Comparing lane based and lane-group based models of signalised intersection networks

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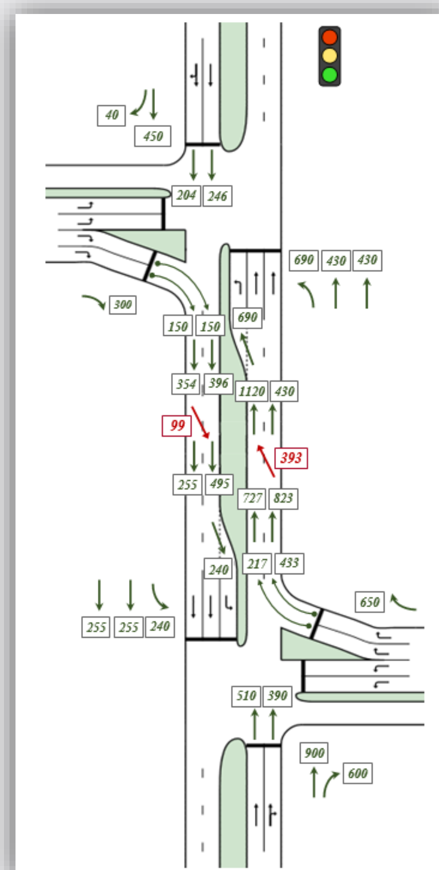
The Paper

Comparing lane based and lane-group based models of signalised intersection networks

Two analytical approaches for modelling signalised intersection networks are compared:

- traditional model based on lane groups or links through aggregation of individual lane conditions
- a new lane-based model of upstream departure and downstream arrival patterns as well as midblock lane changes.

The differences between the two models are expected to be particularly important in evaluating closely-spaced intersections with high demand flows where vehicles have limited opportunities for lane changes between intersections.



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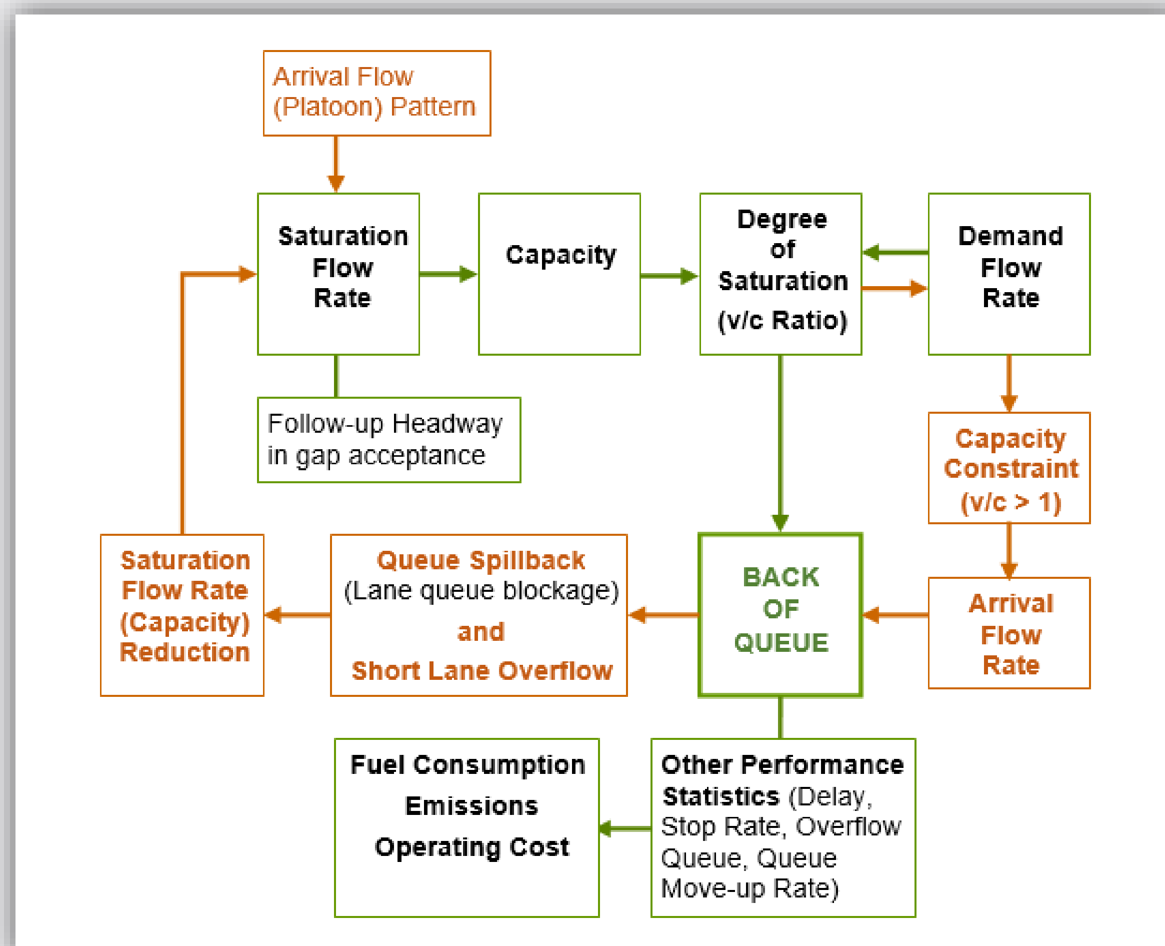
Summary:
Unique Features of the Lane-based Network Model

The **lane-based analytical network model** described in the paper was implemented in the **SIDRA INTERSECTION** software in recent years.

The **orange-coloured boxes and lines** in this flow chart show the unique aspects of this model.

The central role of **Back of Queue** (average and probabilities) in this process is emphasised.



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Related Publications -1

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1. AKÇELIK, R. (2013). Lane-based micro-analytical model of a roundabout corridor. CITE 2013 Annual Meeting, Calgary, Alberta, Canada.
2. AKÇELIK, R., SMIT, R. BESLEY, M. (2014). Recalibration of a vehicle power model for fuel and emission estimation and its effect on assessment of alternative intersection treatments. TRB 4th International Roundabout Conference, Seattle, WA, USA.
3. AKÇELIK, R. (2014). Modeling Queue Spillback and Upstream Signal Effects in a Roundabout Corridor. TRB 4th International Roundabout Conference, Seattle, WA, USA.
4. YUMLU, C., MORIDPOUR, S. and AKÇELIK, R. (2014). Measuring and Assessing Traffic Congestion: a Case Study. Paper presented at the AITPM Annual Meeting, Adelaide, Australia.
5. AKÇELIK, R. (2014). A New Lane-Based Model for Platoon Patterns at Closely-Spaced Signalised Intersections. Paper presented at the 26th ARRB Conference, Sydney.

Continued >>

Related Publications - 2

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6. NICOLI, F., PRATELLI, A. and AKÇELIK, R. (2015). Improvement of the West road corridor for accessing to the New Hospital of Lucca (Italy). Paper presented at the *21st International Conference on Urban Transport and the Environment (URBAN TRANSPORT 2015)*, Valencia, Spain.

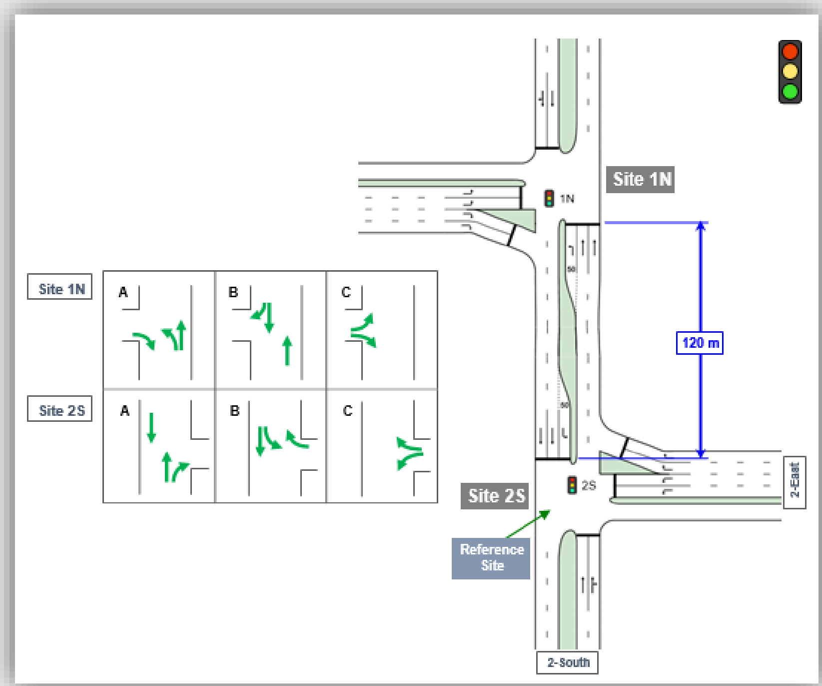
7. AKÇELIK, R. (2015). Modelling signal platoon patterns by approach lane use and movement class. Paper presented at the 21st International Conference on Urban Transport and the Environment (URBAN TRANSPORT 2015), Valencia, Spain, June 2015.

8. AKÇELIK, R. (2015). Development of Network Signal Timing Methodology in SIDRA INTERSECTION. Presentation at the New Zealand Modelling Use Group Conference (NZMUGS 2015), Auckland, New Zealand, Sep 2015.

9. AKÇELIK, R. and BESLEY, M. (2015). Alternative Intersection Analysis Using SIDRA INTERSECTION. Presentation at the ITEANZ Innovative Intersections Seminar, Melbourne, November 2015.

The Presentation

- Lane-based Network Model
- Movement Classes
- Signal Platoon Model
- Example: Staggered T intersection
- Findings
- Conclusions



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Lane-based Network Model

A lane-based model is particularly important in evaluating

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

Developed for the SIDRA INTERSECTION software.

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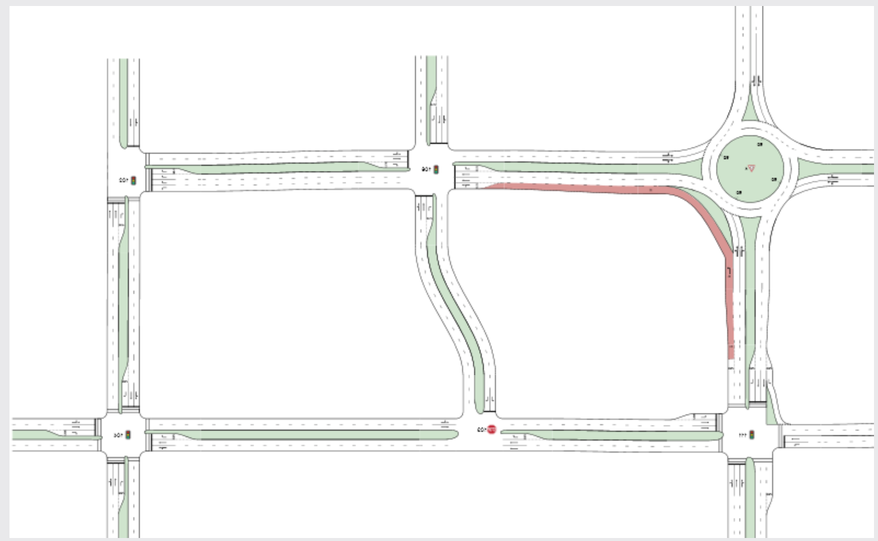
Basic Aspects of the Lane-Based Network Model

- Lane-based modelling for intersections
- Lane-based network model with lane changes
- Lane blockage, capacity reduction and capacity constraint using an iterative method
- Importance of back of queue model and lane-based probability of blockage
- Use of Special Movement Classes for closely-spaced intersections
- Signal platoon model



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Importance of Lane-Based Modelling

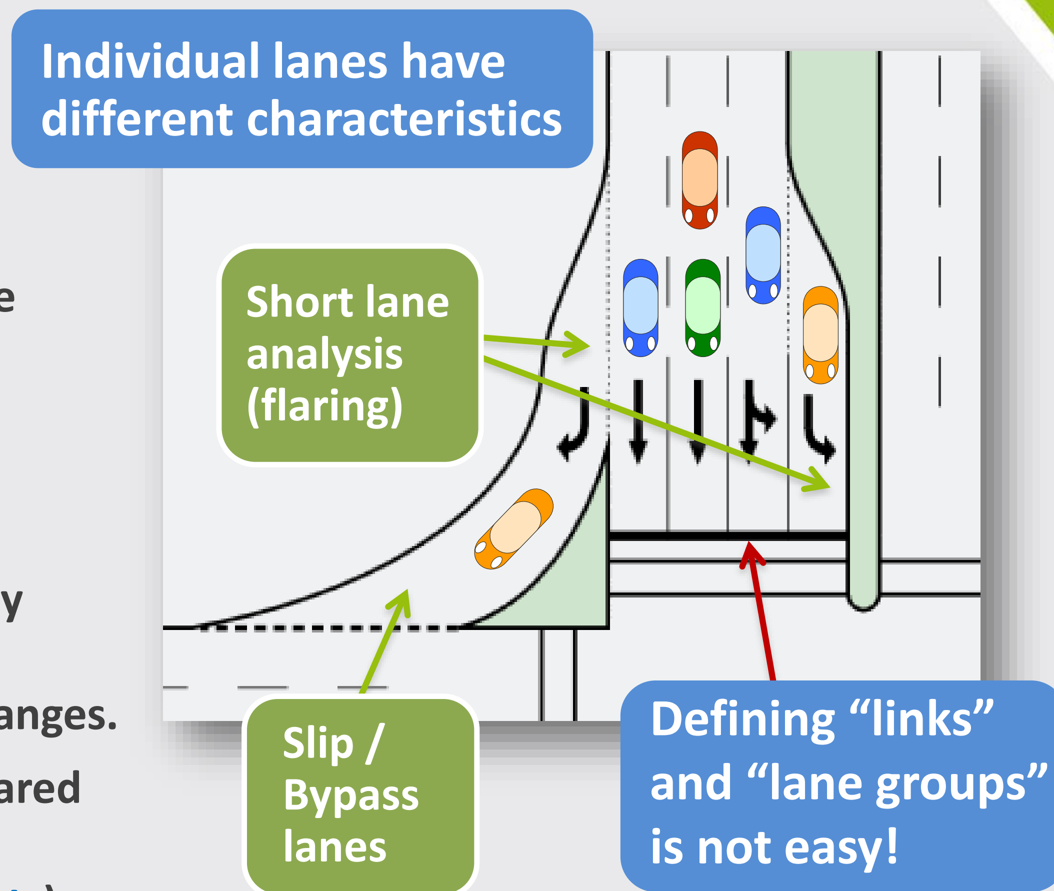
LANE-BASED

Input >> MODEL >> Output

Important for

- INTERSECTIONS
  Unequal lane flows, De facto exclusive lanes, Short lanes, Slip/Bypass lanes, Circulating lane use and Dominant - Subdominant lanes at roundabouts
- NETWORKS
  Lane queues, queue spillback, capacity constraint, signal platoon arrival and departure patterns, midblock lane changes.

More realistic and reliable analysis compared with traditional lane group (link) - based methods (e.g. HCM except for roundabouts).



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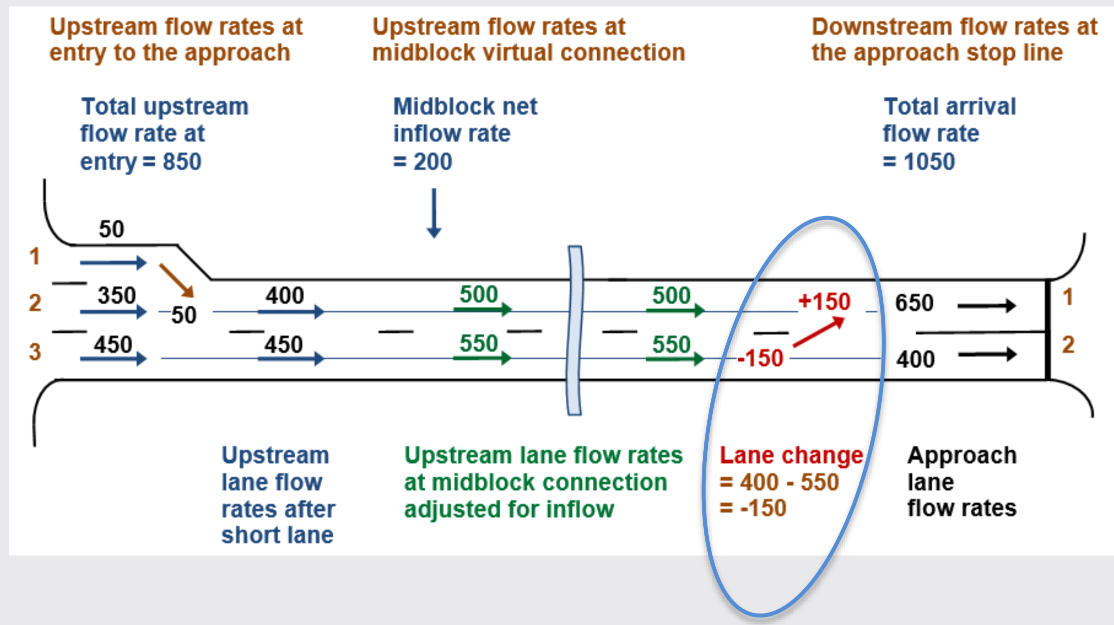
Lane-Based Network Model: Midblock Lane Changes

Matching of Upstream and Downstream Lane Flow Rates:

- Implied and specified midblock lane changes
- Effect of this on platoon arrival patterns at signals

Tools to minimise midblock lane flow changes on short internal approaches:

- Special Movement Classes
- Lane Movement Flow Proportions
- Lane Utilisation Ratios



Lane-Group (Link) Based Modelling

In traditional lane-group (link) based network models:

- individual lane conditions are aggregated
- there is not sufficient information about queue lengths, lane blockage probabilities, backward spread of queues, and so on
- there are unnecessary approximations in the saturation flow estimation process and this affects:
  - capacity estimation therefore estimation of all performance parameters including queue length
  - signal timing (cycle time and green time) calculations.

Lane level of detail helps with capacity and performance estimation as well as signal timing analysis.

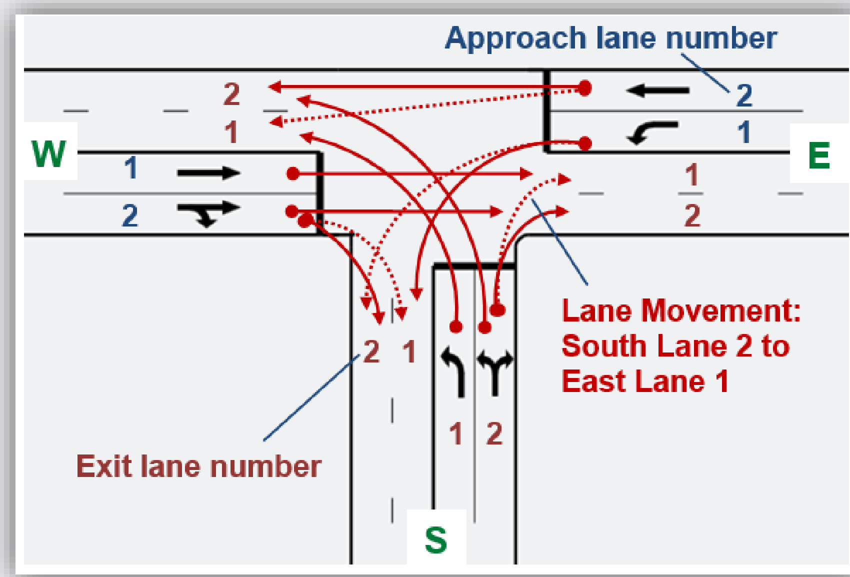
Departure Patterns at Upstream Lanes

Backward spread of congestion (reduced upstream capacity) ⟷ **Capacity constraint (reduced downstream arrival flows)**

Backward spread of congestion and capacity constraint are highly interactive with opposing effects.

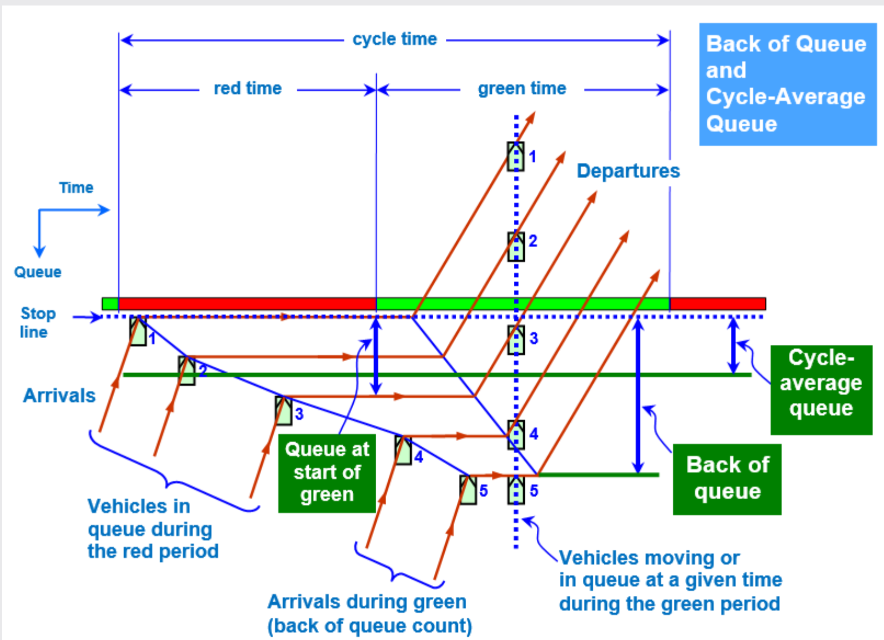
SIDRA INTERSECTION uses a network-wide iterative process to find a solution that balances these opposing effects.

Lane Movement Flow Proportions



Importance of Back of Queue Model

Back of Queue Percentile and **Probability of Blockage** values are based on the **variability of back of queue** values in individual lanes



Back of Queue is important for modelling of **short lane overflow** and **queue spillback in networks**

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Movement Classes

Light Vehicles

Heavy Vehicles

Buses

Bicycles

Large Trucks

Light Rail / Trams

User Classes
(for special movement treatment)

Special Movement Classes >>

Combined with the lane-based method, Movement Classes allow modelling of Bus Priority Lanes, Bicycle Lanes, and so on …

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Special Movement Classes

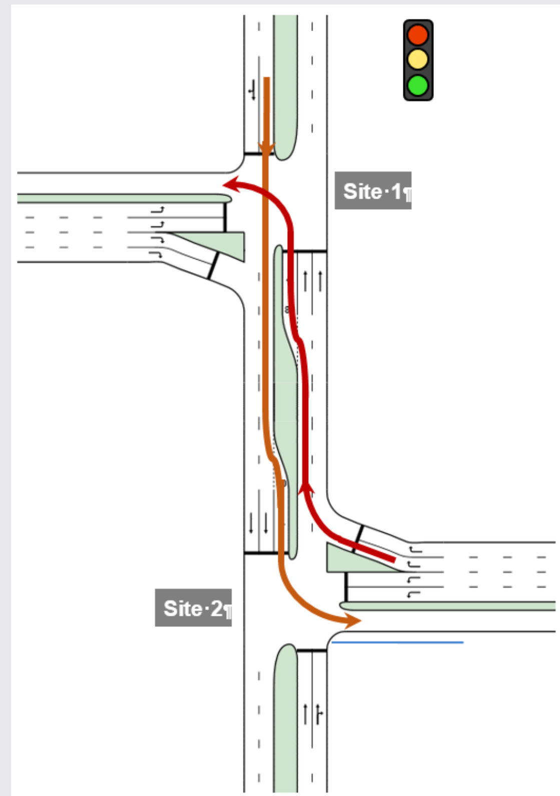
Examples of Special Movement Classes include:

- dogleg movements at staggered T intersections, and
- through movements at external approaches that become turning movements at downstream internal approaches.

These movements can be assigned to separate lanes and separate signal phases, and their second-by-second platoon patterns can be tracked through the network separately.

The use of Special Movement Classes allows better estimation of unequal lane use at closely-spaced intersections.

This improves the quality of signal platoon modelling and is expected to produce better results in assessing signal coordination quality using signal offsets.



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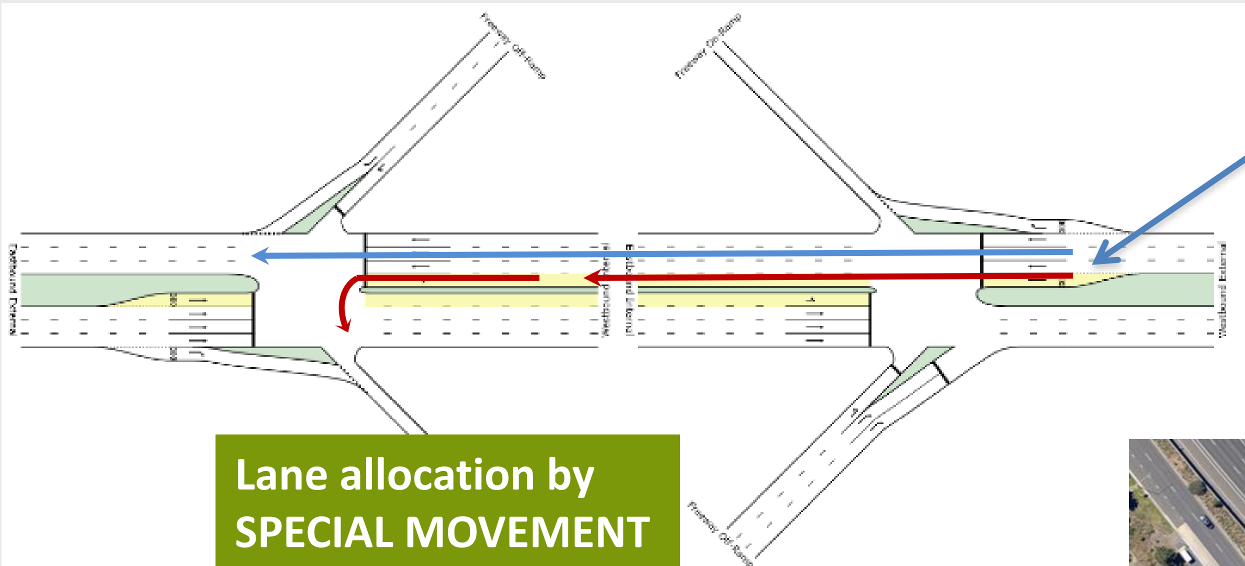
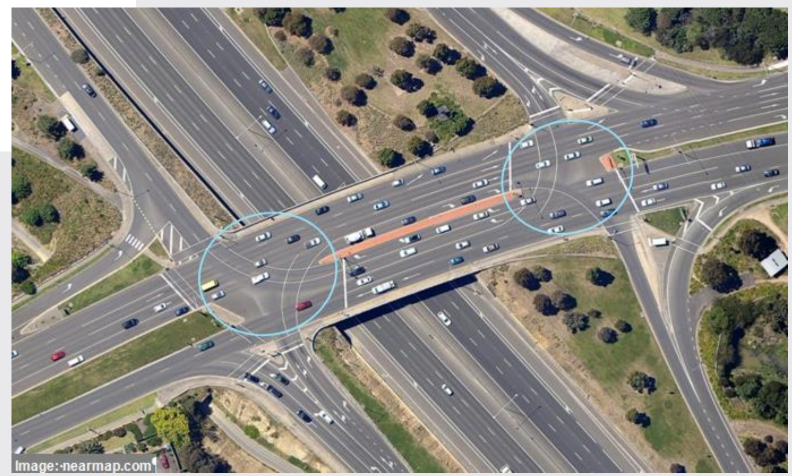
Special Movement Classes:
Freeway Diamond Interchange Example



THROUGH traffic in different lanes have different destinations downstream

Lane allocation by SPECIAL MOVEMENT CLASSES for turning movements



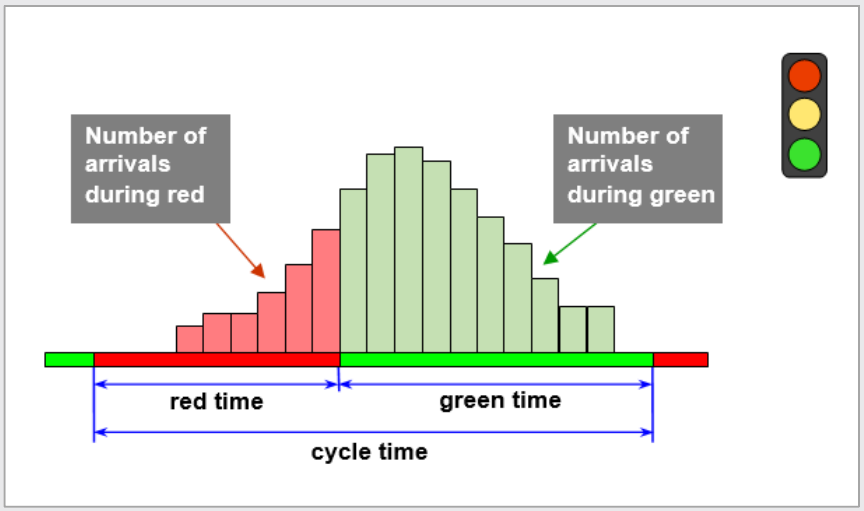
Signal Platoon Model

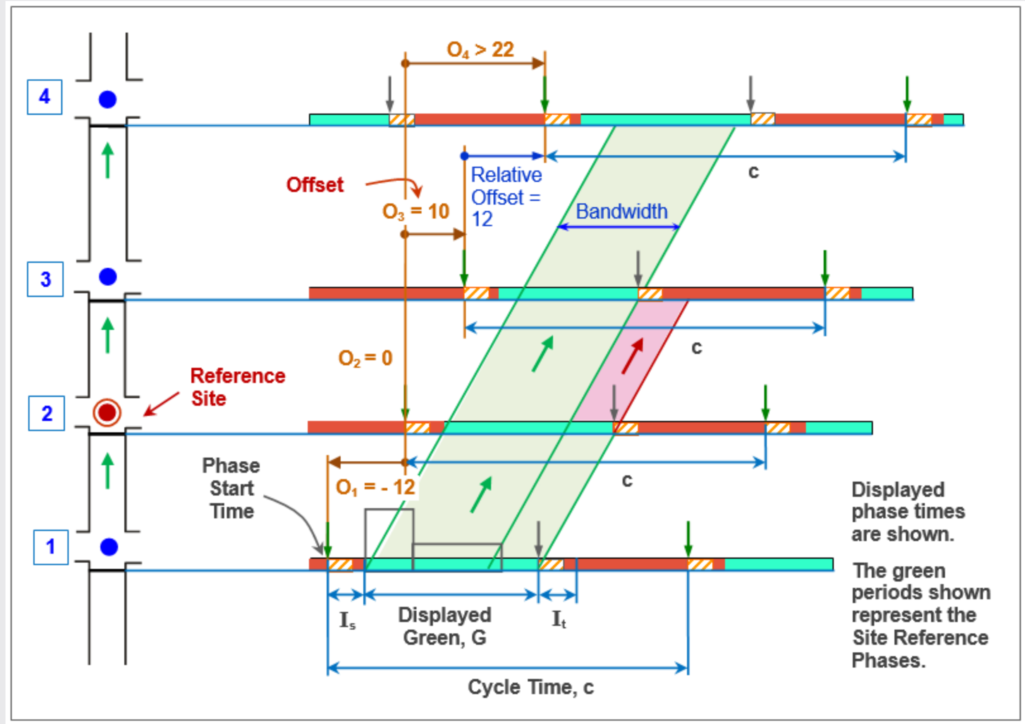
Using **signal offsets** for signal coordination, **LANE-BASED (not link-based) second-by-second platoon patterns** are modelled to estimate

Percent Arriving During Green

Platoon Ratio

Arrival Types





Signal Platoon Model

Modelling of departure patterns (including estimation of saturation flow rates) at upstream lanes takes into account

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

Second-by-second downstream arrival patterns from upstream departure patterns take into account arrival flow and saturation flow rates of individual lanes at both upstream and downstream intersections.

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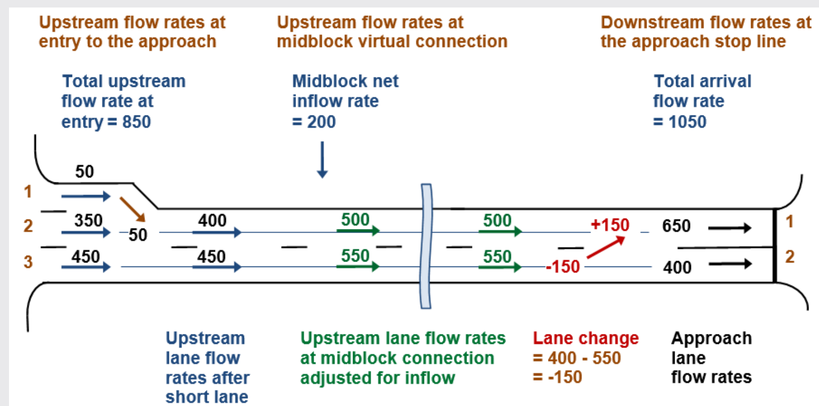
Lane-based Modelling of Signal Platoons

The **lane-based** modelling of **platoon arrival patterns** at downstream approach lanes takes into account:

- **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,
- **midblock inflow and outflow rates** implied by turning volumes, and
- **Movement Classes** (Light Vehicles, Heavy Vehicles, Buses, etc.) due to different lane use and approach cruise speeds.



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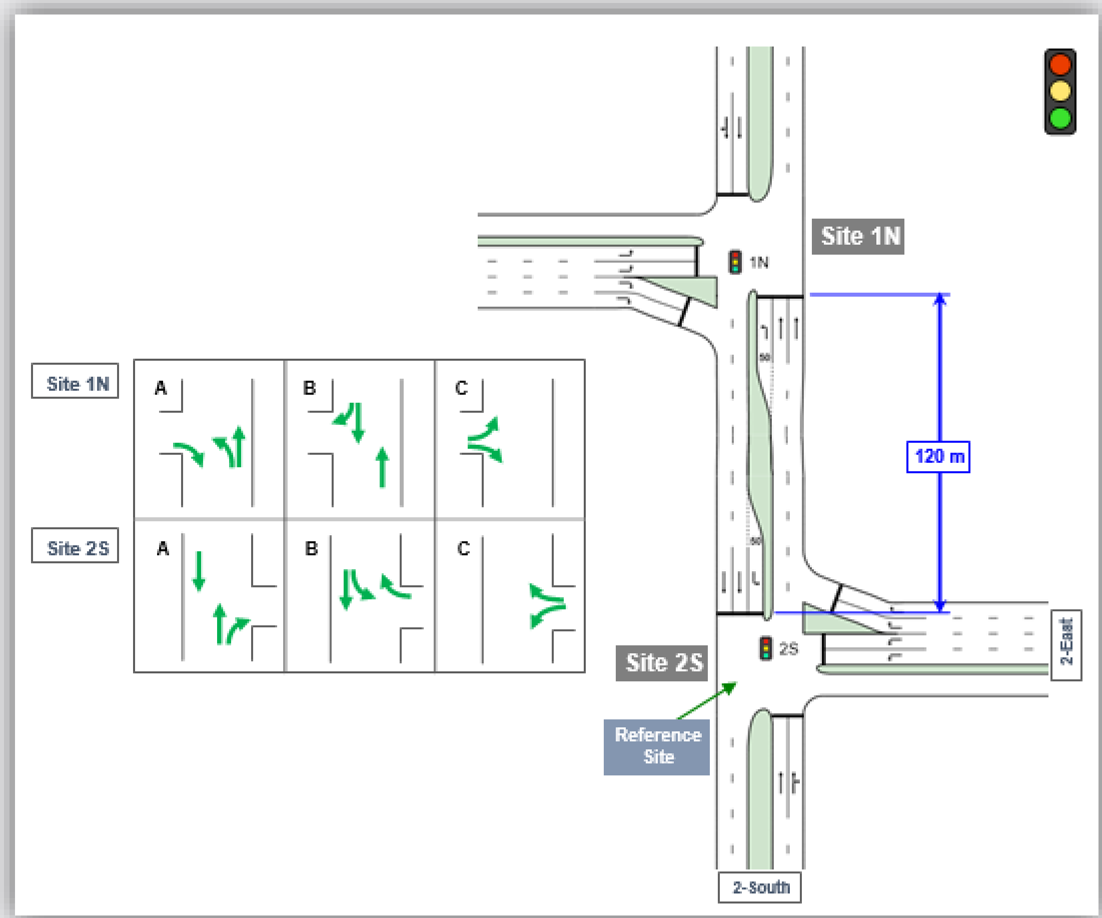
Example : Staggered T intersections

A detailed example of **staggered T intersections** with 120 m distance between them is presented.

Detailed description is given in the paper.



Lane-Based Analysis Scenarios

Two lane-based analysis scenarios are considered to investigate the differences between the network model results including signal platooning and the resulting performance estimates with and without the use of Special Movement Classes and unequal lane use specifications to minimise midblock lane changes.

Both scenarios use default Lane Movement Flow Proportions (100% flow to the most direct exit lane).

Many other analysis scenarios are possible considering different lane use patterns and Lane Movement Flow Proportions.

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

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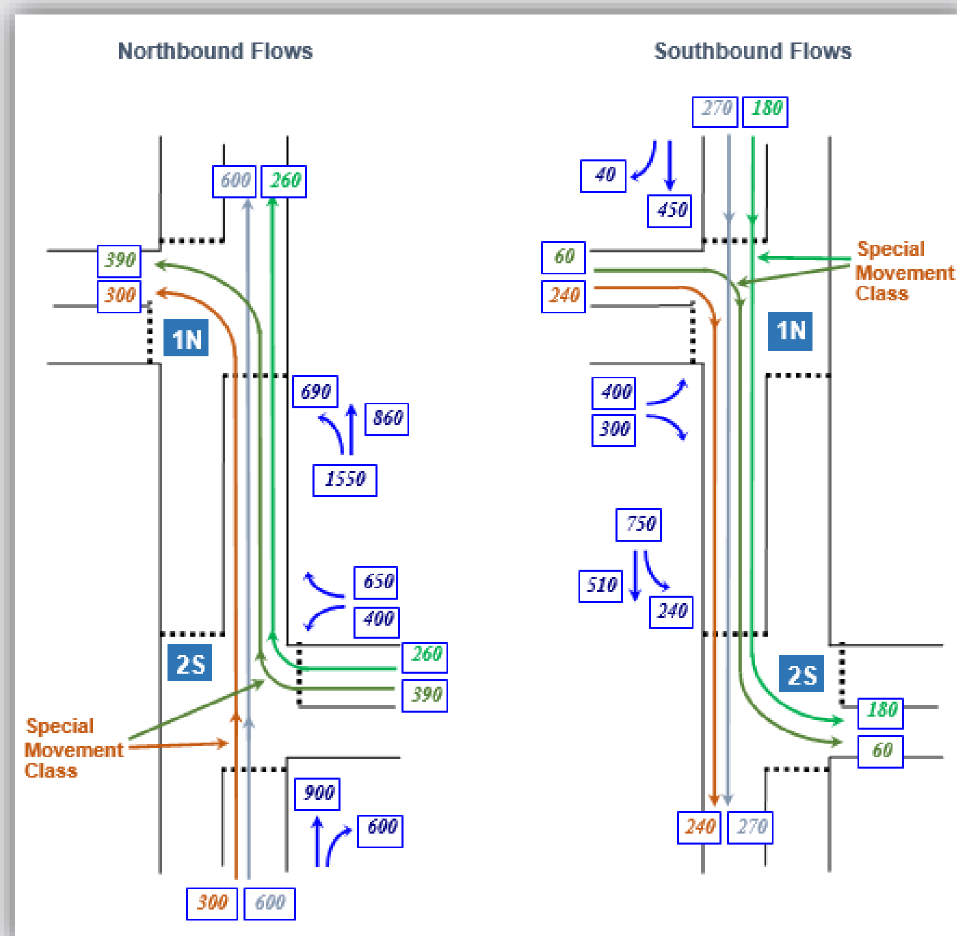
Site and Network Origin-Destination Flows

The method uses intersection turning volumes (**Site Origin – Destination [OD] flows**) as network flow input.

Network OD flows that match the Site OD flows are also used for analysing differences between lane-based analysis scenarios **with and without knowledge of Network OD flows**.



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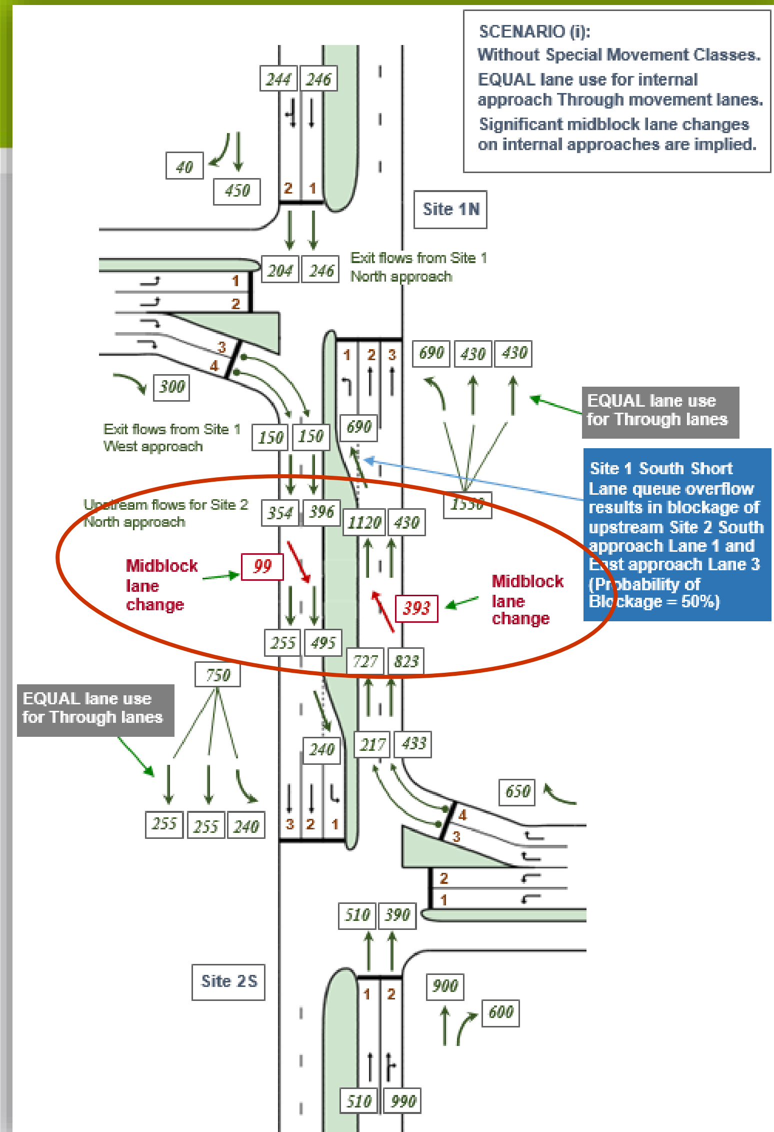
Lane-Based Analysis Scenario (i)

Only the Site OD flows (intersection turning volumes) are known at each intersection, and the **Network OD flows are not known**.

Special Movement Classes not used.

Equal lane use (equal lane degrees of saturation) applies to lane groups. This results in **significant midblock lane changes**.



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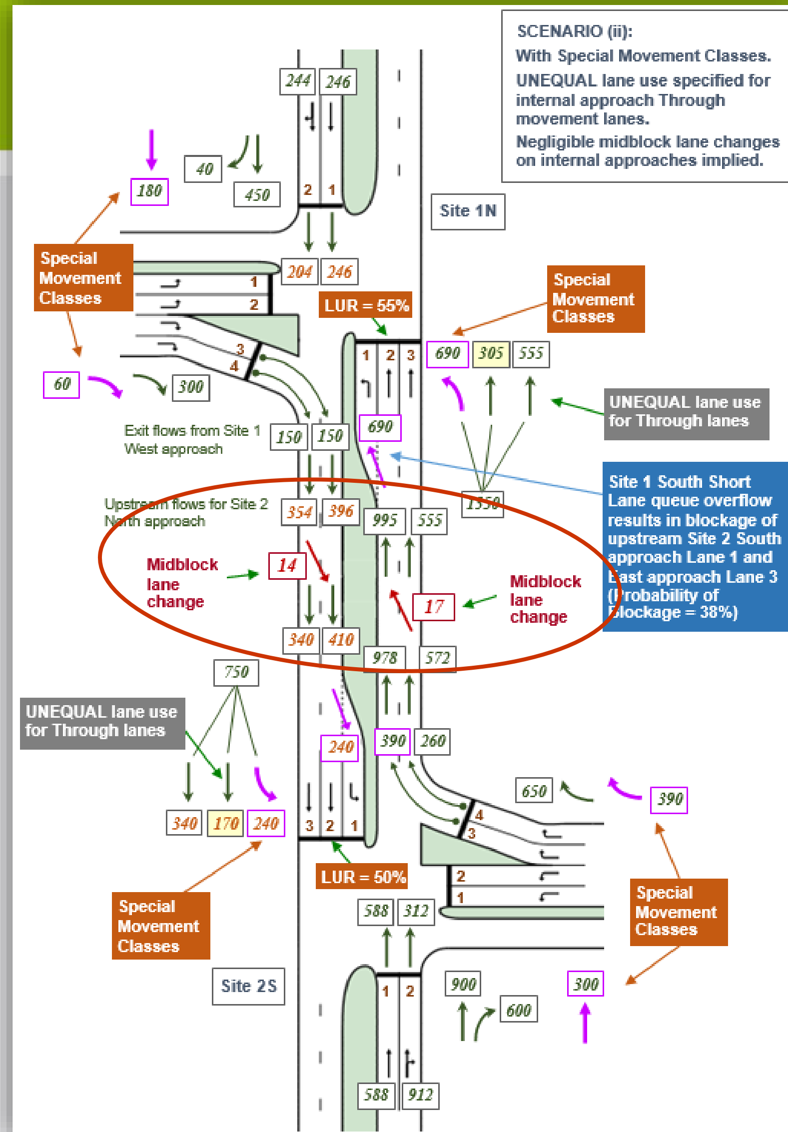
Lane-Based Analysis Scenario (ii)

Network OD flows are known in addition to the Site OD flows.

Special Movement Classes are assigned to upstream and downstream lanes according to destinations at the downstream intersection.

Lane Utilisation Ratios less than 100% are specified for internal approach Through movement lanes at both intersections in order to **minimise midblock lane changes**.



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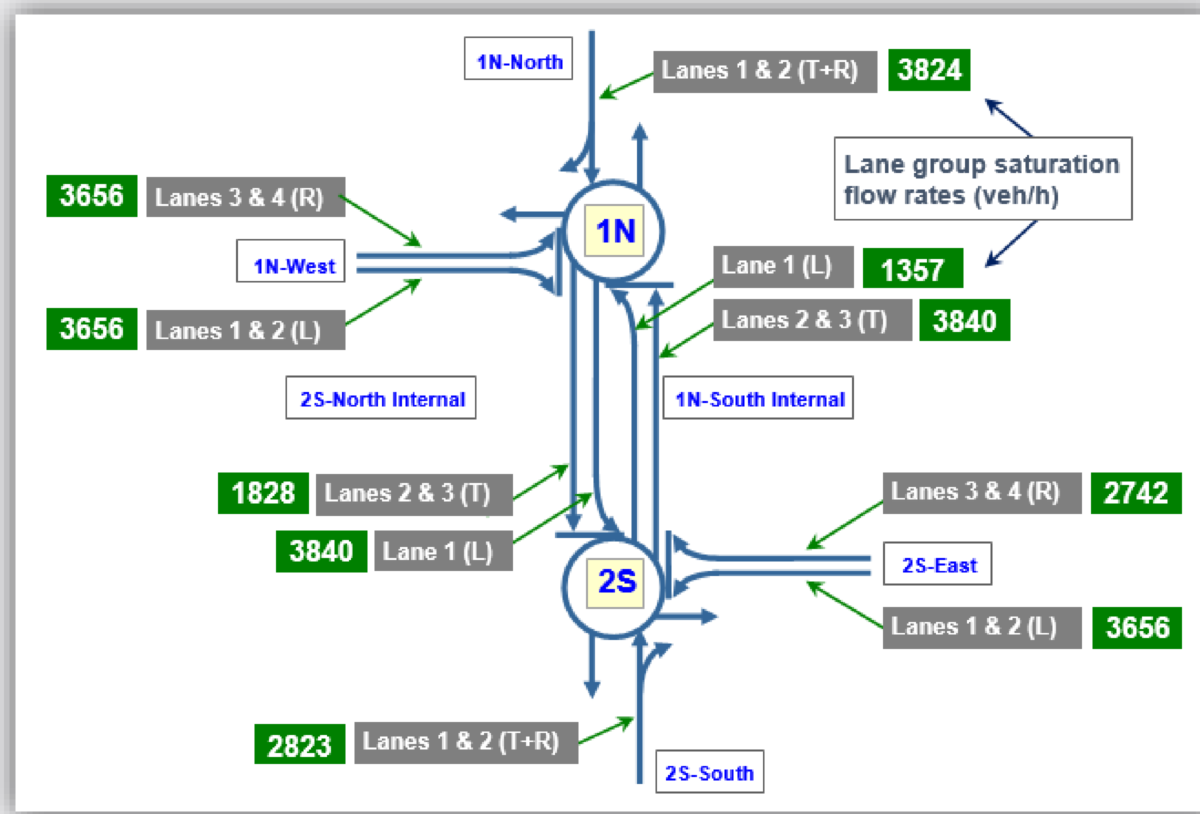
Lane-Group (Link) Based Analysis: Aggregate Saturation Flow Rates

Lane-group (link) based network model of the example for Scenario (i) is given here. This model aggregates multiple lanes into a single lane group (link).

The link saturation flow rates shown are calculated manually from SIDRA INTERSECTION lane saturation flow estimates. These allow for short lane, lane blockage and unequal lane use effects.



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Results for Lane-based Model Scenarios (i) and (ii)

Lanes and Lane Groups	Arrival Flow (veh/h)	Saturation Flow (veh/h)	Degree of Saturation (v / c)	Per cent Arriving During Green (%)	Platoon Ratio	Average Delay (s)	95th %ile Back of Queue (m)
LANE BASED MODEL Analysis Scenario (i) Network OD Volumes NOT known. Special Movement Classes or Unequal Lane Use NOT specified.							
LANE BASED MODEL: Site 1N - South approach [Saturation Flows program-determined]							
Lane 1	690	1357	0.897	58.8%	1.038	34.9	196
Lane 2	430	1920	0.292	76.2%	0.994	3.3	39
Lane 3	430	1920	0.292	66.6%	0.869	4.4	54
LANE BASED MODEL: Site 2S - East approach [Saturation Flows program-determined]							
Lane 3	217	914	0.790	30.0%	1.000	45.1	72
Lane 4	433	1828	0.790	30.0%	1.000	40.5	133
LANE BASED MODEL Analysis Scenario (ii) Network OD Volumes known. Special Movement Classes and Unequal Lane Use specified.							
LANE BASED MODEL: Site 1N - South approach [Saturation Flows program-determined]							
Lane 1	690	1459	0.835	45.4%	0.801	23.8	171
Lane 2	305	1920	0.207	98.0%	1.278	0.3	2
Lane 3	555	1920	0.377	90.6%	1.181	1.7	24
LANE BASED MODEL: Site 2S - East approach [Saturation Flows program-determined]							
Lane 3	390	1143	0.991	34.4%	1.000	89.9	201
Lane 4	260	1828	0.413	34.4%	1.000	30.0	62

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Results for Lane-Based Model Scenario (i) and the Lane Group (Link) Based Model

Lanes and Lane Groups	Arrival Flow (veh/h)	Saturation Flow (veh/h)	Degree of Saturation (v / c)	Per cent Arriving During Green (%)	Platoon Ratio	Average Delay (s)	95th %ile Back of Queue (m)
LANE BASED MODEL Analysis Scenario (i) Network OD Volumes NOT known. Special Movement Classes or Unequal Lane Use NOT specified.							
LANE BASED MODEL: Site 1N - South approach [Saturation Flows program-determined]							
Lane 1	690	1357	0.897	58.8%	1.038	34.9	196
Lane 2	430	1920	0.292	76.2%	0.994	3.3	39
Lane 3	430	1920	0.292	66.6%	0.869	4.4	54
LANE BASED MODEL: Site 2S - East approach [Saturation Flows program-determined]							
Lane 3	217	914	0.790	30.0%	1.000	45.1	72
Lane 4	433	1828	0.790	30.0%	1.000	40.5	133
LANE-GROUP BASED MODEL Saturation flow rates and signal timings from LANE BASED model Scenario (i) used.							
LANE-GROUP BASED MODEL: Site 1N - South approach [Saturation Flows specified]							
Group 1 (Lane 1)	690	1357	0.897	41.0%	0.724	41.0	124
Group 2 (Lanes 2 & 3)	860	3840	0.292	82.2%	1.072	2.9	30
LANE-GROUP BASED MODEL: Site 2S - East approach [Saturation Flows specified]							
Group 2 (Lanes 2 & 3)	650	2742	0.790	30.0%	1.000	38.2	95

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Findings -1

The following can be observed from the results given for the example:

- Equal lane use assumption implies high midblock lane change values in Scenario (i). This is not expected in real-life operations when the distance between the two intersections is small.
- With the use of special movement classes for lane assignment based on the knowledge of network OD flows, the implied midblock lane changes are reduced but still significant. Various assumptions are possible to minimise midblock lane changes when real-life observations of lane use are not available. In this paper, unequal lane use is specified for internal approach Through movement lanes in Scenario (ii). This minimises the midblock lane changes.

  This is expected to be a more realistic representation of real-life operations in this case.

Findings - 2

- The analysis results for this example demonstrate significant effects of unequal lane use and lane blockage of upstream lanes (queue spillback) on the capacity and performance of the network.
- Signal timings get affected by unequal lane use as well, and these in turn affect platoon characteristics, delay and queue length results.
- Both the lane-group (link) based model and Scenario (i) of the lane-based model underestimated the delay and queue length on the East approach of Site 2S due to the assumption of equal lane use. On the other hand, in Scenario (ii) of the lane based model, the use of Special Movement Classes identified the unequal lane use and resulted in high degree of saturation, delay and queue length values in Lane 3 of the East approach at Site 2S.

Findings - 3

- The lane-group (link) based model does not estimate performance of individual lanes. The differences in individual lane values can be significant. Average delay and queue length values per lane group can hide larger values of delay and queue length for individual lanes used by the movement when there is significant unequal lane use.
- The lane-based model involves estimation of saturation flow rates including the effects of short lanes and lane blockages. While this is a dynamic process, the saturation flow rates used for the lane-group based analysis in this paper are constant values derived from lane saturation flow rates estimated by SIDRA INTERSECTION for the specific conditions of Scenario (i).

Conclusions -1

Two lane-based analytical network model scenarios and a lane-group (link) based network model were analysed using the SIDRA INTERSECTION software.

The resulting signal platoon characteristics and the delay and queue length estimates were compared using a staggered T intersection network example.

It is shown that these models can give significantly different results.

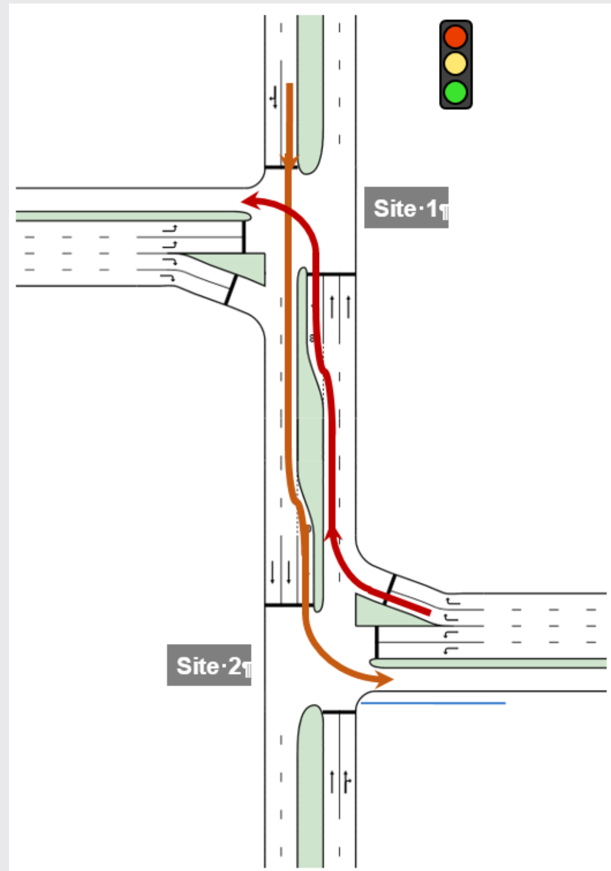
Conclusions - 2

The importance of the modelling of unequal lane use at closely-spaced intersections is emphasised.

This method coupled with a lane-based model allowing for

- the backward spread of congestion,
- upstream capacity constraint,
- special movement classes,
- midblock lane changes,
- as well as features such as short lane overflow

is expected to produce better results in assessing signal coordination quality and optimising signal offsets.



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Further Work Recommended

Further analyses of different lane use scenarios are recommended for their effects on signal platoon patterns and resulting performance estimates.

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!

Dr Rahmi Akçelik

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