ENHANCED ROUNDABOUT METERING

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ABSTRACT
Roundabouts are widely used traffic control measures that function particularly well under balanced, light-to-medium approach traffic flows. However, even moderate flow imbalance can cause disruption and lengthy delays. One solution is to meter traffic on one or more of the approaches to increase both the entry capacity of the roundabout and reduce delay. In this paper the early-stages of a joint project between NICTA and the Roads and Traffic Authority of New South Wales (RTA) to develop novel control methodologies for roundabout metering are discussed, some preliminary results presented and future plans outlined.

KEYWORDS
Roundabout, Traffic, Metering, Control, Signals, Hidden Markov Model

INTRODUCTION
Modern roundabouts that use the yield (give way) control rule are known to cease operating effectively when there are widely disparate traffic flows on conflicting arms \cite{1}. Even a modest amount of circulating traffic can cause problems. The standard solution is to meter the roundabout so that up-stream detector occupancy on one arm (the control arm) causes a red (stop) signal to be applied to the conflicting (metered) arm thereby allowing the queue on the occluded (control) arm to (partially) discharge. The installed signals usually only display yellow and red and are frequently augmented with illuminated message boards that inform motorists whether the roundabout is operating normally or is being metered. Such signalisation can significantly increase the entry capacity of a roundabout and reduce delay \cite{2}.

In this paper we discuss a joint project undertaken by NICTA and the Roads and Traffic Authority of New South Wales Roads (RTA) aimed at developing a more efficient roundabout metering system.
THE YALLAH ROUNDABOUT
The work described below concerns the performance of the Yallah roundabout which is located at the intersection of the Princes and Illawarra Highways some eighty kilometres south of the city of Sydney, Australia (and just south of the major industrial centre of Port Kembla). An aerial photograph of the site is shown in Figure 1 above. For the following discussions it is useful to keep in mind that Australian’s drive on the left.

The northern approach is divided so that southbound through traffic does not enter the roundabout. However, all northbound traffic passes through the roundabout. A signalised junction under SCATS control is located approximately one kilometre south of the roundabout. Before roundabout metering was deployed, vehicle queues frequently extended beyond the signals on the southern approach and for a significant distance on the western approach.

The traffic problems, illustrated in Figure 1, are easily stated:

• In the morning peak (blue, solid lines in Figure 1) northbound through traffic on the Princes Highway blocks left turning traffic from the Illawarra Highway
• In the afternoon peak (red, dashed lines in Figure 1) vehicles turning right from the Princes Highway into the Illawarra Highway block northbound through traffic on the Princes Highway

Additionally, the northern approach to the roundabout permits vehicle speeds of 70 km/h and so queuing back from the roundabout in the northerly direction is a safety hazard and must be mitigated.
Considerable delay is also experienced on weekends and vacations due to people travelling to and from holiday destinations on the NSW South Coast.

ROUNDABOUT METERING
In line with the signalisation methodology recounted in the Introduction, inductive loops were installed approximately 100-150m back from the roundabout entry lines on the three approaches. The signals (installed on the northern and southern approaches only) and associated stop lines are approximately 20m back from the roundabout entry lines. The signals are fully actuated and only operate when needed.

The control uses three phases:
Phase A: all off—roundabout operating
Phase B: north red
Phase C: south red

Vehicle presence on the northern approach loops calls phase A (safety constraint)
Vehicle presence on the southern approach loops calls phase B
Vehicle presence on the western approach loops calls phase C

Transitions between all phases are allowed. Calls to phase A override all other calls.

The maximum permitted red time is 50 seconds on the northern approach (phase B) and 45 seconds on the southern approach (phase C) respectively. When no demands are present no signals are displayed and roundabout rules apply.

ENHANCED ROUNDABOUT METERING
NICTA and the RTA are collaborating on the Smart Transport and Roads Project (STaR) which is a major element of NICTA’s research and development effort in Intelligent Transport Systems. One aim of this project is to exploit low cost sensor and constraint programming technologies to deliver model-based control for greater traffic efficiency. The aim is to achieve a significant and measurable reduction in delays and vehicle stoppages over and above current adaptive traffic control systems [3]. In particular, for the signalised Yallah roundabout, the objective is to reduce delay even further than that achieved using loop detector presence measures under the basic control strategy above. The initial goal is to realise greater than 5% improvement in roundabout performance compared with conventional metering.

Existing signal control is generally limited by two factors. Firstly, controllers usually have a poor understanding of the traffic situation. The expense of reliable sensors and adequate computing resources has previously made real-time situation awareness prohibitive. Secondly, computing resources have been constrained, limiting control to simple reactive adaptive strategies.

Under the STaR Project, NICTA and the RTA are investigating more advanced model-based proactive controllers. These controllers ideally have full knowledge of the relevant traffic situation and can proactively switch lights by predicting and evaluating the outcome of various future scenarios. Situation awareness is developed using Bayesian filtering techniques, data-fusing multi-modal sensor observations into a coherent estimate of the traffic state. Near-optimal control is actuated using
principles of Markov decision processes and real-time receding horizon planning. These enhanced control strategies are being implemented for the Yallah roundabout test-bed in three stages.

**Stage I**

The emphasis in Stage I is on the implementation and testing of a complete integrated system that is able to piggyback on and use the failsafe functions of the existing RTA controller. For this stage, traffic state estimation is restricted to estimating queue length on the roundabout approaches using a hidden Markov model (HMM). Queue length observation updates are derived from the existing inductive loop detectors using techniques developed at NICTA by building on [4]. Process updates to the model are based on estimated inflows and outflows. Figure 2 shows a snapshot of a Paramics micro-simulation of the Yallah roundabout with the queue-length distributions on each of the approach lanes shown in the inset.

![Figure 2: Micro-simulation of the Yallah roundabout. Queue-length distributions on each of the approaches are shown in the inset — queue-length vs probability](image)

The exploitation of existing sensors in conjunction with HMM Bayesian filtering provides a real-time estimate of queue length distributions. This is a better estimate of traffic state than that achieved by just triggering presence at loop detector locations. The controller for stage I is a parameterised timed automata that can take advantage of the queue-length output from the HMM. The basic operational features of the automata are shown in Figure 3. Switching between phases occurs when the estimated queue length on the control arm exceeds a predetermined threshold. It would be conceivable to vary the threshold dynamically based on measured traffic flow and such enhanced control, which also utilises no additional sensor infrastructure, will be considered in the future.
Stage II
The accuracy of the queue length estimation can be increased by fusing the data from the inductive loops with that obtained from eight video cameras that have been installed on-site. The main purpose of Stage II is to gain confidence in our video systems and to understand the benefits in sensing accuracy that can be gained from data fusion.

Figure 3: Stage I enhanced control strategy based on probabilistic queue lengths

Stage III
Once the total system is demonstrated successfully on the real roundabout, stage III will enhance the estimation of the traffic state with enhanced observation updates from the video cameras. Instead of just tracking queue-lengths, the traffic model will track individual vehicles as they enter and leave the roundabout. The curb-side controller uses a micro-simulation based model to estimate the traffic state and receding horizon informed search to find near-optimal control policies.

The HMM enhanced control solutions have wider application in situations where knowledge of queue-length is important for improving traffic flow or for safety reasons. Applications include freeway ramps, turn-bays and tunnels. Stage II traffic state estimation and proactive control can be applied to all signalised intersections and has been demonstrated in simulation to show reductions in delays of up to 80% over conventional adaptive traffic control strategies.

Simulation
Simulation of the roundabout was carried out with (Quadstone) Paramics [5] using a plan-accurate model as the basis for computing the performance of the system under different traffic loads and control regimes. Traffic flow data was provided by the RTA.

In order to ease the transition from simulation to real-world deployment it was decided that the simulation system should be as close to the deployed system as possible. The RTA maintains a software emulation of their kerbside controllers called
WinTraff and this is readily interfaced to Paramics. Loop data was extracted directly from Paramics and transformed into hardware detector card serial format. NICTA control signals were injected by intercepting and modifying the network stream connection between WinTraff and Paramics. Using similar techniques the reported signal phase data was extracted. By making this effort only minimal changes are required when moving NICTA control software from simulation to hardware deployment. More will be said on this matter below.

Three scenarios were considered:
1. Normal roundabout operation (red, dashed)
2. RTA signalised roundabout (blue, solid and dashed)
3. NICTA signalised roundabout (green, solid)

The colours and line styles refer to those in Figure 4(a) and (b) below.

The input traffic demand profiles were provided by the RTA and were based on forward projections from a pre-signalisation traffic survey. The peak traffic flows used in the simulation for the
- morning peak: 420 vehicles/hr from the north (U-turn allowed), 2070 vehicles/hr from the south and 1010 vehicles/hr from the west; and for the
- afternoon peak: 950 vehicles/hr from the north (U-turn allowed), 1630 vehicles/hr from the south and 580 vehicles/hr from the west.

![Figure 4: Roundabout performance comparison](image)

Figure 4 clearly shows the enormous performance gains achieved by signalising the roundabout. It is interesting to note that both the delay and the duration of the peaks are reduced when the roundabout is metered. The reduction in duration of the peak being due to the reduction in vehicle delay: the same number of vehicles can proceed through the roundabout in less time. The performance improvement in the PM peak is probably greater than that shown because the queue lengths generated extend back to beyond the point where cars are injected into the simulation.
The ‘combing’ on the graphs in Figure 4 is due to the cars on the Southern approach being modulated by a set of fixed-time signals located approximately one kilometre south of the roundabout.

Figure 4(b) shows a modest, but still significant, reduction in delay—7% over the full simulation period—that can be made by using estimated queue lengths instead of detector presence for switching between phases. However, these gains were achieved using only software changes which could be implemented on the controller hardware.

HARDWARE
The RTA isolates NICTA equipment from direct control of the traffic signals by providing a phase demand interface to existing kerbside controller hardware. In this way all safety constraints are maintained by the RTA. Of course, the ultimate failsafe is afforded by falling back to basic roundabout operation. It should be noted that the hardware interface is fully emulated in the software simulation described above. Thus when moving from simulation to kerbside hardware only the hardware I/O software modules need to be changed which makes software verification relatively straightforward.

Hardware System Architecture
In order to produce a system that is easily expandable a novel distributed all IP based architecture was adopted. Loop data is converted to an IP stream using a Moxa NPort5210 Serial (to IP) Server. Current light status and the phase demand signals are input to and output from a SeaLevel Systems 410E Digital I/O Server. A schematic is shown in Figure 5 below.

Figure 5: Hardware architecture
Each blade comprises an Intel Core2 Quad 2.4 GHz CPU and 2 Gb RAM. Such large computational capacity has been installed to allow easy implementation of control and (video) sensing software for research purposes. The performance of the hardware far exceeds that required for signal control.

CONCLUSION AND FUTURE WORK

It is evident from Figure 4(a) that signalising a roundabout produces an enormous improvement in throughput and a concomitant reduction in vehicle delay and is clearly a useful technique for extending the useable lifetime of the road infrastructure. Figure 4(b) shows that by using the available infrastructure in novel ways it is possible to achieve worthwhile performance gains. Given that avoidable congestion costs an average of 1% GDP in most developed countries even a modest 5% improvement in traffic throughput comes to a substantial saving.

Stage II will necessitate the modelling of video vehicle detection in the simulation framework and it is hoped to extend this work to arbitrary vehicle position and velocity sensor modelling for Stage III. This work will flow through to our work on more general signal control technology.

It is hoped that Stage I will ‘go live’ at the end of August 2009 and that the results of the field trial will be reported in a future ITS World Congress.

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REFERENCES