Transportation Research Procedia
Volume 15, 2016, Pages 1–13
ISEHP 2016. International Symposium on Enhancing Highway Performance

Managing motorways and urban arterials in Australia: Country Report for Australia

Rod Troutbeck[1], Dennis Walsh[2] and Miranda Blogg[2]
[1]Troutbeck & Associates, Australia and Queensland University of Technology
[2]Queensland Department of Transport and Main Roads, Australia.
rod@troutbeck.com.au, dennis walsh@tmr.qld.gov.au, miranda.blogg@tmr.qld,gov.au

Abstract
Australian States have been investing heavily in managed motorways. It was acknowledged some time ago that motorways that had slow moving congested traffic caused considerable loss of value to the community. The concepts of "Productivity" and "Reliability" were applied to Motorways and have since become key performance indicators used to rate motorway systems. The approach to motorway management has extended overseas practices although different algorithms have being developed in Australia.
Management of motorways cannot be undertaken without consideration of the urban arterial network. It is therefore important to see the network as a whole noting that drivers tend to change their routes so that both the motorways and the arterial must work in unison to provide the level of service to the user. It is therefore important that the performance of the arterial road system be maximised. The paper outlines some of the research that is directed at maximising the arterial road, using detectors on the departure side of signalized intersections to evaluate the potential for operational improvement.
This paper describes recent work in Australia to better manage motorways and arterial roads to be as effective as possible. The paper does not cover all Australian research in this area, but outlines a few cases in more detail.

Keywords: Motorways, arterial roads, control systems, optimisation.

1 Introduction

Traffic management on the road network is becoming increasingly important. For instance, the demand for travel measured in vehicles-kilometres of travel will increase by over 17 per cent in the next decade and the construction of new roads will only increase the road space by about 4 per cent on Melbourne's roads (Gaffney, Lam, Somers, Johnston, & Boddington, 2015). It is becoming more important to manage the use of roads rather than attempt to build sufficient new roads to satisfy the demand.

Selection and peer-review under responsibility of the Scientific Programme Committee of ISEHP 2016

doi:10.1016/j.trpro.2016.06.001

This paper describes recent work in Australia to better manage motorways and arterial roads to be as effective as possible. The paper does not hope to cover all Australian research in this area, but outlines a few cases in more detail.

2 Managed Motorways

In 2007 Austroads, an association of state Australian Road Authorities, published the national performance indicators for network operations (Troutbeck, Su, & Luk, 2007). The five performance indicators were established as follows

- "Traveller Efficiency (Travel Speed) – this indicator monitors congestion in terms of speeds. It is derived from spot speeds on freeways measured directly using point sensors such as a pair of loops. On arterial roads, it can be derived from the inverse of travel times estimated from an ATC system. This indicator does not use histograms for its reporting and uses a single number for each performance measurement period (all the other four indicators use histograms for performance reporting).
- Traveller Efficiency (Variation from Posted Speeds) – this indicator monitors the proportions of a road network at various levels of deviations from posted speed limits on freeway or arterial road links.
- Traveller Efficiency (Arterial Intersection Performance) – this indicator monitors the proportion of an arterial road network at various levels of congestion.
- Reliability (Travel Speed) – this indicator measures the variability of speeds by calculating the coefficient of variation. It is displayed as the proportions of a road network at different levels of variability in a measurement time period.
- Productivity (Speed and Flow) – this indicator is based on the product of speed and flow. A high productivity is achieved if both speed and flow are maintained near maximum values, i.e. near free-flow speed and capacity flow. It is displayed as the proportions of a network at various levels of productivity in a measurement period. "

The last performance measure was based on the earlier paper by Werner Brilon at the fourth International Symposium on Highway Capacity (Brilon, 2000). Brilon established the concept of "efficiency" for roads being the product of speed and flow along a road length, Brilon based this term on analogies with mechanics where force was "equivalent" to the number of vehicles passing a point and power, the rate of doing work, was equivalent to "efficiency".

In the Austroads Report the term "productivity" was used. Essentially the usefulness of the road system to the economy of a city or region was due to the "productivity" of the road or network. The concept was at first hard to appreciate. The question was then asked why multiply these terms together. One reason given is that flow describes how many vehicles can make the trip and speed quantifies the quality of the trip as delay quantifies the quality of a trip under the HCM.

It was also realized that the capacity of a freeway or the flow at which it breaks down is not a constant that is often implied in the textbooks but rather a stochastic variable (Brilon, Geistefeldt, & Regler, 2005; Eleftreiadou, Roess, & McShane, 1995). The stochastic nature calls for a more intelligent motorway control system.

2.1 Motorway management -Victoria

At about the same time as the Austroads performance indexes were being developed, the Victorian road authority, VicRoads, was concerned about the loss of "productivity" when the motorway is congested and the traffic flow breaks down causing the average speed to drop and the flow to be decreased. The solution was to manage the use of the motorway through ramp metering to minimize the impact of the freeway breaking down. Vicroads in a recent report on frameworks for managed motorways (Gaffney, Lam, Somers, Johnston, & Boddington, 2015) presented an example of this loss of productivity shown in Figure 1.

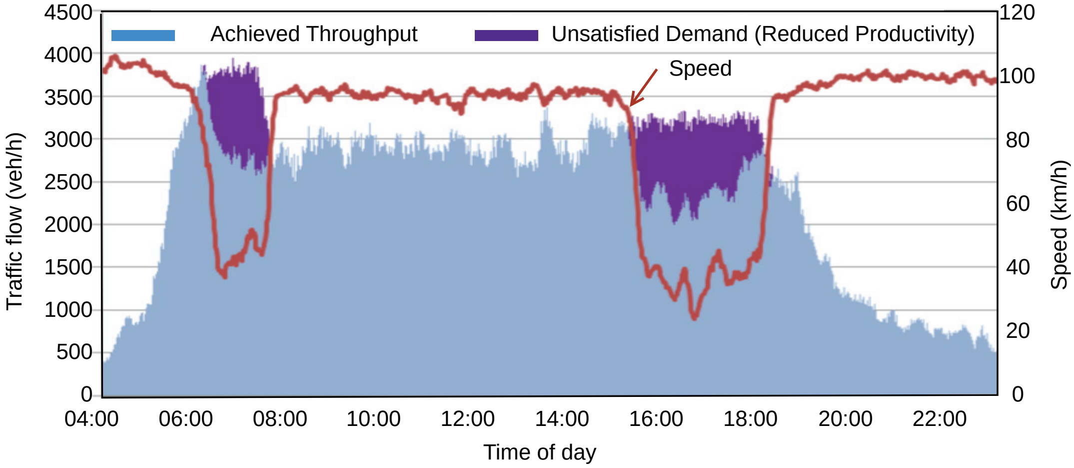

Figure 1: Demonstration of reduced productivity. Kwinana Freeway (redrawn from Gaffney et al, 2015)

The Victorians used a heuristic traffic-responsive feedback control strategy, HERO, to manage queues and freeway flows by metering ramps (Papamichail, Papagrorgeiou, Vong, & Gaffney, 2009). They stated:

"The AM peak evaluation (6:00 am to 9:00 am) revealed a 4.7% increase in average flow on the freeway between Warrigal Road and High Street (on top of the previous system) and a 35% increase in average speed; while the PM peak evaluation (5:30 pm to 6:30 pm) showed an 8.4% increase in average flow and a 58.6% increase in average speed."

Using the Austroads performance indicators, the use of HERO significantly improved the operation as shown in Figure 2.

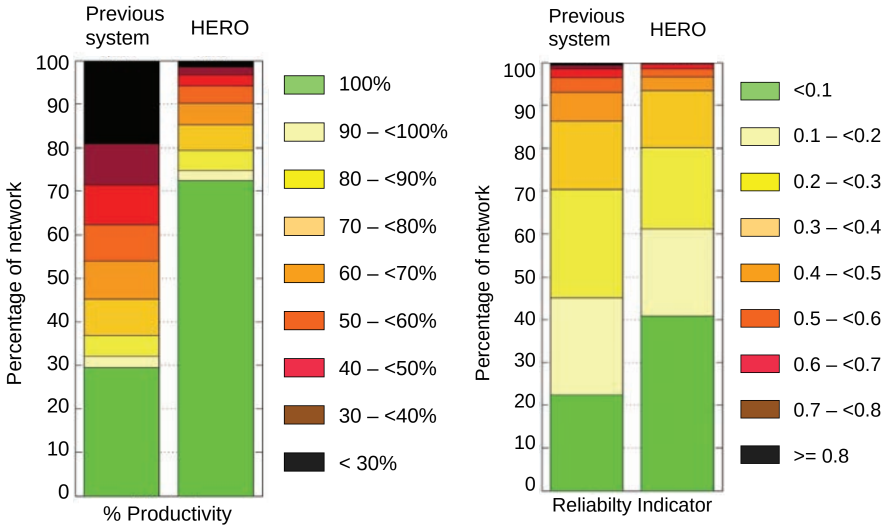

Figure 2: Austroads performance indicators; Productivity and Reliability.
(Light green is considered to be excellent and black to be very poor)

The system is more reliable, more productive and has a greater proportion of time and road length with the average speeds closer to the speed limit. The use of the Victorian ramp metering system has become the standard approach used by other Australian road Authorities.

Gaffney, Lam, Somers, Johnston, & Boddington (2015) indicated that there are a number of techniques and tools used to manage motorways . They refer to foundation intelligence that includes speeds, volume and occupancy detectors, closed circuit TV and weather and environmental monitoring systems currently in use. VicRoads are planning to develop an automatic incident detection system and congestion alarms. They note that while information can currently be made available to road users through variable message signs and the web, there is also a need for intervention control. Currently this is through:

- a lane use management system on the freeway that guides drivers to leave a lane and displays variable speed limits,
- the control of the entry ramp usage through HERO and
- an arterial road interface system at signalised intersections of the entry ramp and urban arterial road.

A number of systems are under development or are planned in Australia for development these include:

- Dynamic variable speed limits (DVSL) which slows traffic on the approach to a congested area or bottleneck so that the effects of the critical bottleneck are lessened by avoiding flow breakdown at the critical area. The process is to smooth flow so that it is more stable through the critical area. Queensland Department of Transport and Main Roads are developing a “High flow” algorithm to support this task (see below).
- Automatic incident detection (AID) through traffic measures rather than management system operators. Queensland Department of Transport and Main Roads are developing a “Queue Detection and Queue Protection” algorithm to support this task (see below).
- Arterial road management system that is aimed at adjusting the system to provide a means to better compensate for the consequences of motorway management systems. At present this is done in SCATS through action lists, which are time-consuming to establish and maintain. In STREAMS it is done through the strategy manager facility.
- Exit ramp management system particularly when the exit traffic exceeds the storage on the exit ramp. The signal control at the intersection of the exit ramp and arterial road will need to adjust to the length of queues on the exit ramp and to any queuing of the arterial road that prevents the traffic on the exit ramp leaving.
- End-of-motorway management system, which controls traffic entering and leaving motorways at the end of the systems.
- Entry ramp management system, which limits the entry lane usage on low volume ramps to further enhance flow stability of the motorway.
- Wide area network dispersion (WAND) from the freeway during times when a significant incident occurs. Motorists are informed about traffic conditions and given advice to leave the motorway at a number of upstream points.
- Motorway dynamic re-configuration. This would typically be closure of entry or exit ramps in order to improve traffic flows.
- Congestion alarms through a number of different sensors and algorithms.

2.2 Motorway management -Queensland

The Queensland department of Transport and Main Roads have also applied the motorway management systems installed in Victoria. Faulkner, L., Dekker, F., Gyles., D, Papamichail, I., and

Papageorgiou, M. (2014) reviewed the performance of the ALINEA and HERO systems previously used in Victoria on a motorway near Brisbane, Australia. Figure 3 shows plots of detector occupancy for a morning peak and location along the motorway heading towards the centre of Brisbane. The route is approximately 17 km long and in the before case had operated under isolated, time of day, fixed time ramp signalling control for almost 20 years.

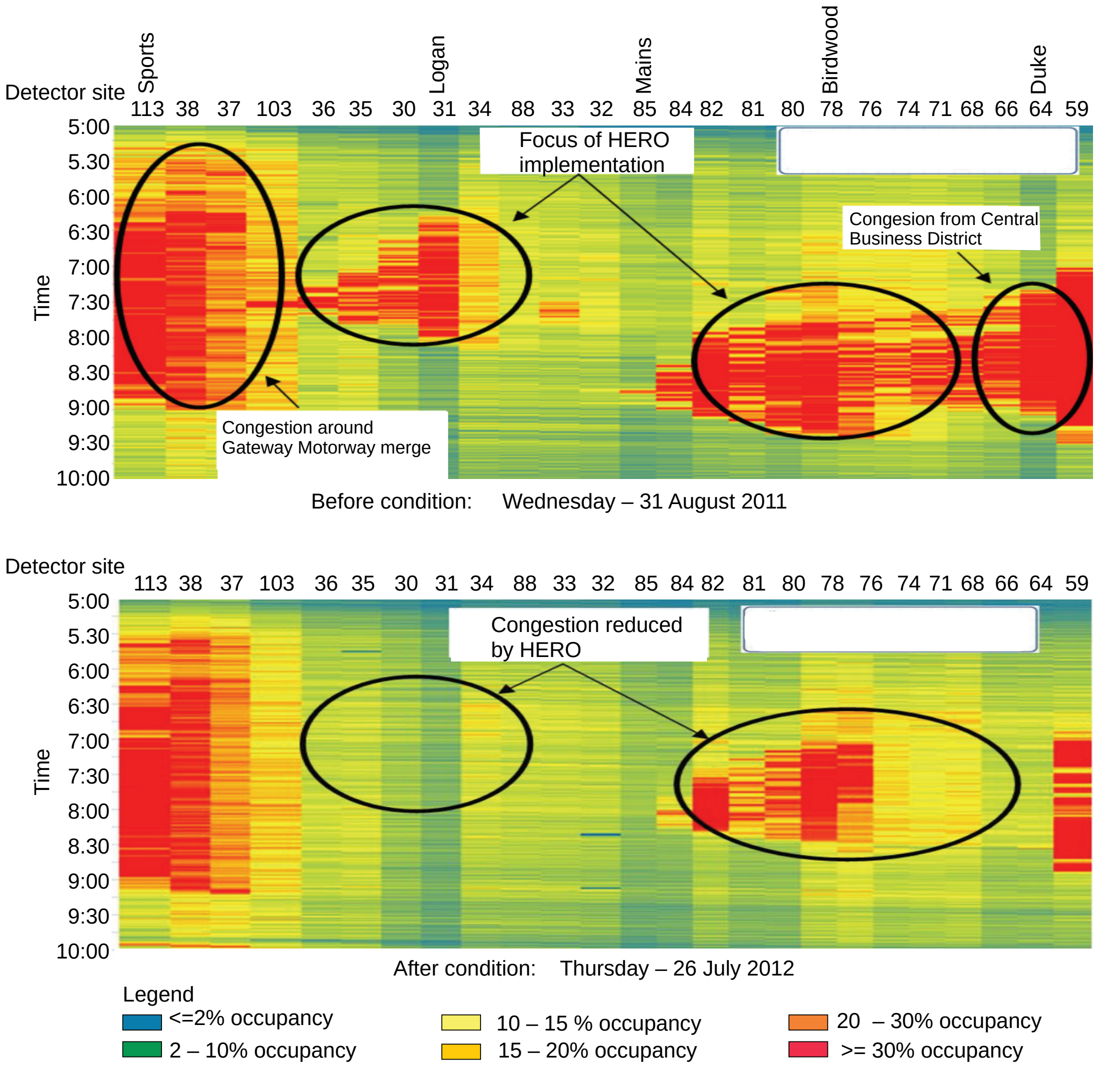

Figure 3: Occupancy plots from Faulkner et al (2014)

The conclusions reached are:

- Average AM peak inbound travel speeds have increased by 7% from 70 km/h to 75 km/h.
- Average AM peak inbound traffic flows have increased by 4% with an additional 150 vehicles per hour throughput.
- Average AM peak inbound travel productivity has improved by 8%.
- The proportion of AM peak inbound trips with good reliability has improved by 37%.

- The benefit cost ratio ranged from 14.9 to 13.8 depending on the discount rate.

Queensland Department of Transport and Main Roads is moving towards the implementation of algorithms to assist traffic operations which to date has been predominately manual. The current focus is the timely detection of events such as queues and congestion with detector technologies, and in response algorithms will calculate dynamic, fully flexible responses to manage traffic events using Lane Use Management System with Variable Speed Limits (VSL) and Lane Control functionality. This research addresses the first two items for future development listed above from the Vicroads report.

The algorithms are designed:

- To manage the operating speed and thus improve the traffic flow by reducing the likelihood of congestion,
- To manage the operating speed of congested traffic conditions, if congestion occurs and to restore the operating speeds as quickly as practicable to decrease the total delay to motorists,
- To reduce the risk and severity of traffic crashes (especially secondary crashes) by reducing the speed of vehicles as they approach significant congestion, an incident, a traffic queue or motorway stoppage;

There are two aspects to these algorithms. The first is a "High Flow" algorithms, which monitors and manages the onset of congestion and the second is the "Queue Detection and Protection" algorithm, which, as the name suggests, monitors and controls the development of queues.

The "High Flow" algorithm uses detector data to sense when the flow of the road is approaching capacity. When demand on a motorway section approaches capacity, and the probability of flow breakdown increases. In these conditions, flow breakdown is often triggered by traffic turbulence (for example: one vehicle braking to allow an aggressive driver to merge onto the motorway). The "High Flow" algorithm displays a reduced speed to better manage traffic flows and to reduce the impact and onset of flow breakdown and congestion to keep the motorway traffic running.

When the "High Flow" algorithm is no longer able to keep the traffic moving and queues develop, it hands over traffic management responsibilities to the "Queue Detection and Queue Protection" algorithm to manage incidents and queues on the motorway, where the event causes either stationary, or slow moving queues within high-speed environments. The algorithm uses detector data to sense queuing events and will act to protect the back of the queue by implementing a speed reduction to 60 km/h to reduce the speed of the approaching traffic to the back of a queue, thus reducing the likelihood of further or secondary incidents or collisions. Both algorithms modify the speed limits while lane control is still a manual operation.

From some preliminary indications, these algorithms are expected to demonstrate:

- Improved detection and response times.
- Improved responsiveness to changes on the network. It is not simply the first response, the algorithms update the recommended response in real-time, and are able to track changing traffic conditions and update the VSL and Lane Control response. This way the algorithms can effectively manage the propagation of queues or congestion and moving events where previously these responses relied on manual monitoring and intervention.
- Improved consistency and reliability of VSL and Lane Control response.

A recent report (Boddington and Johnson, 2015) demonstrated that the "Queue Detection and Queue Protection" (QDQP) algorithm showed significant improvements in incident detection rate and response time, with no incorrect triggers. During operation of the QDQP algorithm, drivers reduced their speeds in advance of the queue in apparent response to the QDQP speed reductions; however, there was a reduction in overall speed compliance. This may be due to the spacing of the gantries in advance of the back-of queue, requiring drivers to reduce their speeds for distances in excess of 1 km.

Under high flow operation, the throughput at the subject lane drop bottleneck showed some improvement; however, the small sample size and impacts of downstream queueing meant that the result could not be confirmed as statistically significant. For high flow speed changes, the average vehicle speed was normally more than 10 km/h higher than the new speed limit immediately before the change. By the time the HF speed reduction was implemented, the average vehicle speed was mostly 10 to 12 km/h higher than the new speed limit. This shows that the high flow algorithm was actively reducing the speed limit while the traffic speed was reducing.

3 Arterial Road Management

The management of traffic along arterial roads and freeways is important for the effective use of the infrastructure. Users would ideally like traffic control systems that require them to stop infrequently by providing long green waves through a number of signalised intersections. If the user is required to stop then the duration of the stop should be short. This has formed the basis of the traffic control systems available today.

As systems become more responsive to traffic conditions so the quality and quantity of traffic data needs to increase. Control systems that use upstream detectors as well as detectors near the stop line will have improved system performance when the data about approaching vehicles to the signalised intersection are more extensive and accurate.

The use of upstream detectors is not new and their usefulness has been documented previously. Bretherton (2007) discusses current and future developments of the English traffic control system SCOOT (Split Cycle Offset Optimisation Technique) and states:

"Detectors should be positioned 10 to 15 metres downstream of the preceding junction to provide good prediction of the arrivals at the stopline, but particularly to enable SCOOT to react when a queue is about to exit block the upstream junction. Some congestion on the approach to a junction is probably inevitable, but problems rapidly increase when a queue on one link spills back and reduces the discharge from another junction."

A number of authors (Eghtedari 2006; Gettman et al 2007; Kobayashi and Tajima 2005; Moon et al 2006; Smaglik et al 2006, 2008) have indicated that upstream detectors are desirable for adaptive traffic control, so that queues at the stop line depart before the platoon arrives from an up-stream intersection and queue spill back across intersection is avoided.

True adaptive systems evaluate queue lengths and turning flow patterns. Some systems are attempting this by using detectors to develop a series of 'standard plans and flow profiles'. Effective prediction of the traffic conditions can only be obtained with improved estimates of arrival patterns, queue lengths and turning patterns. Upstream detectors provide a convenient method of estimating these quantities.

Upstream detectors were installed on Oxley Drive on the Gold Coast, Australia. The detectors were located on the departure side of upstream of three intersections and two pedestrian crossings along Oxley Drive. Some of the results of this study are described below.

3.1 Value of reliable detector data

Detector data is only useful if it is credible and accurate. In a given green period, the number of vehicles leaving one approach must be equal to the number of vehicles detected on the departure detectors (upstream from the next intersection). In short the sum of in-comings must be equal to the sum of the out-goings across the intersection.

The detectors close to the stop line are often unable to discriminate between closely following vehicles or may double count vehicles. Using the upstream detectors will provide both a check on the accuracy of the detectors and determine if the detectors have failed through widely different counts.

The pedestrian crossing near Lae Drive had dual loops on the departure side. The detector counts for the 16-hour period from 5:00 to 21:00 were approximately 12,500 vehicles. The two departure detectors were within 4 vehicles, while the approach detectors were greater than the departure detector counts by 27 vehicles in the southbound direction and 112 vehicles in the northbound direction. The approach detectors had vehicles queueing across them and were deemed to be less accurate.

The number of vehicles between the two detectors is the cumulative number of vehicles that cross the approach detectors minus and the cumulative number of vehicles that cross departure detectors. If the system is accurate, the cumulative number of arrivals cannot be less than the cumulative number of departures. A correction could be applied to the data to allow for the differing sensitivity of the approach and downstream detectors. (This sensitivity is not only a loop property by also a function of geometry of the intersection and the location of the loops). This correction could be evaluated over a number of days and stored as a detector attribute. It was found that there was only a weak relationship between the difference between the arrival and departure counts and traffic flow. ($R^2 < 0.05$) It was therefore not possible to adjust the data depending on traffic flow.

A fourth order exponential smoothing function was used to provide a trend line to the raw arrival minus departure count data. The variance of the data around the fitted line was estimated from the preceding 100 data points. A base line was then estimated from the trend line minus 1.64 times the estimated standard deviation and the base line provided a short-time estimate of the number of vehicles between two stations without predicting negative estimates.

The value of accurate information from detectors cannot be overstated. The STREAMS control system put substantial effort into identifying data that may be corrupt and the processes to deal with these data.

3.2 Study outcomes

The difference in the cumulative counts from the upstream and approach detectors represents the number of vehicles in the link. The difference in the counts from the upstream and approach detectors during a time period is equal to the sources (or sinks) and the change in the number of vehicles queueing at the downstream detectors and the change in the density of vehicles in the link.

Figure 4 lists the total number of vehicles recorded at the various detector sets for 10 minute periods. The arrivals counts have been adjusted where possible to provide better estimates and, for the sake of the discussion, are taken as being accurate. The counts were from 5:00 am to 9:00 pm. The traffic is light with similar queues at both the start and end of the counting period. Hence the difference in the cumulative counts at 21:00 represents the sources and sinks over that 16-hour period. The small plots in this figure show the link departures have a strong correlation with the link arrivals for 10-minute counts. While these plots in Figure 4 show a reasonable consistent trend across the day, the trend for different periods of the day can also be produced. Knowing the size and location of potential sinks and sources will assist in predicting the queue lengths at an intersection.

The time between the lights turning green and the first vehicle crossing the downstream detectors can be estimated from the data from the departure detectors. The Queensland system STREAMS does not use detectors at the stop line but a little further upstream. This assists in predicting queue lengths. However the departure detectors will be able to estimate both saturation flows and the lost times if a correction is made for travel time between the stop line and the departure detectors.

The passage of vehicles after the lights have changed to amber can be detected using the downstream detectors. The travel time from the stop line to the departure detectors needs to be incorporated into the calculations. As an example, at the Coombabah school crossing about 0.04 per cent of passing vehicles ran the red light in the northbound direction.

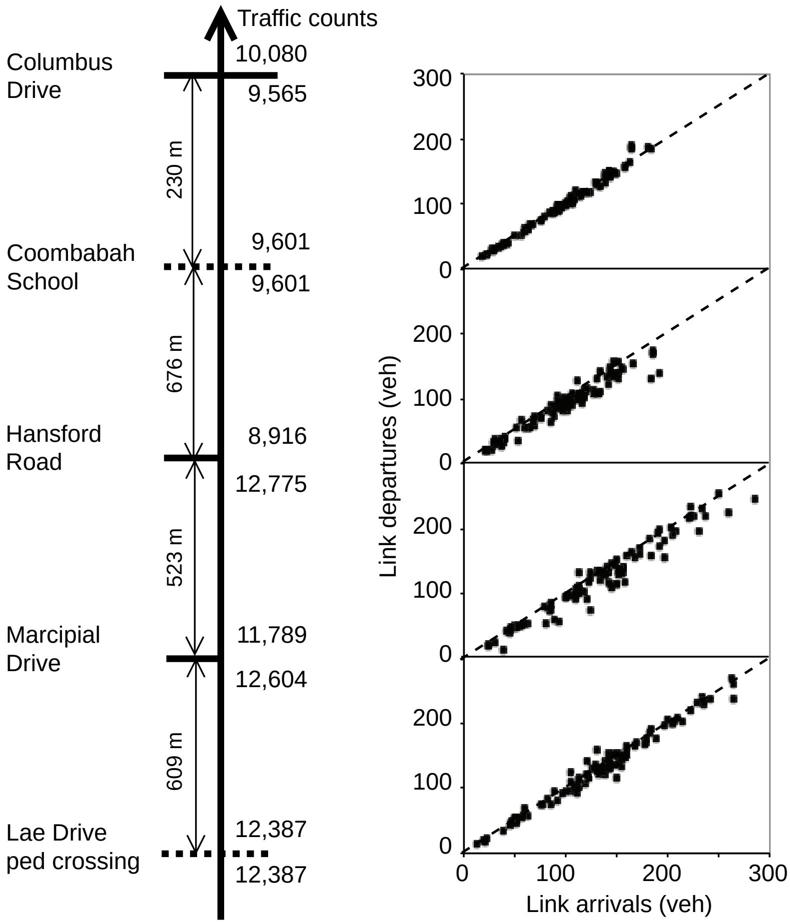

Figure 4: Number of vehicles along Oxley Drive in the northbound direction. The dotted lines represent pedestrian crossings. The graphs on the right show the link arrivals and departures in 10-minute periods

The departure detector data from one intersection and the approach data from another intersection can be used to predict travel times by looking at the detector patterns. The proportion of departure detections were most closely matched with arrival detections downstream at a travel speed is 69 km/h (in both directions). This is independent of the speed limit on the road.

Troutbeck (2008) concludes that the use of upstream detectors will improve the quality of the arrival and platoon data. The data will need to assessed and adjusted at times, but this is a normal part of reviewing the inputs and either deleting data and/or using default information, not updating traffic characteristics for a short time, or adjusting the data using other information.

The time between the lights turning green and the first vehicle crossing the downstream detectors can be estimated from the data from the departure detectors. The Queensland system STREAMS does not use detectors at the stop line but a little further upstream. This assists in predicting queue lengths. However the departure detectors will be able to estimate both saturation flows and the lost times if a correction is made for travel time between the stop line and the departure detectors.

The passage of vehicles after the lights have changed to amber can be detected using the downstream detectors. The travel time from the stop line to the departure detectors needs to be incorporated into the calculations. As an example, at the Coombabah school crossing about 0.04 per cent of passing vehicles ran the red light in the northbound direction.

The departure detections, phasing sequence and timing data can be used together to identify turning movements if there is a single shared lane on the approach. These data can be consolidated and used to identify abnormal traffic or a detector fault.

In the longer term this data may be able to identify the turners and assist in developing a traffic management system that provides a better green wave for the through traffic.

The departure detector data from one intersection and the approach data from another intersection can be used to predict travel times by looking at the detector patterns. The proportion of departure detections were most closely matched with arrival detections downstream at a travel speed is 69 km/h (in both directions). This is independent of the speed limit on the road.

Troutbeck (2008) concludes that the use of upstream detectors will improve the quality of the arrival and platoon data. The data will need to assessed and adjusted at times, but this is a normal part of reviewing the inputs and either deleting data and/or using default information, not updating traffic characteristics for a short time, or adjusting the data using other information.

Given that the detectors can be adjusted for their sensitivity and can be checked to provide reasonably accurate results, then the upstream detectors can provide:

- Better arrival and traffic demand information.
- Better estimates of queue length
- Estimates of queueing times
- Detector count correction
- Improved platoon identification
- Estimation of signal start-up lost times
- Estimation of saturation flows
- Better evaluation of the sources and sinks
- Recording the volume of turning traffic
- Travel times along a road link
- Red light running count

These are seen as benefits for managing traffic. Their use will assist in reducing the lost time through blocked intersections and through overloaded links. Although Queensland Department of Transport and Main Roads have not widely incorporated upstream detectors in the field, they have used upstream detectors to manage queue spill back at isolated locations. Widespread use of upstream detectors has not been contemplated at this stage.

4 Signal control flexibility

Traffic control on arterial roads needs to be optimised to improve co-ordination. This can be time consuming and, at times, it will be unable to produce significant change. Queensland Department of Transport and Main Roads has been developing a process to identify the flexibility for a control system to produce progression in both directions. The process does not optimise the signal settings, but rather is an aid to plan activities to retime and optimise routes. Some networks or segments of a network show significant flexibility in that the cycle time and the offsets can be changed and still produce good progression, while other segments have a very limited set of conditions when two way progression is possible.

The process looked at two measures. The first quantifies the ability of the control system to provide progression to drivers who leave one intersection at the start of the green and to move through the downstream intersection on a green band. This measure also provides an indication of whether vehicles are likely to be stopped at the downstream intersection.

The second measure looks for progression for a platoon that leaves the upstream intersection within the green time and can arrive at the next intersection in the green period. Both measures can be used to describe the flexibility of the arterial to provide progression

The approach is to successively review the progression between two intersections in both directions. The assessment of the arterial is then based on consideration of the performance of all links (in both directions).

Data requirements include:

- Green time ratios for both major directions and for all intersections,
- The distance between intersections,
- The design platoon speed (generally assumed to be the speed limit, although this is not essential)
- The proportion of the green period for the queued vehicles at the end of the red period to depart (expressed as a proportion of the cycle time)
- The design (or desired) length of the platoon (again expressed as a proportion of the cycle time.)

The process calculates the proportion of the platoon that is stopped for cycle times between 90 and 160 s and for the offset between 0 and the cycle time. The results are plotted in bands as shown in Figure 5a (for one direction). Using results for both directions, the conditions that provide for progression in both directions are shown as a green band in Figure 5b. The area of the green band is used to calculate an index to classify links and routes. The larger values of this index, (and the larger the area of Figure 5b) the greater is the flexibility to control a link.

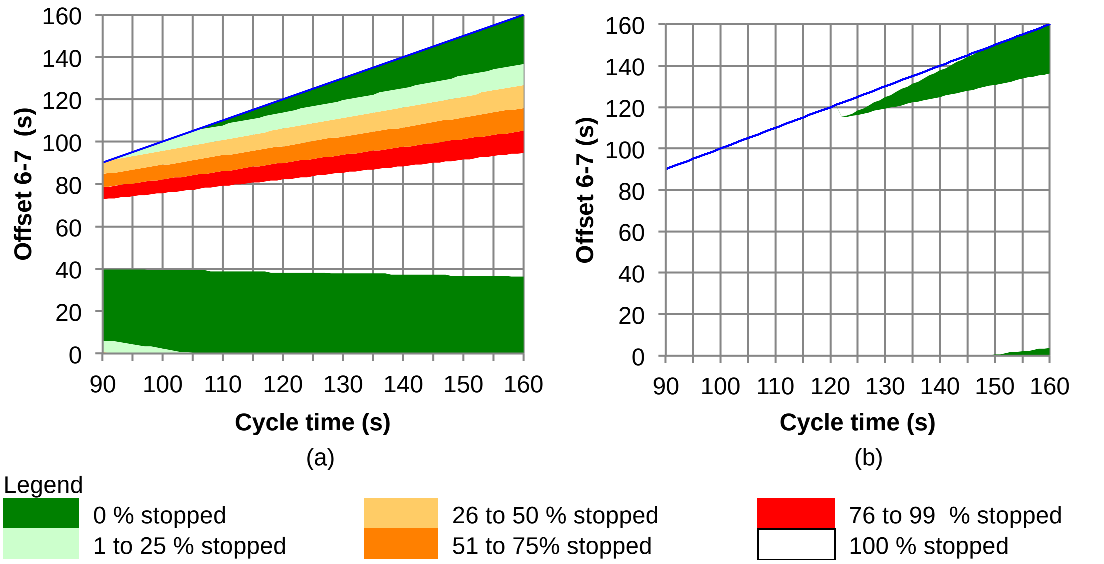

Figure 5: Progression (proportion of platoon stopped) in one direction (a) and in both directions (b).

A measure of the progression when the platoon leaves the first intersection after the start of green is calculated in a similar fashion and again an index is calculated to compare links and routes.

This approach is being investigated to establish a priority list for re-evaluating the co-ordination of routes. A question remains, should a route that shows few chances to be optimised because it is a difficult route, in fact be at the top of the list. These indices provide information about the flexibility of the system for successful optimisation. How this information is used is up to the analysist.

5 Discussion and conclusions

The management of congestion of motorways and urban arterial roads is becoming increasingly more important. The ability to build new roads and transport infrastructure is becoming increasingly more difficult. Australian State road agencies are now putting more emphasis on managing roads.

Congestion is a community issues in a number of ways. It creates delays, environmental costs and in some cases more importantly a health issue. The community relies on rapid responses from ambulances and medics, fire-brigades and so on. This is not possible if the network is congested.

A number of Australian states have been using ALINEA and HERO control systems to better manage motorways. The experience has been positive, with improvements in traffic flow and average speeds. Occupancy plots of traffic on a motorway have shown a significant improvement. It is expected that these control systems will be used by other states in the future.

Queensland Department of Transport and Main Roads is evaluating new algorithms to identify high flow conditions on motorways and then to identify queueing. A control system is being developed based on variable speed limits and a lane use management system. Early indications are positive.

Urban arterial road management has typically been based on SCATS and STREAMS traffic control systems. Queensland Department of Transport and Main Roads has investigated the use of departure detectors to provide an increased understanding of the operation of an urban arterial road, and in particular the queues that form on these roads. Added to this the Queensland Department of Transport and Main Roads is investigating a process to quantify the flexibility of a route to provide good progression.

References

Bretherton, D. (2007) *"SCOOT MC3 and current developments"* Presented at 86th Annual Meeting of the Transportation Research Board, Washington DC, January 2007,

Brilon, W. (2000). Traffic flow analysis beyond traditional methods. *4th International Symposium on Highway Capacity* (pp. 26-41). Transportation Reserch Research Board.

Brilon, W., Geistefeldt, J., & Regler, M. (2005). Reliability of freeway traffic flow: A stochastic concept of capacity. *Proceedings of the 16th Internetional Symposium on Transportation and Traffic Theory*. College Park, Maryland.

Boddington, K. and Johnson, D. (2015) ARRB (Investigation of Road User and Operational Benefits to TMR of Improved Speed Management analysis of QDQP/HF) ARRB Research Group.

Eghtedari, A. (2006) "Measuring the benefits of adaptive traffic signal control: case study of Mill Plain Blvd. Vancouver, Washington." Presented at 85th Annual Meeting of the Transportation Research Board, Washington DC, January 2006.

Eleftreiadou, L., Roess, R. P., & McShane, W. R. (1995). Probabilistic nature of break-down for highway capacity analysis. *Transportation Research Record , 2027*.

Faulkner, L., Dekker, F., Gyles., D, Papamichail, I., and Papageorgiou, M. (2014) Evaluation of Hero Coordinated Ramp Metering Installation at the M1.M3 Freeway in Queensland Australia. *93rd Annual Meeting Transportation Research Board.* Transportation Reseach Board. Washington DC.

Gaffney, J., Lam, P., Somers, A., Johnston, D., & Boddington, K. (2015). *VicRoads Managed Motorway Framework*. Kew, Australia: VicRoads Technical Services.

Gettman, D., Shelby, S., Head, L., and D Bullock, D. (2007) *"Data-driven algorithms for real-time adaptive tuning of offsets in coordinated traffic signal systems"* Presented at 86th Annual Meeting of the Transportation Research Board, Washington DC, January 2007.

Kobayashi, M. and Tajima, T. (2005) *"Development and Verification Experiment Results of the New Real-time Signal Control Based on Traffic Arrival Prediction"* Paper presented at the 84th Annual Meeting of the Transportation Research Board, Washington DC, January 2005

Papamichail, I., Papagrorgeiou, M., Vong, V., & Gaffney, J. (2009). HERO coordinated ramp metering implemented at the Monash freeway. *89th Annual Meeting Transportation Research Board.* Transportation Reseach Board. Washington DC.

Moon, Y J, Lee, S. and Park, Y. (2006) *"Development of Wireless Interface Signal Control System for Dynamic and Optimal Management (WISDOM) - Project Summary and System Architecture"* Presented at 85th Annual Meeting of the Transportation Research Board, Washington DC, January 2006.

Smaglik E J, Bullock, D. M. and Urbanik. T. (2006) *"Evaluation of Flow Based Traffic Signal Control Using Advanced Detection Concepts"*. Paper presented at the 85th Annual Meeting of the Transportation Research Board, Washington DC, January 2006

Smaglik E J, Bullock, D. M. and Urbanik. T. (2008) *"Bench Implementation of Restricted Flow Bottleneck Identification and Flow Based Phase Termination"* Presented at 87th Annual Meeting of the Transportation Research Board, Washington DC, January 2008.

Troutbeck, R., Su, M., & Luk, J. (2007). *National performance indicators for network operations.* Austraods Report Ap-R305/07, Sydney, Australia

Troutbeck, R. J. (2008) *Evaluation of the benefits of using upstream detectors to manage traffic.* Report to Queensland Transport and Main Roads

Acknowledgement

The views expressed by the authors in this paper do not necessarily represent those of the Queensland Department of Transport and Main Roads or any other Australian state road authority.