Modelling signal platoon patterns by approach lane use and movement class

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ABSTRACT

A "lane-based" signal platoon progression model has been developed for the SIDRA INTERSECTION software package as part of a lane-based network model that involves blockage of upstream intersection lanes by downstream queues (backward spread of congestion) and capacity constraint applied to oversaturated upstream intersections. Unlike traditional network models that use aggregate models of "links" or "lane groups", the lane-based model can provide information about upstream departure and downstream arrival patterns, queue lengths, lane blockage probabilities, proportion of traffic arriving during green, and so on at an individual lane level. The model takes into account midblock lane changes that apply to signal platoon patterns. This is particularly important in evaluating closely-spaced (paired) intersections with high demand flows where vehicles have limited opportunities for lane changes between intersections. These requirements are important in modelling the forward movements of platoons for estimating performance measures (delay, back of queue, stop rate) as a function of signal offsets, geometric design and flow conditions.

The modelling of signal platoon patterns is further enhanced by using the Movement Class facility of the SIDRA INTERSECTION software. This is implemented by assigning two types of movements negotiating the network to Special Movement Classes, namely: (i) Through movements at external approaches which become turning movements at downstream internal approaches, and (ii) dogleg movements at staggered T intersections. These movements can be assigned to separate lanes and separate signal phases, and their arrival and departure flow patterns (second-by-second platoon patterns) can be tracked through the paired intersection system separately. This improves the quality of signal platoon modelling and is expected to produce better results in assessing signal coordination quality and optimising signal offsets. The use of Special Movement Classes also helps to estimate unequal lane use cases at external approaches of a paired intersection system, a factor which also affects signal platoon patterns. A staggered T-intersection example is presented to demonstrate the difference in performance estimates obtained with and without the use of Special Movement Classes.

Keywords: traffic operations, network (transport) modelling, traffic signals
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The presentation:

Basic features of the lane-based platoon model
- Lane-based model
- Arrival and Departure patterns
- Signal platoon model (including platoon dispersion)

Movement Classes
Example: Staggered T intersection

Conclusions
Basic features of the lane-based platoon model

“Lane-based” platoon model as opposed to the use of "links" or "lane groups":

A new analytical lane-based method for determining platoon patterns at closely-spaced signalised intersections.

Developed for the SIDRA INTERSECTION software.

Traditional network models use links or lane groups:

- individual lane conditions are aggregated
- insufficient information about queue lengths, lane blockage probabilities, backward spread of queues, and so on as these need lane level of detail.

Lane-based model for intersections

LANE-BASED MODEL

More realistic and reliable analysis compared with approach-based and lane group (link) - based methods (various UK models and US HCM).

- General: Unequal lane flows, de facto exclusive lanes, short lanes, slip/bypass lanes (give-way/yield, continuous, signals).
- Roundabouts: Circulating lane use; Dominant and subdominant lanes.
- NETWORK Model (lane queues, lane blockage, signal platoon arrival and departure patterns).

Try defining “links” and “lane groups”!
Lane-based model for NETWORKS

Lane Movements

Origin – Destination (OD) Movements

Lane Changes

Second-by-second platoon patterns move accordingly
The lane-based model is particularly important in evaluating

- closely-spaced intersections
- high demand flows
- where vehicles have limited opportunities for lane changing between intersections.

The new lane-based method derives second-by-second downstream arrival patterns from upstream departure patterns taking into account arrival flow and saturation flow rates of individual lanes at both upstream and downstream intersections.
Modelling of departure patterns at upstream lanes takes into account:

- capacity reduction due to lane blockage by downstream queues
- reduced arrival flows at downstream lanes due to capacity constraint at oversaturated upstream lanes
- lane movement flow proportions at the upstream intersection.

Backward spread of congestion (reduced upstream capacity) and capacity constraint (reduced downstream arrival flows) are highly interactive with opposing effects. SIDRA INTERSECTION uses a network-wide iterative process to find a solution that balances these opposing effects.
Arrival patterns at downstream lanes

The modelling of platoon arrival patterns at downstream approach lanes takes into account:

- Platoon Dispersion
- Midblock lane changes based on matching of upstream and downstream lane flow rates. These are different from lane changes for entry into short lanes included in the model.
- Any midblock inflow and outflow rates (including uniform arrival flow patterns for inflow) implied by turning volume specifications are also taken into account.
- Movement Classes (Light vehicles, Heavy Vehicles, Buses, Large Trucks, etc.) due to different lane use and approach cruise speeds.

The model improves assessment of signal coordination quality and optimisation of signal offsets.

NETWORK TIMING and Platoon Patterns

The second-by-second arrival patterns determined by the program as a function of signal offsets are used to calculate Percent Arriving During Green, \( P_G \), and Platoon Ratio, \( P_A \), for each approach lane for use in performance calculations.
Arrival patterns at downstream lanes

Platoon Dispersion: a unique model (optional)

Movement Classes in SIDRA INTERSECTION

Movement Classes
Light Vehicles
Heavy Vehicles
Buses
Bicycles
Large Trucks
Trams/Light rail
User Classes (for special treatment)
Network Example: Signals and Roundabout with Bus lane

SIDRA INTERSECTION Training Workshop Example

Analysis of closely-spaced intersections can be enhanced by using Special Movement Classes based on User Classes in SIDRA INTERSECTION.

When the Network OD flows are known, external approach movements that continue as turning movements on internal approaches can be treated as Special Movement Classes.

These movements can then be assigned to upstream and downstream lanes according to their downstream destinations. This was found to improve the lane-based modelling of second-by-second platoon patterns further.
Network Example: Freeway Diamond Interchange

Doncaster Road - Eastern Freeway, Melbourne

Through traffic in different lanes have different destinations downstream

Lane allocation by SPECIAL MOVEMENT CLASSES for turning movements

Network Example: Fully Signalised Roundabout

Cemetery Road East - Swanston Street, Melbourne

Through traffic in different lanes have different destinations downstream

Lane allocation by SPECIAL MOVEMENT CLASSES for turning movements

Network Displays
Network Example: Staggered T Intersections

ARRB Conference 2014 paper
A detailed example is presented using various analysis scenarios to investigate basic aspects of the lane-based network model in relation to signal platooning.

Staggered T intersections with 180 m distance between them.
Detailed description is presented in the ARRB Conference 2014 paper (available for download on www.sidrasolutions.com/Resources/Articles).

Site OD flows and Network OD flows
Site Origin-Destination (OD) flows (intersection turning volumes) are used as network flow input by the software.

Network OD flows that match the Site OD flows perfectly are used for analysing differences between analysis scenarios with and without knowledge of Network OD flows.
Network OD flows

Downstream turning movements treated as Special Movement Classes (Special Turns LV and Special Turns HV)

Network Example: Staggered T intersections

Lane Disciplines
Special Movement Classes (Special Turns LV and Special Turns HV) are allocated to specific lanes
Analysis Scenarios

Various analysis scenarios can be considered to investigate the differences between signal platooning and the resulting performance estimates according to the assumptions about approach lane use and exit lanes chosen in departing from an intersection.

The differences between the analysis scenarios can be identified according to differences in midblock lane change implications for internal approach lanes.

Many analysis scenarios are possible considering different lane use patterns, Special Movement Class use, and Lane Movement Flow Proportions. The ARRB Conference 2014 paper was limited to three analysis scenarios. Scenario (ii) of the ARRB paper and Scenario (i) with Special MCs are given below.

Analysis Scenario (i) with Special Movement Classes

- Network OD flows are known in addition to the Site OD flows.
- Lane Movement Flow Proportions for Site 1 West Right and Site 2 East Right movements are specified based on known Network OD flows.
- Equal lane use for all Through approach lanes. This results in implied midblock lane changes.
• Network OD flows are known in addition to the Site OD flows.

• Lane Movement Flow Proportions for Site 1 West Right and Site 2 East Right movements are specified based on known Network OD flows.

• Equal lane use for all Through approach lanes. This results in implied midblock lane changes.

Analysis results for the example

In the next three slides, results are given for:
• Scenario (i) with Special Movement Classes and
• Scenario (ii) without Special Movement Classes (as in the ARRB Conference 2014 paper).

The purpose of comparison is to test the effect of modelling with and without Special Movement Classes.

Detailed tables for other scenario comparisons are presented in the ARRB Conference 2014 paper (available for download on www.sidrasolutions.com/Resources/Articles).
### Lane results

**Comparison of results for Through LANES on Site 1 South internal (Northbound) approach**

<table>
<thead>
<tr>
<th>Approach Lane</th>
<th>Arrival Flow (veh/h)</th>
<th>Capacity (veh/h)</th>
<th>Degree of Saturation (v / c)</th>
<th>Per cent Arriving During Green (%)</th>
<th>Platoon Ratio</th>
<th>Average Delay (s)</th>
<th>95th %ile Back of Queue (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Analysis Scenario (i) with Special Movement Classes for downstream turns</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>South Lane 2</td>
<td>635</td>
<td>988</td>
<td>0.643</td>
<td>86.5%</td>
<td>1.684</td>
<td>5.2</td>
<td>85</td>
</tr>
<tr>
<td>Lane 3</td>
<td>635</td>
<td>988</td>
<td>0.643</td>
<td>75.8%</td>
<td>1.457</td>
<td>10.7</td>
<td>102</td>
</tr>
<tr>
<td><strong>Analysis Scenario (ii) without Special Movement Classes</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>South Lane 2</td>
<td>635</td>
<td>988</td>
<td>0.643</td>
<td>68.9%</td>
<td>1.227</td>
<td>16.0</td>
<td>132</td>
</tr>
<tr>
<td>Lane 3</td>
<td>635</td>
<td>988</td>
<td>0.643</td>
<td>75.8%</td>
<td>1.457</td>
<td>10.7</td>
<td>102</td>
</tr>
</tbody>
</table>

### Movement results

**Comparison of results for Left and Through MOVEMENTS on Site 1 South internal (Northbound) approach**

<table>
<thead>
<tr>
<th>Movement</th>
<th>Arrival Flow (veh/h)</th>
<th>Degree of Saturation (v / c)</th>
<th>Percent Arriving During Green (%)</th>
<th>Platoon Ratio</th>
<th>Average Delay (s)</th>
<th>95th %ile Back of Queue (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Analysis Scenario (i) with Special Movement Classes for downstream turns</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>630</td>
<td>0.425</td>
<td>88.1%</td>
<td>1.074</td>
<td>6.0</td>
<td>40</td>
</tr>
<tr>
<td>Thru</td>
<td>1270</td>
<td>0.643</td>
<td>81.1%</td>
<td>1.560</td>
<td>8.0</td>
<td>102</td>
</tr>
<tr>
<td><strong>Analysis Scenario (ii) without Special Movement Classes</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>630</td>
<td>0.425</td>
<td>89.0%</td>
<td>1.085</td>
<td>5.9</td>
<td>37</td>
</tr>
<tr>
<td>Thru</td>
<td>1270</td>
<td>0.643</td>
<td>86.8%</td>
<td>1.342</td>
<td>13.4</td>
<td>132</td>
</tr>
</tbody>
</table>
Intersection results

Comparison of results for Site 1
(Cycle Time = 100, Phase Times: 57, 13, 30 for both Scenarios)

<table>
<thead>
<tr>
<th>Arrival Flow (veh/h)</th>
<th>Degree of Saturation (v / c)</th>
<th>Average Delay (s)</th>
<th>95th %ile Back of Queue (m)</th>
<th>Total Operating Cost ($/year)</th>
<th>Total CO₂ Emission (kg/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Analysis Scenario (i) with Special Movement Classes for downstream turns</strong></td>
<td>3720</td>
<td>0.898</td>
<td>17.3</td>
<td>157</td>
<td>761,907</td>
</tr>
<tr>
<td><strong>Analysis Scenario (ii) without Special Movement Classes</strong></td>
<td>3720</td>
<td>0.898</td>
<td>19.2</td>
<td>157</td>
<td>794,784</td>
</tr>
</tbody>
</table>

Findings

The following can be observed from the SIDRA INTERSECTION results for the example:

- There are significant differences in platoon characteristics (percent arriving during green and platoon ratio) modelled per lane and per movement. As a result, there can be significant differences in performance statistics estimated on a per lane and per movement (lane group) basis.

- Although the performance estimates for different analysis scenarios look close generally, the differences in individual lane values can be significant especially for the back of queue estimates when:
  - the approach (midblock) distance between intersections is low and lane blockage effects are likely to come in, and
  - when sensitivities are higher at higher degrees of saturation.
Findings

- The use of **Special Movement Classes** improves the quality of estimation of signal coordination effects and this can have a significant impact on performance estimates, especially the queue length (and the corresponding probability of blockage).
- **Average delay values per movement can hide larger values of lane delay when there is significant unequal lane use.**

Conclusions

A lane-based analytical network model that derives second-by-second platoon patterns as a function of signal offsets for signalised intersections is discussed. The importance of modelling individual lane departure and arrival patterns, and consideration of implied midblock lane changes have been emphasised.

This method coupled with a lane-based model allowing for the **backward spread of congestion** and upstream **capacity constraint** is expected to produce better results in **assessing signal coordination quality** and optimising signal offsets.

There are significant differences in **platoon characteristics modelled per lane and per movement**, and with and without the use of the **Special Movement Class** method. As a result, there can be significant differences in performance statistics.
Conclusions

Performance statistics estimated on a per lane and per movement (lane group / link) basis may lead to different conclusions. Lane performance values are better indicators of intersection operating conditions.

Detailed analyses as described in this presentation are justified for important projects involving design of networks of closely-spaced intersections as in this example.

Real-life surveys of lane use at closely-spaced intersections and analyses using micro-simulation to compare results with those from analytical models are recommended.

END OF PRESENTATION

Thank you!

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