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Lane-Based Micro-Analytical Model of a Roundabout Corridor

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NOTE:

This paper is related to the analysis methodology used in the SIDRA INTERSECTION software package.

Lane-Based Micro-Analytical Model of a Roundabout Corridor

Rahmi Akçelik

ABSTRACT

There is a need for better modeling of network performance, especially the spread of queues in congested networks, so that system-wide effects are better indentified. This is important in handling small network design cases such as freeway interchange roundabouts or roundabout corridors with greater confidence. This paper describes a lane-based micro-analytical network model and demonstrates it using a detailed example of staggered-T roundabouts. The model has been developed recently and implemented in the SIDRA INTERSECTION software.

Two fundamental elements of the model are (i) determining the backward spread of congestion as queues on downstream lanes block upstream lanes, and (ii) applying capacity constraint to oversaturated upstream lanes for determining exit flow rates, thus limiting the flows entering downstream lanes. These two elements are highly interactive with opposing effects. Establishing the relationship between upstream and downstream lane flow rates and identifying lane change implications are also important aspects of the model. Estimation of lane capacities, lane flows and lane queues for downstream and upstream approaches is essential for reliable modeling of network performance since these parameters are highly interdependent.

The new lane-based analytical network model differs from traditional network models which rely on modeling of "approaches" or "links" based on aggregation (and therefore losing details) of individual lane conditions, and are more concerned about forward movement of vehicle platoons. These models cannot identify backward spread of congestion reliably since saturation levels of individual lanes can differ significantly. Lane under-utilization due to various causes will also have substantial impacts on network performance.

INTRODUCTION

Historically, analytical network models have been concerned more about modeling forward movement of vehicle platoons than backward spread of queues between intersections and capacity constraint (demand starvation) related to oversaturated intersection conditions. While all these elements are important, the lack of modeling 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.

At the same time, traditional analytical network models have been *link-based* models where *links* represent *lane groups* in which traffic conditions of individual lanes are aggregated and therefore lost in more aggregated traffic units. Such link-based network models cannot identify backward spread of congestion for closely spaced intersections. An *approach-based* method is a more extreme case of this where differing conditions of traffic in all approach lanes are aggregated to some assumed average (balanced) condition.

While estimation of individual lane capacities, lane flows and lane queues are important in assessing performance of a single intersection, this becomes even more important in modeling closely spaced intersections. Lane capacities, lane flows and lane queues for downstream and upstream approaches may be highly interdependent in cases of closely spaced intersections, and therefore, a lane-based method is essential for reliable modeling of network performance.

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), therefore queue blockage probabilities of individual lanes on an approach can differ significantly,

(iii) lane under-utilization can exist due to various reasons including differences in 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 lane change implications within a short distance where long queues exist is also an important consideration.

A lane-based micro-analytical network model which satisfies these requirements has been developed and implemented in the SIDRA INTERSECTION software Version 6 *(1)*. The basic aspects of this network model are described briefly in the next section followed by a detailed example of staggered-T roundabouts to demonstrate it.

There is extensive literature on the roundabout analysis model used in the SIDRA INTERSECTION software including modeling of roundabout metering signals *(2-18)*. SIDRA INTERSECTION offers options for the use of *SIDRA Standard* and *HCM 2010* models for roundabout capacity estimation *(15, 16, 19-21)*. The SIDRA Standard roundabout capacity model with the *Standard Right* model version with metric units has been used for the example presented in this paper.

A NEW LANE BASED NETWORK MODEL

Two 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, and

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

These 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 (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 for 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 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 movements departing from each approach lane to their exit lanes as well for determining the *queue blockage effect* of each exit lane on each approach lane at an intersection.
- *Queue blockage probabilities* are used to adjust (reduce) capacities at upstream intersection lanes according to lane-by-lane *queue blockage effects*, thus emulating *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 next iteration. An equilibrium solution is sought subject to various parameters that control iterations.

Output reports highlight the differences between demand flow rates and arrival flow rates to indicate quickly where lane blockage effects exist. Lane blockage probabilities and capacity adjustment values are also included in output.

An example of staggered-T roundabouts is given in the following section to demonstrate the model.

EXAMPLE

The case of two T-shaped roundabouts placed with 50 m distance between them as shown in *Figure 1* is considered as an example to demonstrate the lane-based network model.

The roundabout geometry and volume data as well various other parameter values are shown in *Figure 1*. In this example, the volumes between the two intersections have been matched perfectly in order to make understanding of results easier.

Two different analyses have been carried out to indicate the levels of accuracy that can be expected:

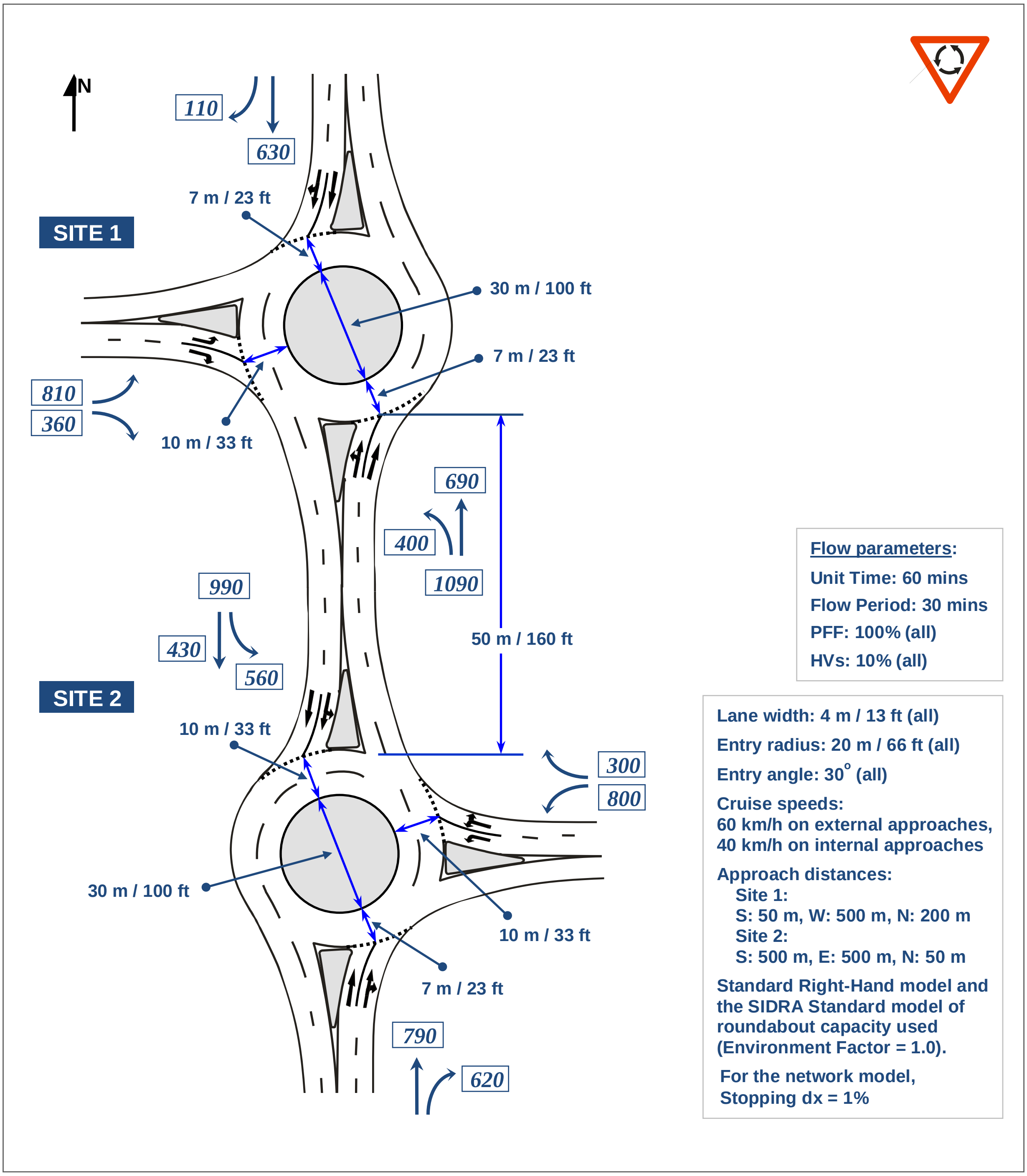
Analysis (i)*: *Default Lane Flows. It is assumed that only Turning Volumes are known at each intersection (network origin - destination flows are not known). Default settings are used generally (no Lane Movement Flow Proportions, "Set as Dominant" for roundabout lanes or Lane Utilization Ratios are specified).

Analysis (ii)*: *Balanced Lane Flows. It is assumed that the *Network Origin - Destination* flows are known in addition to the intersection turning volumes as shown in *Figure 2*. The following parameters are set in order to achieve balanced lane flow estimates for internal approaches:

- Lane Movement Flow Proportions are specified as follows:
  - Site 1, West approach: 42.0% to Exit Lane 1 and 58.0% to Exit Lane 2 on South approach, and
  - Site 2, East Approach: 33.3% to Exit Lane 1 and 66.7% to Exit Lane 2 on North approach.
- Upstream to downstream lane flow balance is sought for Northbound and Southbound movements by specifying the following parameters:
  - Site 1, South approach, Lane 1: "Set As Dominant" and LUR = 96%. "Set As Dominant" reverses lane flow values between Lanes 1 and 2, keeps the relative lane capacities stable and the LUR tries to achieve the required lane flow balance.
  - Site 1, North approach, Lane 1: "Set As Dominant" (LUR program determined). This reverses lane flow values between Lanes 1 and 2. Program determined LUR is sufficient in this case.

In both cases, 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%).

Northbound and Southbound movements are investigated in relation to matching of upstream and downstream (approach) lane flows for the two cases.



Flow parameters:
Unit Time: 60 mins
Flow Period: 30 mins
PFF: 100% (all)
HVs: 10% (all)

Lane width: 4 m / 13 ft (all)
Entry radius: 20 m / 66 ft (all)
Entry angle: 30° (all)
Cruise speeds:
60 km/h on external approaches,
40 km/h on internal approaches
Approach distances:
Site 1:
S: 50 m, W: 500 m, N: 200 m
Site 2:
S: 500 m, E: 500 m, N: 50 m
Standard Right-Hand model and the SIDRA Standard model of roundabout capacity used (Environment Factor = 1.0).
For the network model, Stopping dx = 1%

Figure 1 - Example: staggered-T roundabouts

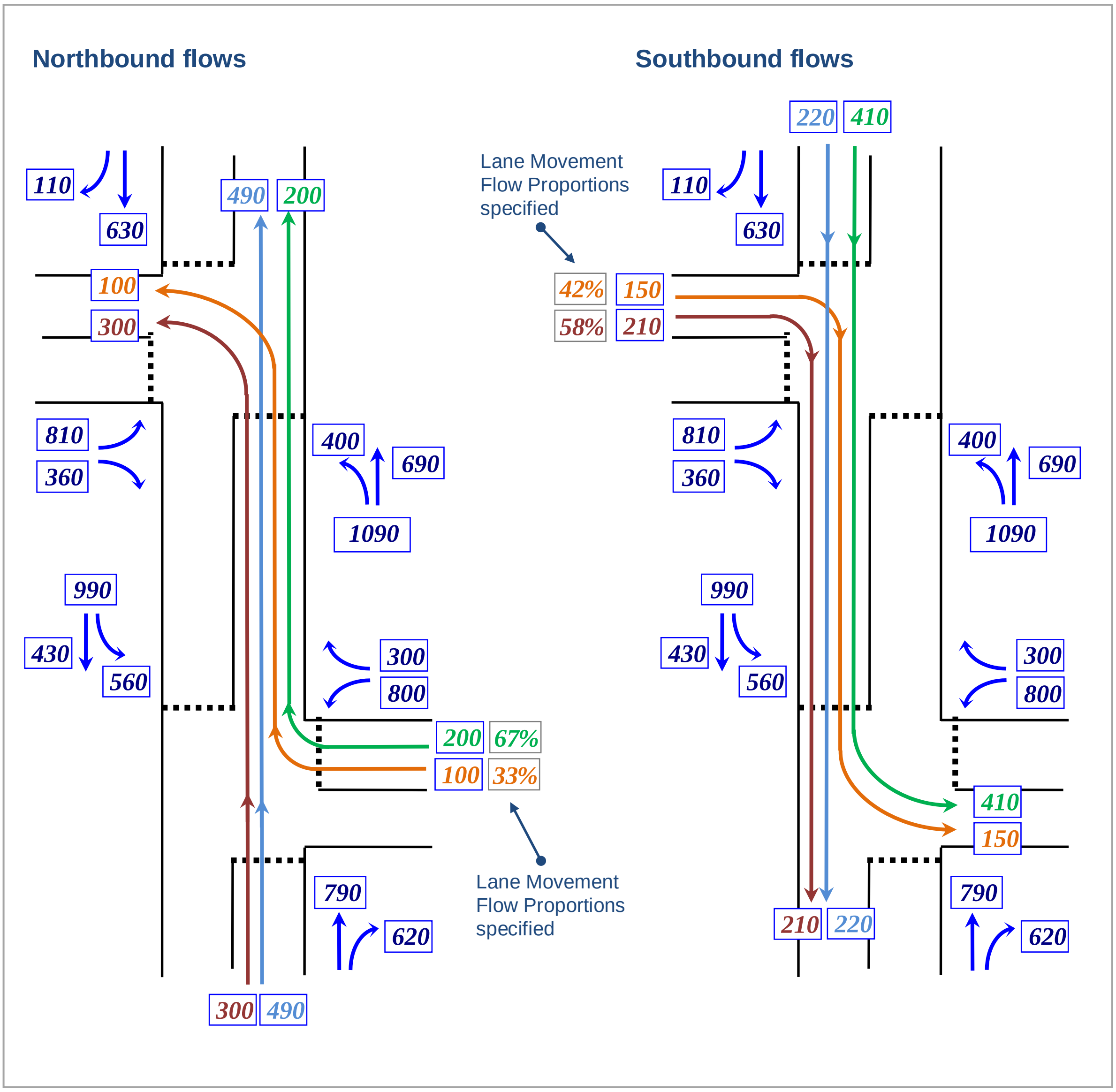


Figure 2 - Network origin - destination flows for the example shown in *Figure 1*

In *Analysis (i)* based on defaults only, the Northbound upstream and downstream (approach) lane flows for Site 1 South approach and the Southbound upstream and downstream lane flows for Site 2 North approach do not match well (*Figure 3*).

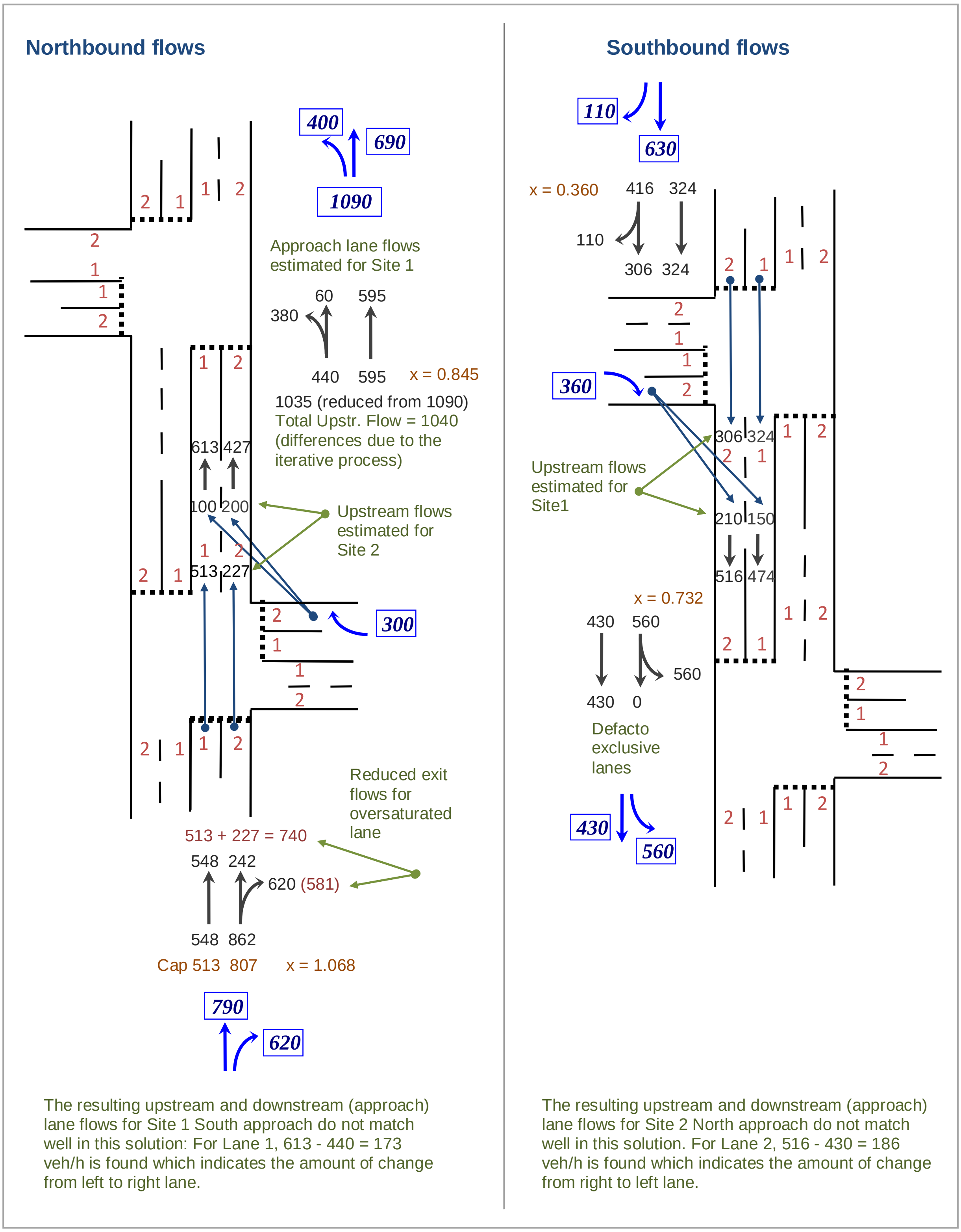
In *Analysis (ii)*, the upstream and downstream lane flows for internal approaches (Site 1 South approach and Site 2 North approach) are seen to match reasonably well (*Figure 4*).

Analysis (ii) requires extra analysis effort to achieve matching upstream and downstream (approach) lane flows. This may be justified for important projects involving design of small-sized networks as in this example, especially when the network origin-destination flow information is available.

It is interesting to compare results from *Analysis (i)* and *Analysis (ii)* as summarized in *Table 1* for an indication of adequacy of analyses based on default lane flows. The results for this example indicate that analysis based on default lane flows may be adequate for large-scale network analyses. However, it is recommended that this issue is investigated further.

However, it should be noted that the level of accuracy of results also depend on the number of network model iterations. The low value of the Stopping dx parameter (1 %) used for this example resulted in the maximum number of iterations (10) which is the basis of the results given in *Table 1*. A stopping dx parameter which is 3 % or lower led to 6 or more iterations and gave similar results for this example.

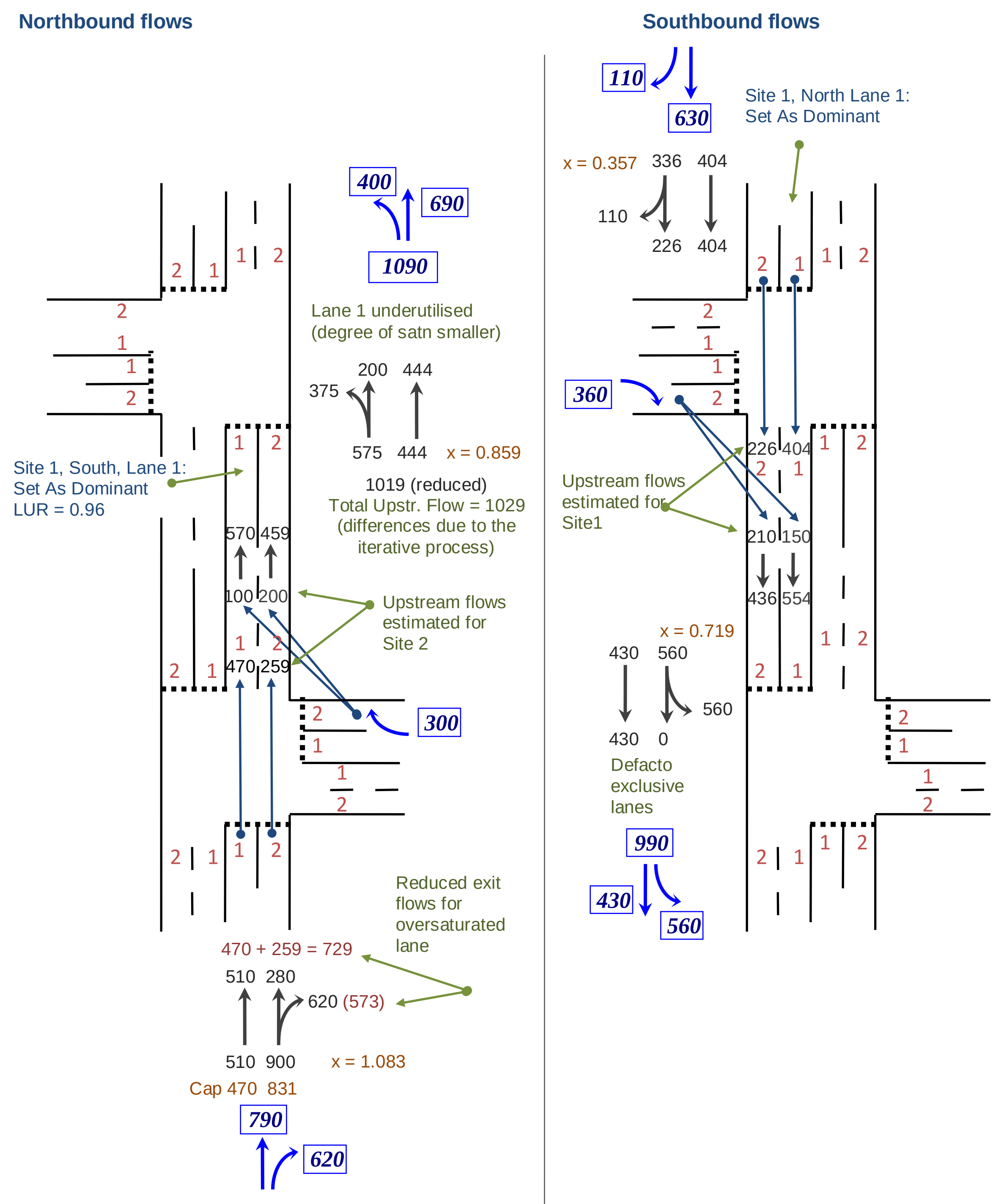
The example also demonstrates that there are many side-effects of changes in arrival flows due to downstream queue blockages and resulting upstream capacity reductions. For example, changes in circulating flow rates and the lane balance of circulating flows result in roundabout entry lane capacity changes, and changes in Lane Movement Flow Proportion values specified affect lane capacities through changes in lane blockage effects.



The resulting upstream and downstream (approach) lane flows for Site 1 South approach do not match well in this solution: For Lane 1, 613 - 440 = 173 veh/h is found which indicates the amount of change from left to right lane.

The resulting upstream and downstream (approach) lane flows for Site 2 North approach do not match well in this solution. For Lane 2, 516 - 430 = 186 veh/h is found which indicates the amount of change from right to left lane.

Figure 3 - *Analysis (i): Default Lane Flows* - lane flow results for Northbound and Southbound Movements



For Site 1, South approach Lane 1, "Set As Dominant" and LUR = 96% are specified. The resulting upstream and downstream (approach) lane flows for Site 1 South approach match reasonably well.

For Site 1, North approach, Lane 1, "Set As Dominant" is specified. The resulting upstream and downstream (approach) lane flows for Site 2 North approach match reasonably well.

Figure 4 - *Analysis (ii): Balanced Lane Flows* - lane flow results for Northbound and Southbound Movements

Table 1 - Comparison of results for Analysis (i) with Default Lane Flows and Analysis (ii) with Balanced Lane flows

Approach Lane	Arrival Flow (veh/h)	Capacity Adjustment (%)	Degree of Saturation (v/c ratio)	Average Delay (s)	Level of Service	Queue Length (m)		Prob. of Blockage (%)
						Average	95th %ile	
Analysis (i)								
SITE 1								
South Lane 1	440[a]	0.0%	0.845	36.5	D	41	101	32.9%
Lane 2[d]	595[a]	0.0%	0.845	25.0	C	49	121	47.1%
North Lane 1	324	-2.9%	0.360	6.6	A	8	21	0.0%
Lane 2[d]	416	0.0%	0.360	6.5	A	9	22	0.0%
West Lane 1[d]	810	0.0%	0.833	21.2	C	29	73	0.0%
Lane 2	360	0.0%	0.500	9.0	A	9	22	0.0%
Intersection	**2945[a]**		**0.845**	**18.7**	**B**	**49**	**121**	
SITE 2								
South Lane 1	548	-30.4%	1.068	156.3	F	185	459	19.4%
Lane 2[d]	862	-16.3%	1.068	124.6	F	239	593	31.7%
East Lane 1[d]	732	0.0%	0.869	24.7	C	36	88	0.0%
Lane 2	368	-33.7	0.869	56.3	E	46	113	0.0%
North Lane 1[d]	560	0.0%	0.732	19.1	B	24	59	10.2%
Lane 2	430	0.0%	0.690	11.5	B	19	47	3.4%
Intersection	**3500**		**1.068**	**70.7**	**E**	**239**	**593**	
Analysis (ii)								
SITE 1								
South Lane 1[d]	575[a]	0.0%	0.825	28.4	C	45	111	39.4%
Lane 2	444[a]	0.0%	0.859	31.4	C	43	107	36.7%
North Lane 1[d]	404	-2.5%	0.357	5.8	A	9	22	0.0%
Lane 2	336	0.0%	0.357	7.3	A	8	20	0.0%
West Lane 1[d]	810	0.0%	0.840	22.1	C	32	79	0.0%
Lane 2	360	-1.1%	0.509	9.5	A	10	24	0.0%
Intersection	**2931[a]**		**0.859**	**18.8**	**B**	**45**	**111**	
SITE 2								
South Lane 1	510	-35.8%	1.083	180.3	F	191	475	20.8%
Lane 2[d]	900	-14.1%	1.083	103.5	F	258	641	36.5%
East Lane 1[d]	710	0.0%	0.830	22.4	C	30	73	0.0%
Lane 2	390	-28.8%	0.830	42.1	D	38	93	0.0%
North Lane 1[d]	560	0.0%	0.719	18.4	B	22	56	8.2%
Lane 2	430	0.0%	0.678	10.8	BA	18	45	1.8%
Intersection	**3500**		**1.083**	**73.3**	**E**	**258**	**641**	

[d] Dominant lane on the approach

[a] Arrival Flow reduced due to upstream capacity constraint

Average Control delays (including geometric delay), and average and 95th percentile back of queue length values are shown.

Probability of Blockage indicates the probability of back of queue exceeding the available storage space.

Capacity Adjustment indicates percentage reduction in capacity as a result of downstream lane queue blockage.

Roundabout Level of Service results are based on the **SIDRA Roundabout LOS** method.

CONCLUDING REMARKS

A lane-based micro-analytical network model has been described and a detailed example of staggered-T roundabouts has been presented to demonstrate the model. Further experience is needed in order to establish the most effective use of the model in practice. This paper has explored the levels of accuracy to be sought in relation to the need to balance upstream and downstream lane flows for internal approaches. The results for this example indicate that analysis based on default lane flows may be adequate for large-scale network analyses. However, it is recommended that this issue and other aspects of the model are investigated further to establish appropriate levels of accuracy in model results depending on the purpose of the analysis.

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