

RTA and NICTA:

Innovating on Successful Traffic Management

Philip Kilby

Principal Research Scientist, NICTA, and
Adjunct Fellow, Australian National University
Locked Bag 8001, Canberra ACT 2601, Australia
Philip.Kilby@nicta.com.au

Fraser Johnson

Manager, Network Performance Development
Roads and Traffic Authority of New South Wales
Australian Technology Park, Eveleigh, NSW 1430 Australia
Fraser_JOHNSON@rta.nsw.gov.au

ABSTRACT

The Roads and Traffic Authority of New South Wales (RTA) and NICTA are engaged in an ongoing research collaboration. SCATS is an area wide adaptive traffic control system developed during the 1970's that continues to be developed by the RTA. SCATS is one of the most widely used and successful traffic control systems, with installations in 141 cities across 24 countries. The RTA is working with NICTA to further develop some of the innovations emerging from previous research and development.

The RTA is the NSW State Government's road authority, responsible for roads and traffic throughout the state of NSW in Australia.

NICTA is the Australian Government's Centre for Excellence for research into Information and Communications Technology.

The collaboration is allowing the RTA and NICTA to research methods for improving traffic control in specific, difficult situations. This paper briefly outlines the research being currently conducted by NICTA as part of this collaboration.

Introduction

SCATS (RTA, 2010) was originally developed to control traffic in Sydney, Australia. Over time it has developed into a truly international product, and is now used in 141 cities in 24 countries to control over 32,000 intersections world-wide. It is one of the most successful and widely-used traffic control systems throughout the world.

NICTA is Australia's Centre of Excellence for research in Information and Communications Technology. Established in 2004, NICTA has quickly grown to employ more than 400 researchers and support some 300 Ph.D. students in labs in Sydney, Melbourne, Canberra and Brisbane. NICTA's research covers a diversity of information and communications technologies and conducts its work in a selected set of clearly defined 'impact areas'. Research in one of these impact areas is the subject of this paper. The research with the RTA is being conducted as part of the Smart Transport and Roads (STaR) project (NICTA, 2010). A multi-disciplinary team is conducting the research, with backgrounds in traffic engineering, discrete optimization, artificial intelligence, constraint programming, and optimal control. The aim of this research is to deliver benefits in road traffic and transport operations.

History

The initial five years of the NICTA/RTA collaboration has delivered a number of technologies with potential to be incorporated into the RTA's traffic management portfolio (Chong-White 2008, Geers *et al.* 2009). Recently, the collaborators successfully completed trials of a prototype system for improving traffic flows at a signalized roundabout at a major highway junction to the south of Sydney. The system uses a method for estimating the length of queues based on information from upstream loop detectors. In simulation tests completed before installation, the enhanced, state-based control algorithm was able to reduce delay overall, and particularly during the periods of highest usage. This methods used to evaluate this project are being presented elsewhere at the ITS World Congress 2010 conference (Geers, 2010).

Project Aims

Ongoing research is focused on a number of key areas of interest to the RTA. Of particular interest is the handling of oversaturated conditions – when the amount of traffic has increased to the point where vehicles must stop several times before clearing a congested link. These heavily congested periods are frustrating for drivers, and are potentially a source of avoidable fuel wastage and emissions. NICTA is investigating ways of avoiding or postponing over-saturation situations, and of alleviating them when they do arise.

NICTA will be seeking to extend the use of the queue length estimation technology that emerged from the initial collaboration. One key indicator in identifying the areas of high congestion mentioned above is the advent of longer queues. NICTA is looking at whether the technology can be used to automatically detect these queues even as they are forming. If so, the system will be able to raise an alarm when a traffic queue has grown to the extent that the roadway is approaching its nominal capacity, so that continuing to allow traffic to enter the link becomes inefficient. Upon seeing the alarm, the traffic control system may then able to take alternative steps to avoid wasted green time.

SCATS is an adaptive traffic control system – the length of green time adapts automatically to traffic conditions. NICTA is working with the RTA to develop a method to automatically calculate *fixed-time* plans based on recent traffic history. Such plans are useful in some parts of SCATS operation as a source of reference or selection as required. These requirements include SCATS features such as operator intervention and fallback operation. Questions that may be investigated include automatically partitioning days into periods of similar demand, determining appropriate (sets of) traffic conditions on which to base plans, and the automatic synthesis of robust plans.

SCATS coordinates traffic signals through a number of existing facilities. It determines when traffic signals can be grouped to facilitate coordination, and automatically establishes and dissolves these groupings. NICTA is examining the ways higher-level traffic models can be applied to the question of coordination, and will compare these with the existing facilities in SCATS.

First Phase: Coordination

The first phase of the project is focused on the coordination of traffic signals. SCATS has established methods for forming groups of traffic signals that work together to provide coordination. However, with world-wide interest in reduction of green-house gases, the question of coordination becomes even more important, and leads us to look anew at the question of when to use coordination .

We use word *coordination* to mean adjacent intersections having the same cycle time, and an offset defining the time relationship between known points in the cycles at the adjacent intersections, calculated to ensure that at least one movement from the upstream intersection is able to pass through the downstream intersection without stopping, or with reduced probability of stopping.

Reducing vehicle stops is important in consideration of green-house gas emissions because a higher level of emissions of CO₂ (and other pollutants such as hydrocarbons and nitric oxide) are emitted during acceleration from stop. Colyer (2001) reports that “vehicle emissions are generally highest while vehicles are accelerating and lowest while idling”, a finding supported in other research such as Tong *et al.* (2001), Denis *et al.* (1994) and Kelly and Groblicki (1993). Colyer reports, for example, in a 1996 Oldsmobile Cutlass sedan, emissions of CO₂ rising from 0.65 mg/sec while idling, to 33.83 mg/sec during acceleration in some tests. Reduction in vehicles stops should lead to a reduction in the time spent in these acceleration events.

Coordination is usually achieved by matching cycle times at adjacent intersections. Each intersection has a *desired cycle time*, which will depend, *inter alia*, on the phasing at the

intersection, and the level of demand (number of vehicles wishing to use each phase). Coordination is usually applied to intersections with similar desired cycle lengths. Once the correct offset is established, such coordination comes at little cost – all the benefits of reduced stops and delay for the coordinated movement are gained, with little change to the delay experienced by other movements.

However, this project will also look at what might be called “forced” (in the sense of less natural) coordination – where the intersections have markedly different cycle times. Such coordination comes at a cost. In order to accommodate demand, the longest cycle time must be used. However, some traffic at the coordinated, lower-demand intersection will experience higher levels of delay, waiting for the longer cycle time. This delay is balanced by the decrease in stops and delay of the coordinated traffic. Forced coordination makes sense when this balance is in favour of the coordinated traffic.

Traditionally, minimization of delay was chosen as the key objective in coordination: intersections were coordinated when the overall delay was reduced. The global focus on emissions may change this, however. A stopped vehicle, while accumulating delay, produces a very small CO₂ load. However, a vehicle being forced to stop, and then accelerate back to cruising speed will produce a much higher CO₂ load. If CO₂ emissions are considered important, it makes sense to tip the balance toward coordination: we may accept a higher delay if we can reduce the number of stops significantly.

One way of expressing this trade-off is using an objective z which combines both delays and stops, for example

$$z = \text{delay} + k * \text{stops} \quad (1)$$

where *delay* is measured in seconds/second (i.e. the number of seconds delay accumulated per second) and *stops* is the number of times vehicles stop per second. If the parameter “ k ” is set to a notional penalty, expressed in terms of equivalent seconds of delay per stop, then z is a dimensionless quantity, and k can be used to control the trade-off between delay and number of stops. Typical values for k are 20 (i.e. one stop is equivalent to a 20 seconds delay). Higher values of k emphasize the importance of stops, and we will accept a greater delay to reduce the total number of stops. This, and more general forms of this objective are discussed by Akçelik (1981). NICTA and the RTA will use equation (1), with various values of k to determine the success of the interventions suggested by the research.

NICTA is looking at whether better outcomes can be achieved with increased use of coordination. The thesis we wish to examine is as follows:

- (a) *There are situations where coordination is not currently used, where the objective function (1) can be reduced without excessive increase in the delay component.*

(b) We can identify these situations using the traffic information currently available to SCATS.

In cases where demand for the coordinated movement is high, and demand for other movements is low, the reduction in delay for the coordinated traffic may outweigh the increase in delay for other movements. Hence it may even be possible to achieve an overall reduction in delay using coordination, even if this coordination is “forced” – used when cycle times are dissimilar.

Example

As an example of the situation we wish to be able to identify, we will look at a simulation of two adjacent intersections. These intersections are modelled on actual intersections in Sydney, Australia, with demand profiles similar to those experienced around the morning peak time. We examine using simulation the effect of coordination on the intersections.

The intersection configuration is shown in Figure 1. The two intersections are labelled A and B. The dominant traffic travels between A and B, with A being the major intersection. The phasing design at intersection A is more complex than that at intersection B – there are 5 phases at A compared to 2 phases at B (shown in Figure 2).

In Appendix A we use a well-established method – Webster’s method (Webster, 1957) – to calculate the desired cycle times at each intersection assuming *isolated* operation. The result is a desired cycle time of 142 seconds at A, and 25 seconds at B. The cycle times are quite dissimilar (due to the difference in number of phases, and difference in demand), and is not an obvious choice for direct coordination. It is an example of a situation where the traffic engineer must intervene to ensure intersections are coordinated, and the type of intersection we wish to be able to identify automatically. The control parameters are given in Table 2 in Appendix A.

We wish to examine the effect of “forced” coordination in this case. TRANSYT (Robertson, 1969) is an established method of calculating cycle length, offset and green time for coordinated intersections. We used the software TRANSYT version 12.0 (TRL Software 2010) to calculate the control parameters for intersections A and B for *coordinated* operation. TRANSYT gives a (shared) cycle time of 70 seconds.

Because of the dissimilarity in desired (isolated) cycle times, coordination using “double cycling” is an option. In this case, the cycle length at B would be chosen to be half that at A, so that it would complete two cycles to A’s one. This allows for some coordination with a reduced cycle time (and hence reduced delay). The control parameters for both standard coordination, and double-cycle coordination, are given in Table 3 in Appendix A.

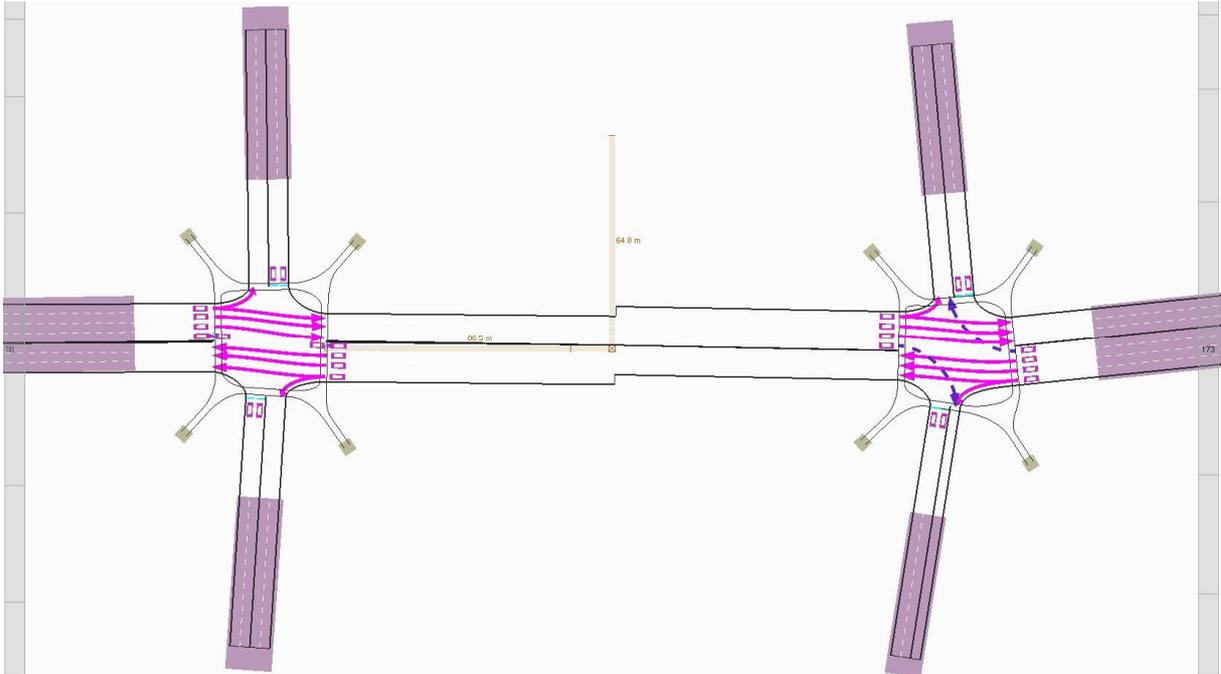


Figure 1 Diagram of adjacent intersections used in the example. Intersection A is on the left, and B on the right
(Commuter2.05 screen image)

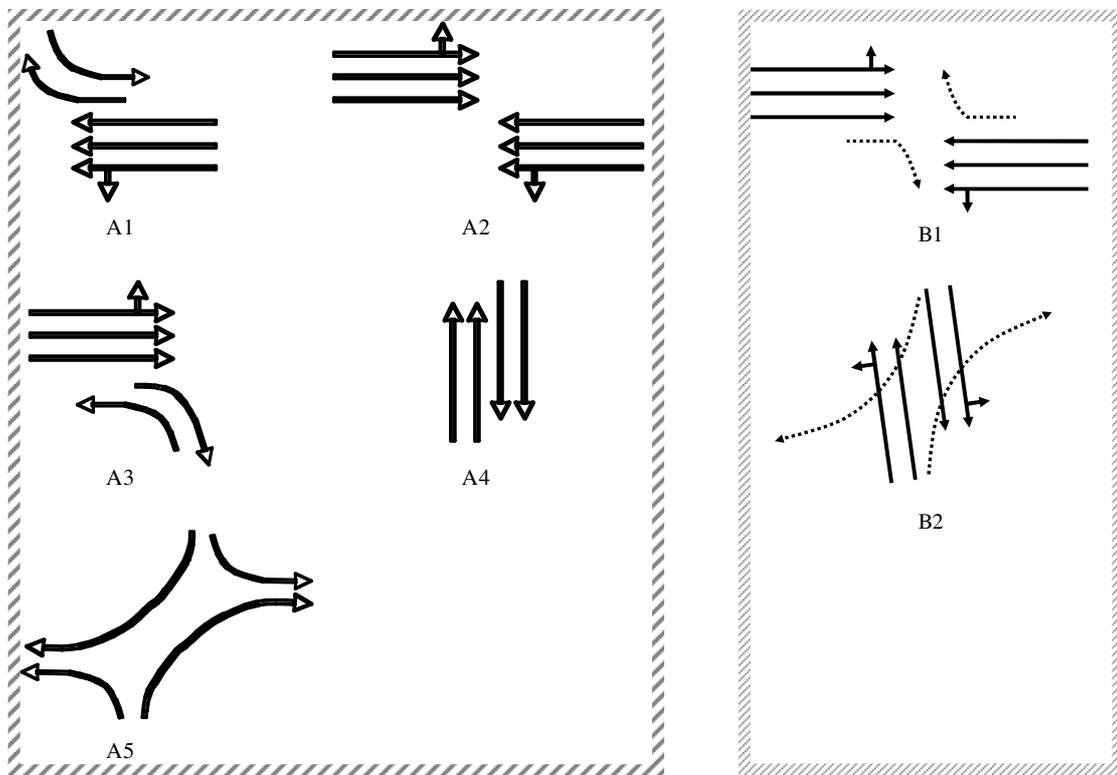


Figure 2 Phase diagrams for intersections A and B. Dotted lines represent opposed flows.

We can now examine the effect of coordination using simulation. *Commuter* version 2.05 (Azalient, 2010) was used to simulate three scenarios:

- Control parameters for independent operation, calculated using Webster’s method
- Control parameters for independent operation, calculated using Webster’s method with double cycling at B
- Control parameters for coordinated operation, calculated using TRANSYT.

Five independent simulation runs of length 90 (simulated) minutes were used for each scenario.

The results of these runs are presented in Table 1. In summary

- Compared to Webster ideal isolated settings, coordination reduces vehicle delay by 19%, and vehicle stops by 2.4%
- Signal coordination using double-cycling at B reduces delay by 30%.. However this delay is at the cost of a 2% increase in vehicle stops

This demonstrates that even in situations where isolated cycle times are quite different, coordination can produce benefit, both in terms of vehicle delay, and vehicle stops. We would expect this to flow on to benefits in reduced green-house gas emissions.

Table 1 Performance comparison between selected signal timings, averaged over all vehicles

	Webster	Coordinated with B Double-cycled	Coordinated
Average speed (km/h)	14.61	18.46	16.80
Vehicle delay (s/v)	53.90	37.69	43.69
Stops	3782	3851	3657

Research questions

The main direction for our research is to develop methods that can identify intersections that would benefit from being coordination, particularly the type of “forced” coordination that may not be currently used. The methods must use only the information already available to SCATS. Presently, SCATS most often uses detectors placed at the stop-line to gather input for its adaptive operation, and so the methods must work principally with that data.

A particular challenge is that stop-line detectors do not provide direct information on the elements of our objective function (1). NICTA must therefore look at surrogate measures for delay and stops, or other markers that will indicate whether a particular intervention will have a positive or negative effect on the objective value.

NICTA is particularly interested in looking at the effect of forced coordination during times of rising traffic demand as the network moves toward peak traffic load. The traffic load at an intersection changes over time, and SCATS adapts to this change in demand by changing the basic traffic control parameters – the phasing, cycle time, phase splits and offsets. We would expect the changes discussed here to have a positive effect in this situation also, linking intersections earlier than may have been done otherwise.

Conclusions

This paper has outlined the research program being undertaken between NICTA and the RTA to respond to the questions raised by increasing traffic demand in cities, and the consequent load on infrastructure, and on the environment. We have outlined the research questions we wish to pursue.

We have also looked at one particular question – that of coordination, and shown that coordination may be desirable, even when desired cycle lengths of neighbouring intersections may be dissimilar. We examined an example which is at an extreme end of the spectrum – intersections where the desired (isolated) cycle times differ by a factor of five. Even in this case, forced coordination can yield benefits in terms of reduced stops, and reduced delay.

Acknowledgements

NICTA is funded by the Australian Government as represented by the Department of Broadband, Communications and the Digital Economy and the Australian Research Council through the ICT Centre of Excellence program. Thanks very much to Chen Cai for help in performing the simulations reported here.

Appendix A – Calculation of control parameters.

We introduce the following notations for discussion on traffic signal timings:

- v_i : arrival rate at vehicles/hour for stage i ;
- s_i : saturation departure rate at vehicles/hour for stage i ;
- y_i : traffic intensity for stage i ;
- l_i : lost time for stage i ;
- L : total lost time – $L = \sum l_i$
- λ_i : effective green proportion of cycle time for stage i ;
- g_i : green time split in seconds for stage i ;
- C : cycle time (seconds)

Optimised signal timings for isolated intersection can be calculated using Webster's formula

(Webster, 1957):

$$y_i = \frac{v_i}{s_i}, \quad (2)$$

$$C = \frac{1.5L + 5}{1 - \sum_i y_i}, \quad (3)$$

$$\lambda_i = \frac{y_i(C - L)}{C \sum_i y_i}, \quad (4)$$

$$g_i = \lambda_i C. \quad (5)$$

Table 2 Calculation of isolated green times and cycle times (in seconds) for intersection A and B using Webster's formula..

	v_i		s_i		y_i		l_i		λ_i		g_i			
	A	B	A	B	A	B	A	B	A	B	A	B		
Phase 1	25	723	1000	1440	0.02	0.50	2	2	0.03	0.75	4	19		
2	616	91	1440	1440	0.43	0.06	2	2	0.46	0.09	65	(2) 6*		
3	78		1000		0.078		2		0.084		12			
4	362		1440		0.25		2		0.27		39			
5	78		1000		0.078		2		0.08		12			
											A	B		
											Cycle length (secs)		142	25

Table 3 Coordinated cycle time and green times (in seconds) calculated by TRANSYT version 12.0 for intersections A and B

	A	B Double-cycled	B
1	9	27	61
2	24	8	9
3	8	27 (Phase 1)	
4	21	8 (Phase 2)	
5	8		
<hr/>			
	A	B Double-cycled	B
Cycle length (secs)	142	25	

REFERENCES

- Akçelik R. (1981). "Traffic Signals: Capacity and Timing Analysis". Australian Road Research Board. Research Report ARR No. 123 (1981)
- Azaliient (2010), "Software", Website, Available at <http://azaliient.com/>.
- Chong-White, C., et al. (2008), "NICTA & RTA Partnership for Traffic Control Innovation", Presented at 15th *ITS World Congress* (New York, NY) Dec 2008.
- Colyar J.D. (2001) "An Empirical Study of the Relationships between Macroscopic Traffic Parameters and Vehicle Emissions", Masters thesis, Graduate Faculty of North Carolina State University
- Denis, M.J., P. Cicero-Fernandez, A.M. Winder, J.W. Butler, G. Jesion (1994) "Effects of In-Use Driving Conditions and Vehicle/Engine Operating Parameters on "Off-Cycle" Events: Comparison with Federal Test Procedure Conditions," *Journal of the Air Waste Management Association*, Vol. 44, pp. 531-538
- Geers, D.G., P. Tyler, B. Hengst, E. Huang and D. Quail (2009), "Enhanced Roundabout Metering" Presented at 16th *ITS World Congress* (Stockholm, Sweden) September 2009.
- Geers, D.G. (2010) "Roundabout Metering: Simulation and Reality", ITS World Conference, Busan Korea, October 25-29 2010.
- Kelly, N.A. and P.J. Groblicki (1993) "Real-World Emissions from a Modern Production Vehicle Driven in Los Angeles," *Journal of the Air Waste Management Association*, Vol. 43, pp. 1351-1357
- NICTA (2010), "Smart Transport and Roads" Website, Available at http://www.nicta.com.au/research/projects/smart_transport_and_roads
- RTA (2010) "SCATS", Website, Available at http://www.scats.com.au/product_base_packg_compnts.html.
- Tong, H.Y., W.T. Hung, C.S. Cheung (2000) "On-Road Motor Vehicle Emissions and Fuel Consumption in Urban Driving Conditions," *Journal of the Air Waste Management Association*, Vol. 50, pp. 543-554
- TRL Software (2010) "TRL Software | Products | Traffic and Network | TRANSYT", Website, Available at <http://www.trlsoftware.co.uk/products/detail.asp?aid=4&c=2&pid=66>
- Webster, F.V. (1957). Traffic signal settings, *Road Research Technical Paper*, No.39, Road Research Laboratory, London.
- Robertson, D.I. (1969). TRANSYT: a traffic network study tool. Report LR253, Road Research Laboratory, Ministry of Transport, Crowthorne, Berkshire.