OPTIMISATION OF TRAFFIC SIGNALS USING A CELL TRANSMISSION MODEL

Olga Feldman* and Mike Maher
School of the Built Environment & Transport Research Institute,
Napier University, 10 Colinton Road, Edinburgh, EH10 5DT
*Corresponding author: Tel.: +44-0131-4552618,
E-mail address: o.feldman@napier.ac.uk

1. INTRODUCTION

Management of transportation networks especially in major cities is impossible without traffic signals, and it is widely accepted that many practical problems remain to be solved. Evolution of traffic flows over complex networks can be predicted over time using macroscopic models, which deal with traffic flow as if it were a fluid, or microscopic ones, which, on the other hand, follow the movement of individual vehicles through time. For example, in microscopic simulation models of traffic such as Paramics or Vissim each vehicle is separately identified and tracked and has its own characteristics, for instance, desired speed, desired separation, reaction time, destination, vehicle type and so on, and produce a lot more output than is ever normally needed. Another problem connected with microscopic models is that because of their complexity the run time for a realistic network can take much more time than it takes in reality, and optimisation of signal settings is difficult because of the need for many repeat runs and “noisy” output, due to the Monte Carlo nature of such models.

The most widely used macroscopic program is TRANSYT, an off-line computer program for determining optimum signal timings in any network of roads for which the average traffic flows are known. The traffic model of the network predicts the value of a Performance Index, which is a weighted combination of all vehicle delays and stops, for any fixed-time plan. When optimising the signal settings, TRANSYT does not take into consideration whether any links are blocked or not. It is assumed that vehicles effectively form a vertical queue at the stop-line, rather than a linear queue back along a link, and the model can then release traffic into what is in fact a blocked link. As a consequence, TRANSYT does not correctly take account of the physical length of the queue and the green starting wave.

Lo (1999) has provided a good summary of traffic signal control models and indicates that none of them is intended for the entire range of the fundamental diagram (see Figure 1)
derived from a flow-fluid analogy (Lighthill and Whitham, 1955; Richards, 1956, (the LWR model)) to describe traffic along directed road links.

A discretised version of the macroscopic modelling approach, cell transmission models (CTM), has recently been developed by Daganzo (1994, 1995) in the USA, by Buisson et al (1996) in France and others. CTM provide a convergent approximation to the LWR model and can be used to predict transient phenomena such as the build-up, propagation and dissipation of queues.

The objective of this paper is to investigate the application of the CTM to signalised networks – in particular signalised roundabouts, where the spatial aspect of queues can be important (as in blocking back).

2. THE CELL TRANSMISSION MODEL

The cell transmission model is a simplified version of the fundamental diagram, usually based on a trapezium form (see Figure 2), and provides simple solutions for realistic networks. It is assumed that a free-flow speed $v$, at low densities and a backward shockwave speed $w$, for high densities are constant ($v \geq w$).
The network is represented as a set of cells with the lengths usually set equal to the distance travelled in light traffic by a typical vehicle in one clock tick. In each cell in each time interval, it is assumed that there is a continuous flow of traffic and that the state is known in terms of a point in its $(q,v,k)$ diagrams. We set the actual flow rate from the upstream cell $i$ to the downstream cell $i+1$ to be the minimum of the sending $S_i$ and receiving $R_{i+1}$ function values:

$$q_{i+1} = \min\{S_i, R_{i+1}\}$$

where

$$S_i = \begin{cases} v \cdot k_i, & \text{if } k_i < k_s \\ q_{\text{max}}, & \text{if } k_i \geq k_s \end{cases} \quad \text{and} \quad R_{i+1} = \begin{cases} q_{\text{max}}, & \text{if } k_{i+1} \leq k_s \\ w \cdot (k_{\text{jam}} - k_{i+1}), & \text{if } k_{i+1} > k_s \end{cases}$$

and $k_i$ is the density in cell $i$ (see Figure 2).

The CTM is based on a recursion where the cell occupancy $n_i$ at time $t+1$ is equal to the number of vehicles that was in that cell before, plus the number of vehicles that entered, minus the number of vehicles that left, i.e.:

$$n_i(t+1) = n_i(t) + q_i(t) - q_{i+1}(t).$$

(5)

To simulate the effect of a traffic signal, we assume that for a signalised cell $i+1$ the inflow $q_{i+1}$ is determined by (2)-(4) if $t \in$ green phase, or is equal to zero if $t \in$ red phase.

### 3. COMPARISON OF THE CTM AND TRANSYT MODELS

For signal optimisation in comparison with TRANSYT the CTM gives no dispersion. As a result, the model does not predict fully realistic traffic behaviour. To avoid this we can change the cell length and, therefore, the cell density (Feldman and Maher, 2002).

Work has also been done to look at the effect of different shapes of the fundamental diagram on platoon dispersion. We use the following family of relations between speed $v$ and density $k$:

$$v = v_0 \left[ 1 - \left( \frac{k}{k_{\text{jam}}} \right)^{\frac{l-1}{1-m}} \right]^{1},$$

where $v_0$ is a free flow speed, $l$ and $m$ are parameters which should be chosen so that the model gives the best agreement with experimental speed-flow or speed-concentration. Thus, the flow-density relations for the CTM are intended for the entire range of the fundamental diagram and the sending and receiving functions are chosen in accordance with
In this case we have platoon dispersion over the link.

As an example we consider a simple link shown in Figure 3.

The parameter values selected include:

- Jam density: 100 vehicles/km (or 0.1 vehs/m);
- Saturation flow: 2500 vehicles/h (or 0.6944 vehs/s);
- Free flow speed: 100 km/h (or 27.7778 m/s).

Then over the distance of 1000m the model gives different platoon dispersion profiles for different parameter values (Figure 4).

**Conclusions**

Tests carried out to study the linking of a pair of traffic signals show good agreement between the two models in the way in which the Performance Index is a function of the offset between the two signals. These tests show that, in circumstances where no blocking back is to be expected, the two models are comparable and give virtually identical results. In
the second example of a signalised roundabout, however, where blocking back may readily occur, the two models show differences in their predictions and in the optimal offsets they produce.

It was shown that if we use simplified form of the fundamental diagram as a triangular or trapezium forms, the CTM gives no platoon dispersion over the link. For more realistic flow-density relations it is possible to set the model so that it does produce platoon dispersion.

Further work will be carried out into comparison of the TRANSYT and CTM models on signalised roundabouts, into continued investigations of platoon dispersion in the CTM for different shapes of the fundamental diagram, and into improved methods for the optimisation of the signal settings with the CTM. We will also use Paramics as an independent “judge” in the future analysis of the models predictions.

References