The analysis of Performance and Capacity at a Roundabout with metering signals

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ABSTRACT

This paper aims to describe a method for the analyzing of capacity and performance of roundabout operating with metering signals. The use of metering signals is a found as a measure to avoid the need of a fully signalized intersection, when the low capacity conditions are observed during peak demand flow periods. Roundabout metering signals are often installed on selected roundabout approaches and used on a part time basis, since they are required, when heavy demand conditions occur during peak periods. These metering signals are used normally for alleviating the excessive delay and queues, due to the gaps created in the circulating stream. The basic principles of the operation of roundabout metering signals shall be explained. This paper shall present some analysis results, when operating with metering signals. A case study for some crucial roundabouts in Albania, shall be part of the results and conclusions must be considered to reevaluate the need, when to use metering signals, or not, at the existing congested roundabouts.

INTRODUCTION

Implementation and continued success of roundabouts in Albania, as in many countries around the world, depend on improved understanding of major factors that affect the operation of roundabouts. Like all other traffic control devices, the road and intersection geometry, driver behavior, light and heavy vehicle characteristics, behavior and requirements of other road users, traffic flow characteristics and operation of traffic control to resolve vehicle to vehicle conflicts (as well as vehicle to pedestrian conflicts) are important factors that influence roundabout performance. Vehicle traffic flow characteristics represent collective behavior of vehicles in a traffic stream as relevant to, for example, car following, queue forming and queue discharge conditions.

The control rule at modern roundabouts is the yield (give-way) rule. Analytical and micro simulation models use gap-acceptance modeling to emulate behavior of entering drivers yielding to circulating vehicles, i.e. finding a safe gap (headway) before entering a roundabout. This behavior is affected by roundabout geometry (size, entry and circulating lane widths, approach and circulating lane arrangements, etc.) which influences such important parameters as sight distance, speed and lane use.[1]

The headway distribution of vehicles in the circulating stream (influenced by queuing on the approach road and effective use of circulating lanes at multi-lane roundabouts) is the controlling variable that determines the ability of approach vehicles to enter the circulating road. This is as important as the critical gap (headway) and follow-up headway parameters of the entry stream in determining roundabout capacity, performance (delay, queue length, number of stop-starts, fuel consumption, emissions, and operating cost) and level of service.

Thus, complex interactions among the geometry, driver behavior, traffic stream and control factors determine the roundabout capacity and performance. The level of traffic performance itself can influence driver behavior, increasing the complexity of modeling roundabout operations.
As a result, an important factor that influences the capacity and performance of traffic on roundabout approach roads is the *origin-destination pattern* of arrival (demand) flows as related to the approach and circulating lane use. This impacts headway distributions of circulating streams, and as a result, affects approach lane capacities and performance. The origin-destination factor and the related issues of *priority reversal* and *priority emphasis* are discussed in some detail due to their relevance to roundabout operating conditions that require metering signals. [2]

When low capacity conditions occur during peak demand flow periods, for example due to unbalanced flow patterns, the use of metering signals is a cost-effective measure to avoid the need for a fully signalized intersection treatment. Roundabout metering signals are often installed on selected roundabout approaches and used on a part-time basis since they are required only when heavy demand conditions occur during peak periods. Metering signals have been used before to alleviate the problem of excessive delay and queuing by creating gaps in the circulating stream. [1]
Case studies of roundabouts where metering signals were used, or could be considered for use have been presented in this paper by the author. These case studies included one-lane, two lane and three-lane roundabouts from different countries of the world with total intersection flow rates in the range 1700 to 5300 veh/h. These case studies also demonstrated the importance of modeling different approach and circulating lane arrangements at multi-lane roundabouts. [6]

THE ORIGIN-DESTINATION (O-D) FACTOR

The O-D factor was first introduced in an earlier version of SIDRA to allow for unbalanced flow effects. (6). The aaSIDRA model contrasts with other methods that treat the roundabout as a series of independent T-junctions with no interactions among approach flows (except that some traditional methods allow for the effect of capacity constraint on circulating flows). While traditional methods may be adequate for low flow conditions, the O-D factor improves the prediction of capacities under medium to heavy flow conditions, especially with unbalanced demand flows. This helps to avoid capacity overestimation under such conditions as observed at many real-life intersections. In all real-life cases considered, the methods without unbalanced flow modeling predict good operating conditions whereas long delays and queues are observed on one or more approaches of such roundabouts. [3]

Figure 1 explains the effect of the O-D pattern. It can be seen that different capacities and levels of performance may be estimated for the same circulating flow rate depending on the conditions of the component streams. The lowest capacity is obtained when the component stream flow rates are unbalanced and the main) (dominant stream is a very large proportion of the total circulating flow, it is in a single lane, and is highly queued on the approach lane it originates from. [5]

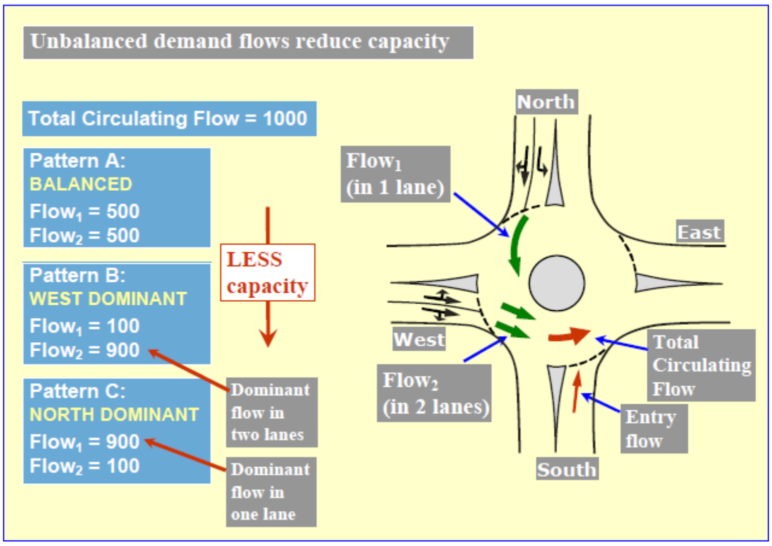

Figure 1 The effect of the Origin-Destination (O-D) pattern on capacity in modeling unbalanced flows

UNBALANCED FLOWS AT ROUNDABOUTS - THE ISSUE

Improved understanding of the effect of the origin-destination pattern of traffic on roundabout capacity, performance and level of service helps towards designing new roundabouts that will cope with future increases in demand levels and solving any problems resulting from unbalanced flow patterns at existing roundabouts. Many real-life case studies show that roundabout capacity and level of service depend not only on the circulating flow level, but also the balance, queuing and lane use characteristics of approach flows contributing to the circulating flow. Unbalanced flow conditions may arise at T-intersection, four-way and freeway interchange roundabouts. [4]

At a roundabout with an unbalanced flow pattern, a traffic stream with a heavy flow rate enters the roundabout against a circulating stream with a low flow rate. Examples of high flow rates per lane at such roundabout cases from Tirana, Albania are described below:

a) Small to medium size single-lane roundabout at the intersection of "Sauk" **1693 veh/h per lane** entering against a circulating flow rate of 67 veh/h has been reported. Sum of entering and circulating flows is 1760 veh/h. The measured follow-up headway and critical gap values for this entry lane are 1.992 s and 2.423 s, respectively. The maximum capacity at zero circulating flow (corresponding to the follow-up headway) is 3600 /1.992 = 1808 veh/h.

b) Small single-lane roundabout at the intersection of "Sheshi Willson" in Tirana City: **1524 veh/h per lane** entering against a circulating flow rate of 60 veh/h has been reported . The sum of entering and circulating flows is 1584 veh/h.

c) Large multi-lane roundabout at the intersection of "Shqiponja": **1397 veh/h per lane** against a circulating flow rate of 83 veh/h in am peak and **1501 veh/h per lane** against a circulating flow rate of 112 veh/h in pm peak. The sum of entering and circulating flows is 1480 veh/h in am peak and 1613 in pm peak. [4]

Unbalanced flows may not be a problem when the overall demand level is low but the problem appears with traffic growth even at medium demand levels. Demand flow patterns and demand levels may change significantly after the introduction of a roundabout, sometimes in a relatively short period of time, because there is no direct control over turning movements unlike signalized intersections.

Modeling of the traffic demand pattern is important in optimizing the roundabout geometry including lane arrangements. This can be achieved for a new roundabout subject to the reliability of traffic demand information, or for an existing roundabout to a smaller extent due to the design constraints imposed by existing geometry. The use of part-time metering signals is a cost-effective measure to avoid the need for a fully-signalized intersection treatment.

ROUNDABOUT METERING SIGNALS - A PRACTICAL SOLUTION TO THE UNBALANCED FLOW PROBLEM

There are many examples of roundabouts with unbalanced flow patterns in Albania, where part-time roundabout metering signals are used to create gaps in the circulating stream in order to solve the problem of excessive queuing and delays at approaches affected by highly directional flows. Roundabout metering signals are usually employed on a part-time basis since they may be required only when heavy demand conditions occur during peak periods. They can be an effective measure preventing the need for a fully-signalized intersection treatment as they are often used on selected roundabout approaches, operational only when needed under peak demand conditions. [6]

There are two types of operation depending on the use of detectors on the metered approach. Operation with no detectors on the metered approach is similar to the semi-actuated operation It is also similar to the operation of signalized pedestrian crossings with pedestrian actuation and no vehicle actuation. The duration of the blank signal condition is determined according to a minimum blank time requirement, or extended by the metered approach traffic if detectors are used on that approach:

a) If the metered approach has detectors, minimum blank time and maximum blank extension time settings are employed with a gap setting for extending the blank time. The timer for the maximum blank extension time setting starts after the minimum blank time. The demand for the blank phase is registered when the first vehicle (during the red phase) is detected by the metered approach detectors. [5]

b) If the metered approach does not have detectors, only a minimum blank time setting is used. The blank period may be terminated after the minimum blank time as soon as a queue detector demand is registered on the controlling approach. The demand for the blank phase is registered automatically as soon as the red phase is introduced.

The introduction and duration of the red signal on the metered approach is determined by the controlling approach traffic. For this purpose, minimum red time and maximum red extension time settings are used with a queue detector gap setting for extending the red time. A queue detector occupancy setting, i.e. the occupancy time for queue detection, is used as an additional queue detector setting to register the demand for the red signal phase. The timer for the maximum red extension time setting starts after the minimum red time (when demand is registered on the metered approach as described above). Table 1 summarizes design and control parameters used for metering signals at various roundabouts in Tirana, Albania. [7]

Table 1 Typical design and control parameters used for roundabout metering signals

Metered approach	
Signal stop-line setback distance	14 -24 m (46 - 79 ft)
Detector setback distance (if detector is used)	2.5 m (8 ft)
Loop length (if detector is used)	4.5 m (15 ft)
Minimum blank time setting	20 - 50 s
Maximum blank extension time settings	30 s
Blank signal gap setting	3.5 s
Yellow time	4.0 s
All-red time	1.0 - 2.0 s
Controlling approach	
Queue detector setback distance	50 - 120 m (164 - 394 ft)
Loop length for the queue detector	4.5 m (15 ft)
Minimum red time setting	10 - 20 s
Maximum red extension time settings	20 - 60 s
Queue detector gap setting	3.0 - 3.5 s
Queue detector occupancy setting: t_{oq}	4.0 - 5.0 s
Yellow time: t_{yR}	3.0 - 4.0 s
All-red time: t_{arR}	1.0 - 2.0 s

CASE STUDY: SHQIPONJA ROUNDABOUT, TIRANA,ALBANIA

A method is described in this section for the analysis of roundabout capacity and performance characteristics with metering signals. This is the intersection of Shqiponja a large circular- multi-lane roundabout shown in Figures 2. The signals were actuated by a queue of vehicles extending back along the North approach to the presence detectors located 90 m (about 300 m) upstream of the yield line. The metering signals were found to reduce the queuing on the North approach substantially. Results of analysis of this roundabout without metering signals were able to estimate the congestion observed at this roundabout while various other methods. Volume data have been modified to demonstrate a case of reasonably large benefit from the use of metering signals. The volumes used in this analysis are given in Figure 3. [4]

Figure 2 Shqiponja Roundabout

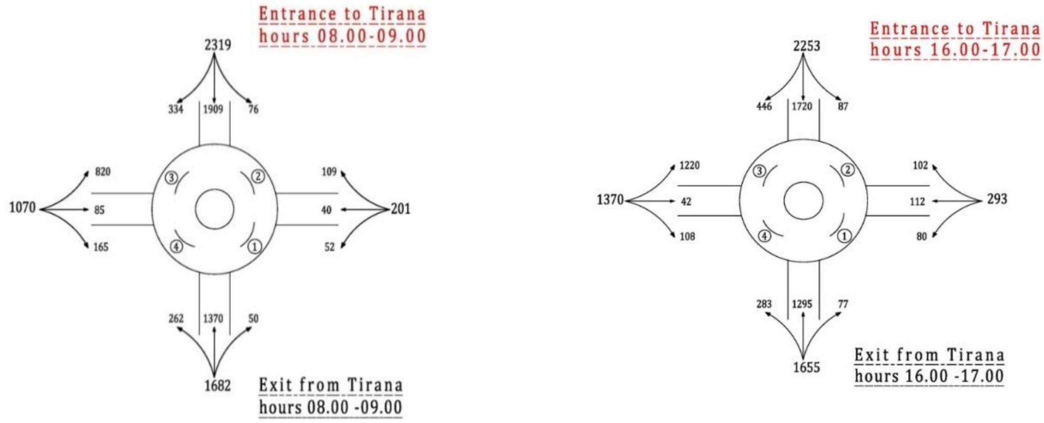

Figure 3 Entrance and exit flows: 08.00-09.00 and 16.00-17.00

THE ANALYSIS METHOD:

The following analysis method was applied for modeling the effects of metering signals, which involved estimating operating characteristics for three operation scenarios using aaSIDRA:

1) **Base Conditions**, i.e. roundabout operating **with BLANK metering signals** on the metered approach. This corresponds to normal operation of the roundabout without metering signals.

2) Roundabout operation when the **metering signals display RED**, i.e. the metered approachtraffic is stopped and the rest of roundabout operates according to normal roundabout rules.

3) Signalized intersection scenario to emulate the operation of **metered approach signals** in order to determine the performance of the metered approach.

The analysis results indicate that:

1) As expected, metering signals reduce delay and queue length on the controlling approach but increase delay and queue length on the metered approach. This limits the overall benefit that can be obtained from metering signals.

2) For the controlling approach, the average delay and queue length appear to be reduced significantly (20 - 40 per cent). Availability of queue storage distance on the metered approach is a limiting factor that determines the proportion of time when red signal can be displayed, therefore limiting the benefits from metering signals.

3) Operating cost saving and CO_2 and other emission reductions are significant and may offer a good benefit-cost ratio due to the low cost of implementing metering signals.

Option	Description	Demand Flow (veh/h)	Average Delay (sec)	Worst Approach Delay (sec/veh)	95% Back of Queue (veh)	Total Stops (veh/y)	CO2 (kg/y)	Operating Cost ($/y)
1	No Metering Signals	1,034,400	44.6	82.8	62	1,870,248	327,984	371,179
2	With Metering Signals	1,034,400	37.1	52.4	37	1,479,019	311,885	343,190
	Difference	0	-8	-30	-25	-391,229	-16,099	-27,989
	Per cent difference	0.0%	-16.9%	-36.7%	-40.0%	-20.9%	-4.9%	-7.5%

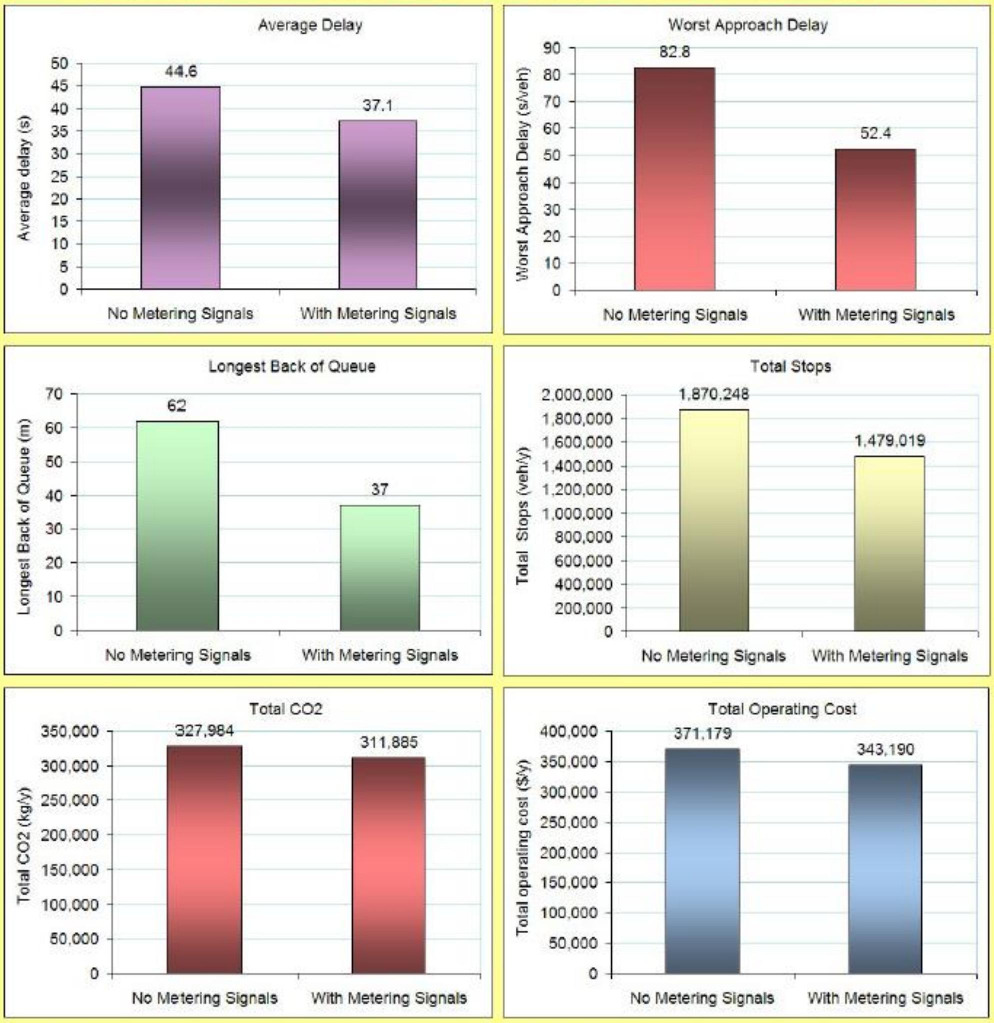

Figure 4 Benefits from metering signals for the Shqiponja Roundabout

CONCLUSIONS

The analysis method described in this paper is an approximate one which involves various assumptions. It is possible that benefits from the metering signals are higher than indicated in this paper considering dynamic variations in demand flows in real-life traffic conditions and residual effects of oversaturated conditions continuing after the periods analyzed. A more comprehensive method has been developed and will be included in a future version of aaSIDRA.

Field observations are recommended on driver behavior at roundabouts subject to metering signal control. In particular, the "saturation flow rate" of the metered approach should be compared with the "capacity rate" of normal roundabout operation (without metering signals) to establish if the metering signals affect driver behavior, i.e. if those vehicles queued at a red signal subsequently display shorter queue discharge (follow-up) headways and accept shorter gaps.

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