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REPRINT

A New Lane-Based Model for Platoon Patterns at Closely-Spaced Signalised Intersections

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NOTE:

This paper is related to the intersection analysis methodology used in the SIDRA INTERSECTION software. Since the publication of this paper, many related aspects of the traffic model have been further developed in later versions of SIDRA INTERSECTION. Though some aspects of this paper may be outdated, this reprint is provided as a record of important aspects of the SIDRA INTERSECTION software, and in order to promote software assessment and further research.

A NEW LANE-BASED MODEL FOR PLATOON PATTERNS AT CLOSELY-SPACED SIGNALISED INTERSECTIONS

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ABSTRACT

This paper discusses a new analytical lane-based method for determining platoon patterns at closely-spaced signalised intersections. The method has been developed for the SIDRA INTERSECTION software. Traditional network models using "links" (or lane groups) based on aggregation of individual lane conditions cannot provide sufficient information about departure and arrival patterns, queue lengths, lane blockage probabilities, backward spread of queues, and so on at a lane level. These are important in modelling signal platoon patterns for estimating performance measures (delay, back of queue, stop rate). This is particularly important in evaluating closely-spaced intersections with 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 in accordance with above requirements. Modelling of *departure patterns* at upstream lanes takes into account (i) probabilities of blockage by downstream queues and the resulting capacity reductions at blocked upstream lanes, (ii) capacity constraint at oversaturated upstream lanes resulting in reduced downstream arrival flows, and (iii) lane choices of movements from approach lanes to exit lanes at the upstream intersection (lane movements). The modelling of *arrival patterns* at downstream approach lanes takes into account implied midblock lane changes. The model is expected to improve assessment of signal coordination quality and optimisation of signal offsets. A detailed example is presented using various analysis scenarios to demonstrate important implications of the lane-based model.

INTRODUCTION

Traditional analytical network models using "links" (or lane groups) based on aggregation of individual lane conditions cannot provide sufficient information about upstream departure and downstream arrival patterns, queue lengths, lane blockage probabilities, backward spread of queues, proportions of traffic arriving during green, and so on at an individual lane level. These requirements are important in modelling the forward movements of platoons at signalised intersections for estimating performance measures (delay, back of queue, stop rate). In particular, estimation of lane queues is problematic with link-based models. These issues are even more important in evaluating closely-spaced intersections with high demand flows where vehicles have limited opportunities for lane changes between intersections.

At the same time, traditional network models have been concerned more about modelling forward movement of vehicle platoons than backward spread of queues between intersections (queue spillback) and capacity constraint (demand starvation) related to oversaturated intersection conditions (Taylor and Abdel-Rahim 1998). Although all these elements are important, the lack of modelling of the capacity-reducing effect of blockage of departures by downstream queues and capacity constraint for oversaturated conditions cannot provide a satisfactory network model for high traffic demand conditions experienced in more recent times. Discussion of the lane-based model used in the SIDRA INTERSECTION software in relation to modelling of lane blockage (queue spillback) effects has been presented in previous papers by the author (Akçelik 2013, 2014). This paper discusses the implications of using a lane-based method for the modelling of signal platoons.

While estimation of individual lane capacities, lane flows and lane queues is important in assessing performance of a single intersection (Akçelik 1980, 1981, 1984, 1989, 1997), this becomes even more important in network modelling. The use of a lane-based model is essential since saturation levels of individual lanes at upstream and downstream locations may differ significantly due to unequal lane utilisation, different levels of lane blockage, and so on. The backward spread of congestion and upstream capacity constraint makes downstream and upstream lane departure and arrival patterns, lane capacities, lane flows and lane queues highly interdependent especially in the case of closely-spaced intersections. A lane-based model is needed to take these interactions into account for reliable modelling of network performance. The model is expected to produce better results in assessing signal coordination quality and optimising signal offsets.

The basic aspects of the lane-based network model are described briefly in the next section followed by a brief discussion of concepts related to modelling of vehicle platoons at signalised intersections and an example using various analysis scenarios to demonstrate important implications of the lane-based model.

A NEW LANE-BASED NETWORK MODEL

The fundamental elements of the lane-based traffic network model developed for, and implemented in, the SIDRA INTERSECTION software Version 6 are:

(i) determination of the backward spread of congestion as queues on downstream lanes block upstream lanes,

(ii) application of capacity constraint to oversaturated upstream lanes for determining exit flow rates, thus limiting the flows entering downstream lanes, and

(iii) modelling second-by-second departure and arrival (platoon) patterns at signals taking into account arrival flow and saturation flow rates of individual lanes at both upstream and downstream intersections.

The first two elements are highly interactive with opposing effects. A network-wide iterative process is used to find a solution that balances these opposing effects. This process is implemented as follows:

- Intersection turning volumes specified as input and adjusted for Unit Time for Volumes, Peak Flow Factor, Flow Scale and Growth Rate parameters are treated as *demand flow rates*.
- Differences between upstream and downstream demand flow rates of internal approaches (resulting from differences in input volumes) are treated as *midblock inflows (volume gains) and outflows (volume losses)*.
- *Capacity constraint* is applied to departures from oversaturated lanes in determining *exit (departure) flow rates*. Accordingly, the exit flow rate is determined as the smaller of arrival flow rate and capacity.
- For each internal approach, *upstream lane flow rates* are determined from exit flow rates according to origin-destination characteristics of traffic departing from all upstream lanes.
- For each internal approach, *arrival flow rates* at downstream (stop line) locations are determined according to upstream *exit flow rates* and *net inflow rates* (midblock inflows and outflows).
- *Flow Proportions* specified as input for *Lane Movements* (i.e. movements linking each approach lane to each exit lane available) are used for assigning origin - destination (turning) flows departing from each approach lane to their exit lanes as well as for determining the *queue blockage effect* of each exit lane on each approach lane at an intersection. *Lane Movement Flow Proportions* reflect lane choices of drivers from approach lanes to exit lanes (possibly to minimise lane changing between intersections).
- *Queue blockage probabilities* are used to adjust (reduce) capacities at upstream intersection lanes according to lane-by-lane *queue blockage effects*, thus emulating the *backward spread of congestion*.
- Reduced capacities at upstream lanes may cause oversaturation and result in lower exit flows. This will lead to reduced arrival flows at downstream intersection lanes, and queue blockage probabilities will be lower as a result. This would mean less capacity reduction during the next iteration. An equilibrium solution is sought subject to various parameters that control iterations.

The reasons why a lane-based network model is needed to identify backward spread of congestion for closely-spaced intersections include the following:

(i) upstream lanes will be affected by downstream (exit) lane queues according to the destinations of movements using upstream lanes,

(ii) saturation levels (v/c ratios) and therefore queue blockage probabilities of individual lanes on an approach can differ significantly,

(iii) lane under-utilisation can exist due to various reasons including differences in the number of lanes available to particular movements on upstream and downstream approaches, and

(iv) the balance of upstream and downstream lane flow rates on an internal approach considering *midblock lane change implications* within a short distance where long queues exist is also an important consideration.

For signalised intersections, second-by-second departure flow patterns derived for upstream lanes are used to derive platooned arrival patterns for downstream lanes taking into account arrival flow and saturation flow rates of individual lanes at both upstream and downstream intersections. The modelling of *departure patterns* at upstream lanes takes into account the saturated and unsaturated parts of each green period (two green periods are allowed) for each upstream lane. Conditions of slip lanes, opposed turns and shared lanes are taken into account. The model used for platoon patterns is discussed further in the next section.

SIGNAL PLATOON MODEL

The modelling of *arrival patterns* at downstream lanes takes into account lane changes due to exit short lanes at upstream locations and approach short lanes at downstream locations, as well as *midblock lane changes* based on matching of upstream and downstream lane flow rates. The second-by-second upstream departure flow patterns are moved forward towards the downstream lane stop lines at the approach cruise speed by applying the required lane changes. Any midblock inflow and outflow rates are also taken into account. The method is applied by Movement Class (Light vehicles, Heavy Vehicles, Buses, Large Trucks, etc.) since each class can have a different approach cruise speed and different lane use.

The term *platoon pattern* is used as a general term to refer to second-by-second arrival or departure flow rate (veh/s) for a signal cycle. The related parameters are discussed in the next section.

The second-by-second platoon patterns determined by the program are used to calculate the following parameters for each approach lane for use in performance calculations: *Percent Arriving During Green*, *Platoon Ratio,* and *Delay and Queue Progression Factors*. The method has its origin in the US Highway Capacity Manual (TRB 2010) for delay calculations (using the Delay Progression Factor), and its extension by the author (Akcelik 1995, 1996) for back of queue, queue clearance time, proportion queued, queue move-up rate and effective stop rate calculations (using the Queue Progression Factor).

For the example given in the next two sections, Percent Arriving During Green and Platoon Ratio parameters are given as determined for individual lanes and movements (lane groups) for three analysis scenarios. For this reason, these parameters are described below.

The Percent Arriving During Green, P_G is given by (see the example shown in *Figure 1*):

$$P_G = N_G / N_C = N_G / (N_G + N_R) \qquad (1)$$

where N_G is the number of vehicles arriving during green period, N_R is the number of vehicles arriving during red period, and $N_C = N_G + N_R$ is the number of vehicles arriving during the signal cycle.

The Platoon Ratio, P_A is given by:

$$P_A = P_G / u = P_G / (g / c) \qquad (2)$$

where P_G is from *Equation (1)* and u = g / c is the green time ratio (g = effective green time, c = cycle time).

The Platoon Ratio is greater than one when more vehicles arrive during green. For *non-platooned (uniform)* arrivals as relevant to isolated intersections, $P_G = u = g / c$ and $P_A = 1.0$ apply.

The average arrival flow rates (veh/h) during the signal cycle, green and red periods are given by:

$$q_{ac} = 3600\ N_C / c \quad (3a)$$

$$q_{ag} = 3600\ N_G / g \quad (3b)$$

$$q_{ar} = 3600\ N_R / r \quad (3c)$$

Therefore, the following relationship applies to Percent Arriving During Green:

$$P_G = q_{ag}\ g / q_{ac}\ c = P_A\ g / c \quad (4)$$

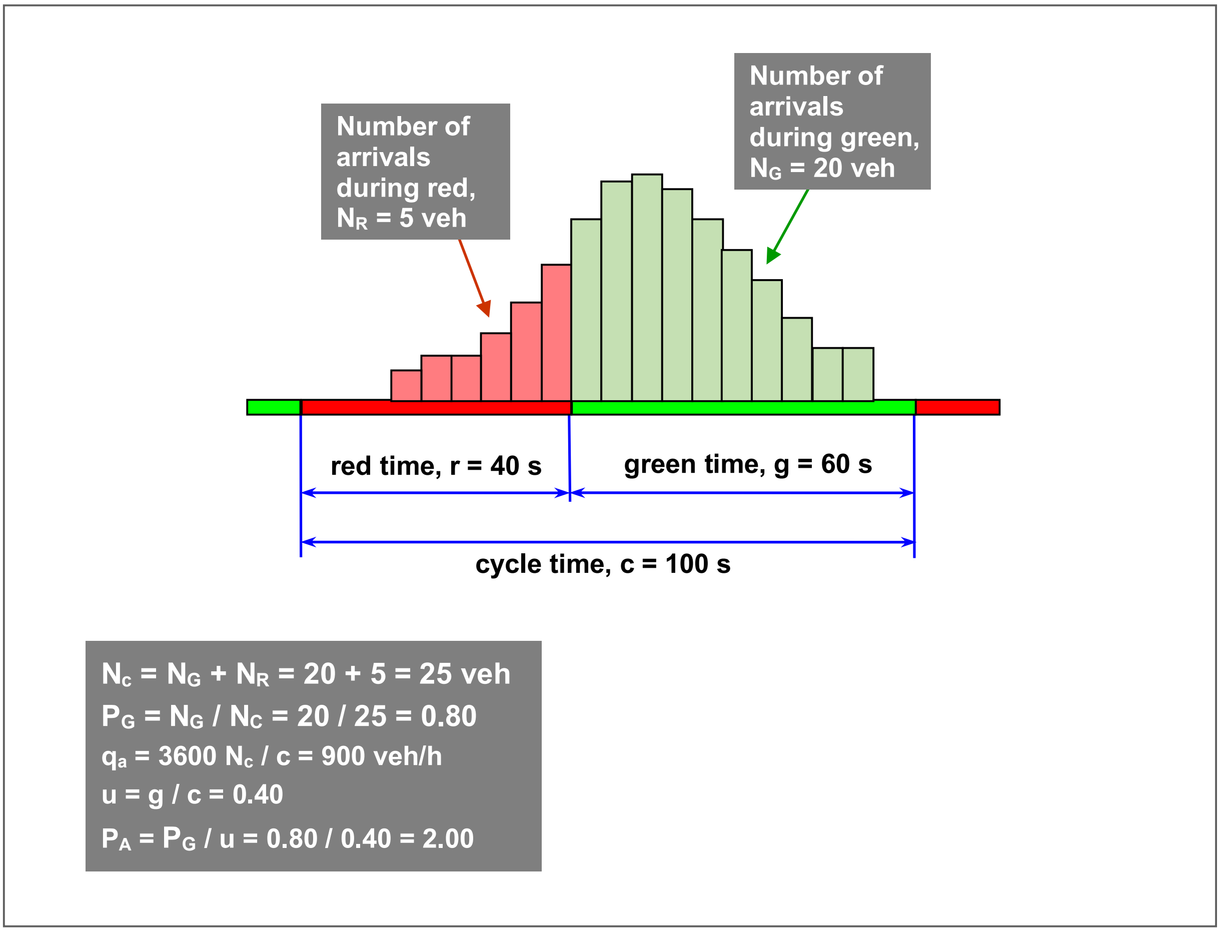


Figure 1 - Definition of Percent Arriving During Green

EXAMPLE

A case of signalised staggered T intersections with 180 m distance between them is considered as an example to investigate basic aspects of the lane-based network model in relation to signal platooning. The intersection geometry, signal phasing and related parameter values are shown in *Figure 2*. Site Origin - Destination (OD) flows (intersection turning volumes) and Network Origin - Destination (OD) flows are shown in *Figure 3*.

The Site OD flows between the two intersections have been matched perfectly for the purpose of this analysis. If the Site OD flows at the two intersections result in upstream and downstream flows which do not match, midblock inflow and outflow values determined by the model are included in the analysis. This does not apply in this example. The Network OD flows that match the Site OD flows are also provided for analysing differences between analysis scenarios with and without knowledge of Network OD flows.

Three analysis scenarios are 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. *Lane Utilisation Ratios* and *Lane Movement Flow Proportions* are the parameters that can be specified as input to the model according to these assumptions. The analysis scenarios are summarised in *Table 1*.

Analysis Scenario (i) assumes that only the Site OD flows (intersection turning volumes) are known at each intersection, and the Network OD flows are not known. *Scenarios (ii) and (iii)* assume that the Network OD flows are known in addition to the Site OD flows as shown in *Figure 3*. These assumptions form the basis of other assumptions in setting the analysis scenarios. Approach and Exit lanes are numbered from left to right in the direction of movement.

For all lanes, *Analysis Scenario (i)* uses default Lane Movement Flow Proportions based on 100% flow to the most direct exit lane. In *Scenarios (ii) and (iii)*, defaults are used for Site 1 North and Site 2 South Through movements, and the values shown in *Table 1* are specified for Site 1 West Right and Site 2 East Right movements based on known Network OD flows.

Table 1: Three analysis scenarios for the example of staggered T intersections

Analysis scenario	Lane Movement Flow Proportions	External approach Through lanes (Site 1 North and Site 2 South)	Internal approach Through lanes (Site 1 South and Site 2 North)	Midblock lane changes on internal approaches
(i)	Default (100% for all)	Equal lane use	Equal lane use	Yes
(ii)	Site 1 West Right: 40% - 60% Site 2 East Right: 70% - 30% (to Exit Lanes 1 and 2)*	Equal lane use	Equal lane use	Yes
(iii)	As in Scenario (ii)	Unequal lane use Site 1 North, Lane 2, LUR = 18.3% Site 2 South, Lane 2, LUR = 53.0%	Equal lane use	No

* For Site 1 North and Site 2 South Through movements in Scenarios (ii) and (iii), default Lane Movement Flow Proportions (100% to the most direct exit lane) are used.

Analysis Scenarios (i) and (ii) assume equal lane use for all Through approach lanes. Equal lane use for approach lanes means that lane degrees of saturation are equal (Akcelik 1984, 1989, 1997). In this example, through lanes have equal capacity values, therefore equal lane use means equal lane flows. Assumption of equal lane use for all approaches results in implied midblock lane changes. These are identified by comparing the upstream lane flows (flows at entry to an internal approach) with downstream approach (stop line) lane flows.

Analysis Scenario (iii) assumes that *there are no implied midblock lane changes*. This is achieved my matching upstream and downstream lane flows for internal approaches. For this purpose, equal lane use is assumed for Through movements at the downstream internal approach and unequal lane use is assumed for Through movements at the upstream external approach. Lane Utilisation Ratios are determined for external approach Through lanes in such a way that there are no implied midblock lane changes. This scenario assumes that drivers select their lanes correctly at the first intersection according to destinations at the next intersection.

All scenarios were analysed using a Network cycle Time of 100 s. Phase Times were calculated applying "green split priority" to internal approach movements (Akçelik 1981, 1990). Phase Times were the same for *Scenarios (i) and (ii)* but varied for *Scenario (iii)* due to unequal lane use.

For signal coordination purposes, Site 2 is the Reference Site (Offset = 0), and Phase A is the Reference Phase for both Sites. For all scenarios, Offset = 16 s was specified for Site 2. This is the travel time offset for the Northbound Through movement. This means that the green time for the Site 2 Through phase starts at 0 seconds and the green time for the Site 1 Through phase starts at 16 seconds. Movement timing diagrams for the Northbound movements for *Scenarios (i) and (ii)* are shown in *Figure 4*. They are similar for *Scenario (iii)*.

Many other analysis scenarios are possible considering different lane use patterns and Lane Movement Flow Proportions. This is discussed further in the section titled Analysis Results. For the purpose of this paper, the presentation was limited to three analysis scenarios.

For all scenarios, the network model iterations were carried out until the difference in any lane degree of saturation is less than 1 per cent (Stopping dx = 1%).

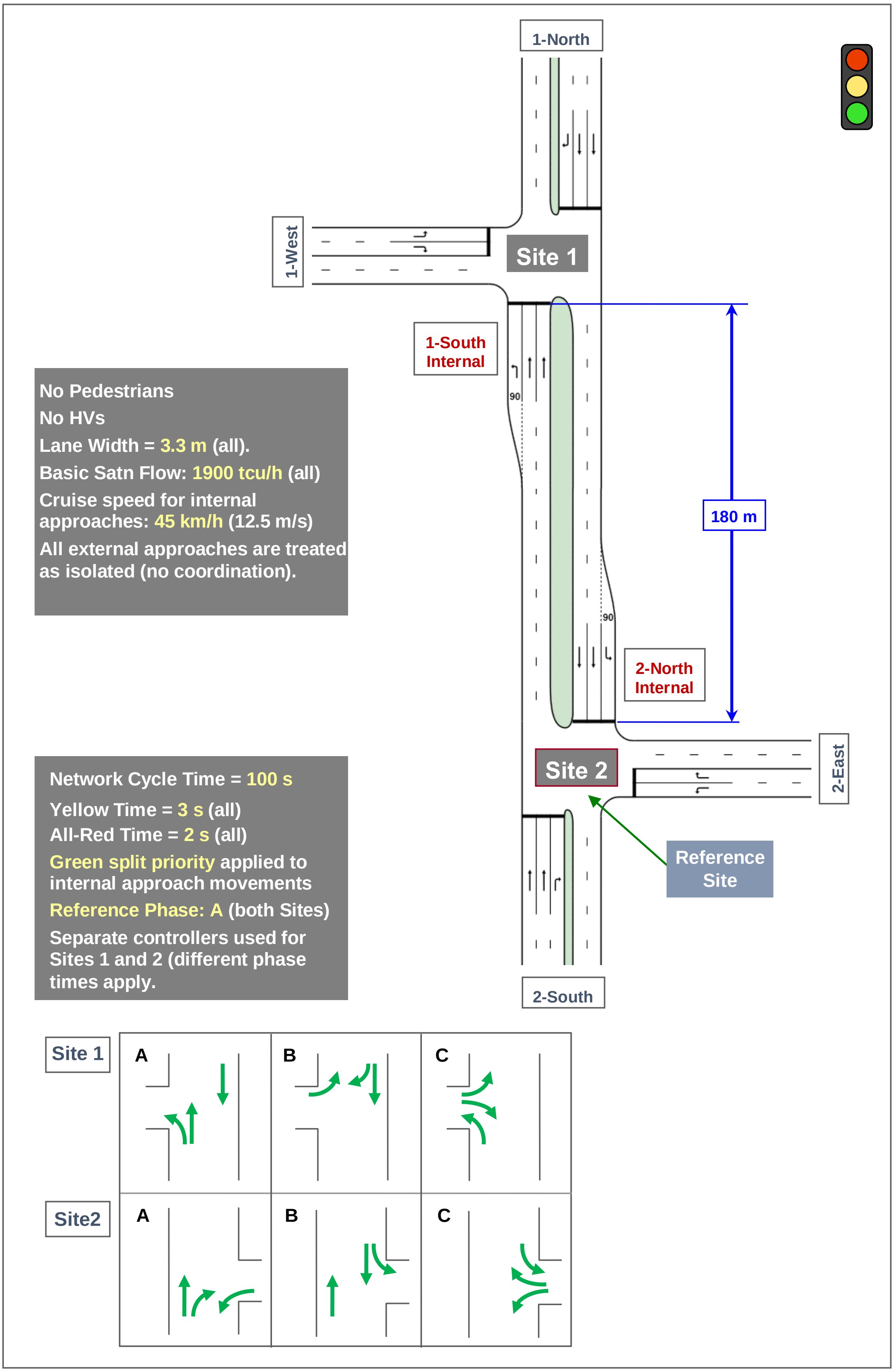


Figure 2 - Example: signalised staggered-T intersections

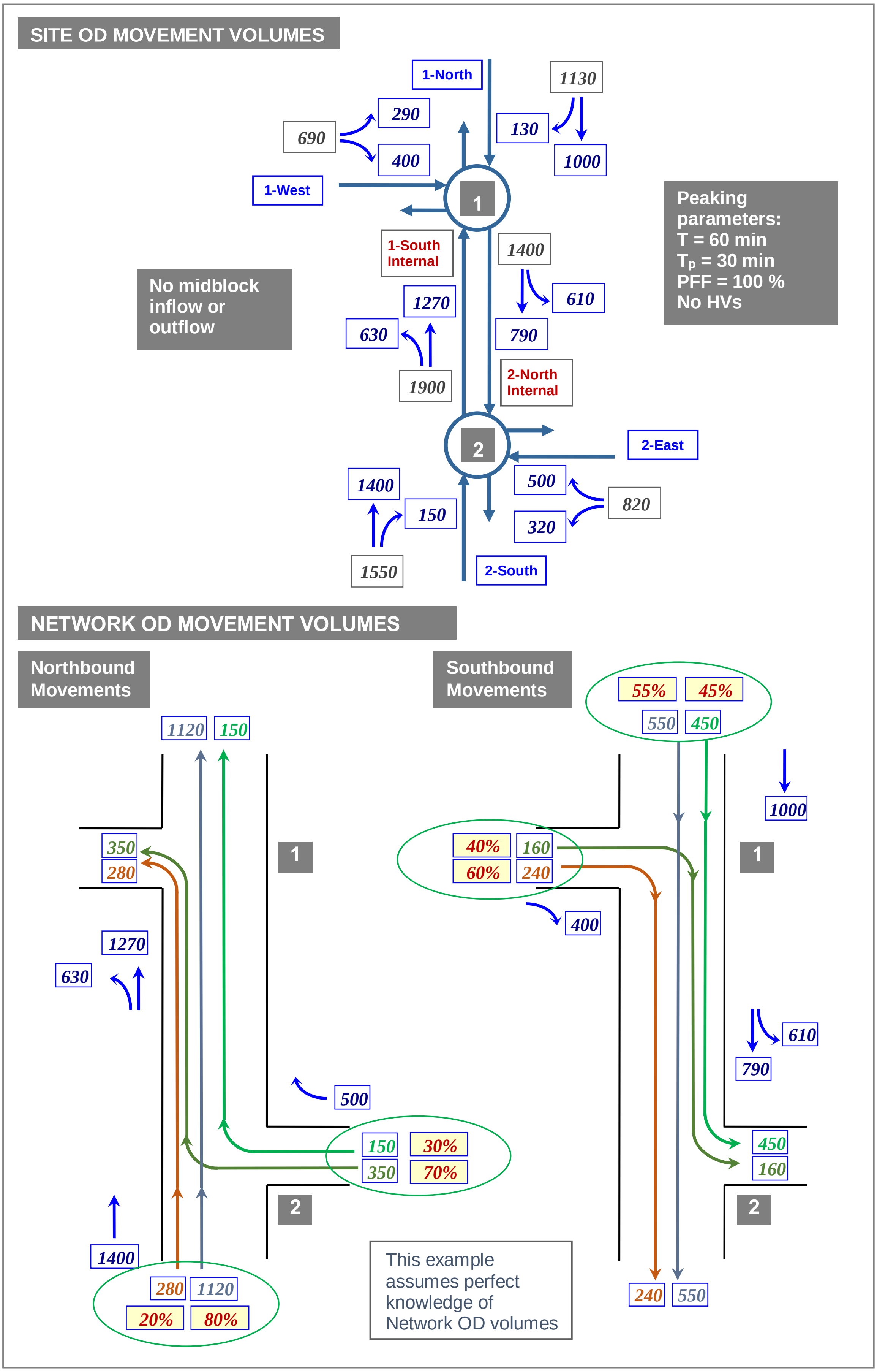
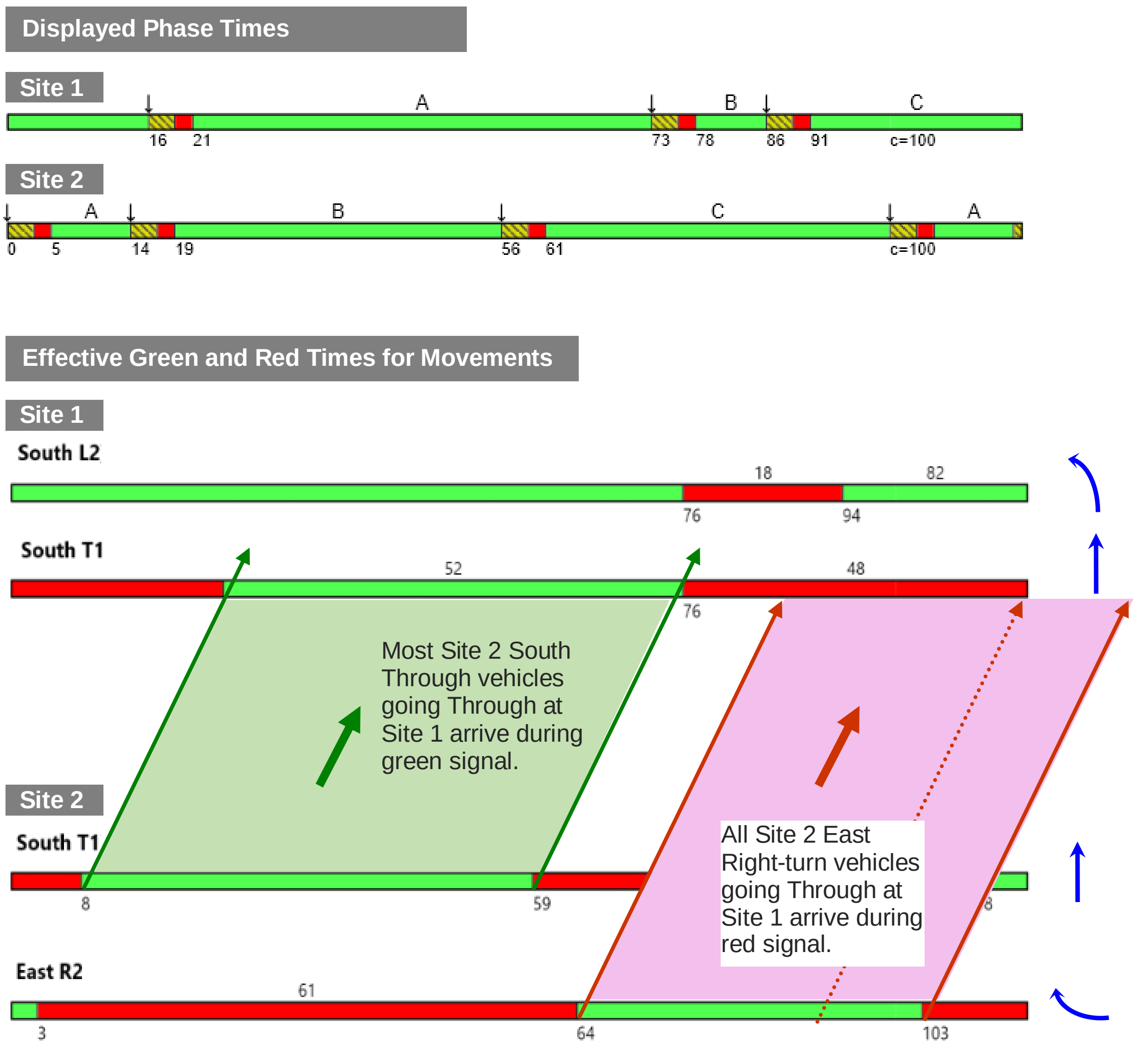


Figure 3 - Site and Network Origin - Destination flows for the example shown in Figure 2



Signal Offsets apply to Phase Change Times (end of previous phase green). In this example, Site 2 is the Reference Site (Offset = 0), and Offset = 16 s is specified for Site 1 (travel time offset for the Northbound movement).

Effective green and red times for movements are derived from displayed phase times using start loss and end gain values of 3 s (default).

Figure 4 - Movement timing diagram for Northbound movements in Scenarios (i) and (ii)

ANALYSIS RESULTS

The upstream and approach lane flows and any implied midblock lane changes for *Analysis Scenarios (i) to (iii)* are shown in *Figures 5 to 7*. Note that the same lane change values for entry into short lanes are included in all analysis scenarios. These are different from "midblock lane changes" based on matching of upstream and downstream lane flow rates.

Comparisons of results for *Scenarios (i) to (iii)* for Through movement lanes on external and internal approaches are presented in *Table 2*. Comparisons of results for *Scenarios (i) to (iii)* for internal Left and Through (platooned) movements are presented in *Table3*. The following can be observed from the results given in these tables:

- 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. The results given in *Tables 2 and 3* are obtained from the SIDRA INTERSECTION software which models capacities and performance measures for individual lanes rather than movements. The value for movements are derived from lane values considering the lanes used by the movement.
- 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, especially 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.
- Average delay values per movement can hide larger values of lane delay when there is significant unequal lane use.
- *Scenario (iii)* demonstrates the relevance of unequal lane use often observed at closely spaced intersections due to the network origin - destination effects. Signal timings get affected by unequal lane use, and these in turn affect platooning, delay and queue length results.

Scenario (iii) requires extra analysis effort to achieve matching of upstream and downstream (approach) lane flows by determining Lane Utilisation Ratios and Lane Movement Flow Proportions. Network OD flow information is needed for the latter. The use of default lane flows (assuming equal lane use) and default Lane Movement Flow Proportions (exit to most direct lane) may be adequate for large-scale network analyses. However, more detailed analysis as demonstrated for *Scenario (iii)* is justified for important projects involving design of small-sized networks as in this example.

Many other analysis scenarios are possible considering different lane use patterns and Lane Movement Flow Proportions. For example, Lane Movement Flow Proportions for Site 1 West and Site 2 East Right movements could be specified as 50% - 50% (to Exit Lanes 1 and 2) when the Network OD flow information is not available.

Another possible scenario is to assume unequal lane use for internal approach Through lanes and equal lane use for external approach Through lanes. For this example, this scenario resulted in lane blockage of upstream lanes when no midblock lane change was assumed. This scenario becomes unrealistic as drivers would be likely to avoid blocking lanes and use underutilised internal approach lanes where queue lengths are much shorter. Assuming unequal lane use but with more balanced lane flows for internal approach Through lanes so that lane blockage did not occur, this scenario indicated implied significant midblock lane changes. This is also unrealistic considering platooned movements between closely-spaced intersections. Refer to previous papers by the author for detailed discussion of lane blockage (queue spillback) modelling (Akçelik 2103, 2014).

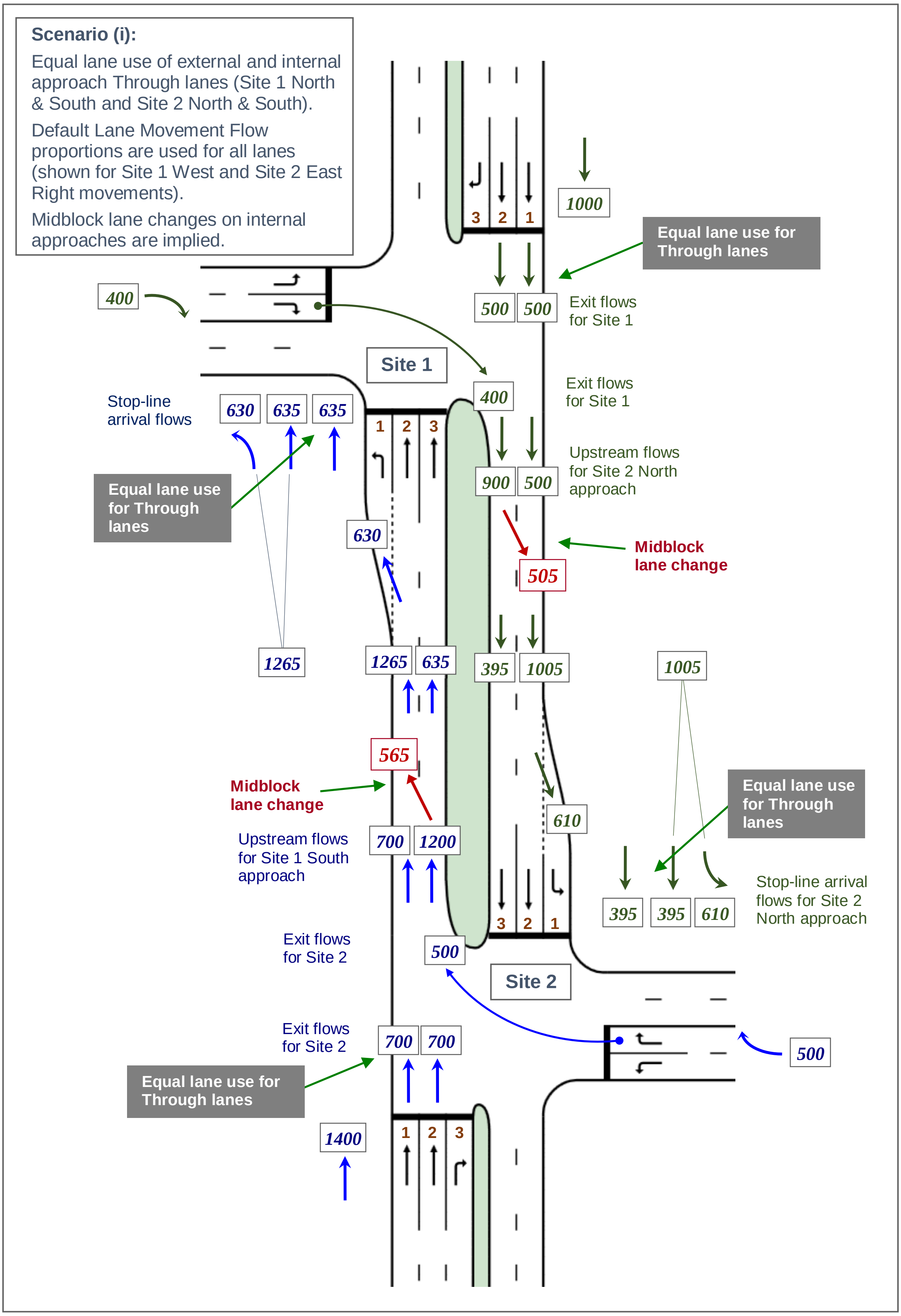


Figure 5 - Scenario (i):- Equal lane use of external and internal approach Through lanes, and default Lane Movement Flow Proportions

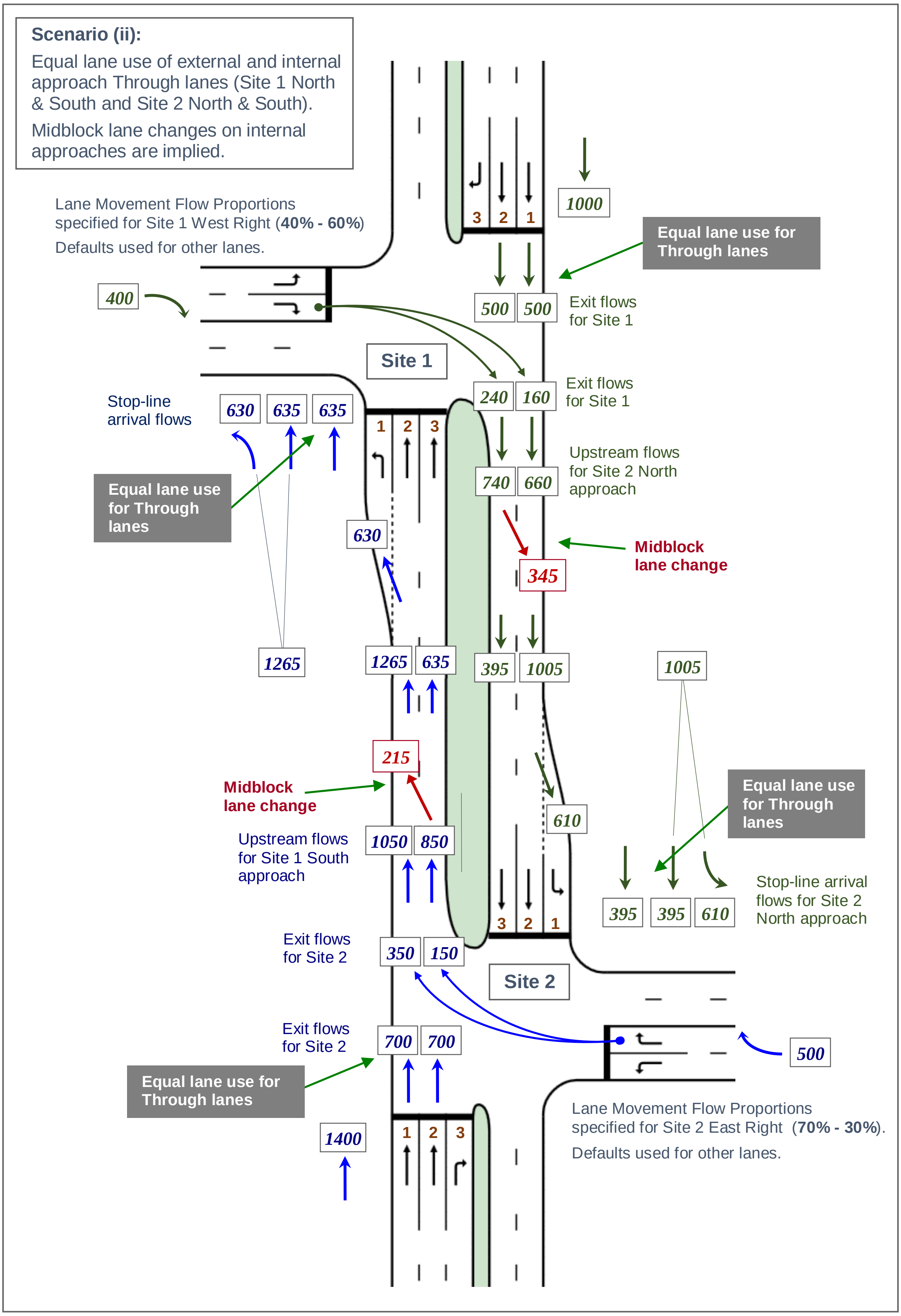


Figure 6 - Scenario (ii):- Equal lane use of external and internal approach Through lanes

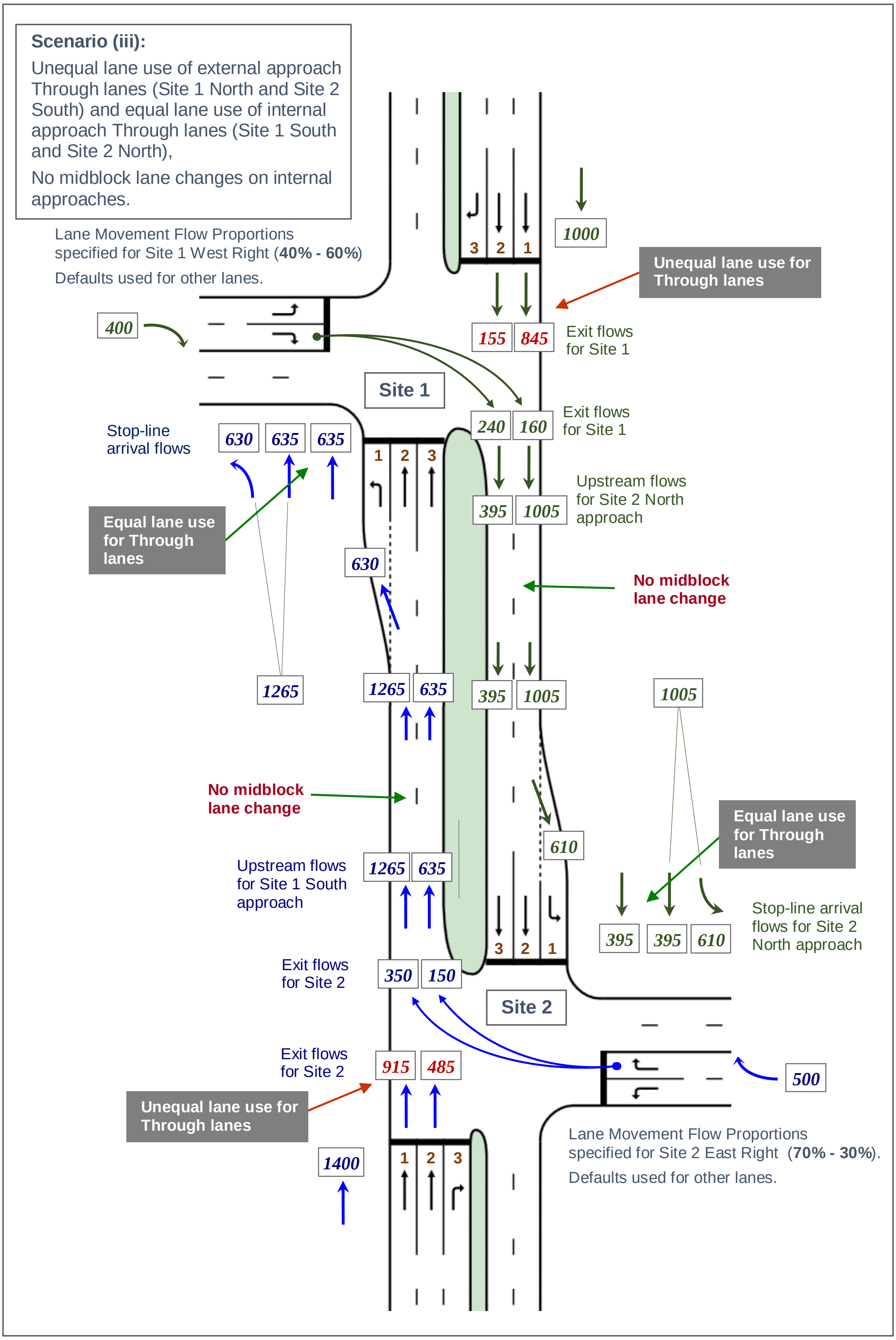


Figure 7 - Scenario (iii):- Unequal lane use of external approach Through lanes and equal lane use of internal approach Through lanes

Table 2: Comparison of results for *Analysis Scenarios (i) to (iii)* described in *Table 1*
(Through movement lanes on external and internal approaches only)

Approach Lane	Arrival Flow (veh/h)	Capacity (veh/h)	Deg. of Satn (v / c)	Percent Arriving During Green (%)	Platoon Ratio	Aver. Delay (s)	95th %ile Back of Queue (m)	Total Operating Cost ($/h)	Total CO2 Emission (kg/h)
Analysis Scenario (i)									
SITE 1	**Cycle Time = 100, Phase Times: 57, 13, 30**								
South Lane 2	635	988	0.643	80.3%	1.544	9.8	88		
Lane 3	635	988	0.643	58.3%	1.122	20.7	144		
North Lane 1	500	1235	0.405	65.0%	1.000	10.6	80		
Lane 2	500	1235	0.405	65.0%	1.000	10.6	80		
Intersection	**3720**		**0.898**			19.8	157	**1646.6**	**531.0**
SITE 2	**Cycle Time = 100, Phase Times: 14, 42, 44**								
South Lane 1	700	969	0.722	51.0%	1.000	22.1	184		
Lane 2	700	969	0.722	51.0%	1.000	22.1	184		
North Lane 2	395	703	0.562	50.9%	1.375	26.4	93		
Lane 3	395	703	0.562	51.8%	1.399	26.0	92		
Intersection	**3770**		**0.921**			23.7	184	**1860.8**	**542.3**
Analysis Scenario (ii)									
SITE 1	**Cycle Time = 100, Phase Times: 57, 13, 30**								
South Lane 2	635	988	0.643	68.6%	1.320	16.1	121		
Lane 3	635	988	0.643	81.5%	1.568	9.3	84		
North Lane 1	500	1235	0.405	65.0%	1.000	10.6	80		
Lane 2	500	1235	0.405	65.0%	1.000	10.6	80		
Intersection	**3720**		**0.898**			19.6	157	**1617.3**	**526.1**
SITE 2	**Cycle Time = 100, Phase Times: 14, 42, 44**								
South Lane 1	700	969	0.722	51.0%	1.000	22.1	184		
Lane 2	700	969	0.722	51.0%	1.000	22.1	184		
North Lane 2	395	703	0.562	52.7%	1.426	25.5	91		
Lane 3	395	703	0.562	52.9%	1.430	25.8	91		
Intersection	**3770**		**0.921**			23.5	184	**1854.0**	**541.3**
Analysis Scenario (iii)									
SITE 1	**Cycle Time = 100, Phase Times: 57, 13, 30**								
South Lane 2	635	988	0.643	68.0%	1.308	16.4	122		
Lane 3	635	988	0.643	69.5%	1.337	15.7	119		
North Lane 1	**845**	1235	**0.684**	65.0%	1.000	13.5	180		
Lane 2	**155**	1235	**0.125**	65.0%	1.000	8.8	20		
Intersection	**3720**		**0.898**			20.7	180	**1684.4**	**539.0**
SITE 2	**Cycle Time = 100, Phase Times: 14, 48 38**								
South Lane 1	**915**	**1083**	**0.845**	57.0%	1.000	24.7	279		
Lane 2	**485**	**1083**	**0.448**	57.0%	1.000	15.0	95		
North Lane 2	395	**817**	**0.483**	53.4%	1.241	22.9	84		
Lane 3	395	**817**	**0.483**	63.1%	1.467	18.6	71		
Intersection	**3770**		**0.921**			24.0	279	**1873.3**	**541.6**

Site 1 South (Northbound) and Site 2 North (Southbound) are internal approaches (platooned arrivals apply)

Table 3: Comparison of results for *Analysis Scenarios (i) to (iii)* described in *Table 1* for internal Left and Through (platooned) movements

Movement	Arrival Flow (veh/h)	Deg. of Satn (v / c)	Percent Arriving During Green (%)	Platoon Ratio	Aver. Delay (s)	95th %ile Back of Queue (m)
Analysis Scenario (i)						
SITE 1 - South Internal (NB)						
Left	630	0.425	90.1%	1.099	5.7	34
Thru	1270	0.643	69.3%	1.333	15.3	144
SITE 2 - North Internal (SB)						
Left	610	0.416	85.1%	1.050	6.6	47
Thru	790	0.562	51.3%	1.387	26.2	93
Analysis Scenario (ii)						
SITE 1 - South Internal (NB)						
Left	630	0.425	86.0%	1.049	6.1	47
Thru	1270	0.643	75.1%	1.444	12.7	121
SITE 2 - North Internal (SB)						
Left	610	0.416	84.8%	1.047	6.3	48
Thru	790	0.562	52.8%	1.428	25.5	91
Analysis Scenario (iii)						
SITE 1 - South Internal (NB)						
Left	630	0.425	88.7%	1.081	5.9	38
Thru	1270	0.643	68.7%	1.322	16.1	122
SITE 2 - North Internal (SB)						
Left	610	0.416	89.6%	1.106	5.8	34
Thru	790	**0.483**	58.2%	1.354	20.8	84

CONCLUSIONS

A lane-based analytical network model that derives second-by-second platoon patterns 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.

A detailed example is presented using various analysis scenarios to investigate the differences in 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 are identified according to differences in *midblock lane change* implications for internal approach lanes. The analysis results show that there are significant differences in platoon characteristics 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 / link)* basis.

One of the analysis scenarios specified unequal lane use on external approaches so that there are no implied midblock lane changes (i.e. assumed that drivers select their lanes correctly at the first intersection according to destinations at the next intersection). This demonstrated the relevance of unequal lane use often observed at closely spaced intersections due to the network origin - destination effects. This analysis requires extra effort to achieve matching of upstream and downstream (approach) lane flows by determining Lane Utilisation Ratios and Lane Movement Flow Proportions. Network OD flow information is needed for the latter.

The use of default lane flows (assuming equal lane use) and default Lane Movement Flow Proportions (exit to most direct lane) may be adequate for large-scale network analyses. However, more detailed analysis is justified for important projects involving design of small-sized networks as in this example.

After the writing of this paper, an enhancement was introduced to the analysis of closely-spaced intersections. When the Network OD flows are known, external approach movements that continue as turning movements on internal approaches (left turns for the example given in this paper) are specified as *Special Movement Classes* using the User Movement Class facility of SIDRA INTERSECTION. 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.

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.

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