Achieving realism in simulation with adaptive signal control

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'Hardware in the Loop' microsimulation is rapidly becoming accepted as a means of assessing the effect of complex signal controllers, UTC, and ITS systems. The premise on which they work is straightforward. Vehicles, signals, signs, detectors and roads are simulated by computer, the software and hardware controlling the traffic is real. The benefit is that all the features and complexity of a control system can be tested by simulation. Including the signal control system in the simulation addresses just one half of the modelling task. The traffic flows arriving at the detector loop and signals must also be truly representative of those in the road network, especially with respect to their variability and randomness. If an adaptive system in a simulation is not presented with truly representative input streams, then it cannot work as it would in reality.

ADAPTIVE SIGNAL CONTROL

Adaptive signal control is not a new idea. In December 1868, the first traffic lights were installed outside the Palace of Westminster in London to allow MPs to cross the road safely. They were manually operated by police officers who varied the display of semaphore 'arms' and red and green gas lamps. As they were operated through observation of the prevailing conditions and through pedestrian requests, they were naturally adaptive in response to traffic. Unfortunately the lights exploded in January 1869 and attempts at signalised traffic control in the UK were set back until 1925.

For many years signals were operated with fixed timings, with green times for each arm of the junction allocated in the ratio of flows. Variation was introduced by changing the timings through the day according to the historic pattern of flows. Such systematic variation can be reasonably accommodated by fixed time systems which follow established patterns relating to the time of day and day of the week (Heydecker 2004). However, a one-year study conducted in 2001 in Utah showed that the five-minute volume fluctuation during the peak period can vary by as much as 74% (Martin, 2003). Pre-timed control cannot dynamically react to this, resulting in increasingly significant delays as flows increase. (Lin and Liao, 1998).

Adaptive signal control works with no preset timing plans. Only the upper and lower bounds of cycle time, green splits and (in networks) offsets are provided. To optimise junction capacity, mathematical algorithms process the real-time traffic demands at the approaches obtained from on-street detectors and produce optimal signal timings in response to variations in traffic. They are therefore able to react to the variability of the traffic flow.

Common adaptive signal control systems include:

MOVA

MOVA (Microprocessor Optimised Vehicle Actuation) was developed by the Transport Research Laboratory (TRL) in the UK in the 1980s. It is a self-optimising signal system to control independent signal controlled junctions, and has been extended to control many co-ordinated control systems such as signalised roundabouts. MOVA has two operational modes. In its uncongested mode, MOVA seeks to optimise competing demands on the approaches by minimising stops and delays. When congestion occurs on one or more approaches, MOVA switches to a capacity maximising procedure.

SCOOT

SCOOT (Split Cycle Offset Optimization Technique) is a cycle-based system developed in the early 1980s by the Transport Research Laboratory for coordinated intersections. It works by gathering information from its vehicle detectors and calculating optimised signal timings that are sent back to local controllers. It predicts total delay and stops for the current signal timings over short, rolling horizons and reacts by changing cycle length and phase splits in small increments.

SCATS

SCATS (Sydney Coordinated Adaptive Traffic System) was created in the early 1990s by the Roads and Traffic Authority of New South Wales to be used in coordinated intersections. It can be considered as a hybrid system, since it adapts to traffic variations by selecting a timing plan from an off-line library of plans. SCATS uses a cycle-based approach. It adjusts cycle times, green time splits within the cycle, and offsets amongst cycles in the network.

HARDWARE IN THE LOOP SIMULATION

Traffic systems that require adaptive signal control are now able to be simulated using the real signal control system interacting with the simulation through a technique known as 'Hardware in the Loop' simulation. This allows the actual signal controller to respond to vehicle detection in a simulation and hence control the simulated signals. The technique replaces the interface layer of the controller with one that communicates directly with the simulation rather than with the on-street devices. Figure 1 shows a typical system architecture.

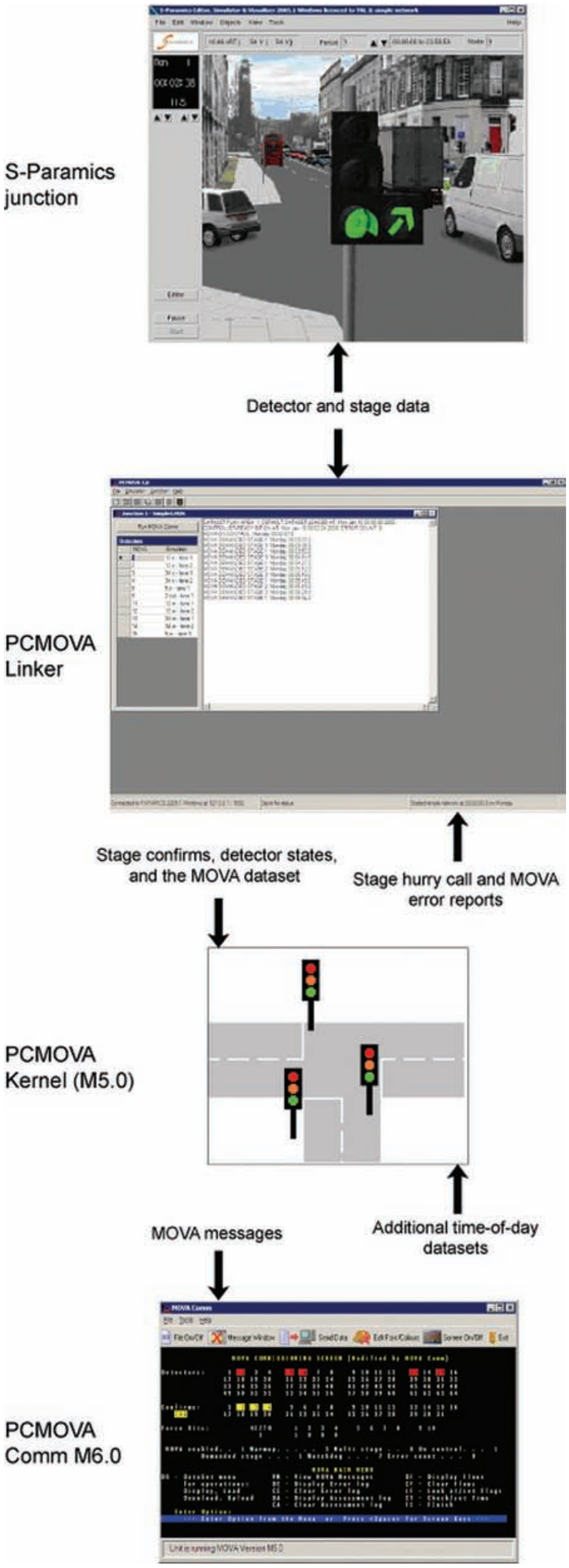


Figure 1: Hardware in the Loop simulation using PCMOVA

Commercial confidentiality of the control algorithms and their inherent complexity will often preclude their accurate reproduction within the embedded signal control capabilities of the simulation software. Hardware in the Loop simulation circumvents these problems by including the actual hardware and/or software of the signal controller, and enables the simulation to include all the features and nuances of the control system (Englebrecht 1999). The technique is superior to one that attempts to reproduce the control algorithm where the full description of that algorithm is complex, commercially confidential, and under continued development with regular new releases.

FLOW VARIABILITY

Including the controller through Hardware in the Loop simulation only addresses one half of the simulation task To enable it to function correctly, the controller must be presented with inputs which represent, in detail, the patterns of flow rates and vehicle arrivals observed on the road. For example, MOVA works by detecting gaps in traffic streams. It may choose to change the signal staging when a suitable gap is available, taking account of demands on approaches currently at red. SCOOT and SCATS adapt to variability in flows and the relative variation between these flows by making constant adjustments to signal timings.

Variations in flow can be categorised into two types: *(Spence 2007)*

- variations in arrival rate over medium term periods of time
- variations in the arrival pattern, platooning and queueing

Arrival rate is influenced by local generators of traffic such as school runs, business parks or the general increase in the peak hours. Major religious or sports events (UTMC04 2001) also have significant impact. Weather affects the flow density and speed and there are predictable daily variations such as weekend effects and holidays. The difference in the times of the peaks and the relative sizes of the peaks gives the variation in relative flows that the adaptive signal controller uses to optimise throughput.

Arrival pattern is influenced by the random variation in vehicle characteristics, each individual will drive slightly differently from the rest and the gaps between vehicles as they follow each other will vary. In uncongested conditions the arrival pattern will be random as vehicles depart from home at uncorrelated times and hence arrive at traffic signal stop lines at similarly uncorrelated times.

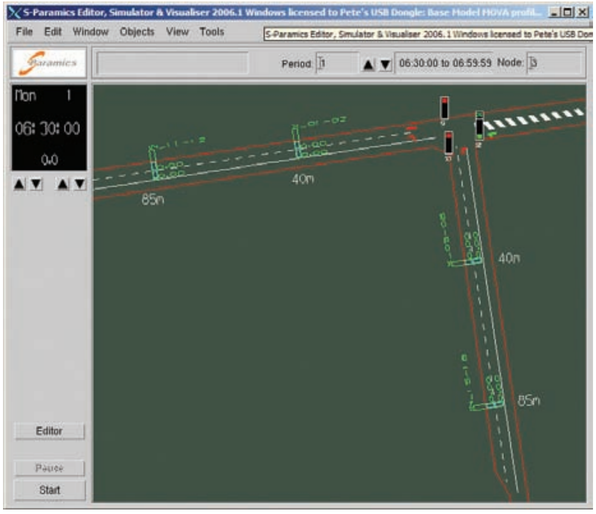
More systematic variations in arrival patterns occur. Another signalised junction upstream of the controlled junction will generate a pulsed traffic flow at a frequency corresponding to the signal cycle time. Bus stops where following traffic cannot overtake have a similar effect, as do school crossing wardens, pedestrian crossings, and opposed right turns where there is no space for vehicles to pass on the nearside. Also, on long rural roads with few overtaking opportunities, platoons may form behind slower moving vehicles or HGVs.

There is also a unique effect on motorways, where a congestion wave passes the entry to a slip road and the flow leaving the motorway is consequently reduced. When this happens the adaptive signal control system at the top of the slip will re-assign green time to the non motorway traffic to clear queues on the surrounding roads.

THE EFFECT OF TRAFFIC VARIABILITY

Traditional macroscopic models providing an aggregated representation of traffic do not permit the modelling of

Figure 2:
Test junction



Period: 1 06:30:00 to 06:59:59 Node: 3

individual vehicles. Instead, all vehicles of a particular group obey the same rules of behaviour. The uniformity of the process does not allow for the detail of vehicle arrival to be simulated. Microsimulation, with its representation of every individual vehicle does simulate the varying arrival patterns at traffic signals and is therefore more suitable to assess the effect of the signal controllers that react to this level of detail.

Fox and Clark (1998) carried out an evaluation of how benefits of a responsive UTC vary according to the amount of variability in traffic flows using a simulation model of Kingston-upon-Thames. Their results clearly demonstrated an advantage of SCOOT over the fixed time counterpart, but more importantly, that the level of benefits vary critically with the amount of traffic flow variation. *Shenoda and Machemehl* (2006) recognised that the benefits of adaptive control as compared to fixed time control vary according to the demand patterns on the approaches.

Li et al. (2006) compared three adaptive controllers (OPAC, TACOS and FLC) against vehicle-actuated control by using both a real and a hypothetical simulated intersection. All systems were tested under four scenarios (low volume levels, high volume levels, platoon arrivals and an incident upstream). The performance of all three systems varied slightly under each scenario, but a general reduction of delay was observed for vehicle actuated control.

Martinez (2007) undertook a similar study to investigate the effect of both the variation of arrival rate and the variation of arrival pattern using PCMOVA and S-Paramics microsimulation. The measure of effectiveness was the time spent in a journey from a point beyond the end of the longest observed queue to the stopline, in effect a measure of the time spent queueing to reach the signals. The base line for the evaluation was the same junction running fixed time signals optimised for green split and cycle time by the S-Paramics Equisat optimiser which equalises the ratio of flow to saturation flow for each stage. The algorithms used by the Equisat calculator are those specified in TRL Research report RR67.

The model was a simple T junction (see Figure 2). The arrival rates on the arms of the junction were controlled by the release profiles in the S-Paramics model. One profile governed demand on the south arm, while another was applied to demand on the east and west arms.

The release profiles were manufactured to show specific values of variance and correlation. Correlation values between +1 and -1 were used with a standard deviation of 0 (flat profile) to 0.025. Figure 3 shows an example of high variance and negative correlation.

For each combination the queue times were aggregated over 5 runs and compared with the times for the fixed time scenario.

Figure 4 shows the mean journey times to the stop lines under the different scenarios. In this test MOVA was able to improve journey times under all conditions, but its performance was significantly better when presented with model arrivals that had variability in flows and non coincident peaks and troughs on each arm. The fixed time signals performed better when the flows showed low short term variability, as the demand and queuing times were even throughout. As expected, there was no variation in journey times due to the correlation of peaks and troughs on each arm, as fixed time signals do not detect these changes.

In a second sequence of tests Martinez varied the pattern of arrival rates at the same junction by extending the model to include signals not previously modelled. Under the same demand as before the journey times were observed to improve again, a result attributed to the ability of MOVA to detect gaps in the traffic approaching a junction and change the signals to make use of these opportunities to minimise time when the junction is not flowing.

Profile: 1 of 2 Name Divisor 1
Profile 1 - all periods

Minutes

Hours	00 - 05	05 - 10	10 - 15	15 - 20	20 - 25	25 - 30	30 - 35	35 - 40	40 - 45
07:00 - 08:00	3,750	4,583	4,583	4,583	5,417	5,417	5,417	5,417	5,417
08:00 - 09:00	4,583	3,750	3,750	3,750	2,917	2,917	2,917	2,917	2,917
09:00 - 10:00	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
10:00 - 11:00	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
11:00 - 12:00	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
12:00 - 13:00	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000

Profile 1, period 1 total 100.0

Profile: 2 of 2 Name Divisor 1
Profile 2 - all periods

Minutes

Hours	00 - 05	05 - 10	10 - 15	15 - 20	20 - 25	25 - 30	30 - 35	35 - 40	40 - 45
07:00 - 08:00	3,750	2,917	2,917	2,917	2,917	2,917	2,917	3,750	3,750
08:00 - 09:00	4,583	5,417	5,417	5,417	5,417	5,417	5,417	4,583	4,583
09:00 - 10:00	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
10:00 - 11:00	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
11:00 - 12:00	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
12:00 - 13:00	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000

Profile 2, period 1 total 100.0

Figure 3:
Release profiles.

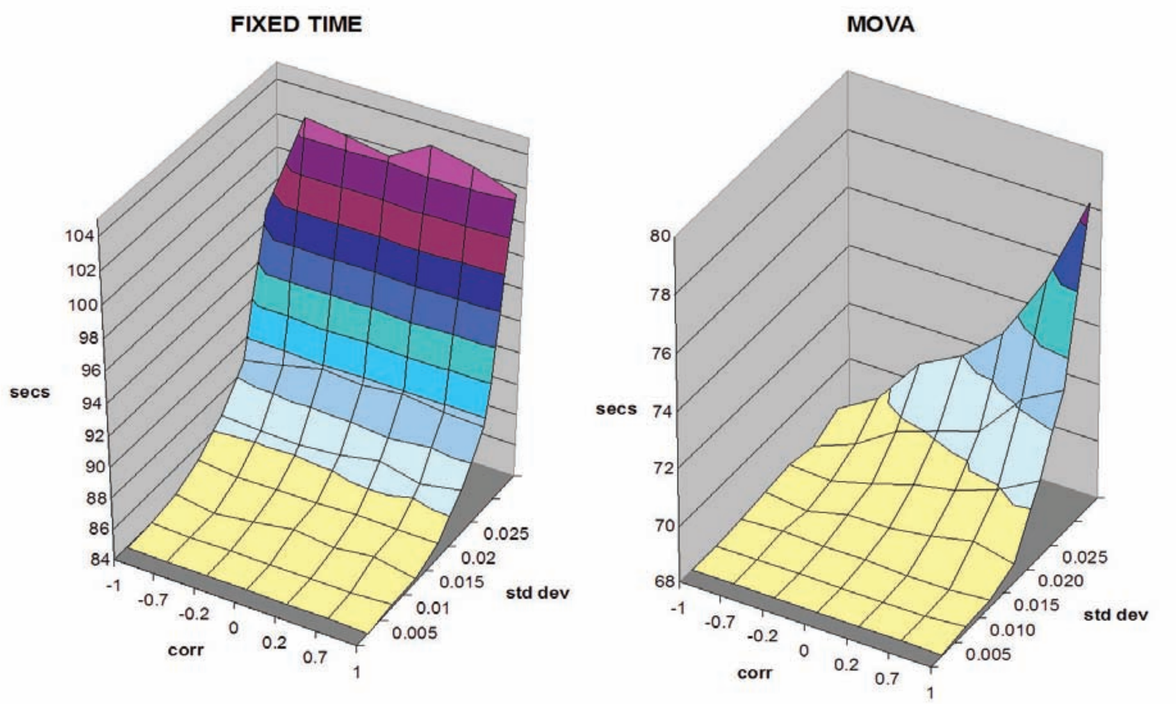


Figure 4:
Mean journey time to stoplines

CONCLUSION

While the tests discussed above were undertaken in a simple situation, it would appear from the results that a modeller can readily influence the conclusion of the exercise through the manner of representation of traffic demand in the model. The following considerations appear important:

1) Properly profiled demands have a major effect on the measured performance of the scheme. These should be programmed into the model to match the surveyed demand profile at short intervals. The use of flat demand will lead to erroneous conclusions.

2) The default pattern of releases in microsimulation software should present random arrivals at junctions adjacent to the release zones in the model within the profiled time interval.

3) Systematic effects that influence the arrival pattern at a signalised junction should be included by extending the model to cover the cause of those effects. The application of microsimulation for large area models has a great benefit in this respect, as the effects of green waves, platooning, and congestion, which are natural consequences of the modelling process, will be realistically simulated on the arms of the controlled junction.

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