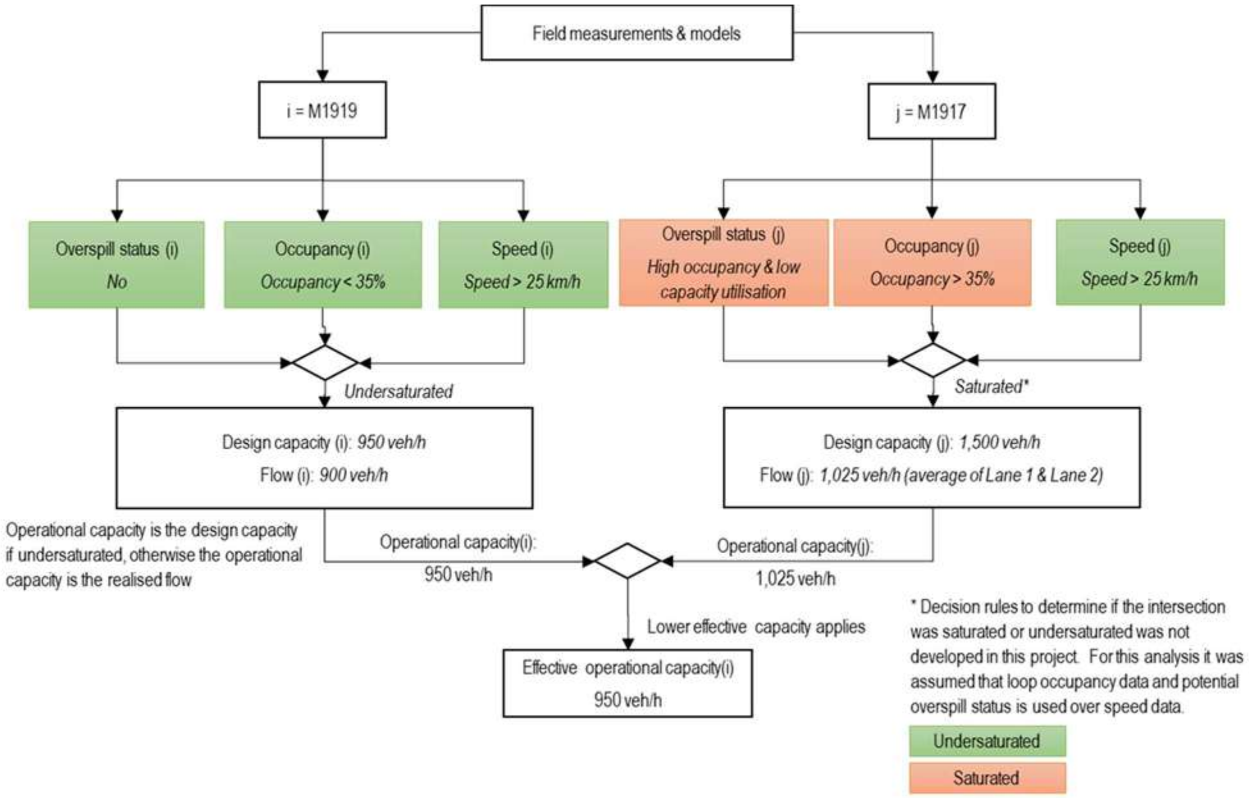


Assuming a saturation flow rate of 1,700 veh/h per lane and a green split it of 55% and 50% in the AM and PM peak, it was estimated that the design capacity of M1919 was 950 veh/h per lane and 900 veh/h per lane during the AM and PM peak, respectively. The realised flow during the AM peak and PM peak was 900 veh/h per lane and 450 veh/h per lane respectively.

4.3.3 ESTIMATING THE REAL-TIME CAPACITY OF M1919 (AM PEAK EXAMPLE)

Figure 4.7 illustrates the application of the methodology described in Section 3 to estimate the capacity of M1919 in real-time during the AM peak period of Day 1. The upstream intersection M1919 was determined to be undersaturated (in Section 4.3.2). The design capacity therefore applies, which was estimated to be 950 veh/h per lane. On the other hand, the downstream intersection M1917 was determined to be saturated. The effective capacity was therefore equal to the realised flow, which was 1,025 veh/h per lane. The real-time capacity of M1919 was the lower value of the operational capacities of the upstream and downstream intersections, which was 950 veh/h per lane.

Figure 4.7 Operational capacity estimation of M1919 during the AM peak



4.4 REAL-TIME CAPACITY OF SAMFORD RD (EASTBOUND, SECTION 3 & 4)

This sub-chapter illustrates the results of the application of the methodology to estimate real-time capacity on Section 3 & 4 of Samford Rd during the AM and PM peak in the eastbound direction. The speed, flow and occupancy plots of intersections are in Appendix A. The real-time capacity of Samford Rd Section 3 and 4 in the eastbound direction during the AM and PM peak periods are illustrated in Figure 4.8 and Figure 4.9, respectively. These figures were derived using the same methodology outlined in Figure 4.7, e.g. see the analysis of M1919 and M1917 in Section 4.3.

During the AM peak, the capacity of Section 3 and 4 varied from 950 veh/h per lane to 1,300 veh/h per lane. During the PM peak, capacity varied from 650 veh/h per lane to 1,150 veh/h per lane.

It was noted that Bluetooth speed data covered sections of the highway and do not have a high enough resolution to assess travel speed between intersections within the section. For example, Section 3 (see Figure 4.2) is composed of three links (i.e. M1921-M1818, M1919-M1917 and M1917-M1918). The available Bluetooth travel speed data covers the entire Section 3; thereby, the operation regime of the three links could not be determined individually leading to inaccurate results. It is recommended to utilise as much detailed data as possible and may require improving the density of Bluetooth readers, where needed.

Figure 4.8 Real-time operational capacity estimation of Samford Rd Section 3 and 4 during the AM peak (eastbound)

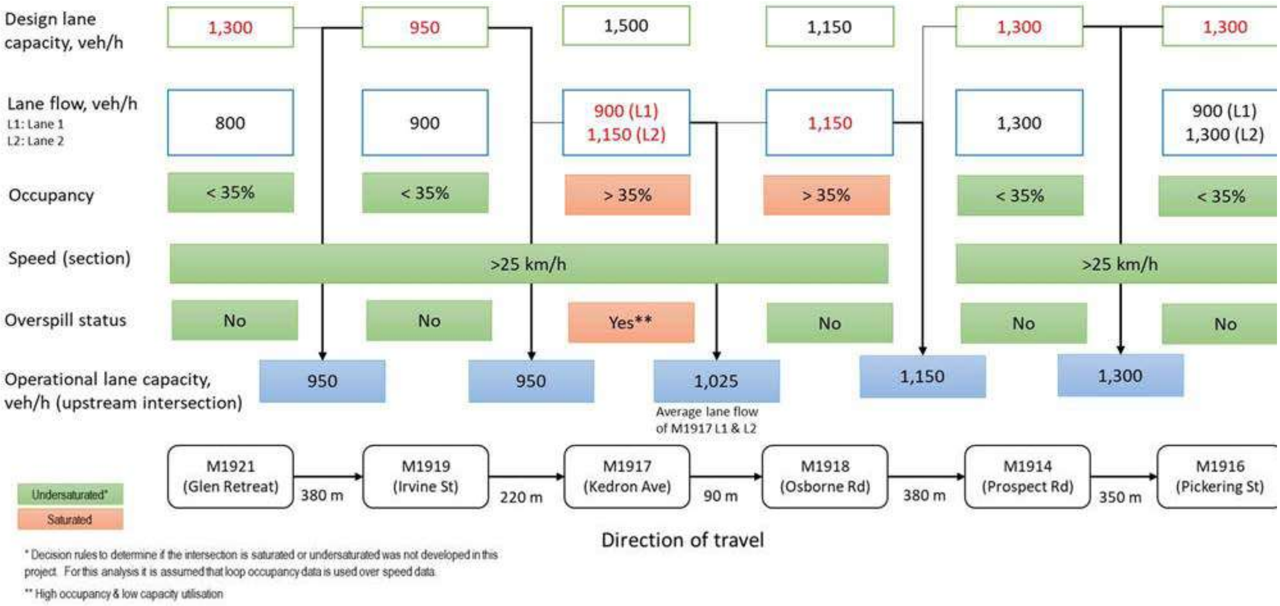
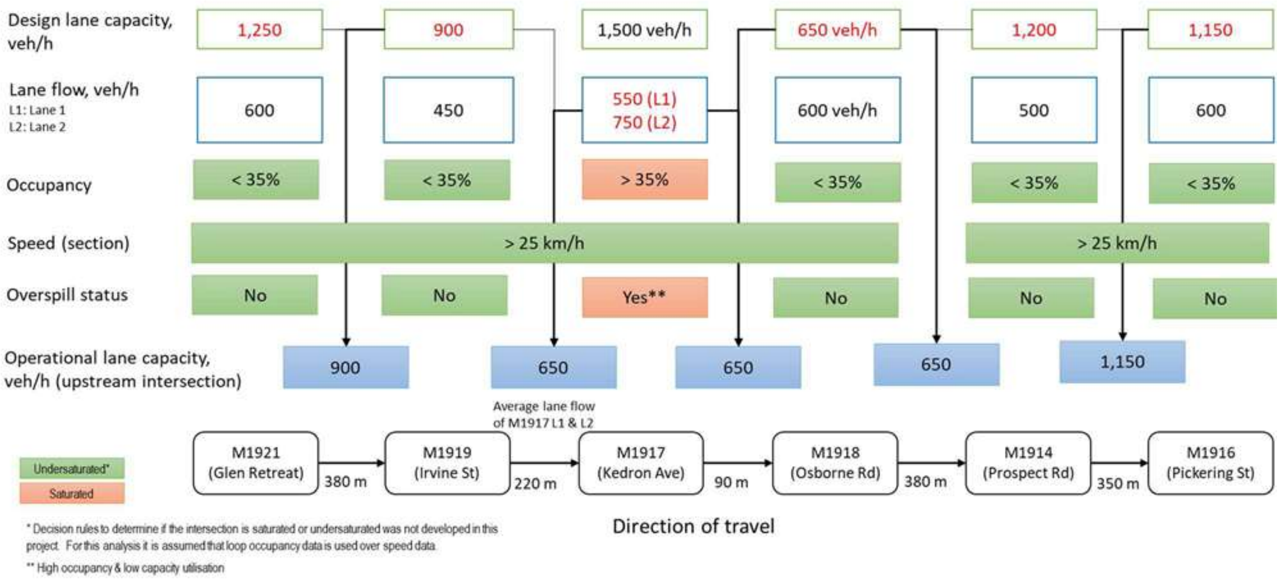


Figure 4.9 Real-time operational capacity estimation of Samford Rd Section 3 and 4 during the PM peak (eastbound)

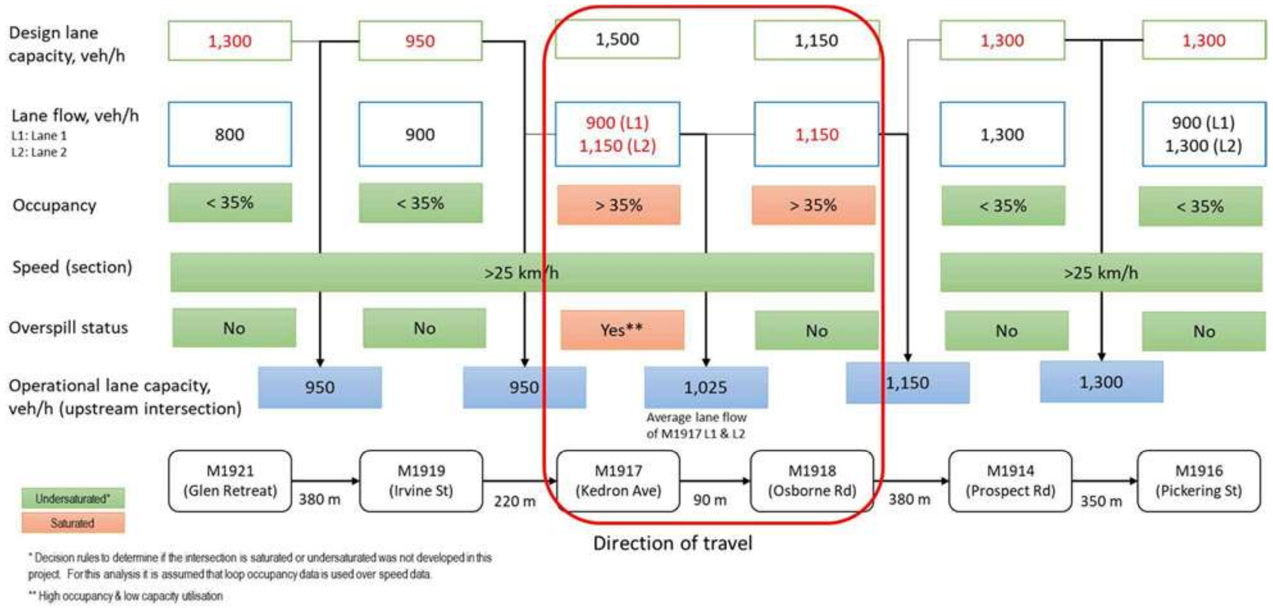


4.5 POTENTIAL COURSE OF ACTION FOR SAMFORD RD

This sub-chapter examines how real-time capacity estimation can be utilised to develop road operations improvement strategies for Samford Rd. In the example described in Section 4.4, Samford Rd/ Osborne Rd (M1918) was identified as a major bottleneck, which impacted the operation on the adjacent upstream intersection M1917. M1917 is only 90 m away from M1918, hence M1917 was vulnerable to queue spill back from M1918.

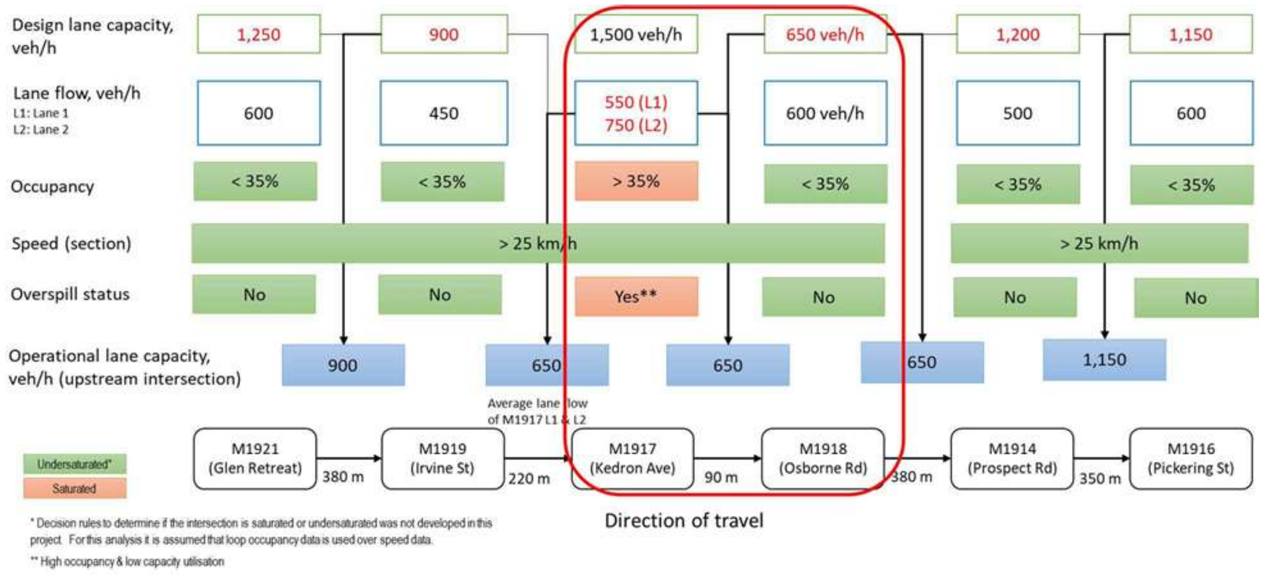
During the AM peak, the capacity of M1918 was limited to 1,150 veh/h per lane as the green split was reduced to around 70%. This constrained the effective capacity of M1917 to 1,150 veh/h per lane although the design capacity on M1917 was 1,500 veh/h per lane, as shown in Figure 4.10.

Figure 4.10 Real-time operational capacity estimation of Samford Rd Section 3 and 4 during the AM peak (eastbound) – bottleneck section M1917-M1918



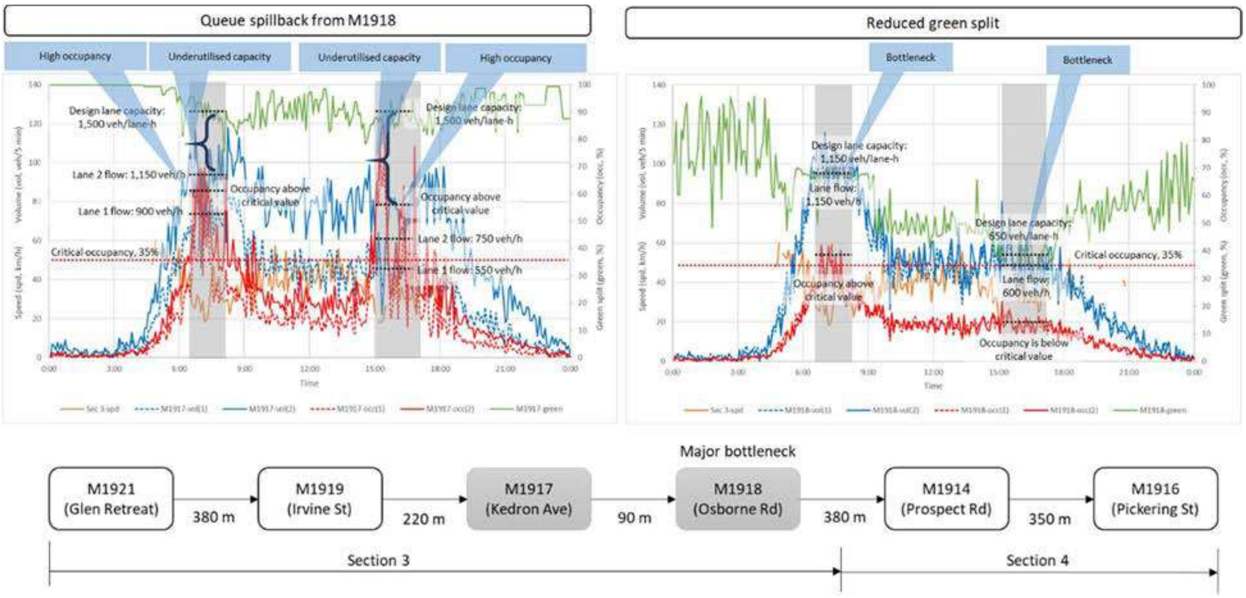
A similar situation occurred during the PM peak period, wherein M1918 capacity was reduced to 650 veh/h per lane as green split was reduced to around 40%. It constrained the capacity of M1917 to 650 veh/h per lane, while the design capacity is 1,500 veh/h per lane, as shown in Figure 4.11.

Figure 4.11 Real-time operational capacity estimation of Samford Rd Section 3 and 4 during the PM peak (eastbound) – bottleneck section M1917-M1918



On both AM and PM peak periods, occupancy on M1917 indicated that it is operating at saturated conditions, which meant that there was sufficient demand but the realised flow was significantly lower than the design capacity, hence vehicles could not fully utilise the available capacity and was indicative of the impacts of a queue spill over. The speed, flow and occupancy at the bottleneck section is illustrated in Figure 4.12.

Figure 4.12 Bottleneck on M1917 – M1918 segment



There are two possible ways that can be considered to improve operation on this bottleneck segment, as follows:

- The underutilised capacity on M1917 may be re-allocated to other movements, such as side traffic or pedestrian movements. This can be accomplished by increasing the share of the cycle time to these movements and reducing the share of the through movement phase on Samford Rd.
- The capacity on M1918 may be increased to prevent queue spill back to M1917. This can be achieved by improving the synchronisation of the through phase on M1917 and M1918, as well as, increasing the green split on M1918.

These two measures may be incorporated in the traffic signal control scheme, which could be automatically implemented once these scenarios are encountered. A possible approach is to introduce the concept of ‘master and slaves’ sites. M1918 could be the ‘master’ and upstream intersections could be the ‘slaves’ until another master is identified. With M1918 as ‘master’, the traffic signal operation can be focussed on monitoring and optimising performance of the critical bottleneck of the corridor. It is expected that these measures could improve operation on Samford Rd. However, potential risks such as rat running need to be studied more closely and managed if needed.

5 MOTORWAY CASE STUDY: CENTENARY HWY

This chapter examines the application of the proposed methodology (Section 3) to determine real- time capacity of a motorway. Centenary Hwy was selected as study area. Only the northbound direction (i.e. towards the city) was analysed.

5.1 CENTENARY HWY STUDY AREA

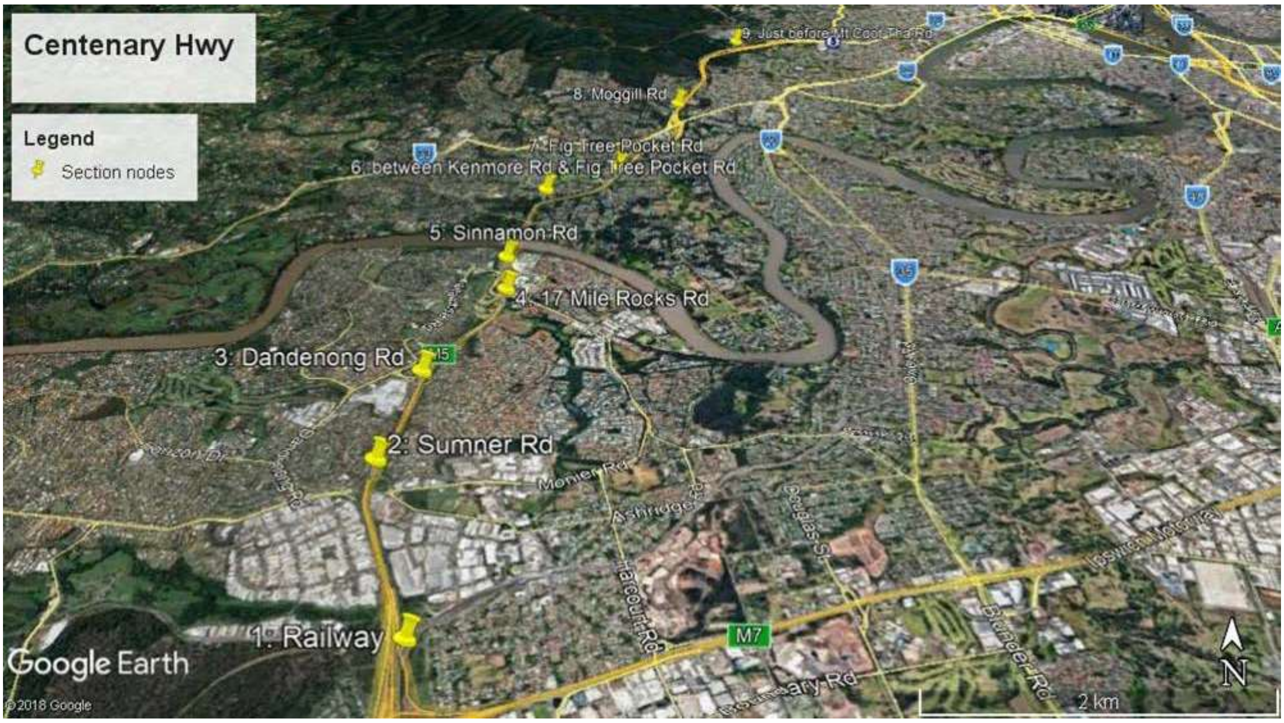
The 10.6-km study area of Centenary Hwy is shown in Figure 5.1, which is composed of eight sections, as shown in Table 5.1.

Table 5.1: Centenary Hwy Study Area

Section	Start	End	Distance (km)	Posted speed limit (km/h)
1	Ipswich Mwy NB on-ramp	Sumner Road	1.1	100
2	Sumner Road	Dandenong Road	1.1	100
3	Dandenong Road	Seventeen Mile Rocks Road	1.4	100
4	Seventeen Mile Rocks Road	Sinnamon Road	0.6	100
5	Sinnamon Road	Kenmore Road	1.3	80
6	Kenmore Road	Fig Tree Pocket Road	0.9	80
7	Fig Tree Pocket Road	Moggill Road	1.9	90
8	Moggill Road	1 km west of Mt Coot Tha Road	2.3	80 – 90[1]

1. *Posted speed limit changes from 90 km/h to 80 km/h at 2 km north of Moggill Road*

Figure 5.1 Centenary Hwy Study Area



Source: Google Earth.

Travel speed data from Bluetooth readers and flow, speed and occupancy data from loop detectors were collected from 12 November 2018 to 16 November 2018 (i.e. Monday to Friday). The attributes of the data sets are in Table 5.2.

Table 5.2: Centenary Hwy datasets

Data	Description
Bluetooth data	The Bluetooth data includes travel speed from end-to-end of each of the eight sections at 5-minute intervals.
Loop data	The loop data includes flow, spot speed and occupancy data in 1-minute intervals. In total 46 detector sites were included in the datasets, as follows: • Section 1: 4 sites • Section 2: 6 sites • Section 3: 6 sites • Section 4: 4 sites • Section 5: 4 sites • Section 6: 4 sites • Section 7: 10 sites • Section 8: 8 sites. For each site, data is available for each lane on the site. Note that lane detectors are labelled from 1, starting from the kerbside lane to the median lane.

Queue detection/queue protection (QD/QP) algorithm coupled with variable speed limit signs are in place on Centenary Hwy Sections 1 – 4 and 8. On typical weekdays, speed limit reduction is activated at 6 to 9:30 AM for Sections 1 – 4 and at 7 to 9 AM for Section 8. The activation threshold for the QD/QP algorithm is when the observed speed drops below 45 km/h and the occupancy is above 25%.

5.2 SPEED PLOTS

The travel speed data (from Bluetooth) was plotted as shown in Figure 5.3. It was identified that Centenary Hwy experienced recurring congestion in the mornings and non-recurring congestion in the afternoon peak. Day 1 (i.e. 12 November 2018) was selected for more detailed analysis. On Day 1, the morning peak was from 06:15 to 09:00 and the afternoon peak was from 16:45 to 18:15. Congestion was reported on Sections 1 to 6. The major bottleneck was located between Section 4 and 6 and the primary cause was the geometric constraints in the area (i.e. Centenary Bridge and the crest after Kenmore Road overpass). A section around 1.5 km upstream and downstream of the bottleneck was selected for more detailed analysis. This section is shown in in Figure 5.2 showing the detectors sites utilised in the analysis. Succeeding sub-chapters would examine this period and location in more detail.

Figure 5.2 Centenary Hwy bottleneck section

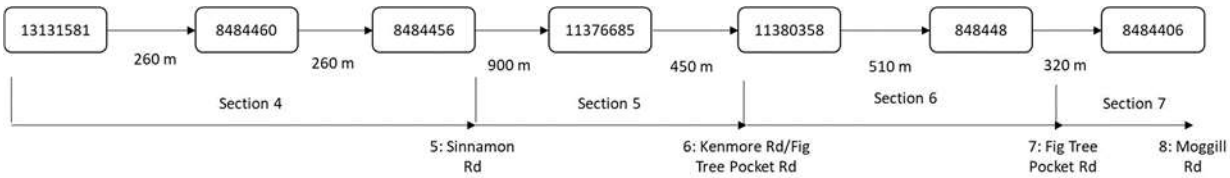
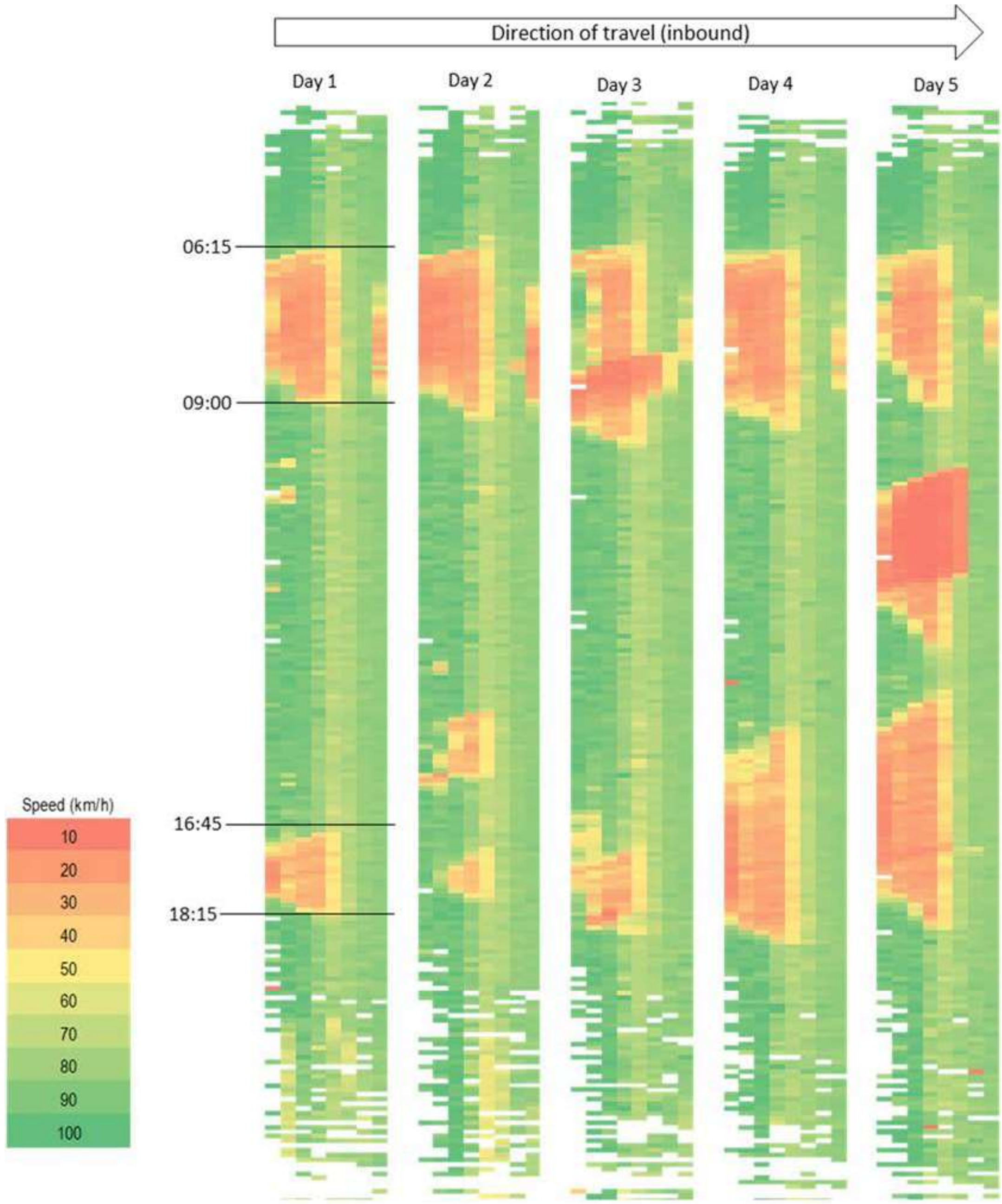


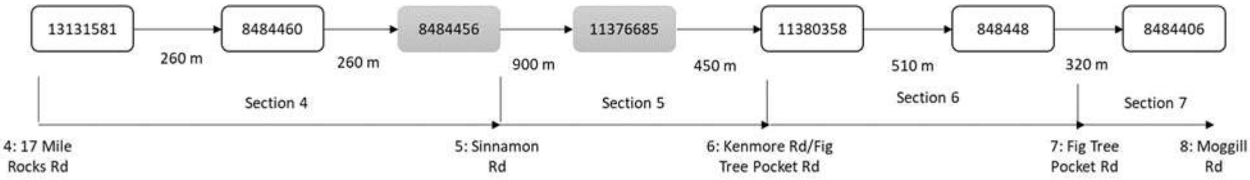
Figure 5.3 Speed plot of Centenary Hwy study area (northbound direction)



5.3 ILLUSTRATIVE EXAMPLE: SECTION 4 & 5 FROM SINNAMON RD TO KENMORE RD

This sub-chapter will illustrate the application of the real-time capacity estimation as outlined in Section 3 . The segment bounded by detector sites 8484456 and 11376685 (highlighted in Figure 5.4) would be used as an illustrative example.

Figure 5.4 Detector site location on Centenary Hwy



5.3.1 CENTENARY HWY NB BEFORE KENMORE RD OVERPASS (DETECTOR SITE 11376685) DAY 1 SPEED, FLOW AND OCCUPANCY

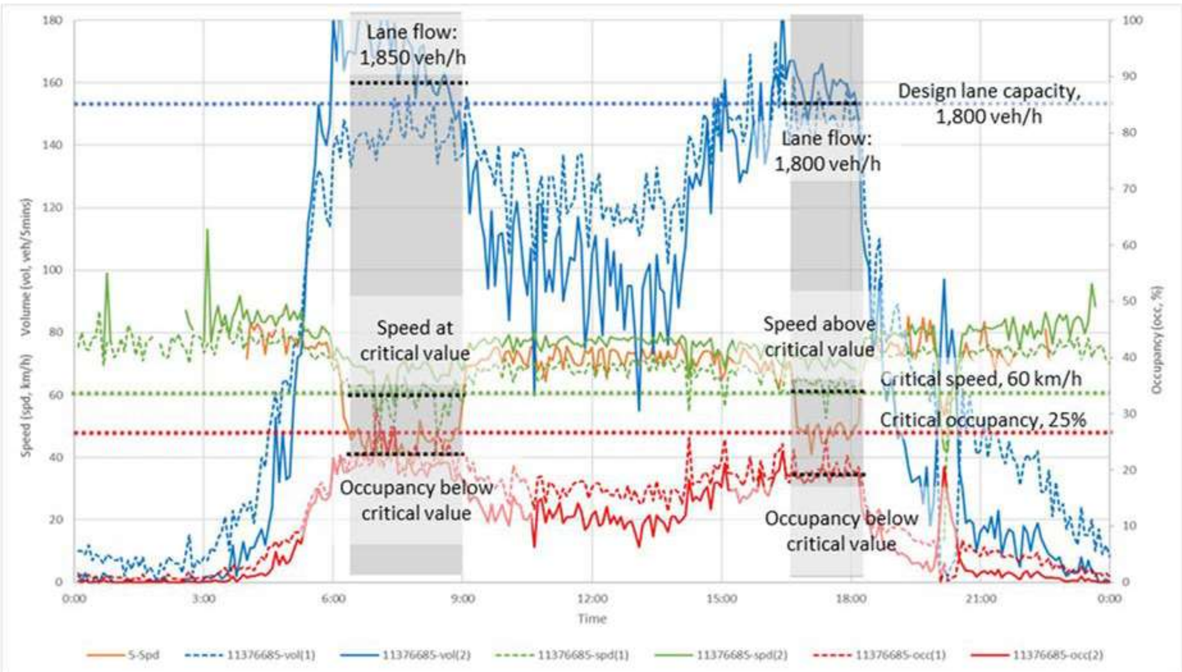
The speed, flow and occupancy data for the detector site after Kenmore Road overpass (11376685) are shown in Figure 5.5. The AM and PM peak periods are shaded in the figure. Critical occupancy value was set at 25%. If occupancy is above this value, then 11376685 would be determined to be operating at saturated conditions. As shown in Figure 5.5, 11376685 was not saturated during the AM and PM peak.

The critical speed was set at 60 km/h (i.e. approximately 80% of the 80km/h operating speed). Note that the speed data for 11376685 included Bluetooth spatial speed data which covered the entire Section 5, as well as, spot speed data on 11376685. For the purpose of analysis, only the spot speeds were considered as the spatial speed data did not have the resolution to specifically assess the 11376685 location. The spatial speeds were included for reference only. Spot speeds were at the critical value of 60 km/h during the AM peak. During the PM peak, spot speeds were above the critical speed. Based on the spot speed data, it was determined that 11376685 was undersaturated. This determination was similar to the determination using occupancy data, described earlier.

It is noted that the Bluetooth spatial speed was below the critical value, indicating the Section 5 as a whole was operating at saturated conditions. This most likely meant that site 11376685 was operating undersaturated, but other parts of Section 5 were operating at saturated conditions.

It was assumed that the theoretical capacity of site 11376685 was 1,800 veh/h per lane.

Figure 5.5 11376685 speed, flow and occupancy on Day 1 (Centenary Hwy northbound)

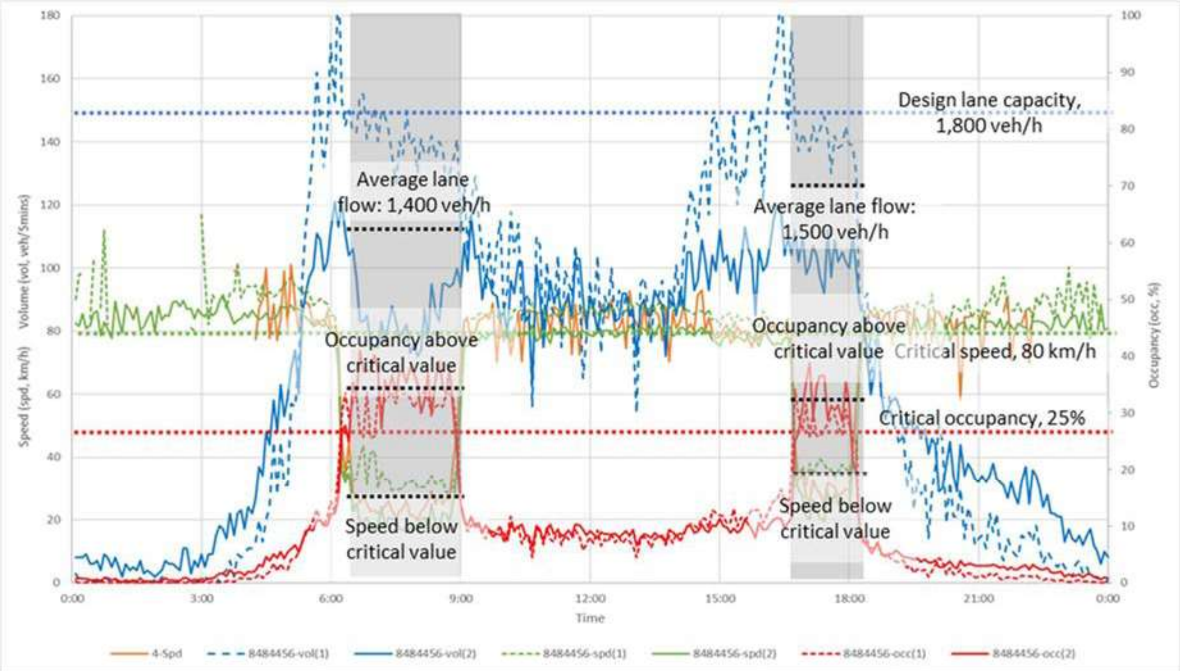


5.3.2 WESTERN FWY NB BETWEEN SEVENTEEN MILE ROCKS RD AND SINNAMON RD (DETECTOR SITE 8484456) DAY 1 SPEED, FLOW AND OCCUPANCY

The speed, flow and occupancy data for the detector site between Seventeen Mile Rocks Rd and Sinnamon Rd (8484456) is shown in Figure 5.6 . The AM and PM peak periods are shaded in the figure. Critical occupancy value was set at 25%. Occupancy was above the critical value during the AM and PM peak.

The critical speed was set at 80 km/h (i.e. 80% of the 100 km/h speed limit). Figure 5.6 shows both the spatial speed of Section 5 and spot speeds at site 8484456. Spot speeds were below the critical speed, indicating that site 8484456 is saturated. The Section 5 spatial speed was used only as a reference, as it did not have resolution to be specific to 8484456. Nonetheless, the spatial speed was also below the critical speed value indicating that the section as a whole was operating at saturation level during AM and PM peak

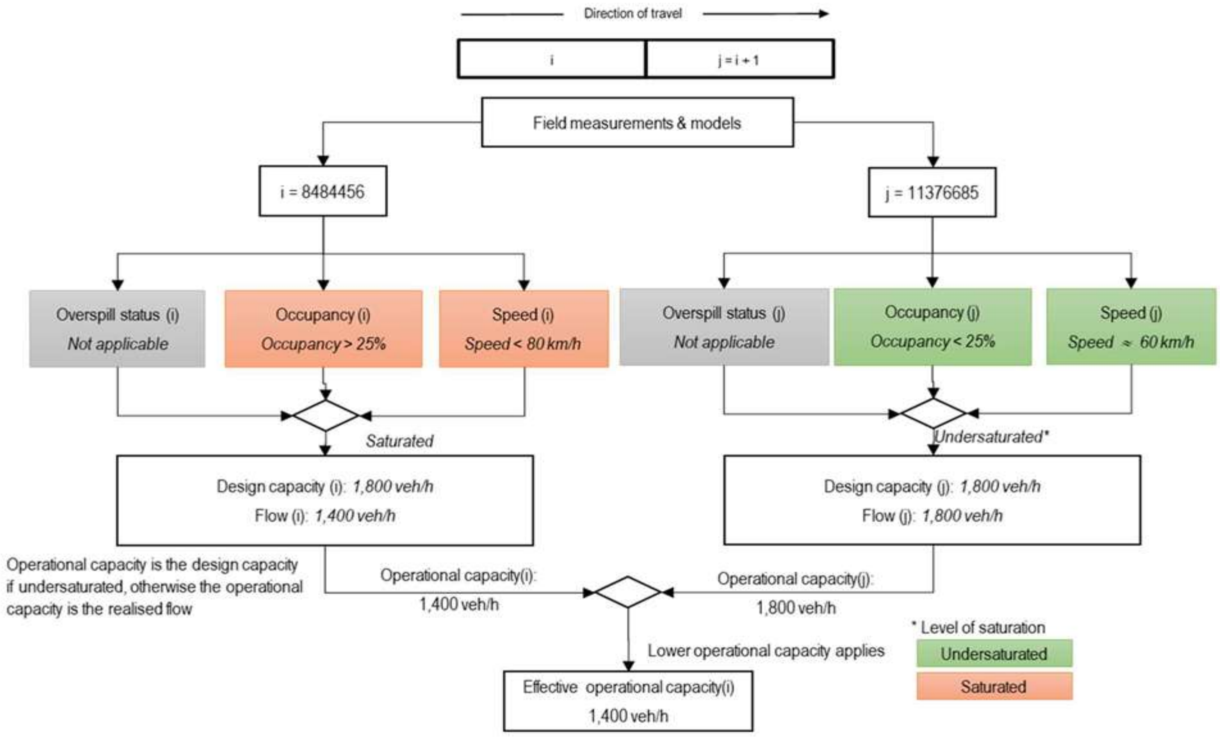
Figure 5.6 8484456 speed, flow and occupancy on Day 1 (Centenary Hwy northbound)



5.3.3 ESTIMATING THE REAL-TIME CAPACITY OF 8484456 (AM PEAK EXAMPLE)

Figure 5.7 illustrates the application of the methodology described in Section 3 to estimate the operational capacity of 8484456 in real-time during the AM peak period of Day 1. The upstream detector site 11376885 was determined to be undersaturated (in Section 5.3.1). The theoretical capacity therefore applies, which was estimated to be 1,800 veh/h per lane. On the other hand, the downstream detector site 8484456 was determined to be saturated. The effective capacity was therefore equal to the realised flow, which was 1,400 veh/h per lane. The real-time capacity of 8484456 was the lower value of the capacities of the upstream and downstream intersections, which was 1,400 veh/h per lane.

Figure 5.7 Real-time operational capacity estimation of 8484456 during the AM peak



5.3.4 REAL-TIME CAPACITY OF CENTENARY HWY FROM SECTIONS 4 TO 7

This section illustrates the results of the application of the methodology to estimate real-time capacity on the bottleneck section of Centenary Hwy during the AM and PM peak in the northbound direction. The speed, flow and occupancy plots of individual detector sites are in Appendix B. The real-time capacity of the Centenary Hwy segment in the northbound direction during the AM and PM peak periods are illustrated in Figure 5.8 and Figure 5.9, respectively.

These figures were derived using the same methodology outlined in Figure 5.7, e.g. see the analysis of 8484456 and 11376685 in Figure 5.7. During the AM peak, the capacity of Sections 4 to 7 varied from 1,400 veh/h per lane to 1,800 veh/h per lane. During the PM peak, capacity varied from 1,450 veh/h per lane to 1,800 veh/h per lane.

Figure 5.8 Real-time operational capacity estimation of Centenary Hwy during the AM peak (northbound)

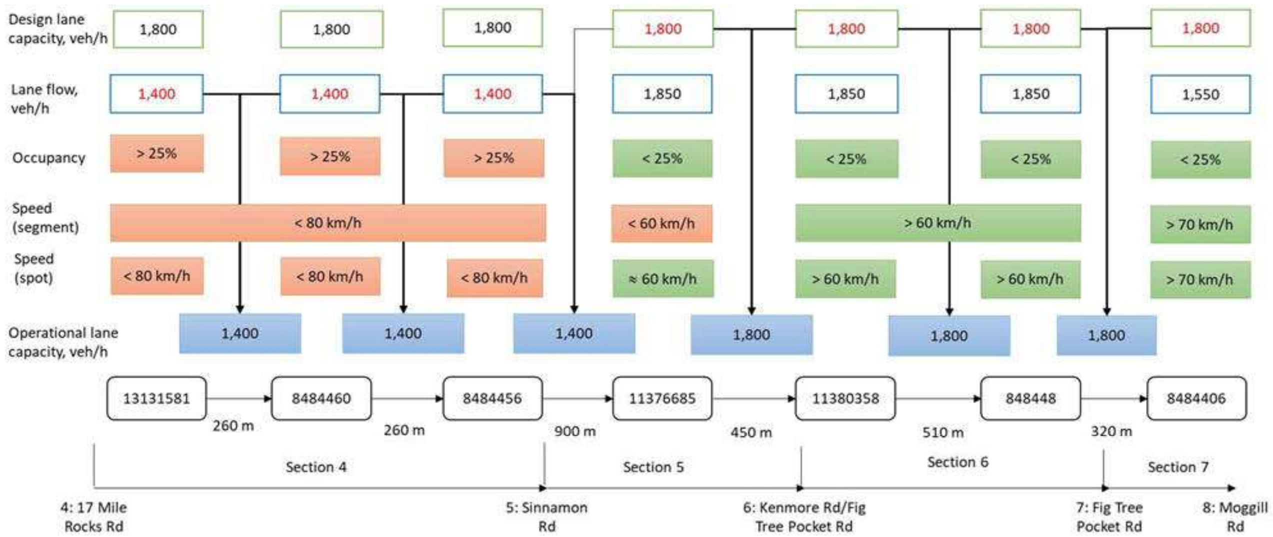
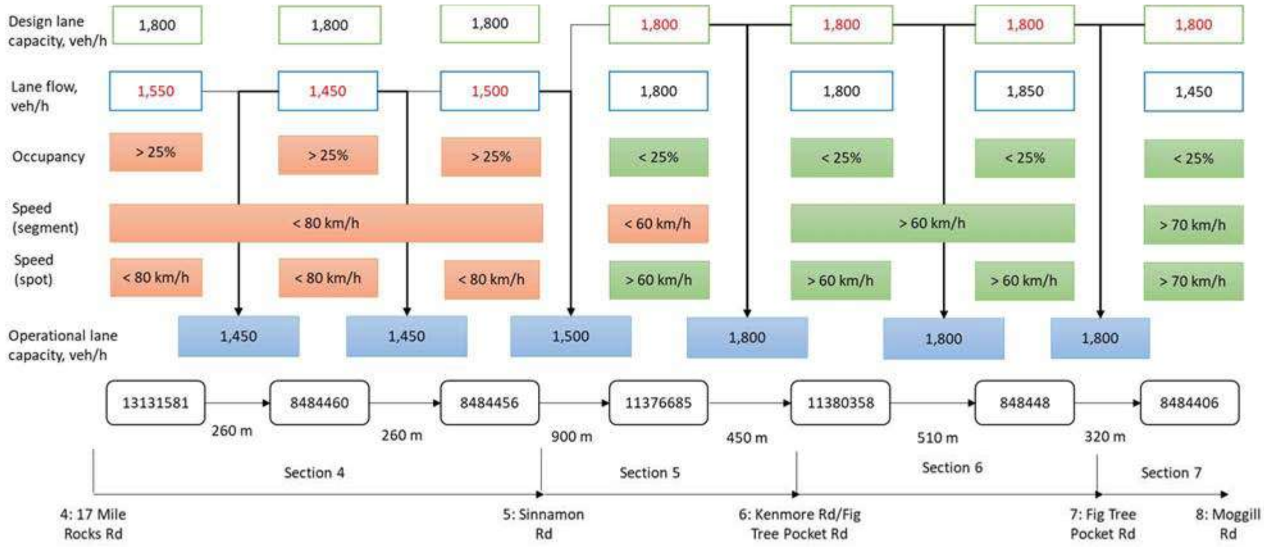


Figure 5.9 Real-time capacity estimation of Centenary Hwy during the PM peak (northbound)



5.4 POTENTIAL APPLICATION/ OPERATION STRATEGY FOR CENTENARY HWY

This sub-chapter examines how real-time capacity estimation can be utilised to improve road operation for Centenary Hwy.

5.4.1 PROACTIVE FLOW BREAK DOWN MANAGEMENT

The detector site located near Sinnamon Road on-ramp was identified as a major bottleneck, which impacted the operation on adjacent upstream sections. It was observed that the operational capacity of Centenary Hwy decreased by 20% when it operated in flow breakdown conditions, as shown in Figure 5.10. This was observed during the AM and PM peak. The detector site which is 260 m upstream also manifested the same capacity drop under flow break down operations, as shown in Figure 5.11.

It appeared that prior to flow break down, the traffic flow momentarily experienced a spike reaching 2,200 veh/h per lane, which was significantly above the design capacity of a motorway of 1,800 veh/h per lane. Operating with traffic flows beyond the theoretical capacity was not sustainable as the risk of flow breakdown increased at these conditions. Once capacity dropped by 20%, the limited operational capacity was sustained for the duration of the peak periods. Hence, Centenary Hwy was operating at sub-optimally at the time when there was significant demand. It is beneficial to prevent flow breakdown from happening or to recover from flow breakdown as quickly as possible. This can be achieved by regulating the flows on the motorway such that the motorway operates optimally at near saturation levels and that traffic flows are sustainable. Although VSL is implemented along this section, the speed reduction is triggered after flow breakdown has occurred as the speed threshold is set to 45km/h. Another method to achieve sustainable flows is to implement ramp metering techniques.

The analysis was made under 5-minute resolution; however, the available data is at 1-minute resolution. The speed, flow and occupancy on the mainline near Sinnamon Road at 1-minute resolution is shown in Figure 5.12. Utilising higher resolution data would decrease the latency of identifying potential flow break conditions, hence proactive measures can be implemented earlier than if 5-minute resolution data is used. Further research on utilising higher resolution data could be considered for further research (e.g. Hall and Gaffney 2019).

Figure 5.10 Capacity drop during saturated conditions – Centenary Mwy northbound near Sinnamon Rd on-ramp, Day 1

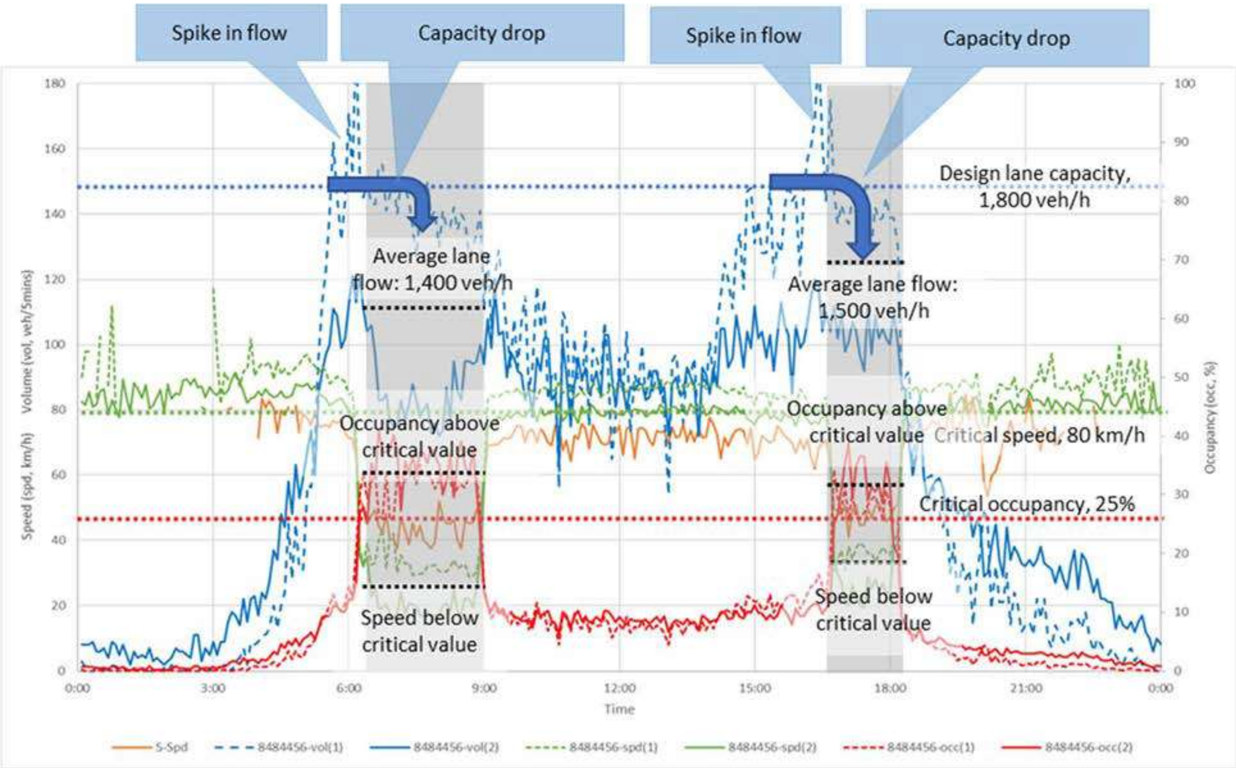


Figure 5.11 Capacity drop during saturated conditions Centenary Mwy northbound between Seventeen Mile Rocks Road and Sinnamon Rd), Day 1

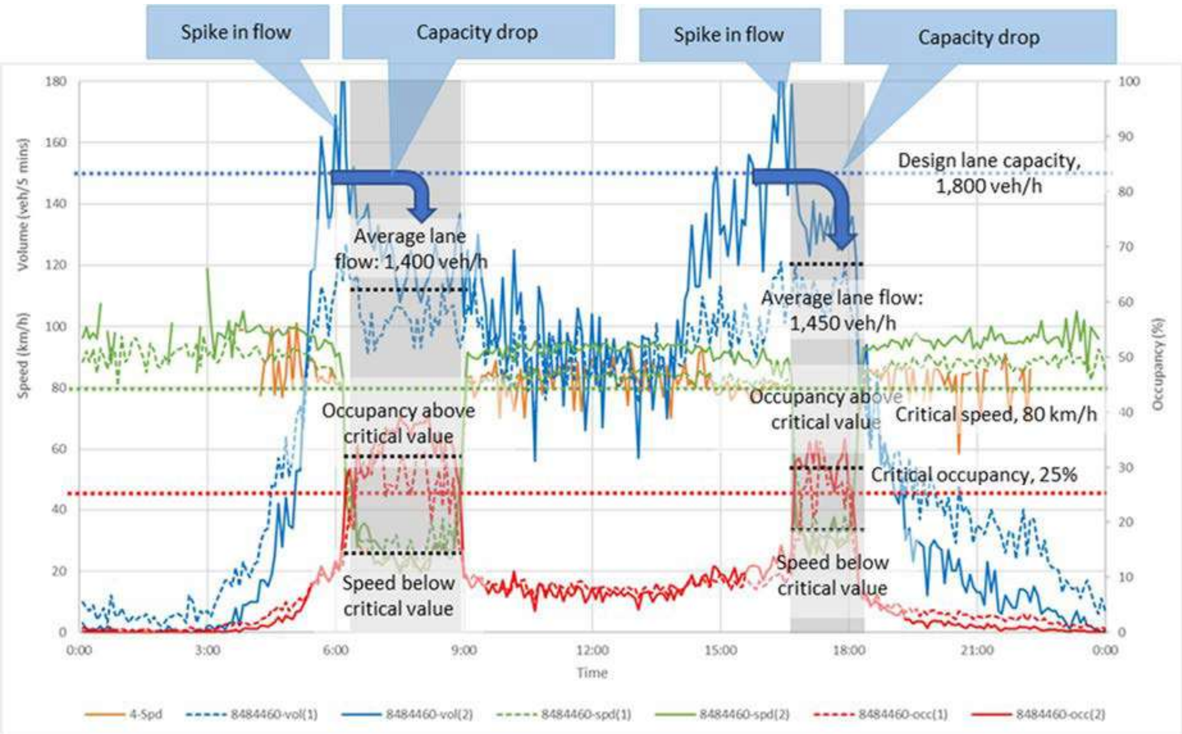
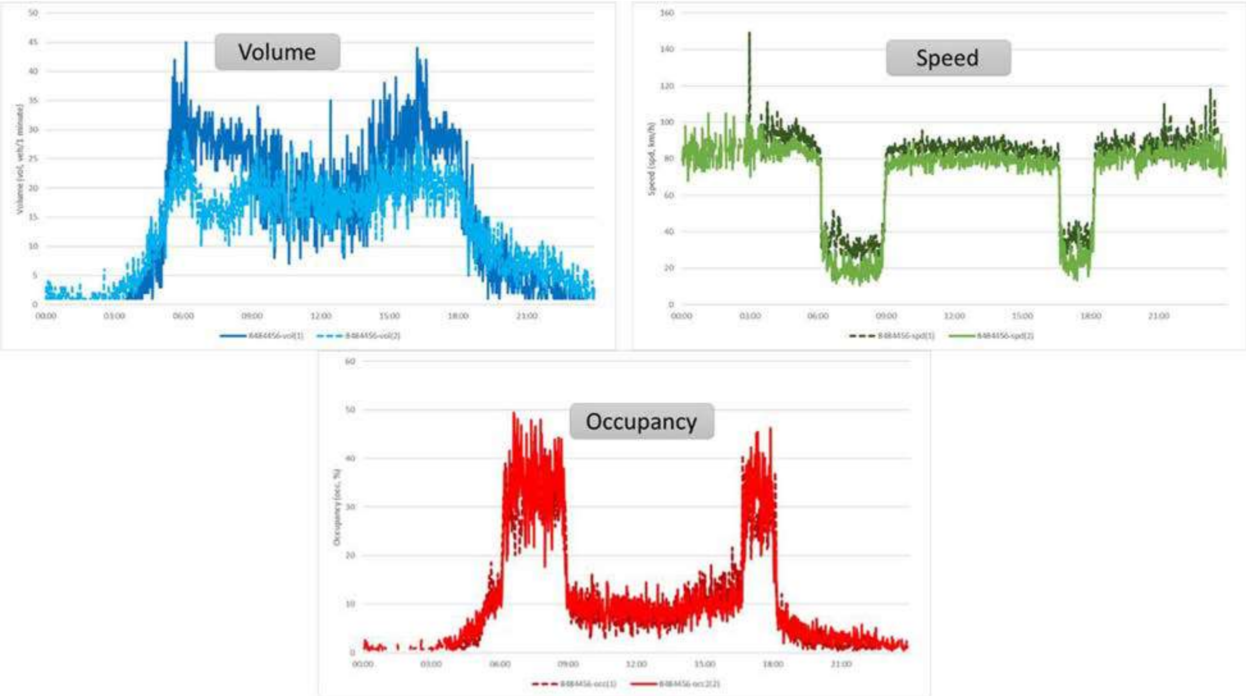


Figure 5.12 Speed, flow and occupancy at Centenary Mwy northbound near Sinnamon Rd on-ramp (8484456) on Day 1 (Centenary Hwy northbound) – 1-minute resolution



5.4.2 MAXIMISING USE OF CORRIDOR CAPACITY

The performance of Centenary Hwy was further examined in the context of the performance of a potential alternative route to the city, which is the Ipswich Mwy. Both routes are approximately the same distance going from the Centenary Hwy - Ipswich Mwy interchange to the city (i.e. about 20 km). Figure 5.13 illustrates the two motorways, including the section nodes for each highway. The section nodes define the end point of available Bluetooth travel speed data. The Centenary Hwy section nodes were described earlier in Section 5.1. The Ipswich Mwy has two sections, i.e.Section 1: Centenary Hwy (westernmost) – Harcourt Rd (1.3 km) and Section 2: Harcourt Rd – Granard Rd (5.4 km).

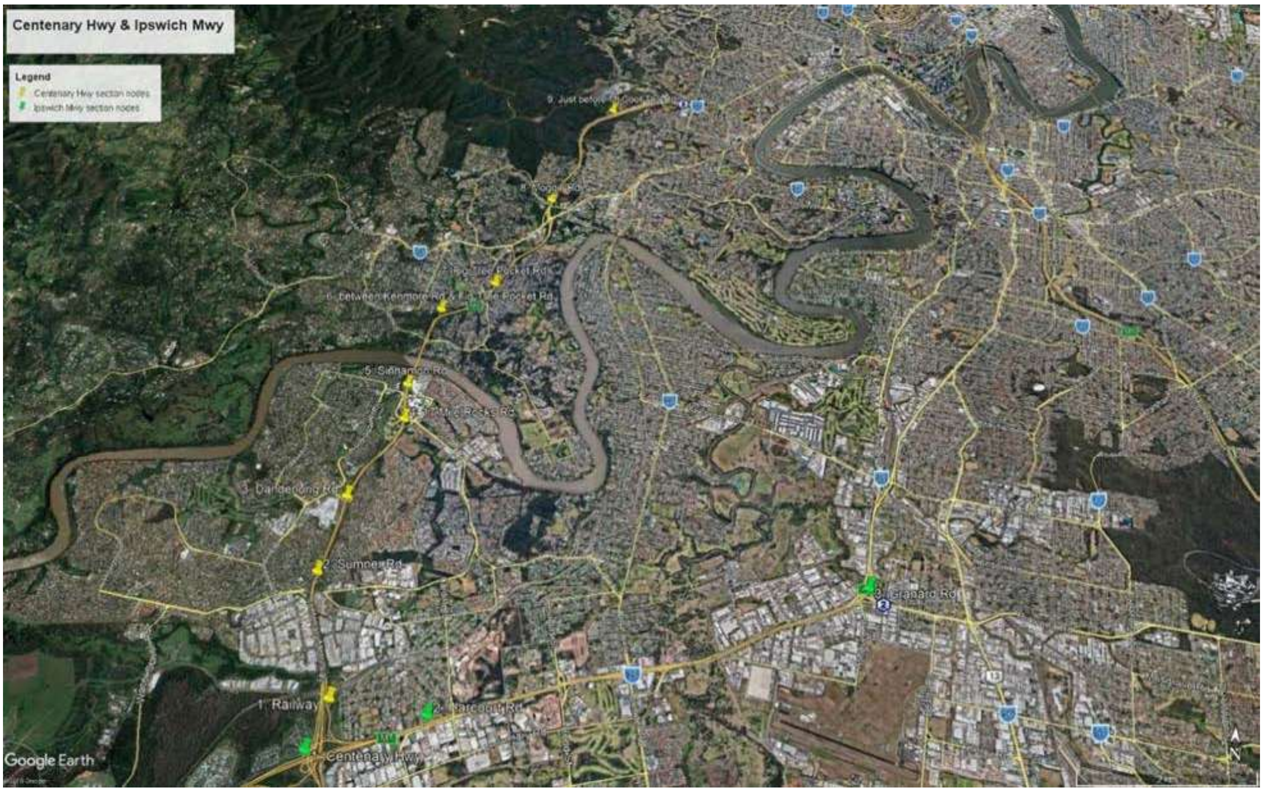
Figure 5.14 illustrates the speed plot of Centenary Hwy and Ipswich Mwy. Over the 5-day period of analysis, there were a number of instances when Centenary Hwy was operating at saturated conditions, while Ipswich Mwy was operating at undersaturated conditions. The speeds on Ipswich Mwy may have been impacted by roadworks which reduced speed limit to 60 km/h. These instances are highlighted in Figure 5.14 and were as follows:

- Day 2 PM peak
- Day 3 PM peak
- Day 4 PM peak
- Day 5 PM peak.

At these instances, Ipswich Mwy had spare capacity which could have been potentially utilised to divert traffic demand from Centenary Hwy. This could have potentially avoided or minimised flow breakdown on Centenary Hwy resulting in lower congestion cost. As an example, the speed, flow and occupancy of detectors sites at Centenary Hwy NB between Dandenong Rd and Seventeen Mile Rocks Rd (8484538) and Ipswich Mwy EB between Centenary Hwy and Harcourt Rd (11399558) on Day 4 are shown in Figure 5.16. The locations on the detectors are shown in Figure 5.15. Figure 5.16 show that during the PM peak, Centenary Hwy was saturated with an effective capacity of 1,550 veh/h per lane, which was about 14% less than its design capacity. At this same time, Ipswich Mwy was operating with a traffic volume of 1,350 veh/h per lane with an operational capacity of 1,800 veh/h per lane, as it operated at undersaturated conditions. Therefore, Ipswich Mwy had a spare capacity of around 450 veh/h per lane which could have been potentially utilised to support Centenary Hwy. If the two motorways could be coordinated, it is possible to improve operations. This could be achieved through effective traveller information systems. If the capacities of both motorways are exhausted, then the system could look for spare capacity on arterial roads. Assigning spare capacity could be prioritised based on road hierarchy and need to be developed and coordinated with key stakeholders.

It is noted that the Queensland Government has announced tenders for the detailed design for a new Centenary Bridge at Jindalee. This initiative was designed to address congestion issues on the Centenary Hwy. This initiative would increase the carriageway capacity of Centenary Hwy and it would be expected to improve the ability of Centenary Hwy to cater to peak traffic demand (Queensland media release, dated 19 March 2019).

Figure 5.13 Centenary Hwy and Ipswich Mwy



Source: Google Earth.

Figure 5.14 Speed plots for Centenary Hwy and Ipswich Mwy (inbound direction)

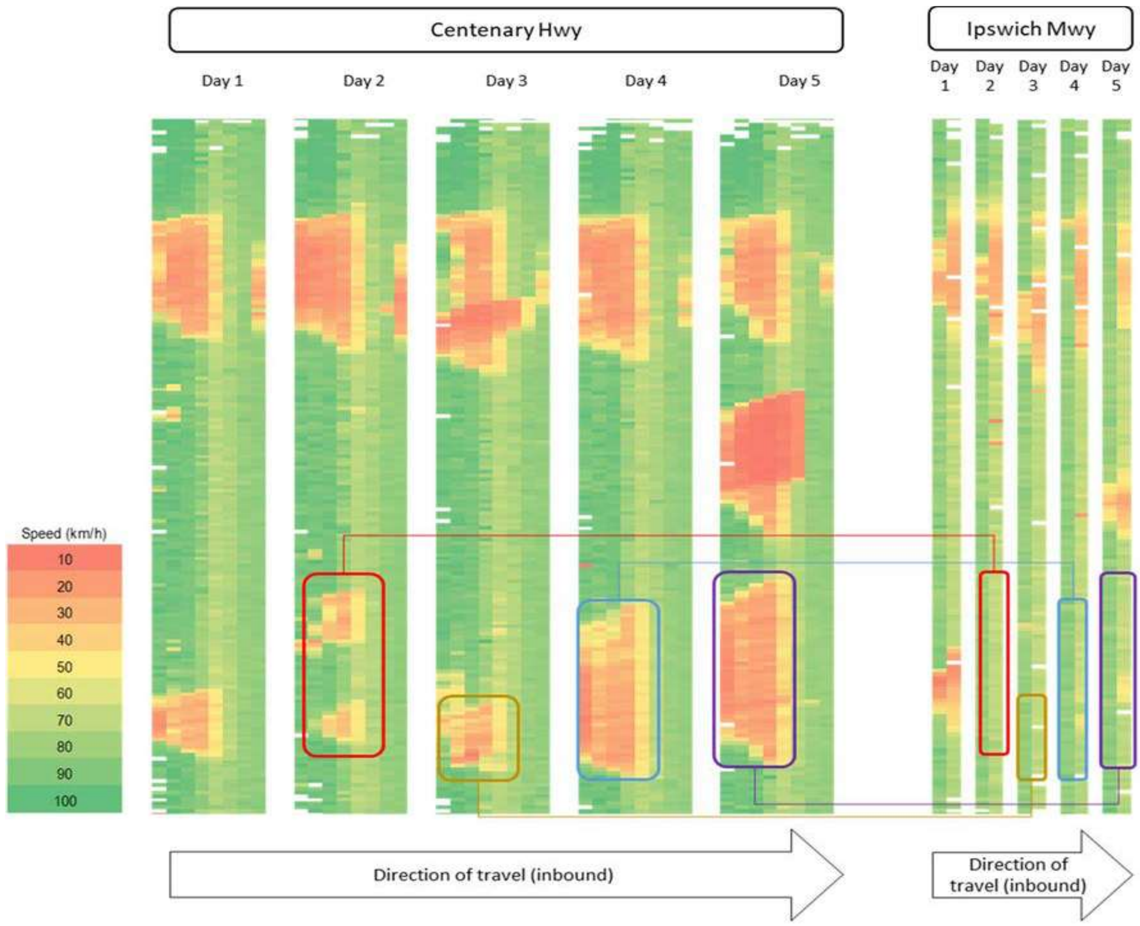
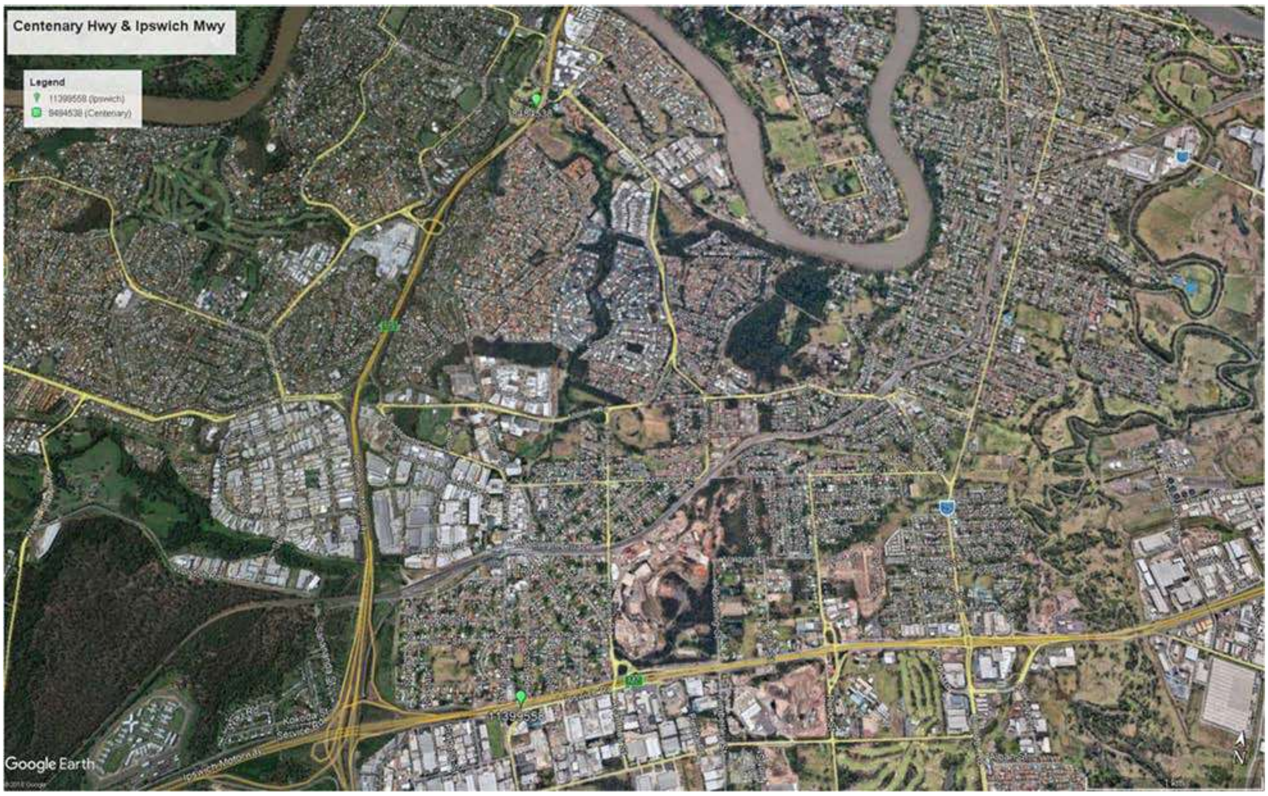
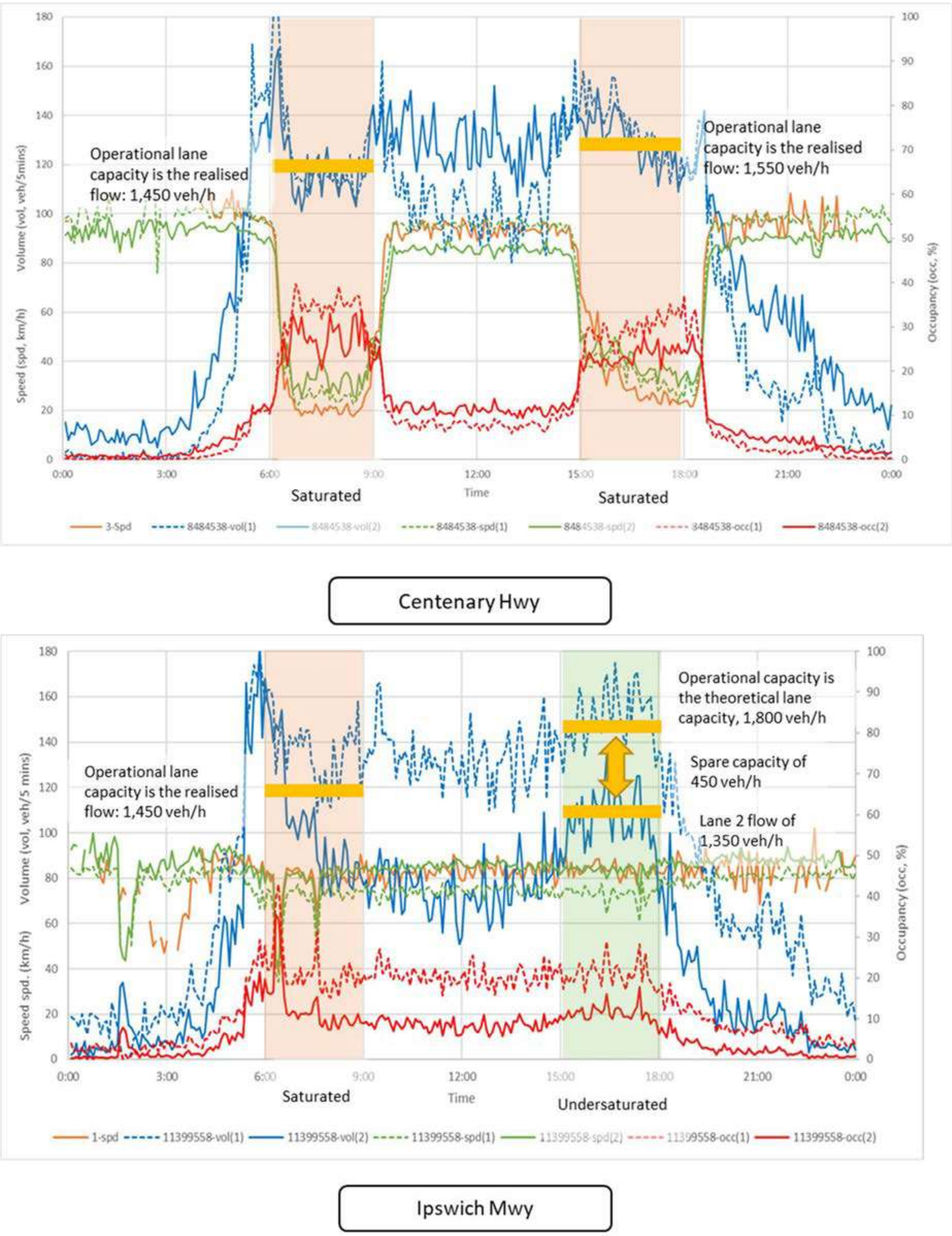


Figure 5.15 Detectors 8484538 on Centenary Hwy and 11399558 on Ipswich Mwy



Source: Google Earth.

Figure 5.16 Speed, flow and occupancy at 8484538 (Centenary Hwy) and 11399558 (Ipswich Mwy), inbound Day 4



6 FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

Stage 1 of the project, 'real-time determination of spare capacity of routes for enhanced management of congested road network' was completed. This chapter summarises the findings, conclusions and recommendations of Stage 1.

6.1 FINDINGS AND CONCLUSIONS

An important factor in assessing capacity is information on the prevailing operational regime of the highway. If the highway is operating in undersaturated conditions then operational capacity is the maximum sustainable flow possible, which can be estimated as the design capacity (i.e. estimated by models) or the highest recorded historical flow. The design motorway capacity is approximately 1,800 veh/h per lane. Arterial road design capacity is dependent on the percentage of time of a traffic signal cycle that is allocated to the movement, i.e. green split. Arterial road capacity is approximately equal to 1,700 veh/h per lane times the green split (as a percentage). On the other hand, if the highway is operating in saturated conditions then the operational capacity is equal to the realised flow. In saturated conditions there tends to be a capacity drop as flow is constrained by start-stop operations or downstream bottlenecks hence the operational capacity in saturated conditions tend to be lower than the design capacity.

Density, speed and queue storage are the indicators of the operational regime of an urban road network. Density is difficult to measure in the field, but it can be approximated by occupancy of detector loops. The approximate critical values of occupancy are 25% for motorways and 35% for departure-side loops for arterials. Critical speed values on motorways is approximately 80% the free flow speed. The critical speed on arterials is approximately 25 km/h or around 40% of the free flow speed. Queue storage is an important consideration on arterials, especially on arterials with relatively short distances between traffic signals. If the queue from downstream traffic signals extend close to the immediate upstream traffic signal site, then the highway would be operating in saturated conditions as the flow is limited by the available downstream queue storage. Queue overspill can be detected if occupancy is high (hence there is demand) and the realised flow is much lower than the design capacity, which is indicative that flows are being constrained by queue overspill.

The availability of flow, speed and occupancy data on motorways and arterials in Queensland are at a level wherein coverage can be considered adequate for real-time capacity estimation. Loop detectors, Bluetooth readers and probe vehicles are primary sources of data in Queensland.

There are, however, limitations in the availability of arterials with departure-side detectors and resolution of Bluetooth speed data. The accuracy of real-time capacity estimation is dependent on the quality, coverage and level of resolution of data.

A methodology to estimate operational capacity in real time was outlined based on the principles described above. The methodology was applied to a motorway and an arterial road. The study areas were Centenary Hwy and Samford Rd, respectively. The case studies demonstrated the feasibility of real-time capacity estimation. The analysis of Centenary Hwy and Samford Rd also identified potential applications of information on real-time capacity which could yield benefits in road operation. These applications included:

- bottleneck capacity management on arterials, which includes increasing green split and improving traffic signal progression when needed; and, improving the utilisation of available capacity of the traffic signal site by distributing underutilised capacity to conflicting movements, if possible
- proactive traffic management measures on motorways to mitigate or manage flow breakdown
- maximising the use of corridor capacity by diverting traffic to optimise use of available capacity between parallel motorway routes on the same corridor.

It was concluded that real-time capacity estimation was feasible, and the incorporation of information on real-time capacity ion road network operations are expected to yield improvements in efficiency in operation, resulting in benefits to the road users through lower congestion cost.

6.2 RECOMMENDATIONS

Key recommendations resulting for this project are as follows:

- It is recommended to develop a system that will incorporate the currently available data to estimate real-time capacity. It is further recommended to develop traffic control strategies and tactics to take advantage of the information. The information would also assist in historical review of current road network operations for off-line applications, such as traffic signal reviews. Hence, it is also recommended to consider the utility of archived real-time capacity estimates for planning purposes.
- It is recommended to review current network of detectors and readers; and, to consider improving the density of detectors and readers, where needed. This report has not reviewed the use of probe vehicle data, which could supplement existing network of detectors and readers. It is therefore recommended to examine the utility of real-time probe vehicle data for real-time capacity estimation.
- Prevention of traffic flow breakdown is an important aspect of road network operation, as capacity drops when flow breakdown has occurred. This significantly constrains the ability of the highway to cope with peak demand, when it is needed the most. This project focussed on the prevailing capacity and it has not examined predictive capacity estimation. Predictive capacity estimation would open the possibilities of proactive traffic management techniques to minimise the probability of flow breakdown. It is recommended to examine methods for predictive capacity estimation.
- The arterial road case studies utilised departure-side detectors. This project has not considered the use of approach-side detectors. Previous research (i.e. Chung and Rosalion 1999) found that stop line detectors on the approach-side did not provide a clear signal to properly identify saturated operation. Given that most arterials in Queensland only have approach-side detectors, it is recommended to revisit the use of approach-side detectors to determine the operation regime of arterials. It may be possible to incorporate Bluetooth speed data to supplement approach-side detector data to improve the detection of saturation for real-time capacity estimation.
- This report focussed on real-time capacity wherein there were no random and temporary events that could impact capacity. These events would include crashes, temporary roadworks, social events and severe weather events. The impacts of these events are considered significant. It is recommended to examine the impact of these events and to incorporate them in real-time capacity estimation.
- It is recommended to develop strategies in assigning demand to available spare capacities in the network, including managing the potential risks of undesirable rat-runs. The strategy needs to consider assigning spare capacity based on priorities determined by road hierarchy. It is beneficial to develop the strategy in consultation with stakeholders.

REFERENCES

Austroads 2010, Balancing traffic density in a signalised network, AP-R369/10, Austroads, Sydney, NSW.

Austroads 2012, Upstream and downstream detection to improve congested network operation, AP-R400-12, Austroads, Sydney, NSW.

Austroads 2015, Austroads guide to traffic management part 2: traffic theory, AGTM02-15, Austroads, Sydney, NSW.

Austroads 2016, Guide to smart motorways, AGSM-16, Austroads, Sydney, NSW.

Austroads 2017, Austroads guide to traffic management part 3: traffic studies and analysis, AGTM03-17, Austroads, Sydney, NSW.

Bhaskar, A, Tsubota, T, Kieu, LM & Chung, E 2014, 'Urban traffic state estimation: fusing point and zone based data', Transportation Research Part C, 48,pp. 120-142.

Blogg, M, Semler, C, Hingorani, M, & Troutbeck, R 2010, 'Travel time and origin-destination data collection using Bluetooth MAC address readers', Australasian Transport Research Forum, 29 September to 1 October 2010, Canberra, PATREC, WA, 15 pp.

Chong-White, C & Mazur, J 2016, 'Reporting empirical marginal costs in SCATS', ARRB Conference, 27th, 2016, Melbourne, ARRB, Port Melbourne, Vic., 15 pp.

Chung, E & Rosalion, N 1999, Arterial road network travel time and congestion monitoring, RC90065, ARRB, Port Melbourne, Vic..

Espada, I and Bennett, P 2015, 'Probe data and its application in traffic studies', IFME World Congress on Municipal Engineering and IPWEA International Public Works Conference, 2015, Rotorua, New Zealand, IPWEA, North Sydney, NSW, 10pp.

Geers, G & Karndacharuk, A 2016, Review of traffic data collection needs and technologies, PRJ-16-054, ARRB, Port Melbourne, Vic.

Geroliminis, N & Daganzo CF 2008, 'Existence of urban-scale macroscopic fundamental diagrams: some experimental findings', Transportation Research Part B: Methodological, Volume 42, Issue 9, pp. 759-770.

Hall, M & Gaffney, J 2019, Designing the next generation traffic management system in Australia, PowerPoint slides, VicRoads, Kew, VIC.

Han, C & Mohajerpoor, R 2017, R47 measuring the excessive congestion cost for arterial roads – Gympie Road case study, report PRJ16077-02, Transport and Main Roads, Brisbane, Qld.

Han, C, Wu, K, Karl, C, Wood, M & Dekker, F 2018, 'Comparison of three data sources for the measurement of excessive congestion costs: a case study', ARRB International Conference, 28th, 2018, Brisbane, ARRB, Port Melbourne, Vic., 15pp.

Luk, JYK 1989, Modelling & monitoring the performance of urban traffic control systems, SR43, ARRB, Port Melbourne, 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, Port Melbourne, Vic, 14 pp.

Luk, JYK 2008 ‘Support information for implementing online NPIs in STREAMS’, contract report VC74151-3, ARRB Group, Port Melbourne, Vic.

Luk JYK, Han C and Byrne M (2016), R22 Measuring On-road Congestion Costs for Multi-modal Travel – Methodology, NACOE project number 010580 Transport and Main Roads, Brisbane, Qld.

Nanthawichit, C, Nakatsuji, T & Suzuki, H 2003, ‘Application of probe-vehicle data for real-time traffic state estimation and short-term travel-time prediction on a freeway’, Transportation Research record, 1855, pp. 49-59.

Transportation Research Board 2010, Highway capacity manual, Transportation Research Board, Washington DC, USA.

Transportation Research Board 2016, Highway capacity manual, Transportation Research Board, Washington DC, USA.

Tsubota, T, Bhaskar, A and Chung E 2014, ‘Brisbane Macroscopic Fundamental Diagram : empirical findings on network partitioning and incident detection’, Transportation Research Board Annual Meeting, 93rd, 2014, Washington DC, TRB, Washington DC, 22pp.

Wang, Y & Papageorgiou, M 2005, ‘Real-time freeway traffic state estimation based on extended Kalman filter: a general approach’, Transportation Research Part B, 39, pp. 141-167.

Wood, M & Johnston, D 2018, ‘Intelligent hybrid data model and cost of congestion methodology’, ARRB International Conference, 28th, 2018, Brisbane, ARRB, Port Melbourne, ppt slides, 13pp

APPENDIX A SAMFORD RD EASTBOUND – SPEED FLOW AND OCCUPANCY GRAPHS

Figure A.1 M1916 Speed, flow and occupancy on Day 1 (Samford Rd eastbound)

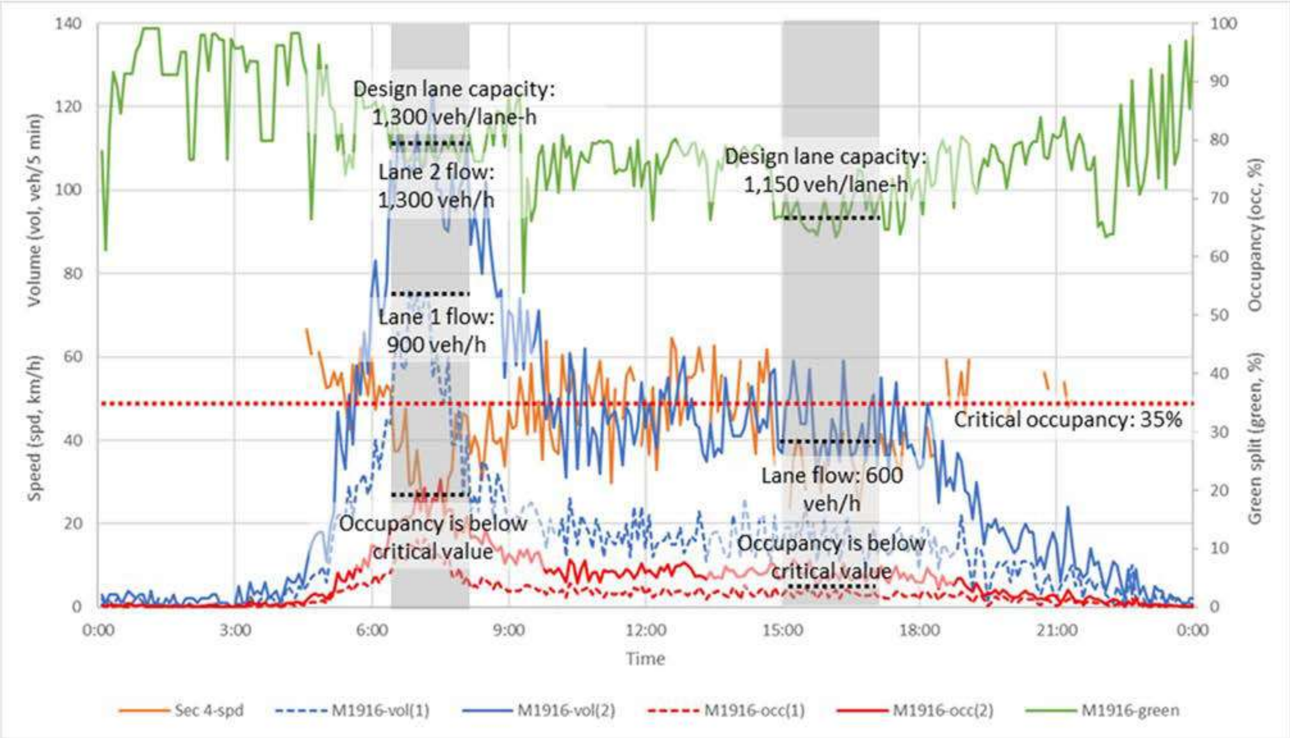


Figure A.2 M1914 speed, flow and occupancy on Day 1 (Samford Rd eastbound)

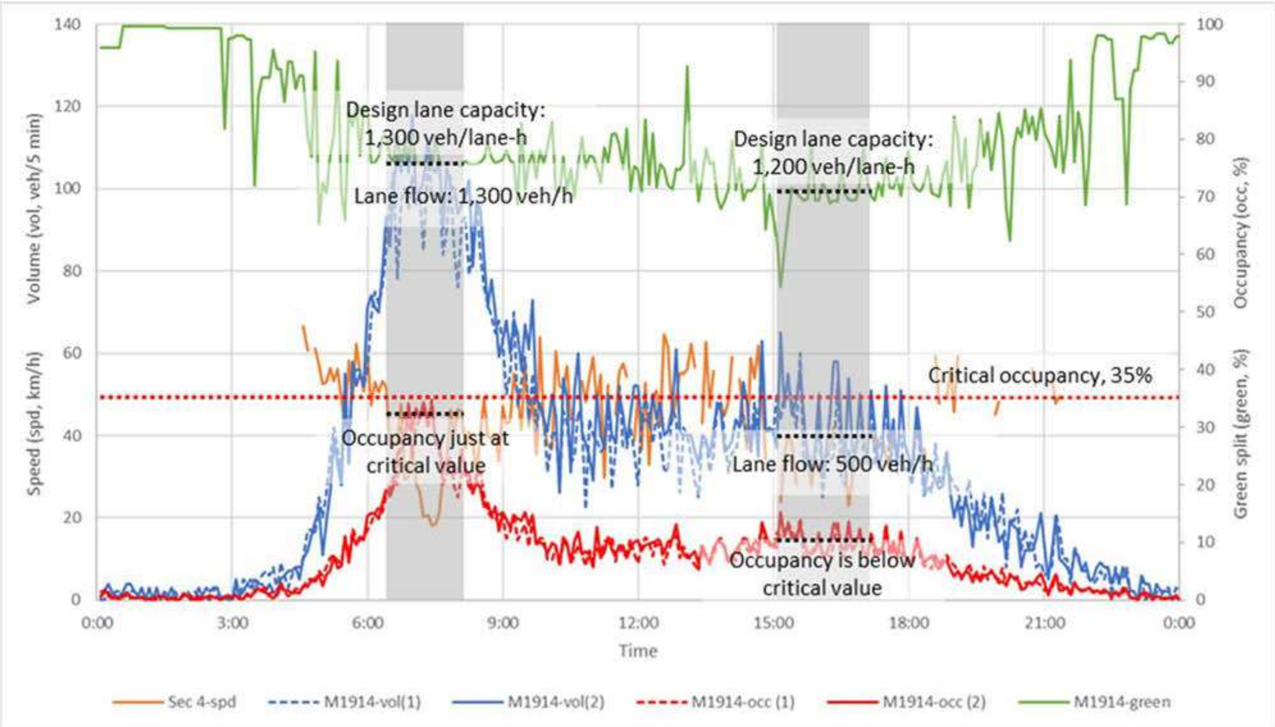


Figure A.3 M1918 speed, flow and occupancy on Day 1 (Samford Rd eastbound)

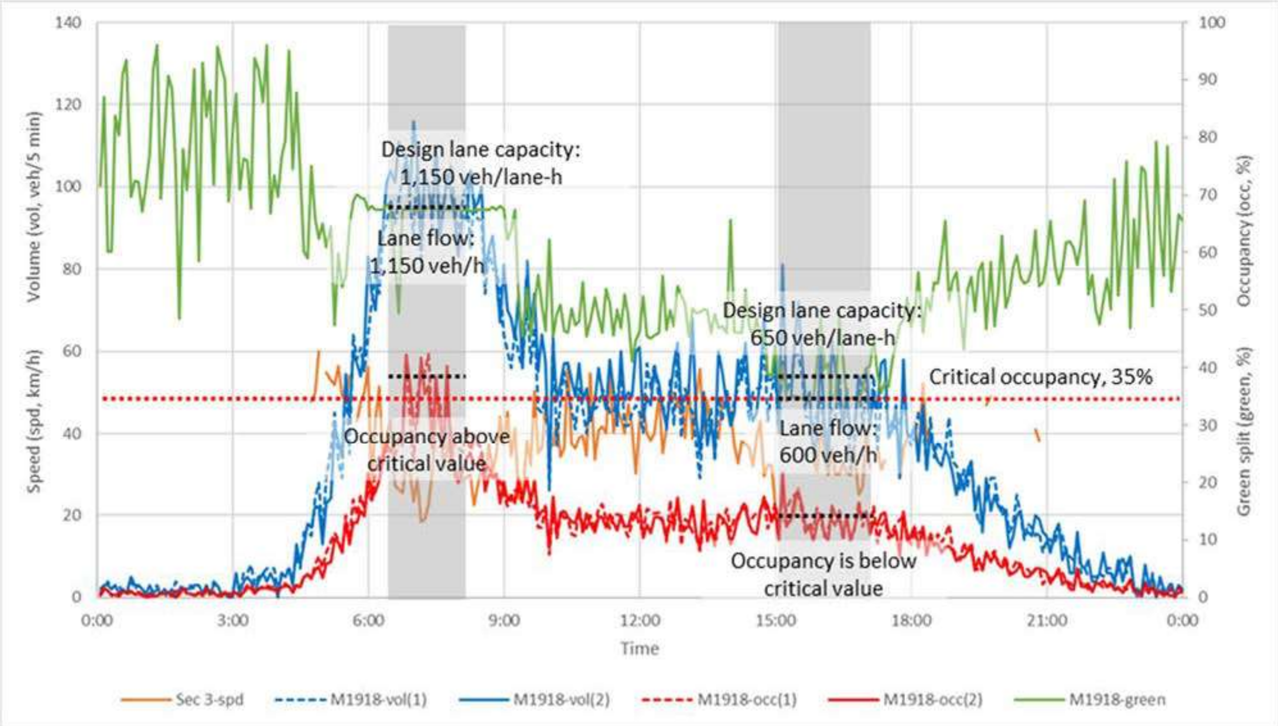


Figure A.4 M1919 speed, flow and occupancy on Day 1 (Samford Rd eastbound)

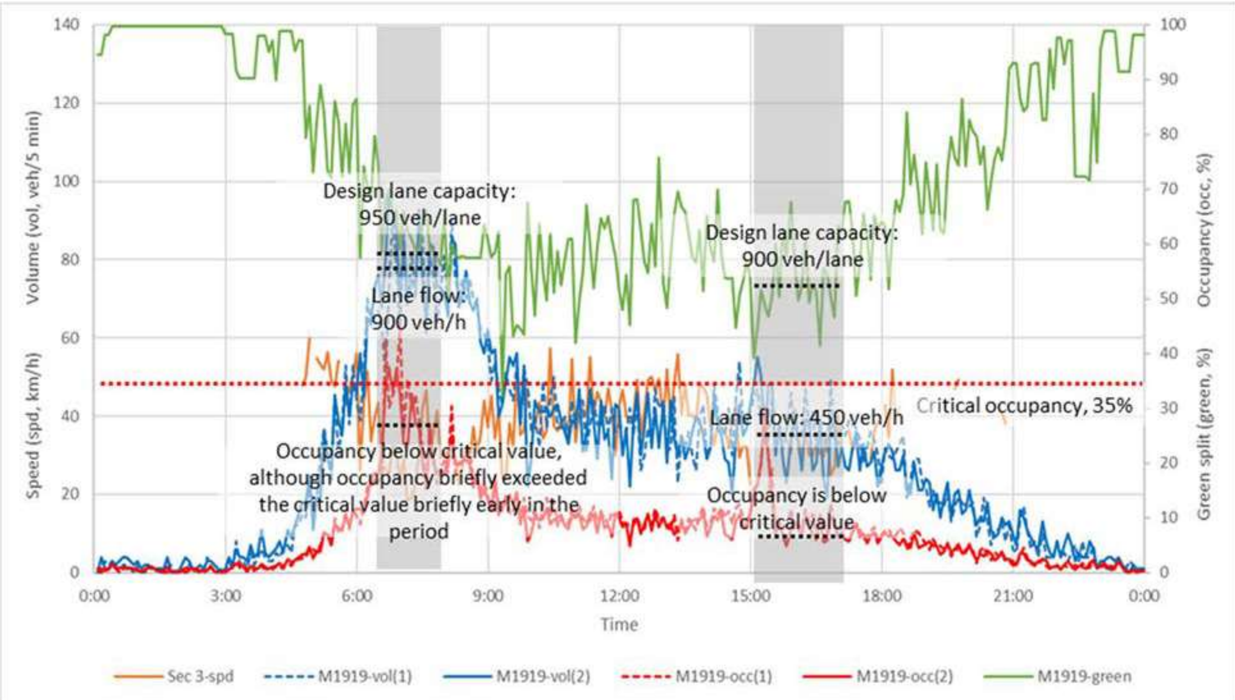
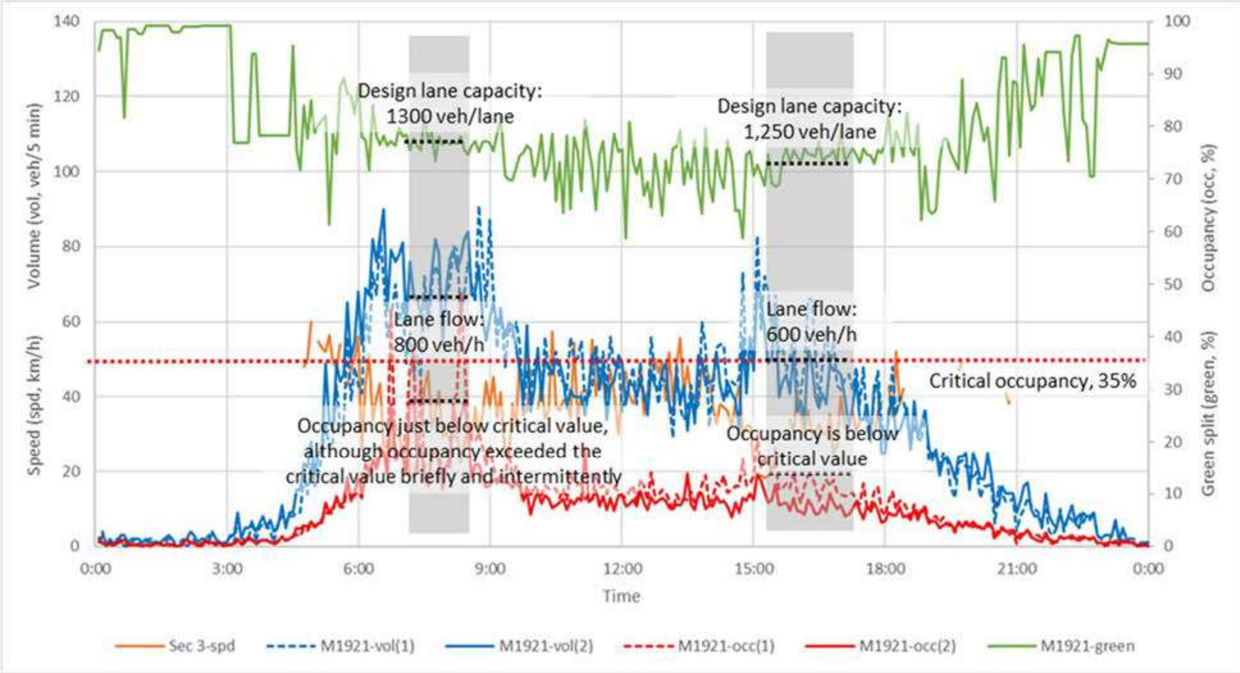


Figure A.5 M1921 speed, flow and occupancy on Day 1 (Samford Rd eastbound)



APPENDIX B CENTENARY HIGHWAY – SPEED, FLOW AND OCCUPANCY GRAPHS

Figure B.1 8484406 speed, flow and occupancy on Day 1 (Centenary Hwy northbound)

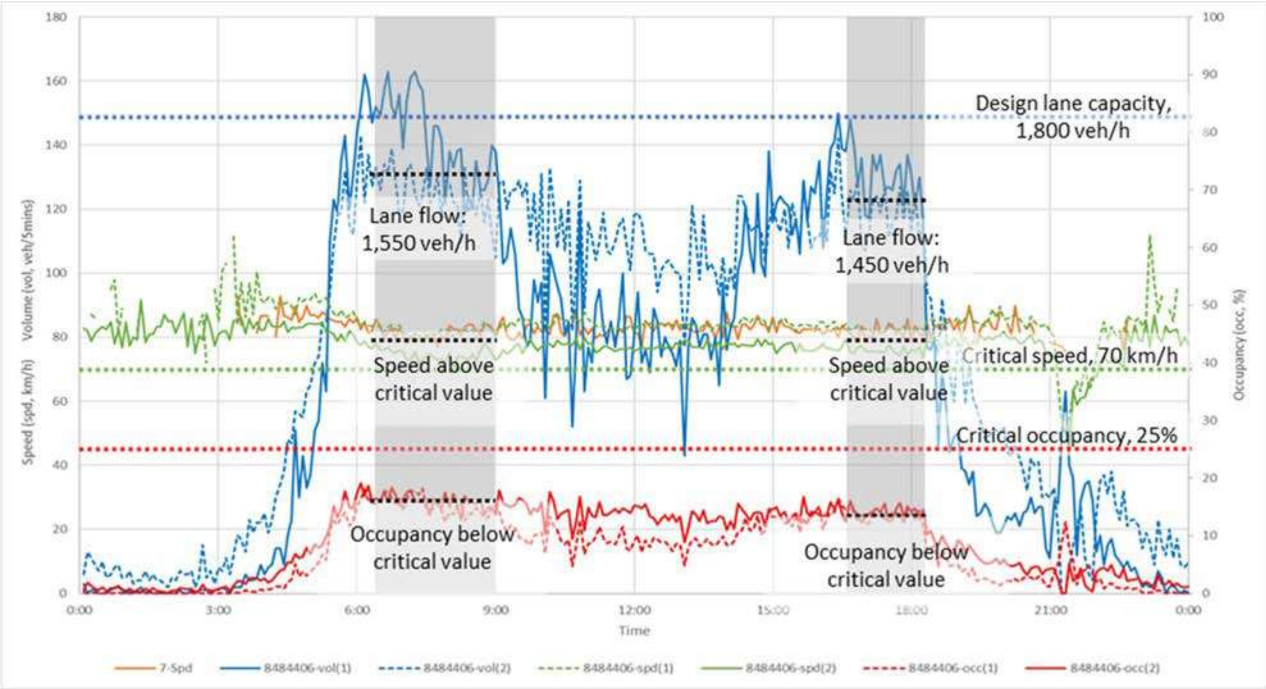


Figure B.2 8484448 speed, flow and occupancy on Day 1 (Centenary Hwy northbound)

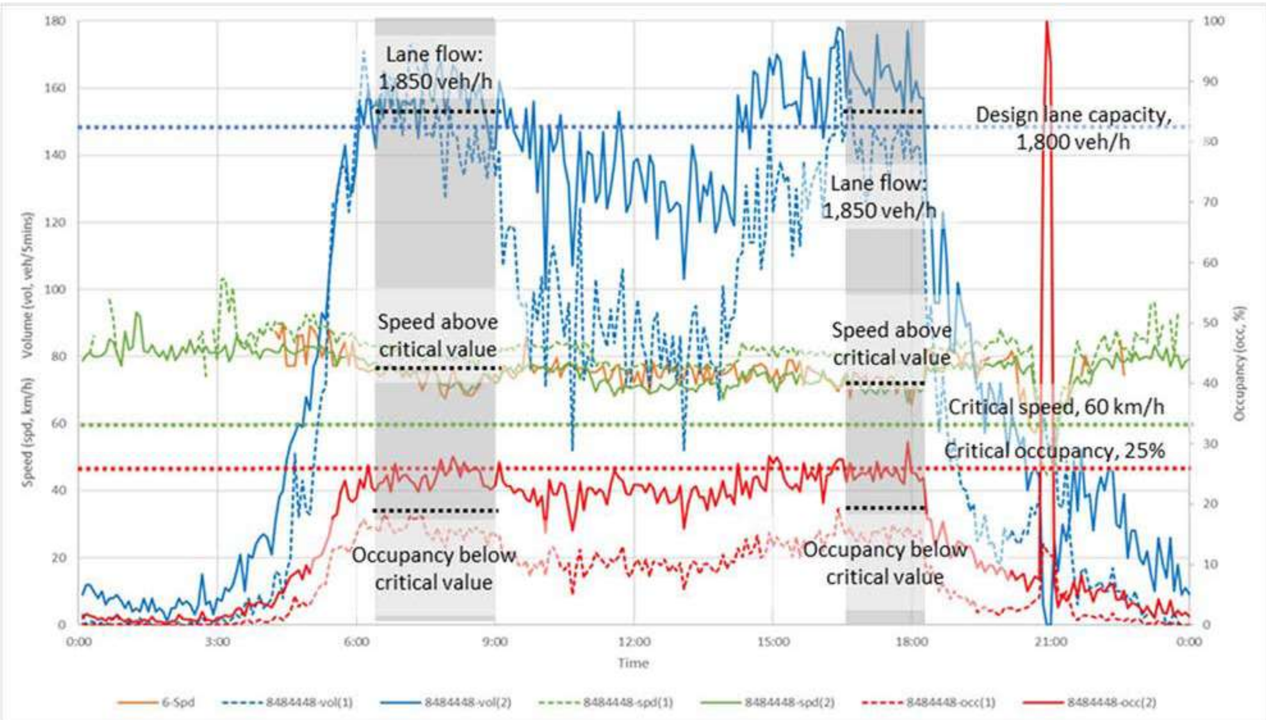


Figure B.3 11380358 speed, flow and occupancy on Day 1 (Centenary Hwy northbound)

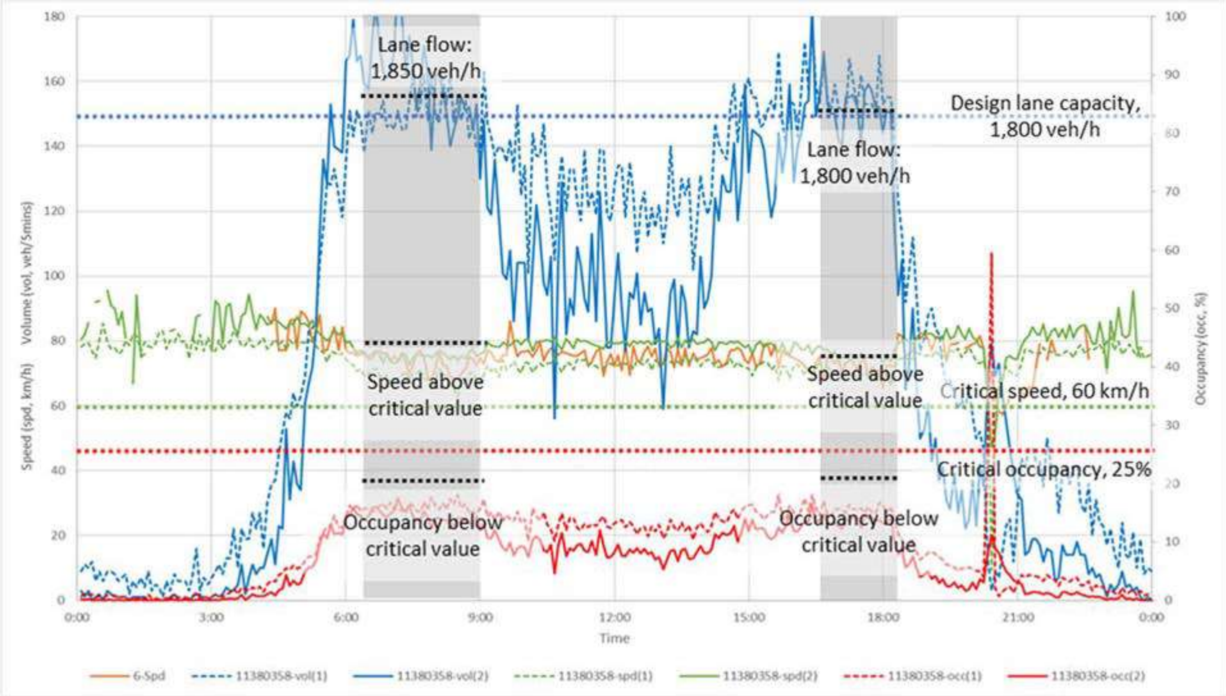


Figure B.4 11376685 speed, flow and occupancy on Day 1 (Centenary Hwy northbound)

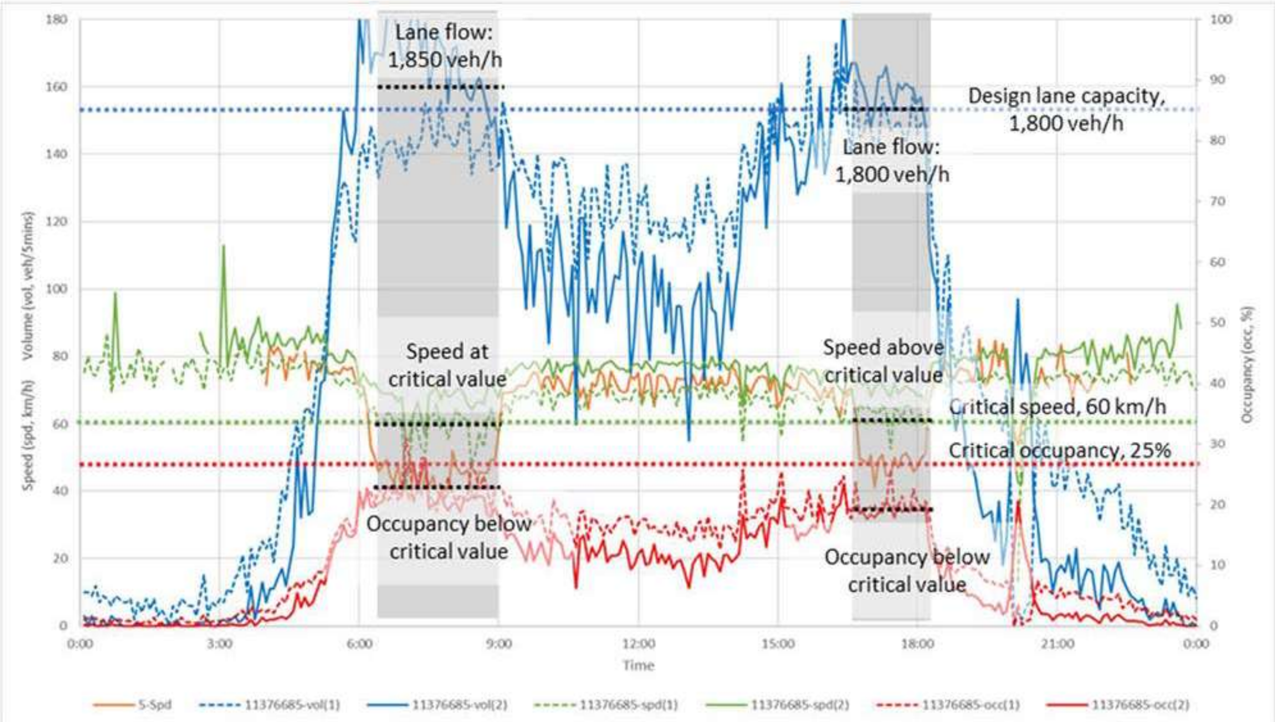


Figure B.5 8484456 speed, flow and occupancy on Day 1 (Centenary Hwy northbound)

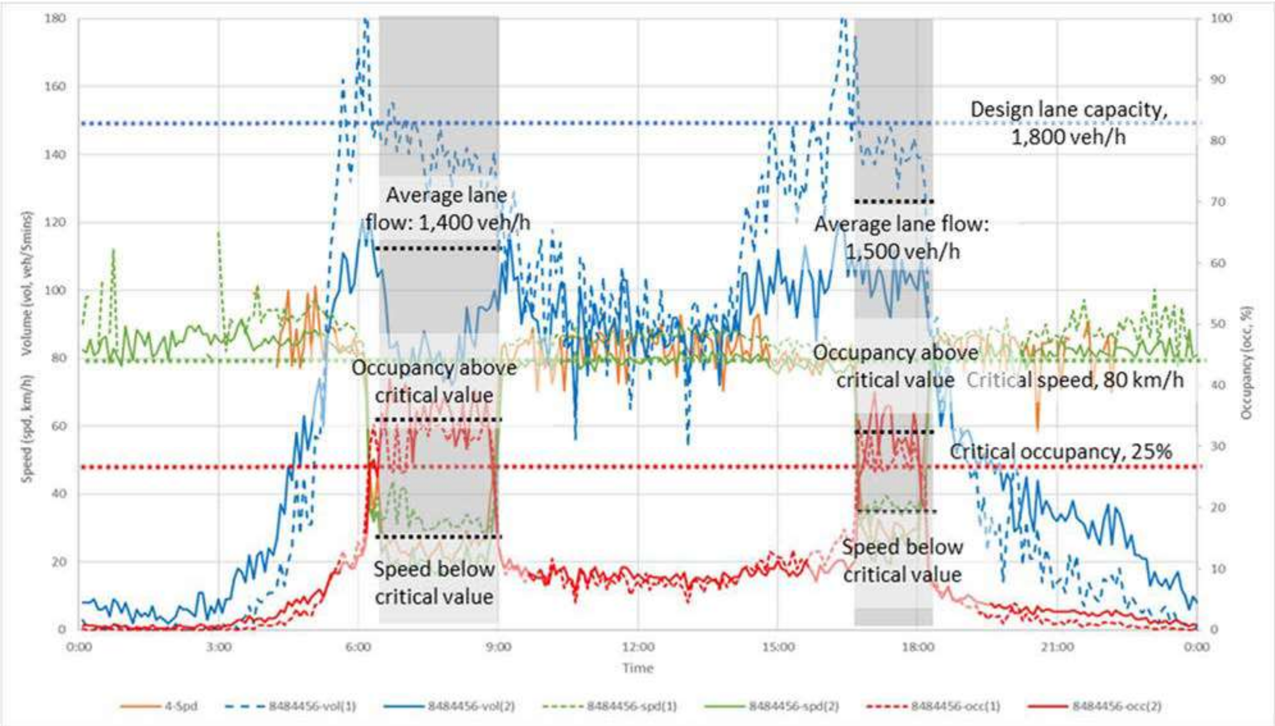


Figure B.6 8484460 speed, flow and occupancy on Day 1 (Centenary Hwy northbound)

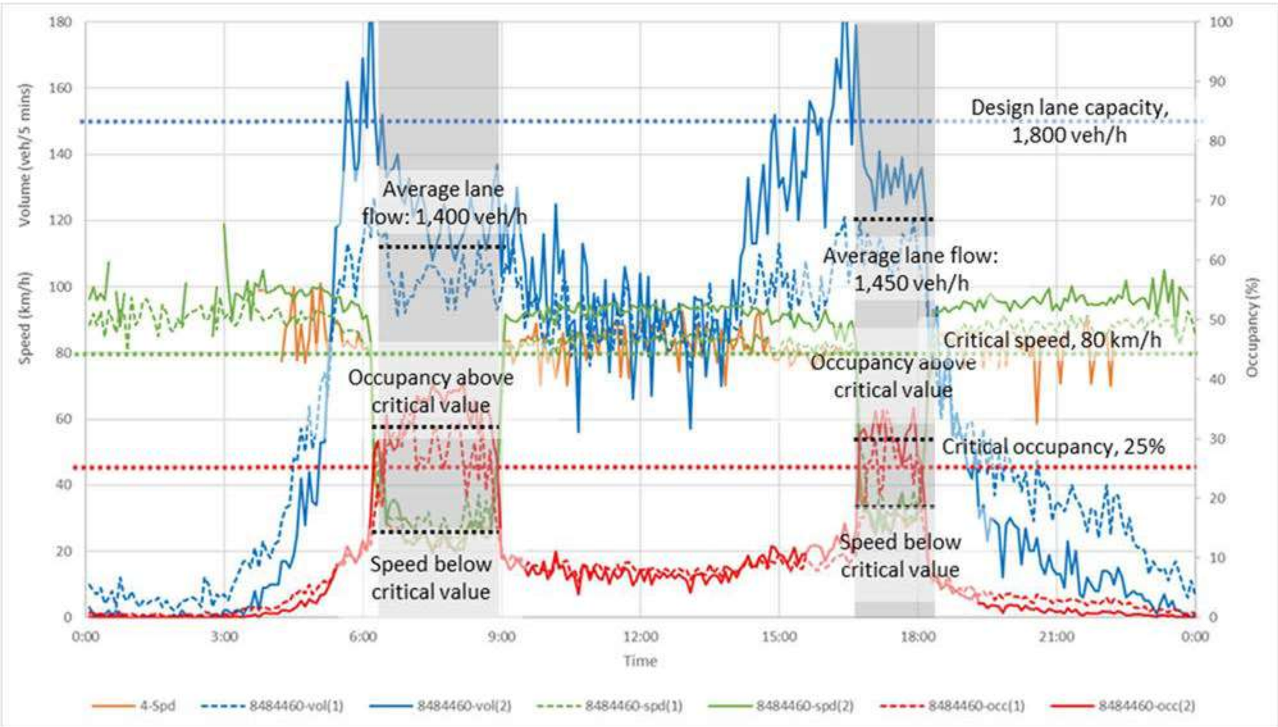


Figure B.7 13131581 speed, flow and occupancy on Day 1 (Centenary Hwy northbound)