A New Design for an Intelligent Event-responsive Urban Traffic Management System

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1 Introduction

The increased availability of real time traffic information and onboard navigation systems (Iguchi 2002; Miles and Walker 2006) is dramatically changing characteristics of individual vehicles in the traffic stream. Drivers are increasingly capable of making well informed route choice decisions during their journeys in attempts to minimise their travel costs. In order to tackle urban traffic congestion problems in the fast approaching information society, the prevalent concept for traffic control system development, which treats traffic as simple stream with stochastic features and focuses on the supply side of the equation (Gartner et al. 1991; Hunt et al. 1981; Mirchandani and Head 2001), is becoming inadequate.

This paper presents a new design of intelligent event-responsive urban traffic management system. Our motivation for designing and developing such systems is to seek answers to the following emerging research questions:

- How to enhance the capability of individual signalized intersection to cater for dynamic changing traffic demand generated by well-informed travellers?
- If the intelligence of intersection traffic signal is the key to the above question, then the next challenge would be how to perform effective central intervention in order to achieve traffic network efficiency and deal with incidents without compromising the local intelligence?
- Further more, how to include transport policy dimension into daily traffic management to achieve broader economical, environmental and social objectives rather than traffic specific ones?

The objectives of this new system design include:

- Enhancing the intelligence of individual intersection traffic signal control using evidential reasoning mechanism to cater for dynamic changing traffic demand generated by well-informed travellers,
- Reducing the frequency and improving the reliability of network wide proactive traffic management through fast multi-source transport data analysis,
- Emphasizing self-learning capability of the system, which would guarantee a continual improvement of traffic network performance over the time of system operation.

Here, we use word ***control*** to emphasize the critical role played by traffic signal at intersection level of traffic management. Meanwhile, we think the word ***management*** is more appropriate to describe the network wide traffic balancing action which the proposed system performs in order to improve traffic network performance.

This paper is organised in five sections. Section 2 reviews the state of urban traffic control and management system development, and introduces our new approach to improve urban traffic management. This approach leads to a new design for intelligent event-responsive urban traffic management system which is presented in Section 3. The conceptual system architecture and basic functions of each building block of this system are discussed in this section. Section 4 highlights the current progress of the system development. Finally, conclusions are provided in Section 5.

2 New approach to improve urban traffic management

Following the introduction of the first computer-based traffic signal control systems in the 1960s, the three generations of the urban traffic control systems (UTCS 1-GC ~ 3-GC) developed by the US FHWA (MacGowan and Fullerton 1979-1980) represented the state of the art in traffic signal control in the 1970s. The different UTCS control strategies were designed to provide an increasing degree of traffic responsiveness, with an expectation to capitalise on the variability in traffic flow and to provide an improvement in urban traffic network performance. However, inherent inaccuracies in the measurement-prediction cycle, frequent transition in signal timing, and centralised control strategies and optimisation procedures were among the possible causes of the poor showing of the responsive UTCS strategies (Gartner 1985). A significant advance towards the truly demand-responsive, that is to adapt to actual traffic conditions rather than use predetermined values, was achieved during the 1980s with the introduction of SCOOT (Split Cycle and Offset Optimisation Technique) in UK (Hansen et al. 2000; Hunt et al. 1981), and SCATS (Sydney Coordinated Adaptive Traffic System) in Australia (Hicks and Carter 2000; Lowrie 1982). SCOOT may be considered an advanced UTCS 2-GC strategy, while SCATS can be considered a UTCS 1-GC variant with the ability to generate timing plans on-line.

In November 1991, US FHWA (1991) called for the development and evaluation of a real-time traffic-adaptive signal control system (RT-TRACS). This led to a new framework for advanced traffic control: multilevel (0-LC ~ 5-LC) design (Gartner et al. 1996). In this new framework, each level in the hierarchy of traffic control systems encompasses capabilities of the lower levels in a nested fashion. 1-LC ~ 3-LC traffic control systems correspond to different UTCS control generations (UTCS 1GC ~ 3-GC) with significant differences and enhancements. The 4-LC system focuses on intelligence such as dynamic traffic assignment capability for proactive control and traffic event responsive, and the 5-LC system emphasises the most efficient use of control strategies based on accumulated expertise and experience under local conditions.

The most recent developments of advanced traffic control systems include RHODES (real-time hierarchical optimised distributed effective system) (Head et al. 1992; Mirchandani and Head 2001), ATSAC (Automated Traffic Surveillance and Control) (Rowe 1991), OPAC (Optimisation Policies for Adaptive Control) (Gartner et al. 1991) and UTOPIA (Mauro and Taranto 1990), which represent the evolution of the RT-TRACS systems towards the 4-LC level.

2.1 Problem analysis

As described earlier, the increased availability of real time traffic information and onboard navigation systems is dramatically changing capabilities of individual vehicles in the traffic stream. The conventional network wide traffic optimisation process, which is based on mid-term traffic demand projection, could countermand both the natural traffic balancing in the network initiated by well informed individual travellers, and local optimisation efforts made by individual intersection controllers in order to dynamically respond to real traffic conditions. Such a drawback was found in early UTCS 3-GC system development (Gartner et al. 1996). The worse case would be instability in the traffic network which is introduced by such frequent central intervention. The term ‘driver-vehicle unit (DVU)’ (Quadstone 2000), which emphasises the individual driver’s behaviour in the microscopic traffic simulation context, is more appropriate to describe the current and future vehicle in the traffic stream. This term implies a strong need for the human centred traffic control and management system to perform reliable proactive / event-responsive traffic management, and to improve the efficiency of traffic networks.

Our proposed intelligent event-responsive urban traffic management system is built on the assumption that individual DVUs have the capacity to dynamically make informed route choice to minimise their individual travel costs. This assumption is based on the current fast pace of real time advanced traveller's information systems (ATIS) and onboard navigation system development and deployment (Iguchi 2002; Miles and Walker 2006). The proposed system emphasizes both the intelligence of individual intersection traffic control and the reliability of network wide proactive traffic management. Therefore, it appreciates and makes use of DVU's dynamic route choice to achieve traffic demand balancing in the traffic network.

2.2 Intelligence of intersection signal control

When each intersection signal controller is treated as an electronic police constable standing in the middle of the intersection, it would be easier to appreciate the fact that a good traffic police constable makes decisions there and then based not on existing signal plans, but on what the traffic is doing at that point in time and how that relates to what it did historically. Hence, the intelligence of intersection signal control stems from how expert traffic knowledge (experience) are organized, how current traffic conditions (evidence) are described, and how evidence based reasoning is performed to determine the signal changing point and its duration.

Effective human reasoning relies on a well defined causal structure. In the context of intersection traffic control, basic elements of such causal structure may include traffic parameters (e.g. volume, occupancy), traffic conditions (e.g. congestion, incident), and capacity of intersection (e.g. cycle time, green time for each movement). Given dynamics and uncertainty associated with urban traffic flow, the better way to quantitatively describe cause-effect relations among these elements would be conditional probabilities.

Bayesian networks (Jensen 2001; Pearl 1986), which are causal probabilistic networks, have become a general representation scheme for knowledge of uncertainty since 1980s. To improve the intelligence of intersection traffic signal control in our proposed system, Bayesian networks are used to construct the causal structure and store existing knowledge related to traffic signal operations. Then they are used as a major inference engine to help generating traffic signal plans based on most current traffic conditions.

We tend to use *State* (instead of absolute value) of traffic parameters to describe traffic, such as traffic volume is 'HIGH'. In fact, traffic state is more meaningful because it is the result of traffic data processing based on local knowledge (site specific). Meanwhile, traffic state is more general, which make it easier to be fed into the causal structure and to be used to perform efficient evidential reasoning.

2.3 Reliability of event-responsive traffic management

Reliable event-responsive traffic management at network level is the key to both traffic network efficiency and effective incident responses (Austroads 2007ab). The reliability and feasibility of such traffic management processes depend on multi-source transport data integration and on fast data processing, information extraction, event recognition and decision making. The above processes form basic functions of our proposed central traffic management. Certainly, these functions cannot be performed effectively at intersection level.

The US Transportation Research Board (TRB) has looked at the issue of data standardisation and specifically with relation to freight data (TRB 2003). The cost of integrating existing data sources was recognised as a major concern. According to Australian National Transport Data Working Group (2004):

> 'The universal view of stakeholders was that the establishment of a single consolidated data collection was both unrealistic and undesirable. The preferred model is for a distributed system, with a small central node serving as a gateway to an array of data holdings which will — in the future as now — be dispersed amongst a wide range of data holders. Initially, the shared data set may be limited in its range, reflecting basic data that jurisdictions make available through the system, and to which other users may have open or restricted access. Over time, as confidence in the shared framework builds, users may see value in adding to the shared dataset to meet broader planning objectives.'

From the National Transport Data Framework, we take two primary foci: 1) a distributed environment for data management is preferred, and 2) as time progresses a more centralised repository would become possible. Meanwhile, the deployment of a centrally located computational grid satisfies both the singular database schema requirement and the distribution of data. In developing our proposed singular extendible database schema for multi-source transport data integration, even if specific data is not available, if it is appropriate, then it would be included in the schema.

In order to provide the computational resources required to manage the large volumes of data inherent in transport system, a new generation of hybrid streaming and transactional database management systems and real-time computer system architectures are required. A database management system is the combination of software systems and a computing architecture that allows for quick and efficient access to interrelated data. To query real-time data over a data set of the order of tens of millions of records and extract relevant and useful traffic information, a distributed object-relational database management system is appropriate. Architecturally, the application of parallel computers and algorithms can improve the performance of computationally intensive tasks (Flynn and Rudd 2004).

3 Conceptual architecture of intelligent event-responsive urban traffic management system

The conceptual architecture of our proposed intelligent event-responsive urban traffic management system is shown in Figure 1. This system consists of two integrated subsystems: the intelligent intersection traffic control system and the central traffic management system.

3.1 Intelligent intersection traffic control

At the core of the intersection traffic control subsystem are two distinct features:

1) responding to most current traffic state prevailing at the intersection rather than to the precise past traffic demand measurements (e.g. *SCATS*) or short term future demand projection (e.g. *SCOOT*, *OPAC*, *RHODES*, etc.), which will be supported by current advanced traffic surveillance methods (Nelson 2002), different traffic detector positioning, and the improved availability of real time traffic data (Iguchi 2002);
2) using both evidential reasoning and logic programming to decide traffic signal changing point and phase length instead of searching for the absolute optimal solution for signal settings.

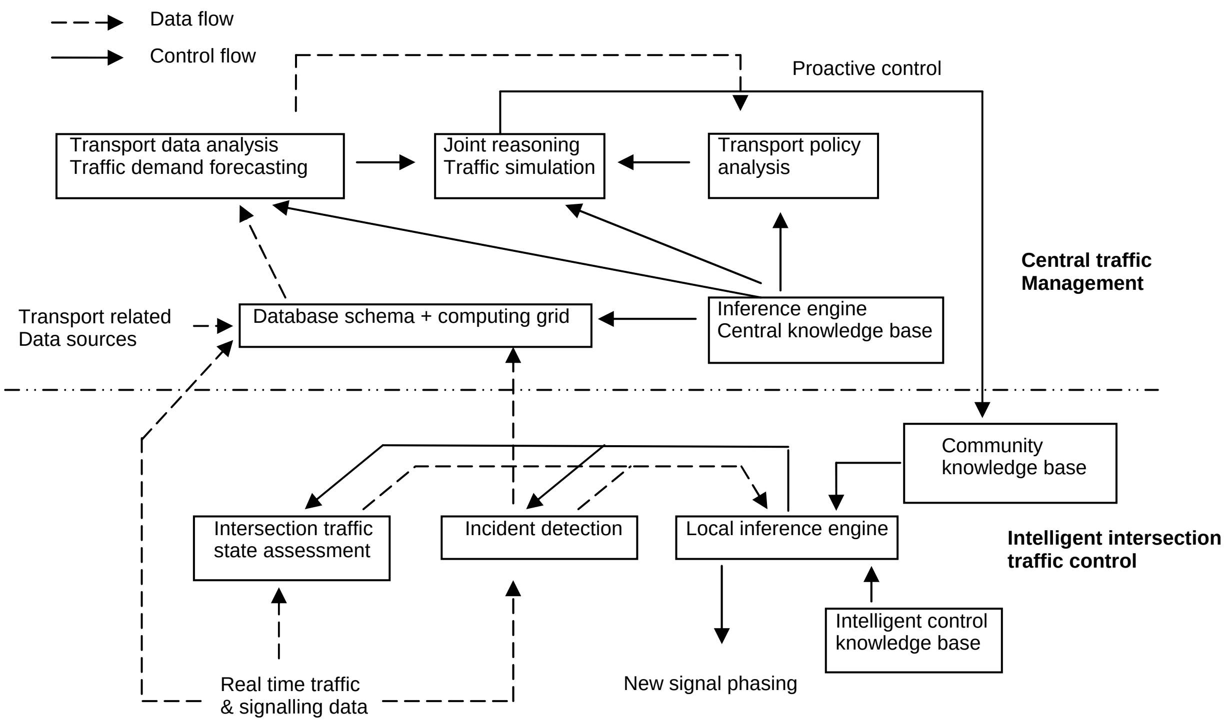

Figure 1 Architecture of the intelligent event-responsive urban traffic management system

In this subsystem, the local inference engine is in charge of intersection traffic state assessment, incident detection and traffic signal settings. The first two tasks are performed through evidence based reasoning. The evidence here refers to both real time traffic measurements and current signal phasing information associated with an intersection. The proposed reasoning tool is a set of Bayesian networks whose key features are detailed in Section 4.

The primary information used to decide new signal phasing are most current traffic states of each approach of the intersection. Felici (2006) suggested that using logic programming to improve traffic signal setting has great potential. Here, logic programming (Truemper 1998) is used cooperatively with the evidential reasoning in the local inference engine to generate new traffic signal phasing. In this way, we could enhance the efficiency of the entire reasoning process by simplifying the knowledge base used by Felici (2006). The incident status, which is first verified by the community knowledgebase and then if necessary by the central traffic management subsystem, helps with the decision on new signal phasing.

The intelligent intersection traffic control subsystem has two separate knowledge bases, the intelligent control knowledge base and the community knowledge base. The intelligent control knowledge base is independent and relatively fixed. It contains expert traffic knowledge (site specific) and is used to perform evidence based reasoning for intersection signal control. The community knowledge base carries 1) the network wide proactive strategies recommended by the central traffic management system for the community (a group of interrelated intersections in which it belongs), and 2) normal coordination strategies for the community. The strategies which are used to timely respond to traffic events at the network level are treated here as proactive strategies. Normally, these strategies work with intersection intelligent control knowledge base to make the final decision on signal phasing. Where necessary, the proactive strategies can override local intelligent intersection traffic control in situations of emergency or special occasions that the intersection controller cannot accommodate in the short amount of time needed.

The intelligent intersection traffic control is performed physically by an intersection controller, a small computational cluster which can communicate with other intersection controllers through a secure internet connection. Together, they form a city-wide computational grid. Each individual controller can 'lend' their spare CPU cycles to those intersections whose computational loads are excessive. This implementation ensures that the investment in intersection controllers is optimised.

3.2 Comprehensive transport data analysis

Network wide proactive traffic management is fulfilled by the proposed central traffic management subsystem through infrequent traffic balancing actions. The comprehensive transport data analysis plays the key role in this subsystem. The major tasks of the subsystem include:

1) assessing transport policy implementation,
2) identifying significant travel demand changes and predicting their evolution,
3) performing timely but infrequent proactive traffic management in response to both traffic events and transport policy initiatives through dynamic intersection grouping, coordination and real time traffic information distribution.

The twin aims of such centralised intervention for individual intersection control are 1) support dynamic route choice made by individual travellers and transport policy decisions made by traffic managers to improve the efficiency of the traffic network, and 2) timely respond to any traffic events.

In the central traffic management subsystem, the singular extendable database schema, distributed computing environment, together with the central inference engine which is supported by the central knowledgebase form the core of the comprehensive multi-source transport data and transport policy analysis system. Real time traffic and signalling data and transport related data (i.e. demographic data, land use data, historical traffic data, etc.) from multiple sources are integrated. By analysing these data, the inference engine may assess the current traffic demand distribution, identify significant traffic demand changes and forecast its future evolution. Such analysis forms the base for network wide event-responsive traffic management. Meanwhile, the data analysis itself can provide valuable traffic information for ATIS systems. The resultant current traffic demand and anticipated future evolution from the data analysis (e.g. based on historical records) may then be used, over the longer term, to assess transport policy implementation and determine needs for future intervention. The final proactive traffic management strategies are decided after joint reasoning process to reduce the potential internal conflicts between the traffic event responses and transport policy decisions. Fast traffic simulation is part of the joint reasoning process.

In our system, two-way communication between the intelligent intersection control subsystem and the central traffic management subsystem exists. Real time traffic and signalling data uploading (from intersection controller to central traffic management system) is frequent, which may occur at each fixed short time period. Incident status uploading takes longer time. In contrast, the proactive traffic management strategy downloading only happens when needed, hence central intervention is infrequent. Importantly, the learning capacity of the proposed system is built on the community knowledgebase that represents the dynamic event responsive strategies. The successful implementation of such strategies for a specific traffic event during real traffic operation will be picked up by the central traffic management system and be stored in the central knowledgebase. Such expert traffic knowledge is cumulative, and the performance of the system can be improved with time of operation.

The design of the intelligent event-responsive urban traffic management system coincides with the concept of 'organic transportation'. Organic transportation is founded in the ideas of holism, selective reductionism, complexity and human behaviour to provide a framework for the holistic management of transport networks (Vogiatzis and Taylor 2006). The proposed system emphasises the need for timely but infrequent network wide traffic balancing rather than the perfect traffic signal optimisation performed at every short time interval (e.g. each traffic signal cycle). Meanwhile, it makes it possible to allocate transport policy priority at intersection control level. Thus the system could use the concept of 'organic transportation' to provide RT-TRACS at the 5-LC level.

4 Current progress

The development and refining of our arterial incident detection algorithm *TSC_ar* (Zhang and Taylor 2006; Zhang and Taylor 2007), have marked the first step towards the proposed intelligent intersection traffic control subsystem (see Figure 1). The key element of the *TSC_ar* algorithm is a Bayesian network which is used to perform evidence based reasoning.

As shown in Figure 2, the Bayesian network consists of a set of nodes and a set of directed links. The nodes include three traffic events (incident: Inc_{1_1}, congestion at both upstream and downstream intersections: Con_{1_1} and Con_{2_1}) and five traffic parameters (turning count at the upstream intersection: $Turn_{1\_1}$, volumes of both intersections: Vol_{1_1} and Vol_{2_1} (representing the major traffic stream), and detector occupancies of both intersections: Occ_{1_1} and Occ_{2_1}). Each traffic parameter has three states (High / Medium / Low) and each traffic event has two states (Yes / No). The directed link between each pair of nodes represents their cause-effect relation. For each node of the network, the combination of such relations is quantified using a conditional probability table which is attached to it (e.g. $P(Occ_{1\_1} \mid Con_{1\_1}, Inc_{1\_1})$ for the node Occ_{1_1}). Both the network topology and its associated conditional probability tables represent existing expert traffic knowledge.

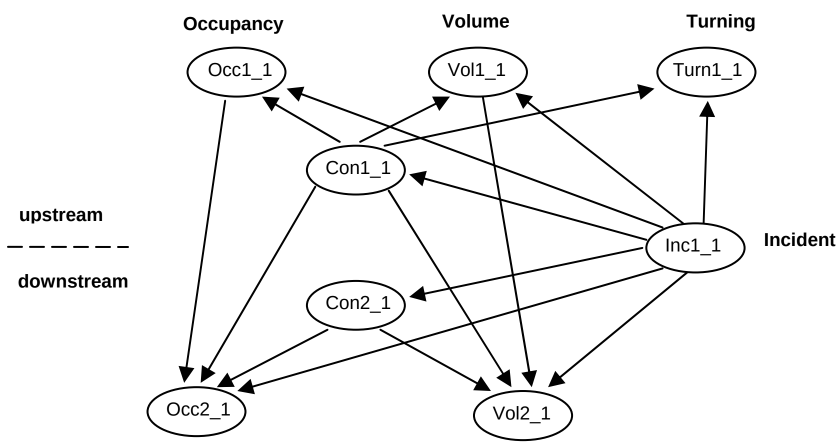

Figure 2 Typical Bayesian network for arterial road incident detection

Site specific traffic knowledge (operators' experience about the specific road) is used to set up thresholds to convert continuous traffic measurements into traffic states at each incident detection interval. Using available states of traffic parameters as evidence, the Bayesian network can update posterior probability distribution of each traffic event using Bayes' rule

$$P(B \mid A) = \frac{P(A \mid B)P(B)}{P(A)} \tag{1}$$

where *P(B|A)* is the posterior probability distribution of *B* given the information about *A* is available, *P(A|B)* is the prior conditional probability distribution of *A* given *B*, which represents expert knowledge about the domain under investigation, and *P(B)* and *P(A)* are probabilities of *B* and *A* respectively.

Table 1 shows the performance of the *TSC_ar* algorithm comparing with other advanced incident detection methods. The DR refers to detection rate, and the FAR stands for false alarm rate. These two measures are used to judge the effectiveness of an incident detection algorithm. The MTTD stands for mean time to detect, which is the average time taken by the algorithm to detect incidents and represents the efficiency of the algorithm. The TSC_ar algorithm testing results are very encouraging. We ascribe the stable performance of the TSC_ar algorithm to its enhanced evidential reasoning capability.

Table 1 Performance of *TSC_ar*, MLF (basic and modular), PNN, SVM_P, vehicle positioning and data fusion algorithms

Algorithm	Source	Data set	Number of incidents	Incident decision threshold / Persistenc e test	Algorithm performance		
					DR (%)	FAR (%)	MTTD (second)
TSC_ar	(Zhang and Taylor 2005)6	Cross Rd	40	70 %	88	0.62	178
MLF	(Yuan and Cheu 2003)	Ave west-Clementi	324	PT=1	60.2	0.24	156
PNN				PT=1	77.2	0.89	155
SVM_P				PT=1	88.9	0.22	149
MLF (modular)	(Thomas et al. 2001)	Coronation Dr	13	PT=2	85	0.64	114
MLF (Basic)	(Khan and Ritchie 1998; Thomas et al. 2001)	Anaheim	108	PT=0	76	1.16	205 (1.63 cycle)
				PT=1	60	0.23	(2.63 cycle)
Vehicle positioning	(Sermons and Koppelman 1996)	Chicago	56	Incident prior < 0.3	68	0	-
Data fusion	(Ivan 1997)	Chicago	90 (training)		93	0	-

Notes:

- DR = detection rate
- FAR = false alarm rate
- MTTD = mean time to detect

If we omit nodes Con_{2_1}, Occ_{2_1} and Vol_{2_1} from the Bayesian network and replace traffic events Con_{1_1} and Inc_{1_1} with new nodes ***Traffic demand*** (for certain approach) and ***Capacity*** (corresponding to effective green for certain traffic movement) respectively, then we may use this modified Bayesian network to infer current traffic demand given certain combination of traffic parameter states and traffic signal settings at real time. Such traffic demand estimate of each approach of the intersection forms an evidence for further reasoning to decide most appropriate traffic signal settings. The logic programming can be applied in this reasoning process and constraints that stem from both traffic safety and certain transport policy initiatives can be considered at the same time. Not that no predefined signal plan is required in the process (except for fixed time control) as expert knowledge about traffic movement have been built in the Bayesian network and been transformed into certain conditions for logic programming. Hence, it is the real traffic demand determines the traffic signal changing point and the phase length, which is what we think intelligent in terms of catering for traveller’s route choice and improving efficiency of the intersection. Our current research concentrates on this part of intersection traffic control subsystem development, which refers to *Intersection traffic state assessment* and *Local inference engine* in Figure 1.

Parallel with the intelligent intersection traffic control subsystem development, the Transport Systems Centre (TSC) has developed a distributed database system with a small scale parallel computational cluster for the analysis of SCATS traffic data, *Nexus II* (Fehlmann 2006; Vogiatzis 2006). *Nexus II* could be treated as the prototype of the *Transport data analysis & Traffic demand forecasting* function block in Figure 2, which is the key component of the central traffic management subsystem. This database has been used to perform a 'pilot' study of Main North Road, an arterial leading north of Adelaide which is characterised by changing land-use zoning, speed limits and mode split. From an initial database of 12 million records of SCATS data, it is now possible to identify the five-minute peak demands of individual signalised intersections along Main North Road (see Table 2).

Table 2 Peak-direction peak-demand occurrence for intersection TCS 32, 31, 25, 15, 272, 252, 195, 196, and 459 for July 2006

Intersection ID	Time
TCS 32 (Adelaide CBD fringe)	8:15
TCS 31	8:05
TCS 25	8:00
TSC 15	7:55
TCS 272	7:40
TCS 252	7:40
TCS 195	7:30
TCS 196	7:25
TCS 459 (Adelaide's northern suburb)	7:35

Table 2 suggests that the peak demand for the through movement of each individual intersection 'moves' along Main North Road towards Adelaide CBD from its northern suburbs. Such information is very important for arterial road traffic signal coordination in order to improve network wide peak period traffic management. By combining SCATS data, information relating to road and intersection geometry with the probe vehicle data collected by the TSC instrumented vehicle, some basic parameters of traffic analysis and management can be calculated. Table 3 highlights some of these parameters. The calculation takes approximately 20 minutes (including set up time). With our added effort to expend the calculation in *Nexus II* towards automation, it is possible for the calculation time to be reduced considerably.

Table 3 Probe vehicle travel time Analysis combined with SCATS data analysis for Main North Road in March 2007

Link	Link Distance (m)	Hour Arrival	Volume (veh/h)	Density (veh/km)	Headway (sec)	Travel Time (sec)
TCS 195 - 252	5536	0700~0800	1936	26.6	1.86	274
TCS 252 -272	3506	0700~0800	1812	43.5	1.99	303
TCS 272 - 277	4553	0700~0800	1603	32.9	2.25	336
TCS 277 - 015	3042	0700~0800	1304	26.6	2.76	223
TCS 015 -025	2852	0800~0900	1729	67.2	2.08	399
TCS 025 -031	2220	0800~0900	2112	76.6	1.70	290
TCS 031 -032	777	0800~0900	1708	62.3	2.11	102

Further information on traffic system performance can be obtained from the instrumented probe vehicles travelling in the traffic stream. Such vehicles can report real time information such as location and instantaneous travel speed, as well as information on travel times on given road sections. As an example, Figures 3 and 4 show some of this information, in this case the speed time profile for a probe vehicle travelling along a radial arterial route in metropolitan Adelaide, in the morning peak on successive days (14/03/07 and 15/03/07), respectively. Figure 3 is the profile recorded on a 'normal day' (14/03/07). On the following day, an incident occurred at a major intersection along the route, and the speed-time profile for this day is shown in Figure 4. The incident involved a broken down truck which blocked one of the through lanes for city bound traffic at the intersection. The two speed time profiles are quite different in nature. In addition to the obvious difference in overall travel time, the speeds of the probe vehicle upstream of the incident location are much slower than those normally experienced on this road. The speeds downstream of the incident are also somewhat higher than normal – on clearing the incident site the probe vehicle then experienced much lighter traffic conditions, a typical phenomenon of blocking incidents of this kind.

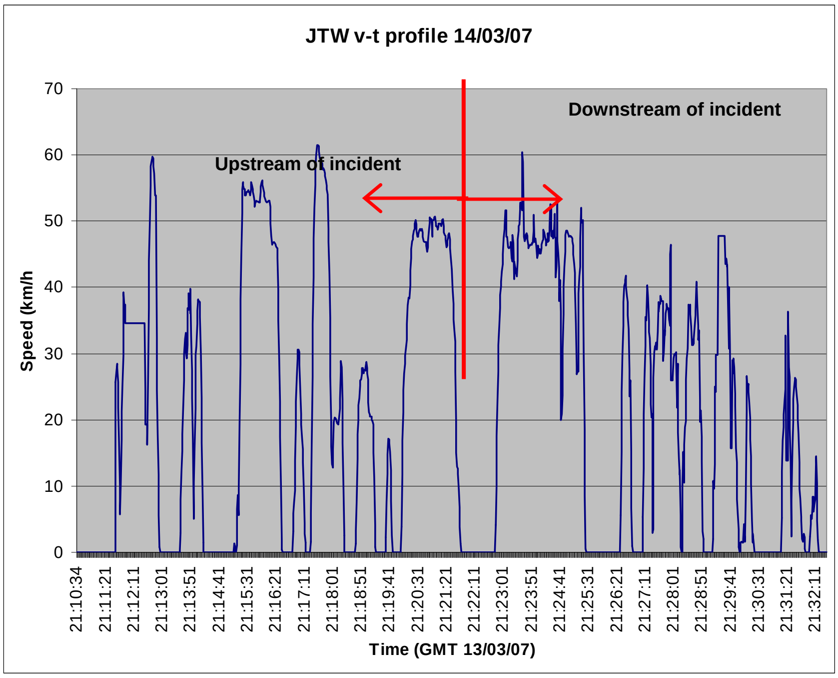

Figure 3 Probe vehicle speed time profile Glen Osmond Rd route, 14/03/07 'normal' day

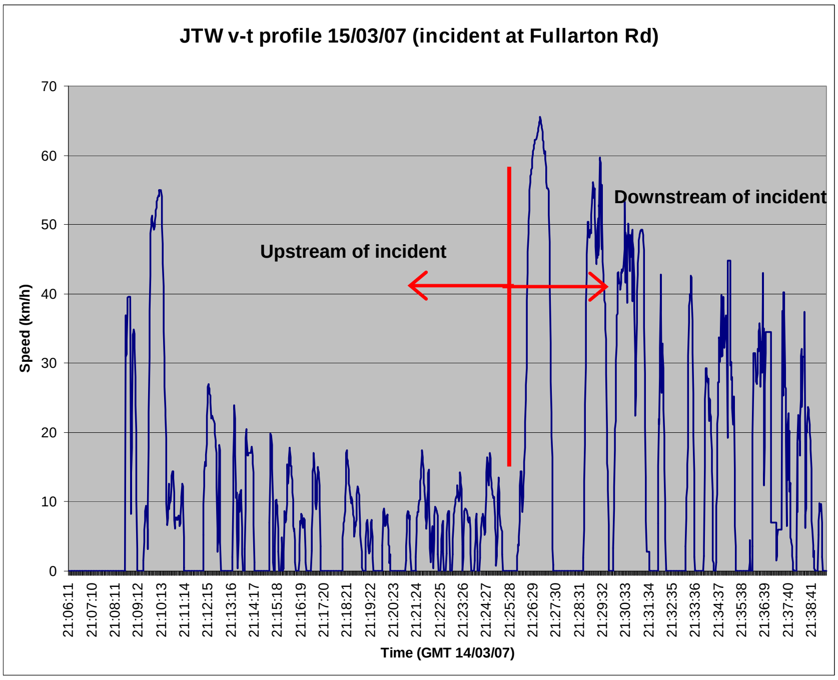

Figure 4 Probe vehicle speed time profile Glen Osmond Rd route with incident, 15/03/07

The microscopic traffic simulation method has been widely used to develop and evaluate advanced traffic signal control systems (e.g. SCOOT, RHODES, etc.). TSC has recently completed the Adelaide City Council area micro-simulation traffic mode, the ACC model (Stazic et al. 2005). This model represents a typical central business district traffic environment in a large scale, which make it an ideal test bed for our proposed traffic management system development and testing. In addition, we have developed a portable software tool using the Paramics application program interface to implement advanced traveller's information system on certain links / areas in the ACC model to investigate traveller's dynamic response to real time traffic information. This specific study will help us to achieve one of major objectives of the new traffic management system development, which is to 'appreciate and make use of DVU's dynamic route choice to achieve traffic demand balancing in the traffic network'.

5 Conclusion

As capital cities become more congested, the benefit gained from the system will benefit countries in which it has been implemented in terms of reduced traffic congestion and impacts on travel cost, environmental cost and road safety. For example, BTRE (2007) estimated that traffic congestion in Australia's major cities cost \$9.1 billion in 2005 and concluded that this would more than double by 2020. The component of total congestion ascribe to incidents ('incident based' or 'non recurrent' congestion) is sometimes reckoned at about 40-50 per cent of total congestion. This component contributes even more to congestion costs, however, because its erratic if not random occurrences cause unexpected and often unavoidable delays and disruption.

The proposed intelligent event-responsive urban traffic management system is envisaged as a human centred traffic control and management system with learning capability. The evidence based reasoning mechanism will make intersection traffic control fully demand responsive and intelligent. The new singular extendible database schema, distributed computing environment, and central knowledge base will support multi-source transport data integration, fast transport information extraction, and transport policy assessment. These capabilities form the base of timely but infrequent traffic balancing at traffic network level to respond to any traffic events and transport policy decisions. The successful development of the arterial incident detection algorithm *TSC_ar* and the traffic data processing and analysing system *Nexus II* have marked the first step towards the intelligent event-responsive urban traffic management system.

References

Austroads (2007a). Improving Traffic Incident Management: literature Review. Austroads Research Report AP-R296/07. Austroads Inc., Sydney.

Austroads (2007b). Review of Current Traffic Incident Management Practices. Austroads Research Report AP-R297/07. Austroads Inc., Sydney.

BTRE (2007). Estimating urban traffic and congestion cost trends for Australian cities. BTRE Working Paper 71. Bureau of Transport and Regional economics, Canberra.

Fehlmann, S, Mitchell, J, Kelly, J & Vogiatzis, N (2006). Nexus: developing a schema to contain disparate traffic data types for parallel distributed processing. In *29th Australasian Transportation Research Forum*, Gold Coast, Australia.

Felici, G, Rinaldi, G, Sforza, A, and Truemper, K (2006). A logic programming based approach for on-line traffic control. *Transportation Research C*, 14, 175 -189.

FHWA (1991). Real-time, traffic adaptive control for IVHS. Report No. DTFH61-92-R-00001, Federal Highways Administration, US Dept of Transportation, Washington DC.

Flynn, M J & Rudd, K W (2004). Parallel architectures. In Tucker, A B (ed), *Computer Science Handbook*. Association of Computing Machinery.

Gartner, N H (1985). Demand-Responsive Traffic Signal Control Research. *Transportation Research A*, 19, 369 - 373.

Gartner, N H, Stamatiadis, C, and Tarnoff, P J (1996). Development of Advanced Traffic Signal Control Strategies for Intelligent Transportation Systems: Multilevel Design. *Transportation Research Record*, 1494, 98 -105.

Gartner, N H, Tarnoff, P J, and Andrews, C M (1991). Evaluation of Optimized Policies for Adaptive Control Strategy. *Transportation Research Record*, 1324, 105 -114.

Head, K L, Mirchandani, P B, and Shepherd, D (1992). A hierarchical framework for real-time traffic control. *Transportation Research Record*, 1360, 82 -88.

Hunt, P B, Robertson, D I, Bretherton, R D, and Winton, R I (1981). SCOOT - a traffic responsive method of coordinating signals. Report TRRL 1014, Transport and Road Research Lab.

Iguchi, M (2002). A perspective on ITS deployment. *JSAE Review*, 23, 173 - 176.

Jensen, F V (2001). *Bayesian Networks and Decision Graphs*, Springer-Verlag, New York.

Lowrie, P R (1982). SCATS: The Sydney Co-ordinated Adaptive Traffic System. *IEE International conference on road traffic signaling*, London, UK.

MacGowan, J, and Fullerton, I J (1979-1980). Development and Testing of Advanced Control Strategies in the Urban Traffic Control System. *Public Roads*, 43(2-4).

Mauro, V, and Taranto, D D (1990). UTOPIA. *6th IFAC/IFIP/IFORS Symposium on Control and Communication in Transportation*, Paris.

Miles, J C, and Walker, A J (2006). The potential application of artificial intelligence in transport. *IEE Proceedings - Intelligent Transport Systems*, 153, 183 - 198.

Mirchandani, P, and Head, L (2001). A real-time traffic signal control system: architecture, algorithms, and analysis. *Transportation Research C*, 9, 415 - 432.

National Transport Data Working Group (2004). *National Transport Data Framework*, Australian Transport Council.

Nelson, L J (2002). Sensors Working Overtime. *Traffic Technology International*.

Pearl, J (1986). Fusion, propagation, and structuring in belief networks. *Artificial Intelligence,* 29 (3), 241 - 288.

Quadstone. (2000). www.paramics-online.com.

Rowe, E (1991). The Los Angeles Automated Traffic Surveillance and Control (ATSAC) System. *IEEE Transactions on vehicular technology*, 40(1), 16 - 20.

Stazic, B., Taylor, M. A. P. and Woolley, J. E. (2005). Traffic microsimulation of the Adelaide CBD road network. Intelligent Vehicles and Road Infrastructure Conference, Melbourne.

Transportation Research Board (2003). A Concept for a National Freight Data Program. Transportation Research Board of the National Academies.

Vogiatzis, N and Taylor, M A P (2006). On Concurrent Holistic-Component Dynamics and Traffic Analysis. In *29th Australasian Transportation Research Forum*, Gold Coast, Australia.

Zhang, K and Taylor, M A P (2006). Effective arterial road incident detection: a Bayesian network based algorithm. *Transportation Research C*, 14 (6), 403 - 417.

Zhang, K and Taylor, M A P (2007). A new concept and general algorithm architecture to improve automated incident detection. In Allsop, R E, Bell, M G H and Heydecker, B G (eds), *Transportation and Traffic Theory 2007*, Elsevier: Oxford, 633 - 659.