REAL-TIME ESTIMATION OF TRAVEL TIMES ON ARTERIAL ROADS – THE ARRB TRAVEL TIME MODEL

Paul Bennett and James Luk, ARRB Group Ltd, Australia
Brendan Marsh, Main Roads Western Australia.

ABSTRACT

Provision of travel time has been identified as a key road user support service which assists road authorities to improve network operation strategies and implement control measures. Travel times are commonly estimated for freeways where they are displayed to road users via variable message signs (VMS) but have proved far more difficult to calculate for arterial roads where traffic flow is interrupted. ARRB Group (ARRB) has developed the ARRB Travel Time Model (ATTM) to calculate real-time travel time estimations at link level (between two signalised intersections) using real-time System Monitoring (SM) data retrieved from SCATS. Link travel times are then summed to provide travel time estimates at segment levels (several links) and at route levels (several segments).

The ATTM calculates travel time as the sum of cruise time, uniform delay and overflow delay. Initially developed in 2004 for Melbourne’s Princes Highway East, the model was extended to produce travel times for buses in dedicated bus lanes with signal priority along Melbourne’s Hoddle Street. In 2007 the ATTM was deployed for the Western Australian Reid and Tonkin highways and work is currently underway to extend this ATTM for the Auslink transport corridor from Kewdale to the Port of Fremantle.

This paper describes and reviews the ARRB Travel Time Model for estimating arterial travel times for general traffic. The paper finds that the ARRB Travel Time Model is robust and has improved in its accuracy since its initial deployment (within 30% at link level, 10% at segment level and 5-10% at route level).

To enhance the system, it is recommended that the system’s configuration be automatically established through interrogation of corporate data sets, additional detectors be provided at slip lanes and SCATS Strategic Approaches be allocated for all approach traffic lanes at all intersections.

INTRODUCTION

Congestion in large urban centres has been increasing and the road networks of some capital cities often operate at, or near, oversaturated conditions, presenting problems for both road managers and road users, particularly when traffic incidents or events amplify or cause unexpected congestion. In such conditions, it is critical for road managers to have a clear and up-to-date picture of how the road network is performing in real time. A road manager can then manage the road system more effectively, through changes to incident management plans or signal control strategies and setting appropriate priorities for road improvement projects. The road users also can significantly benefit from real time traveller information enabling journey amendments (e.g. alternative route selection, adjustment of time of travel or alternative travel mode selection).

While live travel times are already displayed on some freeways in Australia and around the world, the estimation of arterial travel times is challenging as the traffic flow is interrupted with traffic signals and other control devices. The ARRB Travel Time Model (ATTM) was developed to help overcome these challenges and has been implemented on servers at VicRoads and Main Roads Western Australia (MRWA). The ATTM retrieves signal data and traffic volume data from SCATS each minute and then applies algorithms to estimate the travel time.

This paper describes and reviews the ATTM, and is focused upon the two most recent applications along major urban transport corridors in the Perth metropolitan area (including Reid...
and Tonkin highways and a major freight route from Kewdale to the Port of Fremantle). The paper outlines the calibration and validation processes and the strengths and weaknesses of the model and makes recommendations for future improvements.

ARRB TRAVEL TIME MODEL (ATTM)

The ARRB Travel Time Model uses algorithms on SCATS data to calculate model travel times at link level; between two signalised intersections. The accuracy at link level is not expected to be high but more accurate travel times are obtained at route and segment levels. (A route has several segments and a segment consists of several links).

The ATTM was developed to meet the challenge of extending the basic theory (Figure 1) to consider cases of non-uniform arrival and oversaturation. The ATTM has the following structure:

\[
\text{Model Travel Time} = (\text{Progression Factor} \times \text{Uniform Delay}) + \text{Overflow Delay} + \text{Model Cruise Time}
\]

This formula states that travel time along a signalised road with other vehicles is made up of three components:

**Uniform Delay** – this is defined as the delay due to traffic arriving at a traffic signal with a uniform distribution. This delay is due to the red phase at a traffic signal. Proper signal coordination improves traffic progression and hence reduces uniform delay, which is given by:

\[
\text{Uniform delay (sec/veh)} = \frac{0.5 \times r^2}{c(1 - \frac{q}{s})}
\]

where \( r \) is the effective red time (sec), \( c \) is the cycle time (sec), \( q \) is traffic flow (veh/sec) and \( s \) is the saturation flow (veh/sec).

**Progression factor** (PF) is in the range 0.0 to 2.5 depending on traffic conditions and how well adjacent signals are coordinated (Highway Capacity Manual of the Transportation Research Board, TRB 2000). If the factor is 0, there is perfect progression. If it is 1, the signal is assumed operating as an isolated intersection.

**Overflow delay** – Traffic seldom arrives uniformly at a traffic signal so it is necessary to consider an extra delay due to random arrivals and oversaturation due to arrival traffic exceeding the capacity (degree of saturation \( x > 1 \)). The overflow delay in Akcelik (1983) is given by:

\[
\text{Overflow delay (sec/veh)} = 0.25 T_p \left[ z + \left( z^2 + 6(x - x_0) / (Q T_p) \right)^{0.5} \right]
\]

where

- \( T_p \) = duration of the analysis period (e.g. \( T_p = 0.25 \) h or 15 min)
- \( q_a \) = arrival flows (veh/h) and \( q_a \) can be less or more than the capacity \( Q \)
- \( Q \) = capacity (veh/h) and equal to \( s g / c \)
- \( x \) = degree of saturation, \( x = \text{arrival flow} / \text{capacity} = q_a / Q \)
- \( x_0 \) = degree of saturation below which the traffic delay is zero and speed equals free-flow speed
- \( z \) = \( (x - 1) \).

**Cruise time** – This is the travel time less stopped delay on a link. It is dependent on traffic and road geometric conditions. Cruise times should be calibrated for each link. A link cruise time increases with congestion due to more vehicle-to-vehicle interactions.
**DS in SCATS** – The DS value in SCATS is a measurement of how well a green time period is utilised and is available cycle-by-cycle. It is not identical with the x-value in the traditional sense of the degree of saturation over a time period of, say, 15 min. It does correlate quite well with x in undersaturated conditions. DS is structured also to indicate oversaturated conditions at x > 1. The definition of DS is as follows:

\[
\text{DS} \, (\%) = \left( \frac{\text{GT} - S_{\text{act}} + n \times S_{\text{MF}}}{} \right) \times 100\% / \text{GT}
\]

where GT is the green period (sec); S_{act} is the total space time in that green period (sec); n is the number of spaces counted; and S_{MF} is the space time at saturation or Maximum Flow (MF, veh/sec). DS can exceed 100% through the choice of an appropriate loop length (about 4.5 m) and when S_{act} < n \times S_{MF}. DS is also used to estimate the traffic volume when oversaturation occurs (the *reconstituted* volume, V_k) as follows:

\[
V_k = \text{DS} \times \text{GT} \times \text{MF} \quad \text{(veh)}
\]

For example, if DS = 105%, GT = 50 s and MF = 1720 veh/h, then V_k = 25 veh, which will be more than the actual counts because a DS of 105% would imply that vehicles are not moving well in the green phase for this lane. The reconstituted volume represents the real traffic demand in oversaturation conditions, i.e. what the volume could have been if there is enough road capacity. It is used together with DS in ATTM to estimate oversaturation delay.

**Delay time**

The ATTM produces delay times at link, segment and route level. The link delay time (DT_{link}) is defined as the time difference between the model travel time and travel time at the speed limit for the link. The link delay time is calculated using the following formula:

\[
\text{ATTM} \, DT_{\text{link}} = \text{ATTM travel time} - \text{Speed limit travel time}
\]

**Queue length**

Queue length for each link (QL_{link}) is calculated as the total number of queuing vehicles at an intersection. The queue length for segment and route (QL_{seg/route}) are calculated as flow weighted averages. The queue length is calculated using the following formula:

\[
Q_{L_{\text{seg/route}}} = \sum_{i=1}^{n} \frac{l_{i}}{q_{i}} \times Q_{L_{\text{link}}}
\]

where

- \( r \) = the effective red time (sec)
- \( q_a \) = arrival flows (veh/h)
- \( Q \) = capacity (veh/h).

**TRAVEL TIME STUDIES ON ARTERIAL ROADS**

The first travel time studies were funded by VicRoads with the first application of the ATTM carried out on Princes Highway East in Melbourne (Karl et al 2004). The model was then applied to Hoddle Street/Nepean Highway and Springvale Road (Luk et al 2005). It was extended further for estimating bus travel times on Hoddle Street and Victoria Parade (Su et al. 2006). This study calculated travel times for both cars and buses during peak periods, when buses are given dedicated lanes and signal priority, and outside of those periods when buses share these lanes with the general traffic.
In 2008 Main Roads Western Australia funded a study which now provides travel time estimations along the Reid and Tonkin highways. A further study is now being conducted to provide travel time estimations from Kewdale to the Port of Fremantle, beginning on the Tonkin Highway and following a route along the Leach Highway, Stirling Highway and Tydeman Road.

**Calibrating the Model**

The general methodology used to calibrate the model for each route was to plot the model travel times against observed travel times. Thus the initial step in this process is to survey the route in ‘floating’ cars. The term ‘floating’ refers to the method used to stay within a platoon of vehicles when driving along a route. That is, to avoid driving too aggressively or passively to ensure mean travel times are obtained.

Each survey vehicle would drive the route in both directions as many times as possible within the three survey periods; AM (7-9 am), Business (11am-1pm) and PM(4-6 pm). In addition to the driver, a person in the front passenger seat would control two stop watches. The first stop watch was used to measure travel times, recording the progressive time as the car passed through each intersection. The second stop watch was used to time delay within each link. It would be started whenever travel speed dropped below 5 km/h then stopped the moment travel speed exceeded 15 km/h.

System Monitor (SM) data was collected for each region along the survey route for the days surveys were conducted. This SM data contained records from each Traffic Control Signal’s (TCS) cycles over the entire 24 hours of each day. This SM data included signal cycle times (CL) and the green phase times (PT), traffic volumes (Vol) and average degrees of saturation (ADS) for each strategic approach.

Spread sheets were then created for the purpose of calibration. Each spreadsheet was used to calibrate the model based on a particular survey in one direction. These spreadsheets listed the intersection names in the order of the direction calibrated. They then listed the length of each link and the progressive distance of the route. From the survey start time and recorded progressive time through each intersection, the time the survey vehicle passed through each intersection was also added to the spreadsheet. From this, a chart of observed travel time versus distance was plotted.

SM data for the TCS cycles during, or as close to, the minute the survey vehicle passed through each intersection were then copied into the spreadsheet along side the observed travel times. These recorded CL, PT, Vol and ADS values were then used in the calculation of model travel times for each link which were then plotted on the same charts as the observed travel times.

A minimum of twelve charts were created for calibration; two for each direction and survey period (inbound; AM, business, PM and outbound; AM, business, PM).

Generally it was observed that the model either over or under-estimated the travel times when compared to the observed times. In most cases the model also did not pick up excessive delay were experienced by the survey vehicle. Where such discrepancies were found to consistently occur, only two parameters where changed to calibrate the model; the period of flow and the progression factor.

**Validation**

The final step is to run the calibrated model with SCATS data and compare the model travel time estimation with the observed travel times. A further three survey runs were used for model validation. Figures 2, 3 and 4 show the results of the Port of Fremantle to Kewdale (eastbound) AM, business and PM trips. As can be seen in Table 1, the validated ATTM travel times are in close alignment with the observed travel times. The correlation coefficient (R) and coefficient of determination (R²) are over 0.9 at route level, which indicates a high degree of linear statistical relation between the model travel times and the observed travel times.
### Table 1: Comparison between observed and modelled travel times

<table>
<thead>
<tr>
<th>Route name</th>
<th>Model (M) min</th>
<th>Observed (O) min</th>
<th>Difference (M-O) min</th>
<th>% difference (M-O)/O %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kewdale-Fremantle AM</td>
<td>36:39</td>
<td>35:34</td>
<td>1:05</td>
<td>3.05%</td>
</tr>
<tr>
<td>Kewdale-Fremantle BIZ</td>
<td>37:57</td>
<td>37:00</td>
<td>0:57</td>
<td>2.57%</td>
</tr>
<tr>
<td>Kewdale-Fremantle PM</td>
<td>43:04</td>
<td>41:22</td>
<td>1:42</td>
<td>4.11%</td>
</tr>
<tr>
<td>Fremantle-Kewdale AM</td>
<td>41:12</td>
<td>42:52</td>
<td>-1:40</td>
<td>-3.89%</td>
</tr>
<tr>
<td>Fremantle-Kewdale BIZ</td>
<td>32:42</td>
<td>32:23</td>
<td>0:19</td>
<td>0.98%</td>
</tr>
<tr>
<td>Fremantle-Kewdale PM</td>
<td>40:32</td>
<td>41:00</td>
<td>-0:28</td>
<td>-1.14%</td>
</tr>
<tr>
<td>Mean difference</td>
<td>0:19</td>
<td></td>
<td></td>
<td>0.95%</td>
</tr>
<tr>
<td>Standard deviation</td>
<td></td>
<td></td>
<td></td>
<td>2.99%</td>
</tr>
<tr>
<td>95% confidence intervals</td>
<td></td>
<td></td>
<td></td>
<td>± 3%</td>
</tr>
<tr>
<td>Correlation coefficient (R)</td>
<td></td>
<td></td>
<td></td>
<td>0.95</td>
</tr>
<tr>
<td>Coefficient of determination (R²)</td>
<td></td>
<td></td>
<td></td>
<td>0.91</td>
</tr>
</tbody>
</table>

### The ATTM Program

The ATTM programs are written in the programming language ‘C’. Each program has specific parameters for its route, such as maximum flows and minimum and mean cruise times. Further modifications include the adjusting of some parameters used in the travel time calculations in accordance with the calibration carried out for the specific route.

Whereas earlier models only estimated travel times in both directions, the Perth arterial model also estimates delay times and queue lengths. Travel times, delay times and queue lengths are calculated in both directions at the link level. Link travel and delay times are then summed to give travel and delay times for each segment and the entire route in each direction. Weighted average queue lengths are given for each segment and the entire route.

All travel times, delay times and queue lengths that are written to the output text files are smoothed over three minutes;

\[
\text{Smoothed travel time} = 0.5 \times \text{min (now)} + 0.3 \times \text{min (prev1)} + 0.2 \times \text{min (prev2)}
\]

where prev 1 is the min before the present min and prev2 is the min before prev1

The input SCATS data files which the ATTM programs read are identified by date-time stamped filenames. These input files are created by Advantech’s System Monitoring program on the 00 second mark of each minute. To ensure synchronicity, the ATTM program also uses the system clock to read these files at precisely the 30 second mark of each minute. (Refer to Figure 5 for ATTM flow diagram.)

An output text file is produced every minute and is saved to the folder 'OUTFILES' within the ARRB folder. It is named after the date-time it was created; 'MTTYMDD_hhmm.txt' where Y = year, M = month, D = day, h = hour and m = minute. All these output files are retained for at least one month to allow for historic data examination.

The ATTM programs were tested before implementation using SM data files obtained for every minute of the survey days. Figures 6 shows a chart of 24 hour travel times from Kewdale to the Port of Fremantle as calculated by the ATTM program using SM data from Thursday 12th June. Figure 7 shows a similar 24 hour travel time chart for the same day but travelling in the reverse direction from the Port of Fremantle to Kewdale.

### System Architecture

To successfully read SCATS data and compute model travel times, delay times and queue lengths, the ATTM was interfaced with the Advantech System Monitor (SM) reporter program. Developed by Advantech Design, the software development company subcontracted by ARRB.
for these projects, this program consists of two main modules. The first, known as the Advantech SM interface, supplies SCATS data to the ARRB ATTM. The second, known as the Advantech VMS interface, reads and forwards travel time data from the ATTM to a VMS interface.

The Advantech SM reporter program maintains a configuration database. It automatically extracts SA, DS, Vol. VK from the SCATS SM and formats and sends the required data to the ARRB ATTM. This dataset includes data such as subsystem number SS, strategic approach SA, time of day, cycle time CL, volume Vo and Vk, green time PT and degree of saturation DS. Following the generation of the travel time data from the ATTM, the Advantech SM reporter reads the travel time outputs and formats the travel time data into XML packages for onward transmission. These XML packages can be sent to a VMS interface via the TCP/IP network.

This system architecture has successfully been integrated to produce travel times for Hoddle Street in Melbourne. A depiction of the system architecture is provided in Figure 8.

THE PERTH TRAVEL TIME MODELS

In 2007 the Reid Hwy and Tonkin Hwy were chosen by MRWA for development of the first Perth travel time model. Reid Hwy has a length of 14 km and 9 intersections from Marmion Ave in the west to Tonkin Hwy in the east. Tonkin Hwy has a length of 21 km and 9 intersections from Reid Hwy in the north to Kelvin Rd in the south (Figure 9). The route connects the northwest residential areas to the northeast industrial distribution centres and Perth's domestic and international airport in the east.

Following the successful implementation of the Reid Hwy-Tonkin Hwy ATTM on a server at MRWA, a second route was chosen for estimation of model travel times by MRWA. This second route, from Kewdale to the Port of Fremantle, runs East-West and is a major urban freight transport corridor between the distribution centres and airports in the east and the Fremantle Port in the west. (Figure 10)

Located south of the Perth CBD, it begins on the Tonkin Hwy at the Roe Hwy underpass and thus partially overlaps the Reid Hwy-Tonkin Hwy route which runs to the north and east of the CBD. Travelling 3.7 km north-west along the Tonkin Hwy, it then turns into Leach Hwy. Moving south-west, the route covers the entire length of the Leach Hwy which becomes High Street; a total distance of 22.1 km. From High Street it turns north-west along the Stirling Hwy for 1.9 km then west along Tydeman Road for a further 1 km. At the Port of Fremantle it then turns south-west into Port Beach Road where the route ends approximately 200 metres past the Tydeman Road intersection.

Strategic approaches with no detectors

The Kewdale to Port of Fremantle route takes a number of turns. Three of the left turns are through give-way slip lanes; two in the westbound direction and one in the eastbound direction (Table 2).

<table>
<thead>
<tr>
<th>Intersection</th>
<th>Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tonkin Hwy/Leach Hwy</td>
<td>Westbound</td>
</tr>
<tr>
<td>Tydeman Rd/Port Beach Rd</td>
<td>Westbound</td>
</tr>
<tr>
<td>Stirling Hwy/High St</td>
<td>Eastbound</td>
</tr>
</tbody>
</table>

All three of these left turn slip lanes have no detector or traffic signals. Thus for the links from the intersections prior to these left turn intersections, the travel times, delay times and queue lengths are based on estimated cruise times and delay times. These variable delay times were
estimates of the sum of uniform and overflow delays encountered during peak and off-peak periods.

The two intersections of Tydeman Rd/Napier Rd and Leach Hwy/Centenary Ave have no signals in the eastbound direction. For the eastbound links approaching these intersections, model travel time is simply based on the cruise time for the time of day. With no signals to stop eastbound traffic at these intersections, queue lengths were assumed to be zero.

The lack of detectors at “left turn slip lanes”, that required estimated travel times, delay times and queue lengths (for peak and off-peak periods), compromises the accuracy of the model as traffic is interrupted to varying degree at these facilities. It is recommended that detectors be installed at all left turn slip lanes as a part of standard practice.

It is also noted that it is possible to install detectors just to count vehicle numbers and enable presence based signal phase request within the SCATS system. Such detectors do not provide sufficient information for travel time estimation. It is, therefore, also important that all traffic signal detectors be allocated with a Strategic Approach traffic lane allocation as a part of standard practice.

MODEL STRENGTHS AND WEAKNESSES

The algorithms behind the model are based on sound traffic engineering theory and traffic signal modelling and each implementation of the model has produced further refinements to improve the system’s accuracy. This is increasingly providing an accurate outcome in near real time in a manner that is less cost and labour intensive than the traditional floating-car technique of measuring travel times.

The model’s ability to calculate minute-by-minute estimations of travel times at link level makes the system responsive to fluctuations in congestion delays. However, the system is based upon the SCATS Strategic Monitor data set, which is recorded at the completion of each traffic signal cycle, causing a short delay.

The travel time experienced by vehicles at the link level has significant variation from the calculated travel time because vehicles experience differing delays depending on whether they are travelling at the start, middle or end of the traffic signal cycle. Greater accuracy is achieved at the segment and route levels as the fluctuations tend to even out over the entire journey.

The ATTM approach is generally known as an **elemental approach** – each link or element is considered in detail and is calibrated individually where necessary. This is both a strength and weakness because it takes more effort to calibrate and at the same time allows a detailed level of calibration and hence accuracy. More importantly, the elemental approach is the only approach that allows average queue lengths to be estimated. Other approaches such as floating-car travel times by automatic vehicle identification can only provide travel times. These travel times are also usually calibrated at a segment or route level, implying that all performance metrics at a link level are not calibrated; conceptually this is a less accurate method than the elemental approach.

The ATTM is very flexible and can be used for any movement at an intersection where there is detector information. Obviously, for links with no detectors such as left-turn slip lanes, travel times, delay and queue lengths will not be available. Therefore, it is recommended that detectors, with Strategic Approach lane allocations, be installed at all left-turn slip lanes as a standard practice. Other locations where emulated SCATS Strategic Approaches can be implemented are at pedestrian operated signals and before a railway level crossing – the extra detectors will provide more information for travel times and queue length estimation (Luk 2007, Luk et al. 2006).

At present, the ATTM is implemented through a special interface to SCATS. As a system solution, this implementation method is unsustainable in the long-term. It will have to be implemented in the Intelligent Network platform currently investigated by Main Roads WA.
FUTURE DEVELOPMENT AND EVALUATION OF INTELLIGENT TRANSPORT SYSTEMS FOR THE PERTH URBAN CORRIDOR

A high percentage of heavy vehicles travel along the Perth Urban Corridor (PUC) from Kewdale to the Port of Fremantle. The provision of travel time information along this route is a first step for improving freight transport outcomes through this corridor applying Intelligent Transport Systems (ITS).

A weakness of the existing ATTM system is that it is currently independent of corporate systems, unsupported operationally and prone to road network and SCATS system changes. It is, therefore, recommended that an automated bridging system between SCATS, Main Roads’ corporate Integrated Road Information System (IRIS) be developed.

The automated bridging system would provide the added benefit that all approaches may be considered, enabling a network view of the road network to be established. However, the automated bridging system would be limited by the number of traffic signal approaches equipped with ‘Strategic Approach’ data collection capability (the source of the travel time estimation information). To overcome this issue, it is recommended that Strategic Approaches be allocated to all traffic signal detectors within the SCATS system.

Another weakness of the existing ATTM system is that it requires manual calibration. It is, therefore, recommended that a process for automated calibration be developed based upon available floating vehicle data. This would enable the ATTM system to be applied to any road network for lower initial setup cost.

CONCLUDING REMARKS

This paper has demonstrated the feasibility of utilising traffic data from a signal system for the purpose of monitoring the performance of a road network. Through the processing of traffic signal strategic approach data, information meaningful to both road managers and road users such as travel times, delays and queue length can be determined.

The ability to produce seven day, 24-hour performance information based upon traffic signal strategic approach data provides a solid foundation on which other types of data (e.g. from tagged vehicles) can be added or fused to improve information accuracy and network operational performance of the road network.

The ATTM approach aims to give accurate minute-by-minute indication of network performance and thus requires strategic approach data to be available from appropriately located detectors in a road network. The logic algorithms behind the ATTM have proven to work in practice in all implementations of the model.

It was identified that the ATTM applied in Main Roads WA in its current form is unsustainable due to the requirement for manual configuration and calibration of the system. It is recommended that the next phase of this work be to develop capability to overcome these limitations including automated system configuration based upon corporate data sets and integration of floating vehicle data sets to automate system calibration. The outcome would also be enhanced by the inclusion of supplementary strategic approach vehicle detectors on all traffic signal intersection approach traffic lanes.

ACKNOWLEDGEMENTS

The arterial travel time projects in the period 2004-2006 were funded by VicRoads while the Perth arterial travel time projects in the period 2007-2008 were funded by MRWA. The support and comments from many VicRoads and MRWA staff are much appreciated.
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**BIOGRAPHY OF PRESENTING AUTHOR**

Paul Bennett joined ARRB in 2004. He has an Advanced Diploma in Business Systems and is currently undertaking a Masters in Information Technology at Swinburne University in Melbourne. He has been involved with the ARRB Travel Time Model since its first inception on the Princes Highway in 2004, coding the software programs for all versions of the model. Initially involved in the floating car surveys, Paul has now been involved in all aspects of this work, including calibration and validation, and is currently leading the Kewdale to Port of Fremantle travel time project. Having a keen interest in ITS, Paul will be heavily involved in the evaluation of ITS solutions for the Perth Urban Corridor, which marks the next phase of this work. His work at ARRB also includes GIS, database analysis and microsimulation.

(Email: paul.bennett@arrb.com.au)

**SUPPORTING AUTHORS**

Dr James Luk joined ARRB Group in Melbourne in 1975 and had been seconded to RTA NSW and Queensland Main Roads. He also spent a few years with the Nanyang Technological University (NTU) in Singapore as an Associate Professor and has rejoined ARRB since July 2002. James won the 1992 Best Paper Award at the Road Engineering Association of Asia and Australasia Conference, and the 1996 Best Project Award of the Parking Association of Australia. He is also an Adjunct Professor of La Trobe University.

(Email: james.luk@arrb.com.au)

Brendan Marsh completed a Bachelor of Science (Chemistry) and a Bachelor of Engineering (Civil) at the University of Western Australia in 1998 with first class honours; and a Graduate Certificate in Building and Construction Law at Notre Dame University in 2006. Brendan joined Main Roads Western Australia as an Engineering Cadet in 1995 and has extensive experience in road, bridge and traffic engineering, presently acting in the role Network Performance Manager. Brendan is a member of the Stirling Alliance Leadership Team, a member of the Safe Systems Working Group for New Perth Bunbury Highway, represents Main Roads on several Austroads projects within the Network Program (Strategic) and is a corresponding member on World Road Association (PIARC) Technical Committee C.1, Safer Road Infrastructure. Brendan is the Secretary / Treasurer for the Western Australian Branch of the Road Engineering Association of Asia and Australasia (from 2006) and was the Secretary of the Engineers Australia Central Wheatbelt Group in 2004 and 2005, and a finalist for the 2005 WA Young Engineer of the Year award.

(Email: brendan.marsh@mainroads.wa.gov.au)
FIGURES

Figure 1: Delay and queue formation at a traffic signal

Figure 2: ATTM validation (Fremantle to Kewdale, AM peak)
Figure 3: ATTM validation  (Fremantle to Kewdale, business hours)

Figure 4: ATTM validation  (Fremantle to Kewdale, PM peak)
Figure 5: ATTM flow diagram for a route with n Traffic Control Systems and n - 1 links.

Figure 6: Route travel time - Kewdale to Port of Fremantle - Thursday 12th June 2008
Figure 7: Route travel time - Port of Fremantle to Kewdale - Thursday 12th June 2008

Figure 8: System architecture diagram
Figure 9: The Reid Hwy – Tonkin Hwy route

Figure 10: The Kewdale to Port of Fremantle route