Modeling Queue Spillback and Nearby Signal Effects in a Roundabout Corridor

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ABSTRACT

This paper will discuss two aspects of modeling roundabout corridors: (i) a lane-based model of queue spillback, i.e. blockage of upstream lanes by queues formed in downstream lanes and the resulting capacity reduction in those lanes, and (ii) a model of the effect of upstream signals on the capacity and performance of a roundabout located downstream of a signalized intersection. A roundabout corridor example will be provided to discuss both aspects.

When capacity reduction of upstream lanes due to queue spillback results in oversaturated conditions, it is necessary to apply capacity constraint in determining exit flow rates of oversaturated upstream lanes, 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 (including modeling of unequal lane use) is essential for reliable modeling of roundabout corridor (network) performance since these parameters are highly interdependent.

The paper also discusses potential effects of nearby signalized intersections on a roundabout corridor. These include lane blockage by queues formed at downstream signals and bunching of vehicles arriving from upstream signals.

INTRODUCTION

Traditional 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. Although all these elements are important, the lack of modeling 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.

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 the 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. In particular, estimation of lane queues is problematic with this method.

While estimation of individual lane capacities, lane flows and lane queues is 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) and 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 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 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 an example of a roundabout corridor which includes a roundabout interchange, a roundabout with a bus only bypass lane and a signalized intersection with a two-segment bus lane.

There is extensive literature on the roundabout analysis model used in the SIDRA INTERSECTION software including modeling of roundabout metering signals *(2-20)*. SIDRA INTERSECTION offers options for the use of *SIDRA Standard* and *HCM 2010* models for roundabout capacity estimation *(15, 16, 21-23)*. The SIDRA Standard roundabout capacity model using the *US HCM* main model version of SIDRA INTERSECTION with US Customary units has been used for the example presented in this paper. An Environment Factor of 1.1 has been used for all roundabouts in this example.

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 (turning) flows 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 highlighted in output.

EXAMPLE

An example of a roundabout corridor which includes a roundabout interchange, a roundabout with a bus only bypass lane and a signalized intersection with a two-segment bus lane is shown in *Figure 1*. Volumes used for this example are shown in *Figure 2* (light and heavy vehicle volumes shown).

Network Displays shown in *Figure 3* indicate the performance characteristics of the roundabout corridor shown in *Figure 1*.

As can be seen from *Figure 3*, it is estimated that the queues on the West (Eastbound) approach lanes of the signalized intersection (Site 4) block the lanes on the South, West and North approaches of the roundabout (Eastbound movements at Site 3). This results in oversaturated lanes on the West (Eastbound) lanes of Site 3 (roundabout) and therefore capacity constraint applies to these lanes. This means that arrival flows on the West approach of Site 4 (signalized intersection) and the North (Southbound) approaches of Sites 2 and 1 (interchange roundabouts) are reduced.

At Site 3, the East (Westbound) approach lanes indicate unequal lane utilization identified by the program. This is due to the defacto exclusive right-turn lane (Lane 2). As seen in *Figure 3*, the queue in this lane has a small blockage effect on the East and North approach lanes of Site 4 (signalized intersection).

Internal approach lanes at the roundabout interchange do not get blocked since zero circulating flow rates occur for these approaches.

EXTRA BUNCHING DUE TO UPSTREAM SIGNALS

In addition to the effect of signalized intersections close to roundabouts due to lane blockage by queues formed at downstream signals, signalized intersections close to roundabouts will affect downstream roundabouts due to the bunching of vehicles arriving from upstream signals. SIDRA intersection models this effect using a parameter called *extra bunching* (also used for two-way sign controlled intersections) *(11)*. This parameter is used to adjust the proportion of free (unbunched) vehicles according to the proximity of an upstream signalized intersection. A guide for the choice of extra bunching values as a function of the distance to upstream signals and the amount of platooning is given in *Table 1*.

Theoretically, the Extra Bunching parameter does not affect gap acceptance capacity in the case of random arrival distributions (M1 models). This applies to the HCM 2010 roundabout capacity model. However, when the HCM 2010 roundabout capacity model is used instead of the SIDRA standard capacity model and an extra bunching value is specified for the effect of upstream signals, SIDRA INTERSECTION will apply an *Extra Bunching Adjustment Factor* to capacity. The Extra Bunching Adjustment Factor is determined from capacities obtained with and without extra bunching using the bunched exponential model (M3D).

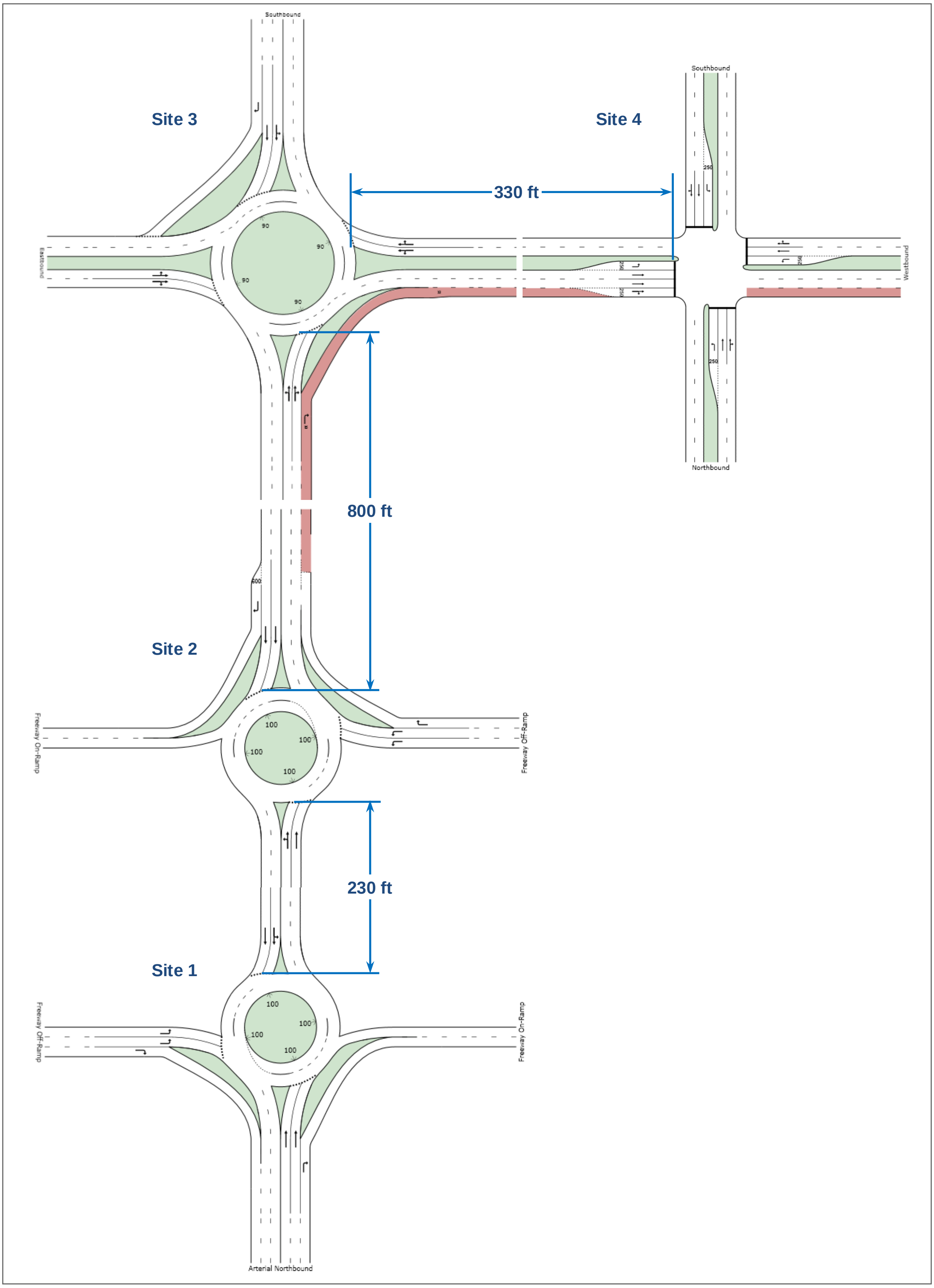


Figure 1 - Example: roundabout corridor with a roundabout interchange and bus lane

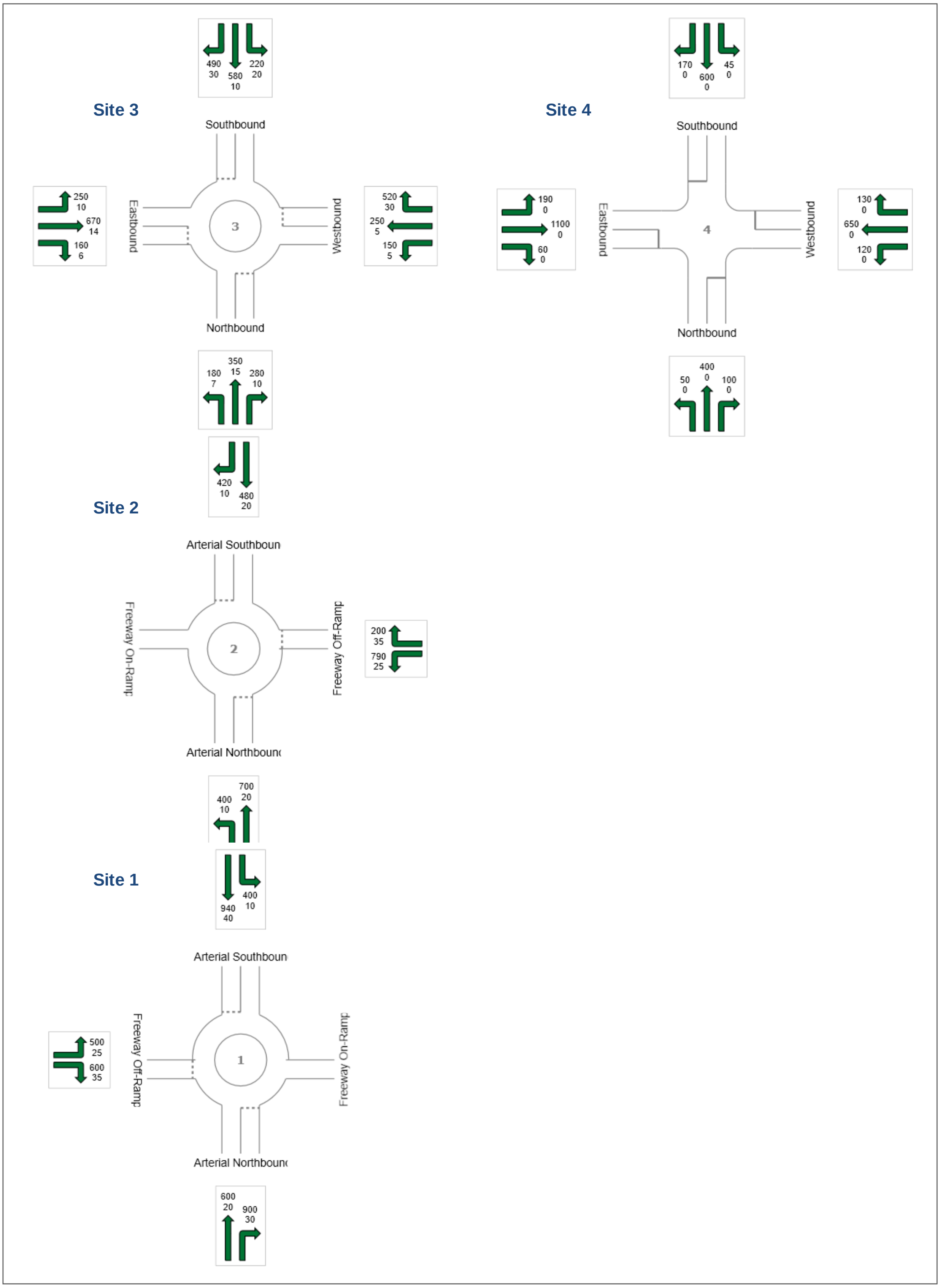


Figure 2 - Volumes for the example shown in Figure 1

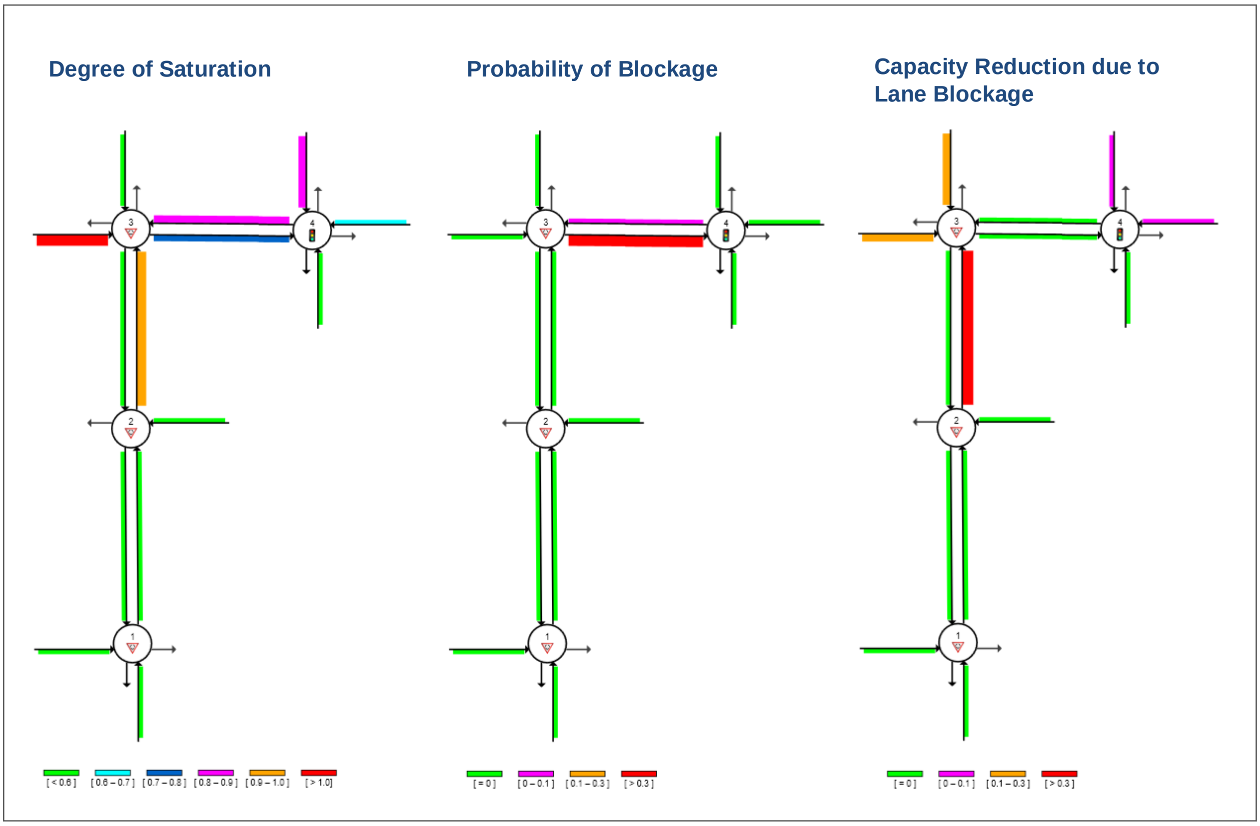
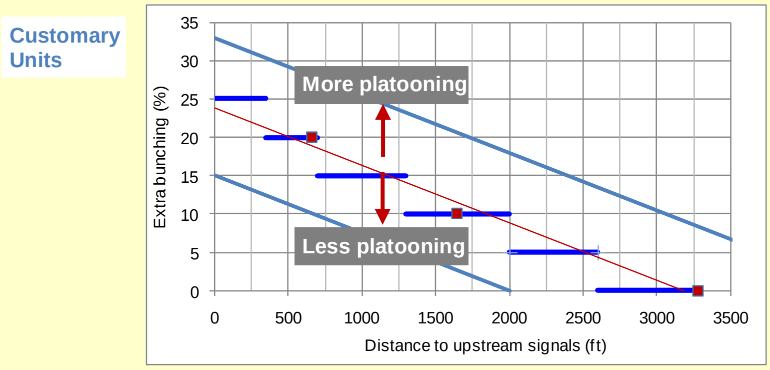


Figure 3 - Network displays for the example shown in Figure 1

Table 1 - A guide for specifying extra bunching data

Distance to upstream signals (ft)	< 350	350-700	700-1300	1300-2000	2000-2600	> 2600
Extra bunching (%)	25	20	15	10	5	0



For roundabouts, SIDRA INTERSECTION determines *effective extra bunching* for each *circulating stream* (according to different components of that circulating stream in terms of the contributing approach streams) using the extra bunching data specified for each *approach*. This method considers that extra bunching for the effect of upstream signals applies to the demand flow arriving at the back of the queue on the subject approach, and the amount of bunching is filtered through the queuing processes at contributing roundabout approaches.

In this example, an extra bunching value of 30% was specified for the East (Westbound) approach of Site 3 (roundabout) due to the effect of departures from South, East and North approaches of Site 4 (Signalized intersection). This had an effect on the capacities of downstream entries (North and West approaches) at Site 3. The proportion queued on the East approach of Site 3 was estimated as 85 per cent which reduced the effect of the extra bunching accordingly.

CONCLUDING REMARKS

A lane-based micro-analytical network model has been described and an example of a roundabout corridor which includes a roundabout interchange, a roundabout with a bus only bypass lane and a signalized intersection with a two-segment bus lane has been presented to demonstrate the model.

Evaluation of the model for real-life roundabout corridors and comparisons with other analytical and microsimulation models are recommended.

Investigations are also recommended in relation to the balance of upstream and downstream lane flows for internal approaches *(18)*.

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