Signal platoon patterns by approach lane use and movement class

Rahmi Akçelik and Mark Besley

33rd Conference of Australian Institutes of Transport Research (CAITR 2015)
Melbourne, February 2015
Signal platoon patterns by approach lane use and movement class

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”! 

Individual lanes have different characteristics

Short lane analysis (flaring)

Slip / Bypass lanes
Lane-based model for NETWORKS

Lane Movements

Origin – Destination (OD) Movements

Lane Movement: South Lane 1 to West Lane 2
Lane-based model for NETWORKS

Lane Changes

Second-by-second platoon patterns move accordingly

Exit lane flow rates of the upstream Site

Inflow Rate or Outflow Rate applies to all lanes uniformly

Upstream lane flow rates at midblock location

Lane change flow rates at midblock location

Downstream lane flow rates at midblock location

Approach lane flow rates of the downstream Site (subject internal approach)

Upstream Section of the Internal Approach

Downstream Section of the Internal Approach
Example with Net Inflow

Second-by-second platoon patterns move accordingly

Lane-based model for NETWORKS

**Upstream flow rates at entry to the approach**
- Total upstream flow rate at entry = 800

**Upstream flow rates at midblock virtual connection**
- Midblock net inflow rate = 100

**Downstream flow rates at the approach stop line**
- Total arrival flow rate = 900

**Upstream lane flow rates after short lane**
- Upstream lane flow rates at midblock connection adjusted for inflow
- Lane change = 550 - 450 = 100

**Approach lane flow rates**
Lane-based model for networks

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.
Departure patterns at upstream lanes

Backward spread of congestion (reduced upstream capacity) → Capable constraint (reduced downstream arrival flows)

Backward spread of congestion and capacity constraint 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.

Displayed phase times are shown. The green periods shown represent the Site Reference Phases.
Arrival patterns at downstream lanes

**Platoon Dispersion**: a unique model (optional)
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

Two-segment lane

BUS SLIP (BYPASS) LANE at roundabout - other traffic use the roundabout entry lane

Approach Distance = 70 m
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

Through traffic in different lanes have different destinations downstream.

Lane allocation by SPECIAL MOVEMENT CLASSES for turning movements.

Doncaster Road - Eastern Freeway, Melbourne
Network Example: Fully Signalised Roundabout

Through traffic in different lanes have different destinations downstream.

Lane allocation by SPECIAL MOVEMENT CLASSES for turning movements.

Network Displays.

Cemetery Road East - Swanston Street, Melbourne
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](https://www.sidrasolutions.com/Resources/Articles) (available for download).
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)

This example assumes perfect knowledge of Network OD volumes

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.
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.
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) are.

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).
### 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>South Lane 2</td>
<td>635</td>
<td>988</td>
<td>0.643</td>
<td>86.5%</td>
<td>1.664</td>
<td>5.2</td>
<td>65</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>

**Analysis Scenario (i) with Special Movement Classes for downstream turns**

**Analysis Scenario (ii) without Special Movement Classes**
## 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>69.8%</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></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3720</td>
<td>0.898</td>
<td>17.3</td>
<td>157</td>
<td>761,907</td>
<td>249,854</td>
</tr>
<tr>
<td><strong>Analysis Scenario (ii) without Special Movement Classes</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3720</td>
<td>0.898</td>
<td>19.2</td>
<td>157</td>
<td>794,784</td>
<td>255,775</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.
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.
Thank you!

Rahmi Akçelik & Mark Besley
www.sidrasolutions.com