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Mapping the capacity and performance of the arterial road network in Adelaide

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Abstract

It is not sustainable to cater for the ever growing demand for travel by simply building more roads in Australian major cities. It is also challenging to manage and operate the existing road network to meet the current travel demand and balance the competition between different modes of travel in order to achieve strategic transport objectives. The key to improving the effectiveness of traffic operation is a clear understanding of the existing network capacity given the current travel demand patterns and signal operation at key intersections.

This paper summarises the work undertaken by the South Australia Department of Planning Transport and Infrastructure in generating network capacity information and presenting them in a simple map format. No specific traffic knowledge is required to understand the map and appreciate the current state of the arterial network, its capacity and performance. The key task of the project is to translate current intersection traffic operation into a GIS map. The map shows colour coded dots and lines. Each dot represents the total through-put of a key intersection or its corresponding performance indicator, the average degree of saturation (flow/capacity ratio) of the critical movements of the intersection. The lines around the dot show the approach volumes of the intersection, which reflect the mid-block link flow patterns. This concise network information can be easily used to support different levels of decision on transport planning and traffic operation.

The capacity map has been used in the department for network operations planning. The current development of the Bluetooth travel time and speed layer of the map will enhance its mid-block traffic performance measures. The capacity map will be used broadly to engage general community about how their road traffic system operates and performs.

1. Introduction

It is not sustainable to cater for the ever growing demand for travel by simply building more roads in Australian major cities. It is also challenging to manage and operate the existing road network to meet the current and foreseeable future demand, and balance the competition between different modes of travel in order to achieve strategic transport objectives. The key to improving the effectiveness of traffic management and operation is a clear understanding of the existing network capacity given the prevalent travel demand patterns and signal operation at key intersections.

The 2014 Austroads Guides to Traffic Management (Austroads 2014) presents network operation planning (NOP) as a fundamental activity to assist road agencies in managing the use of existing infrastructure more effectively and equitably, in a manner that meets government and community goals and expectations. NOP is a relatively recent initiative amongst Australian road agencies that helps to translate high level transport objectives for delivery of road user services into low level guidance on how the road network should be developed and operated. The South Australia Department of Planning Transport and Infrastructure is developing Moving Traffic Plans for Adelaide.

The key step of the NOP process is to assess network performance and identify performance gaps to enable network operation strategy development so that the competing demands for road space and time from various road user groups can be managed effectively. It is critical to understand the existing network capacity and its baseline performance for the Adelaide Moving Traffic Plans development.

This paper summarises the work undertaken by the South Australia Department of Planning Transport and Infrastructure in generating existing network capacity information and presenting them in a simple map format to help transport planning and daily traffic operation. In section 2, the rationale and method used for the capacity map development is discussed. A typical intersection is used as an example to explain the detailed traffic analysis and map building process in section 3. Section 4 presents the initial capacity map of Adelaide Inner and Outer Ring Routes including the adjacent major intersections. Finally, the conclusion and future work are discussed in Section 5.

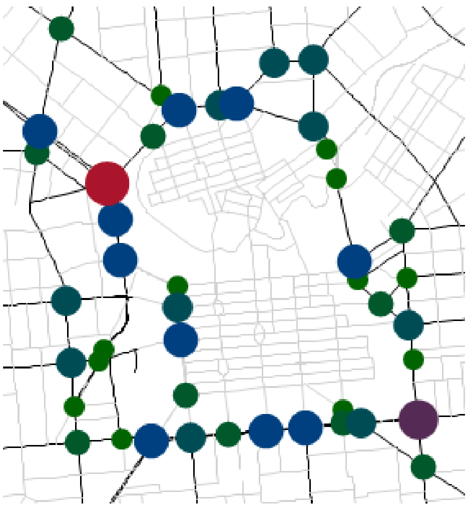
2. Methodology

Both transport planners and network operators want to know the existing network capacity and its performance. This information must be accurate, concise and ideally in a map format so that it can be comprehended and used easily to support network planning and traffic management decisions. On the other hand, daily traffic is so dynamic and complex. A certain traffic flow pattern of the inner urban network is a result of interaction between the natural demand and the responding signal operation of the key intersections/corridors of the network. It is challenging to translate the complex traffic/signal operation into a simple network capacity/performance representation.

2.1 A conceptual capacity map

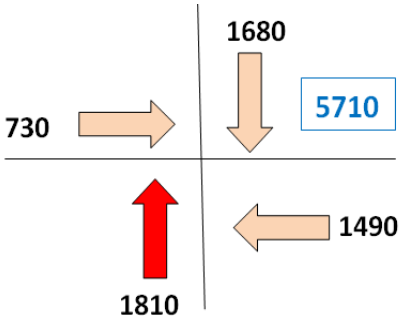
The capacity of an urban arterial network relies heavily on the performance of the key intersections of its major corridors. A GIS map showing the key intersection capacity could be an effective approximation of the network capacity (see Figure 1). The size and colour of each dot may be used as a quantitative representation of the intersection capacity.

Figure 1. A conceptual capacity map

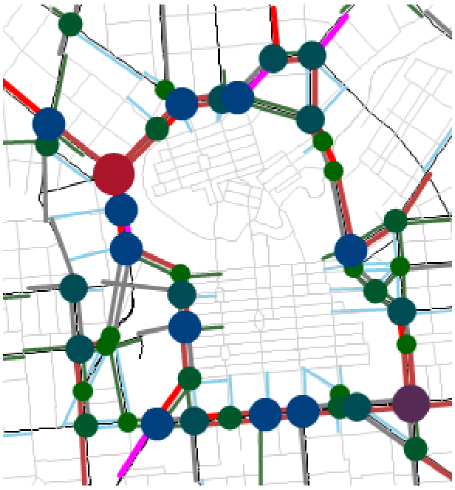


An intersection capacity could be measured by the total intersection throughput (e.g. 5710 veh/h, in Figure 2(a)). In addition, the intersection approach volumes (veh/h) could be added into the map in the form of coloured lines to highlight the network traffic flow patterns (see Figure 2(b)). The colour and thickness of each line represent different traffic flow levels.

Figure 2. Traffic flow patterns



(a) Intersection approach volumes



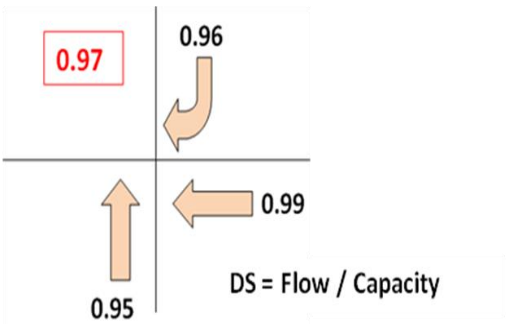
(b) Network traffic flow patterns

2.2 Network performance measure

Before we can claim the capacity map idea is workable, one key question needs to be answered - ***does the intersection throughput equal its maximum practical capacity?*** The answer to the question would be that we don't know exactly – depending on the intersection performance. If a signalised intersection is working at this condition (see Figure 3(a)), then we can be confident that the intersection throughput is a true measure of its real capacity. Note that the arrows in Figure 3(a) represent the three major conflicting movements that dictate the intersection signal operation and its performance. We use degree of saturation (DS, a flow/capacity ratio) to measure the performance of the each movement. The average DS of the three movements (i.e. 0.97) would provide us a clear indication of the intersection performance given its throughput, which helps determine what capacity can be expected from this intersection.

The above discussion suggests that an intersection throughput and its corresponding performance as a whole can reveal the capacity information of the intersection. Therefore, a map of the key intersection performance in terms of the average DS (see Figure 3(b)) would be an integral part of a capacity map.

Figure 3. Traffic performance



(a) Intersection performance

(b) Network performance

2.3 Capacity/performance map building – data & tools

The proposed network capacity/performance map could be treated as a real snapshot of the network traffic operation for a certain period (e.g. AM, PM, business peak periods), which make it very powerful for both network planning and traffic management. The underlying assumption to make it accurate is that all traffic flow and corresponding signal operation data used to produce the map for the period must be collected on the same day across the network. This is particular important for the dense urban network due to the interaction among closely spaced key intersections.

In Adelaide, the major intersection traffic turning count survey has been conducting periodically to capture and track the traffic flow changes over time. The survey data is very detailed but the survey itself is costly, which makes it very difficult to apply to a large area of the arterial network on the same day. On the other hand, all signalised intersections in Adelaide are controlled by the SCATS system (SCATS 2000). The intersection stop line detectors of the SCATS system can provide reliable lane flow data (even though not the complete turning movement counts) over the entire arterial network on any day, which makes the SCATS detector data the primary source for intersection throughput and approach flow estimation.

To quantify an intersection's performance and work out the intersection average DS value, intersection traffic modelling is required. SIDRA (SIDRA SOLUTIONS 2007, Zhang 2013) is the major traffic modelling tool used in this project given its sound theoretical background and detailed analytical outputs. LINSIG modelling package (JCT 2009, Zhang and Excell 2013) is also used to model and verify the complex intersection traffic/signal operations where the SIDRA modelling may not be able to handle properly.

3. Capacity map building process

As discussed in section 2, the major task of the network capacity/performance map building is intersection traffic analysis and modelling in a large scale.

3.1 SCATS detector data processing

The aim of SCATS data processing is to produce

- Intersection throughput and approach flow rates for different times of day (i.e. AM, PM, business peak hours), and
- Accurate intersection turning volumes for traffic modelling.

As discussed in the previous section, we want the capacity/performance map to be a real snapshot of the network traffic operation. We also want the snapshot to be more general and representing a normal weekday. To achieve these objectives, the three-day weekday SCATS data (May 6-8, 2014, Tuesday to Thursday) was collected across the arterial road network in Adelaide. No special events happened on these three days, and weather conditions were fine. For a certain period such as AM peak, a three-day average peak hour intersection traffic volumes was calculated and used for map building.

The majority of signalised intersections in Adelaide have either left-turn slip lanes with no detector installed or shared traffic lanes (one detector covers multiple traffic movements). This means the SCATS detector data itself cannot capture the entire intersection approach flows, and site specific detector data processing is required to convert the lane detector counts into the approach traffic movement counts. In addition, the stop-line SCATS detectors are not designed to distinguish between cars and large commercial vehicles (e.g. buses, trucks, etc.). The vehicle composition information is important for accurate intersection traffic modelling.

To address the above issues, the second data source (the most recent intersection turning count survey data) was brought in, and a special spreadsheet program was developed for data processing. Given the large scale SCATS data processing that is required for the project, the program is essential to maintain both the efficiency and accuracy of intersection turning volume estimation. To facilitate the further discussion on SCATS data processing and intersection traffic modelling, a typical four-way intersection in Adelaide (i.e. the Greenhill Road / Portrush Road intersection, see Figure 4) is used as an example. Portrush Road is part of the eastern segment of Adelaide Outer Ring Route.

Figure 4. The Greenhill Road / Portrush Road intersection

The spreadsheet program was applied to the most recent manual turning count data of the intersection first. It worked out the turning percentage of each approach of the intersection and extracted the commercial vehicle information (see Figure 5(a)). Then the program used this information to process the SCATS detector data and produced the intersection SCATS turning count estimates (see Figure 4(b)) for both the intersection throughput calculation and traffic modelling. So the accuracy of the original SCATS detector data was enhanced for the map building.

Figure 5. SCATS detector data processing

ENTER INPUTS IN 'BLUE' CELLS ONLY. D

MOVEMENTS WITH SCATS DETECTORS

	SCATS Detector ->	1	2	3	4	5	6	7	8
Movements from Entry arm (Refer to Vehicle Turning Movement Survey sheet in ITIMS)	Entry arm	1	1	1	1	3	3	3	3
	First Exit arm	3	3	4	4	4	1	1	2
	Seond Exit arm (incase of shared lanes)								
	Third Exit arm (incase of shared lanes)								
	Entry_TO_Exit	1_TO_2	1_TO_3	1_TO_4	1_TO_5	2_TO_3	2_TO_4	2_TO_5	2_TO_1

Refer to 'Vehicle Turning Movement Survey' and provide percentage inputs in Blue cells only (Leave blanks in any

	Arm	1	1	1	1	2	2	2	2
	Exit Arm	2	3	4	5	3	4	5	1
AM Peak	% of Total Entry Arm Traffic	3%	60%	37%		14%	75%		12%
	CV - % of total Entry to Exit Arm traffic	14%	10%	3%		2%	3%		1%

(a) information extracted from the manual turn count data

Estimated SCATS Vols based on survey count turning proportions		1_2	1_3	1_4		2_3	2_4		2_1
		Portrush Rd N				Greenhill Rd E			
	Arm	1	1	1		2	2		2
	Exit Arm	2	3	4		3	4		1
AM Peak	Cars	49	897	599		199	1065		171
	CV	8	98	18		4	33		2
	Total Vehicles (round to nearest 10)	60	1000	620		210	1100		180

(b) estimated SCATS approach turning counts

In addition to this semi-automatic process, a traffic volume comparison between the estimated SCATS turning counts and its corresponding manual turning counts was performed to identify any significant traffic pattern change and seek explanation (if any change) to improve input data quality for map building. Figure 2(a) (in section 2) shows the data processing results of the Greenhill Road / Portrush Road intersection (AM peak).

3.2 Intersection traffic modelling

The objective of intersection traffic modelling is to reveal the accurate performance of the intersection given its current SCATS signal operation.

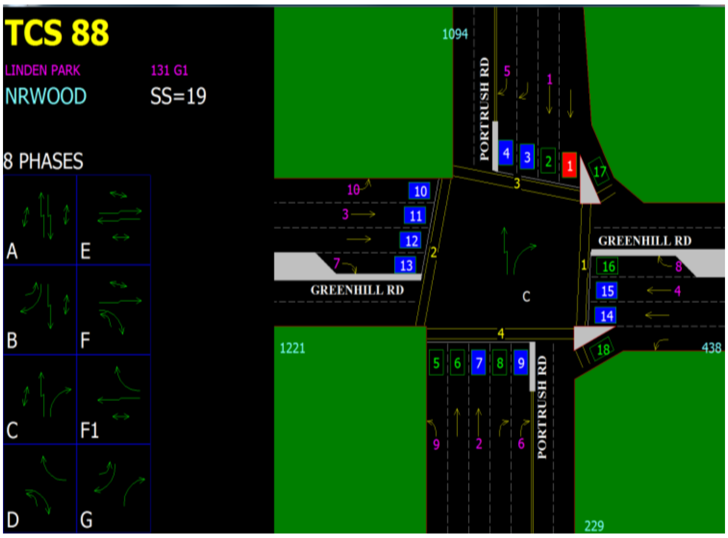
3.2.1 Lane saturation flow rate & SCATS Max Flow (MF)

Generally, the performance of a signalised intersection is determined by its layout, lane capacity, and signal phasing. Figure 6 is the SCATS representation of the Greenhill Road / Portrush Road intersection, which includes:

(a) intersection layout, stop-line detector positioning, the candidate signal phases; and

(b) SCATS detector registered maximum lane flow rates, SCATS MF (SCATS 2000).

Figure 6. Signal operation of the Greenhill Rd/Portrush Rd intersection



(a) intersection layout

Detector	Maximum Flow
1	1650
2	1950
3	1900
4	1900
5	1700
6	1650
7	1850
8	1850
9	1850
10	1550
11	1800
12	1900
13	1700
14	1900
15	2000
16	2000

(b) SCATS MF

SCATS MF is a moving average of the weekday daily lane maximum flow rate (veh/hr) captured by the stop-line loop detector. The assumption is made by SCATS that the maximum flow occurs when vehicles of an average length are travelling at optimum speed. This makes the SCATS MF pcu/hr (passenger car units per hour, in LINSIG) or tcu/hr (through car units per hour, in SIDRA) equivalent in most cases. The SCATS MF, a maximum practical lane flow rate registered by the SCATS detectors, captures the lane geometry features (i.e. lane type, lane width, shared movements), traffic network topology (i.e. spatial relationship between adjacent intersections), and corridor level signal operations (i.e. signal coordination). It is virtually a bridge between the isolated intersection and the corridor/network where it is situated from traffic operation perspective.

In an urban arterial network, it is not rare for multiple major intersections to be closely spaced. As shown in Figure 7, a series of eight major signalised intersections are located about 500m apart along Greenhill Road, which forms the southern segment of Inner City Ring Route in Adelaide. This section of Greenhill Road is a six-lane, two-way, median-separated arterial road. In Figure 7, the colour coded arrows represent different levels of SCATS MF of these major intersections (through lane only).

Figure 7. SCATS MF of the major intersections on Greenhill Road

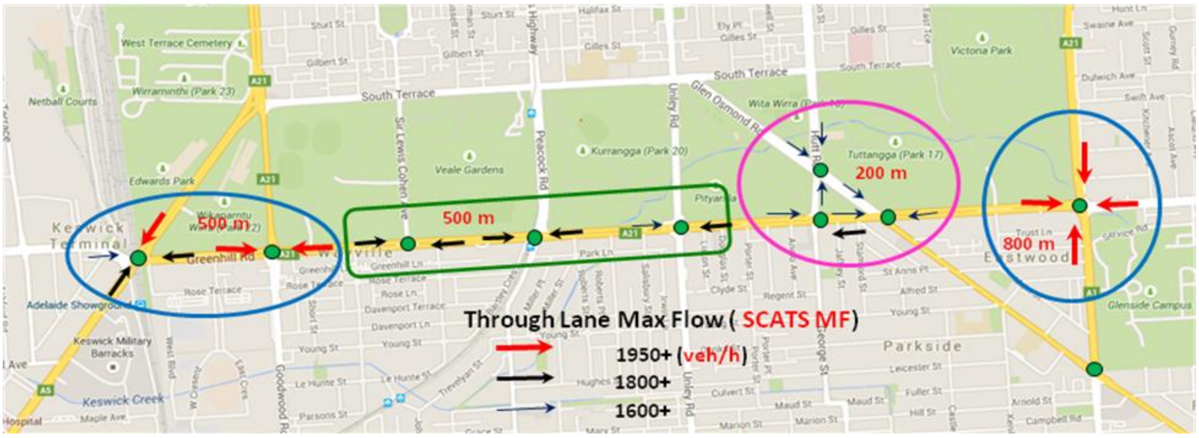


Figure 7 shows that the SCATS MF values decrease when moving from both ends of Greenhill Road (blue circle) to its centre (green circle), even though the geometrical features of these lanes are very similar. It reveals that the heavy turning movements at the intersections constantly disrupted the two-way progression along Greenhill Road, which signal coordination tries to achieve, especially during peak periods. In addition, the close spacing between the intersections can have a significant impact on approach lane capacity, which is particularly evident in the small triangle area within the purple circle in Figure 7. Therefore, it is crucial to use SCATS MF values to guide intersection lane capacity calibration. It not only improves the accuracy of individual intersection modelling, but also helps to capture the realistic network traffic operation.

3.2.2 SCATS signal phasing & intersection average DS calculation

This section is not intended to go through every step of intersection SIDRA / LINSIG modelling. The following discussion is focused on how to select the major conflicting movements of an intersection and use the model generated individual movement DS to calculate the average DS for the intersection.

The SCATS signal control system is a fully adaptive system which responds to traffic demand changes at each intersection in real time. Figure 8 shows the three-day average signal phasing (May 6-8, 2014) of the Greenhill Road / Portrush Road intersection. Note that the SCATS detector count data used for map building was collected on the same three days.

Figure 8. SCATS signal phasing of the Greenhill Rd/Portrush Rd intersection

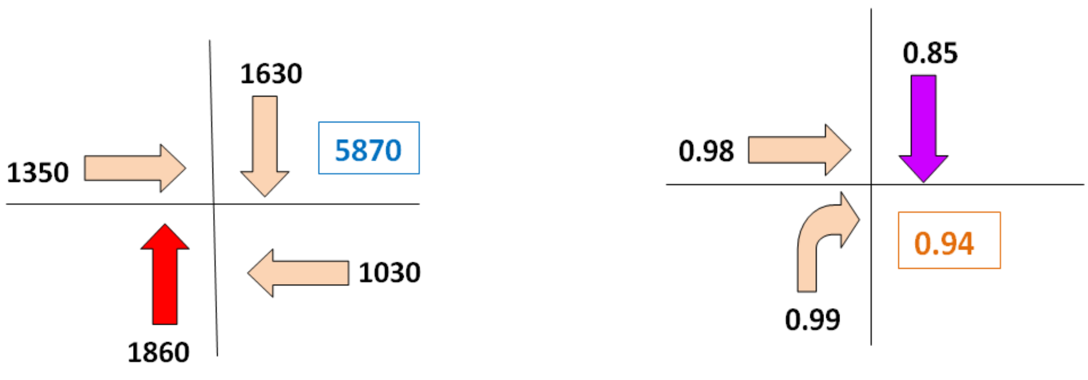
Period	Time	Ave CL	A	B	C	D	D1	D2	E
AM	**0800 - 0900**	130s	40s	26s	21s	-	-	17s	26s
BUS	**1400 - 1500**	130s	35s	22s	25s	16s	-	-	31s
PM	**1700 - 1800**	130s	38s	22s	26s	-	16s	-	29s

The Greenhill Road / Portrush Road intersection is currently running the following signal sequence: B→A→ C→ D→ E. Phase D could be D1 or D2 depending on the time of day. By examining the phase length of A, B & C (Portrush Road movements), it suggests that north-south traffic flow is generally high but stable throughout the day. In contrast, the variation of D phase (Greenhill Road movements) between AM and PM peak hours highlights the tidal flow nature of the east-west movements on Greenhill Road.

To model the accurate performance of each intersection, we need this detailed SCATS signal phasing information, as we did not allow the modelling software to adjust / optimise the SCATS signal phasing. More importantly, the competition between the major conflicting movements for green time at the intersection can be identified from the signal phasing. It is the underlying SCATS voting pattern that enables us to select the right traffic movements for the average DS calculation.

The average DS calculation for the Greenhill Road / Portrush Road intersection (PM peak) is illustrated in Figure 9(b) with the corresponding intersection approach flow patterns shown in Figure 9(a). The DS figure inside the rectangular box (i.e. 0.94 = (0.85+0.98+0.99)/3) is the average DS among the three competing movements. We use this average DS figure as the intersection performance indicator for the PM peak hour. Note that the AM Peak hour intersection capacity and performance have been shown in Figure 2(a) and 3(a) in Section 2 where they are used to explain the methodology of the map building.

Figure 9. The average DS of the Greenhill Rd/Portrush Rd intersection (PM peak)



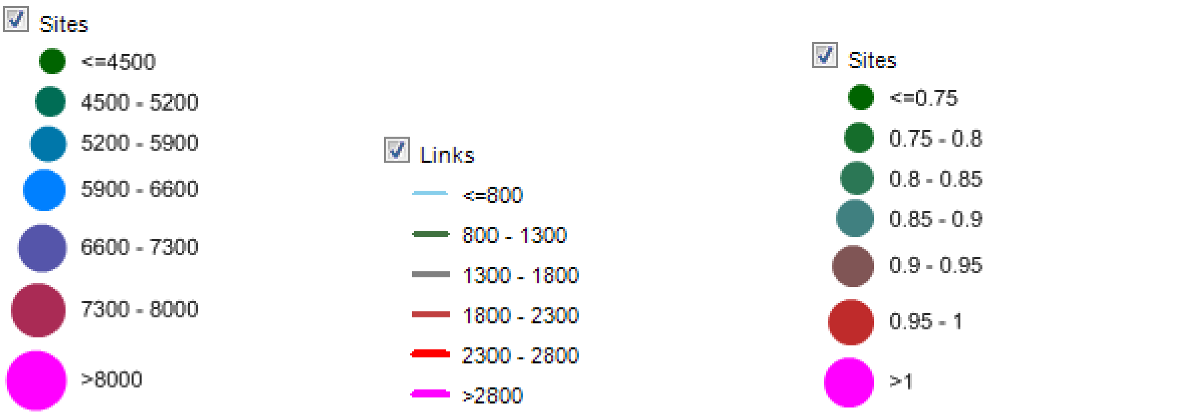
(a) Intersection approach volumes **(b) Intersection performance**

3.3 Mapping tool & legends (thresholds)

The primary objective of producing a GIS based network capacity/performance map is to capture the existing traffic operation and represent it in a way that no specific traffic knowledge should be required to understand the map and appreciate the network performance.

Only colour coded dots and lines are used in the map. The following legends (see Figure 10) explain the threshold values used to gauge the network capacity (i.e. intersection throughput and approach flow rate, veh/h) and performance (i.e. the average intersection DS). With the help of these legends, the map would be self-explanatory.

Figure 10. Legends of the network capacity / performance map



(a) Intersection throughput **(b) approach flow rate** **(c) average intersection DS**

4. Initial results

In this section, we present three sample maps of the Adelaide arterial network (inner area). As discussed earlier, we want to build a self-explanatory map which captures the existing network capacity/performance. It is expected that users would explore and extract the relevant information to meet their specific needs. Therefore, the discussion on each sample map is very brief.

4.1 Understanding the network capacity

As discussed in section 2, the combination of the key intersection throughput and its performance would provide a clear picture of the existing capacity of the arterial road network. Figure 11 (Austroads 2015) shows the AM peak intersection through-put (veh/h) of the central part of the Adelaide arterial road network. The map highlights the busy intersections – the major traffic entry points of the network.

Figure 12 (Austroads 2015) shows the corresponding AM peak intersection performance in terms of average intersection DS when those throughputs are achieved. If an intersection DS is approaching 0.95, then there is virtually no spare capacity left for the intersection. This map highlights the congested areas – the major traffic gates of the network during the peak. The map helps us reviewing the existing traffic/signal operation.

The combination of Figure 11 and 12 helps to paint a realistic picture of the true capacity of the existing arterial network given its current signal operation - a baseline diagram at network level.

Figure 11. Network capacity - key intersection throughput

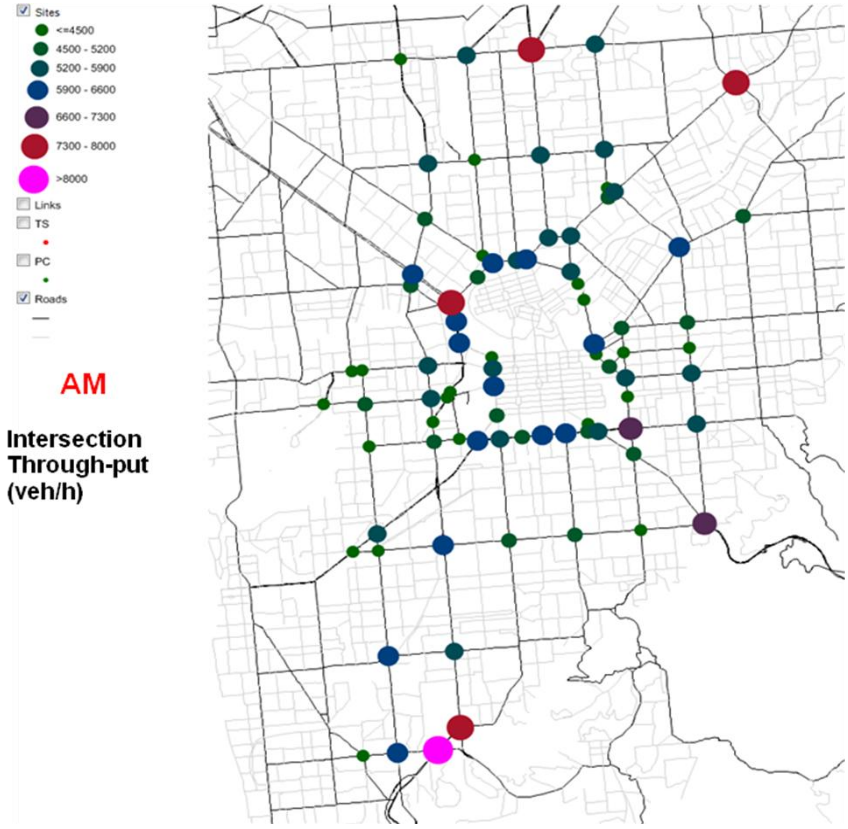
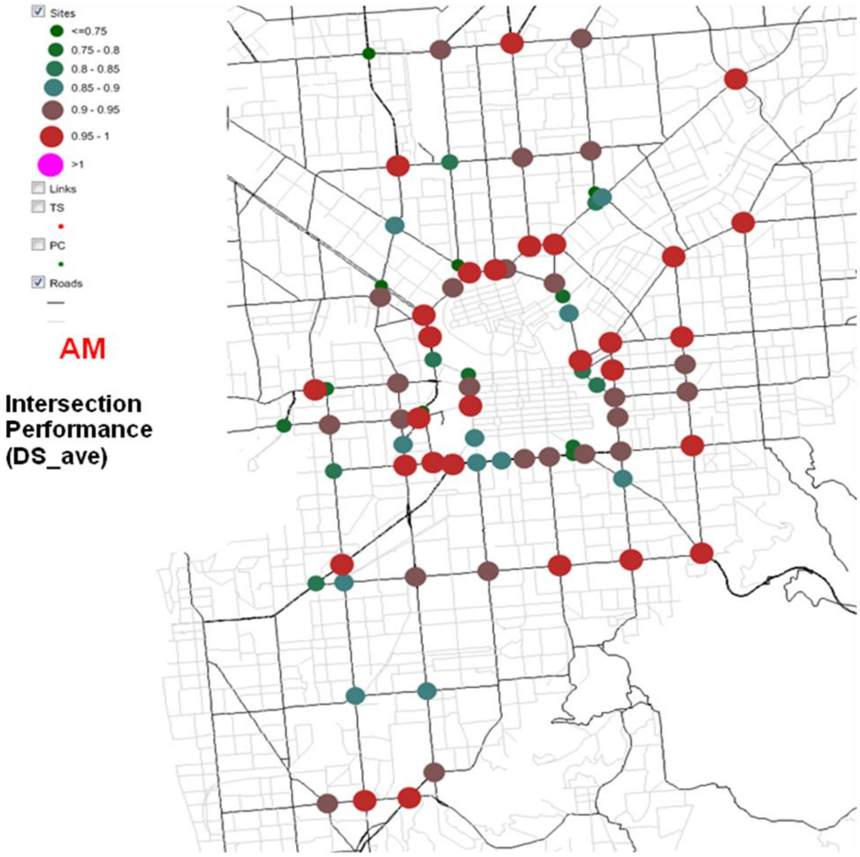


Figure 12. Network performance – average intersection DS



4.2 Understanding the traffic flow patterns

If we combine the intersection performance and the corresponding approach flow pattern, we can produce the Figure 13 map. For readability purpose, Figure 13 shows the Adelaide Inner Ring Route only (orange lines).

Figure 13. Traffic flow patterns & key intersection performance, AM peak

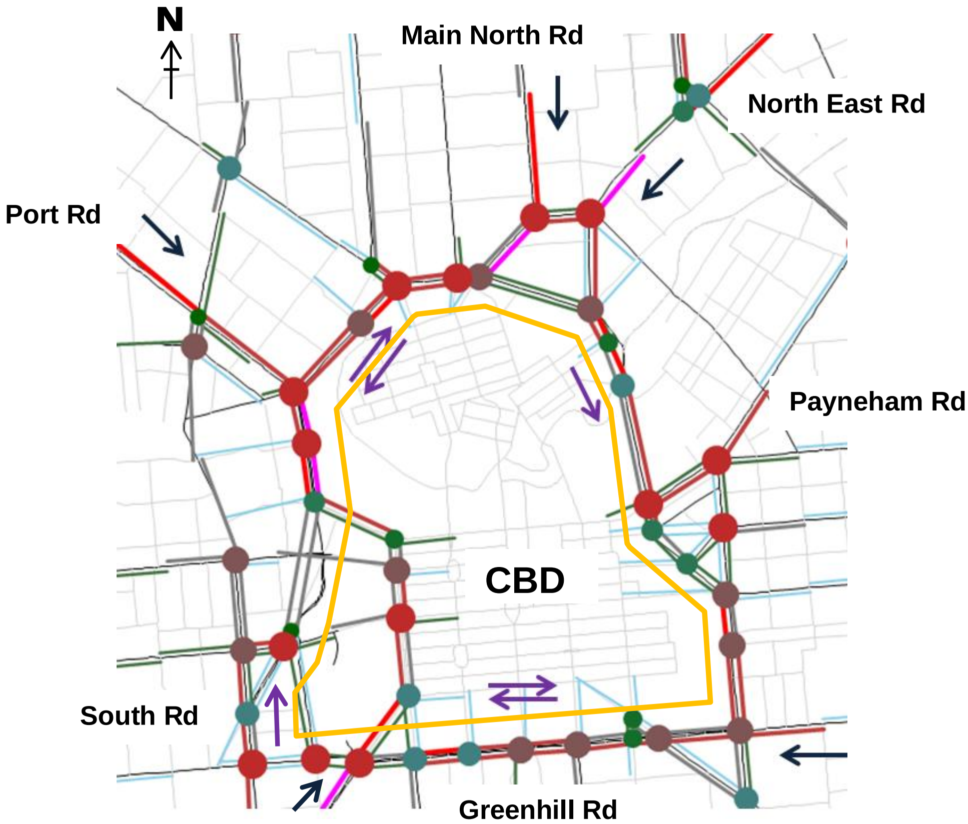


Figure 13 indicates the network wide traffic flow is very tidal in AM peak, and Adelaide CBD is the gravity centre. The traffic on the north-western and southern segments of the Inner Ring Route are very heavy both directions. In contrast, the north-eastern and western segments of the Inner Ring Route experience a tidal flow. At intersection level, the map highlights where the pressure comes from and the resultant intersection performance.

5. Conclusion & Future work

This paper reports on the effort made by the South Australia Department of Planning Transport and Infrastructure in mapping the existing arterial network capacity and performance in Adelaide. The successful development of the first version of the network capacity / performance map demonstrates that the idea of translating the individual intersection traffic operation into a reliable and representative network capacity and performance measure is workable. The key processes which make the map reliable include:

- A stringent network wide SCATS data collection and processing;
- A rigorous lane saturation flow rate calibration in each individual intersection modelling;
- A careful post-modelling analysis to produce representative intersection performance measures.

These processes help to build a virtual link between individual intersection operation and network performance.

Given the fact that no specific traffic knowledge is required to understand the map and appreciate the existing network capacity and performance, the network capacity/ performance map can be easily used to make improvements in traffic operation and assist in development of the future network to move people and goods more efficiently.

The current version of the capacity/performance map focuses on the key intersections of the network. To enhance the mid-block traffic performance measure between any two adjacent key intersections, a Bluetooth travel time and speed layer of the map has been proposed. Currently, the inner Adelaide arterial network has been covered extensively by a Bluetooth receiver system. The enhanced network capacity/performance map will be used in the Operation Moving Adelaide initiative to engage with community.

Acknowledgement

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