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# Capacity and Delay Estimation at Signalized Intersections under Unsaturated Flow Condition Based on Cycle Overflow Probability

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**Abstract**
This paper presents a model for estimating capacity and delay at signalized intersections. Making use of the queuing system at signalized intersections, the capacity can be estimated by measuring the cycle overflow probability at stop-line detectors. Based on a given queuing model, the stochastic characteristics of signalized intersections can be estimated as well. Then, delays and queuing lengths can be obtained using the estimated parameters. The results of the presented model are underlined by a comprehensive sensitivity analysis. Furthermore, a VISSIM simulation study is conducted to demonstrate the capability of the model.

*Keywords:* Signalized intersection; Capacity; Delay; Cycle overflow probability

# 1 Introduction

Capacity at signalized intersections is a basic parameter in urban transport networks. The capacity of a signalized intersection depends on existing geometric, control, weather, and other conditions. Estimation of capacity at signalized intersections is one of the most important topics in traffic engineering and transportation science. If the capacity can directly be measured, the delay or queue length at signalized intersections and thus the traffic performance and quality of service can be calculated according to the functional relationship between delay or queue length and capacity. Unfortunately, under real world traffic conditions, the capacity cannot easily be measured directly for an existing intersection, especially under unsaturated flow conditions where the demand is lower than the capacity.

This paper presents a model for estimating capacity of an existing signalized intersection under unsaturated flow condition based on the cycle overflow probability which can be directly measured by loop detectors at stop lines. The cycle overflow probability is just the proportion of the number of cycles with fully occupied detector during green phases to the total number of cycles. Also the demand can directly be measured by loop detectors at stop lines. According to the queuing theory, the cycle

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overflow probability is a function of the degree of saturation, i.e. a function of demand and capacity. Thus, by measuring the cycle overflow probability and the demand, the capacity can be estimated according to the functional relationship. Based on the given queuing model, the stochastic characteristics of signalized intersections can be estimated as well. Then, delays and queuing lengths can be obtained using the estimated parameters.

The proposed model can be verified by simulation studies under unsaturated conditions. For validation the model, capacities obtained for saturated flow condition (cycles with fully occupied detector during green phases) where the capacity can be considered as the measured flow rate are used as a reference.

The proposed model provides a useful tool for estimating capacity and delay at signalized intersections under unsaturated conditions. Using the proposed model, the capacity and thus the traffic quality of service at existing signalized intersections can directly be estimated using data from loop detectors at stop lines. The model is theoretically reasonable and easily to use for practitioners. The results of the calibration and validation are very promising.

The paper is organized as follows. In the following section 2, a theoretical background and motivation of the proposed model is presented. In section 3, some numerical studies are conducted in order to examine the sensibility of the model and its parameters. In section 4, possible applications of the proposed model are presented and discussed. Then, examples of the model using simulated data are illustrated in section 5. And finally, a conclusion and outlook is given in section 6.

# 2 Theoretical Background

The model derivation in this paper is based on the following basic conditions in traffic modelling: a) under-saturated flow condition, i.e. the degree of saturation $x$ should be less than 1; b) stationary flow state, i.e. the mean value of traffic demand and capacity is constant over time; c) fixed-time signals, i.e. the signal control is independent of demand; and d) M/Bunch/1 queuing system, this indicates that the probability of idling state is not equal to $1 - x$, where $x$ is the degree of saturation. Notice the delay model in HCM (TRB, 2010) and HBS (FGSV, 2015) are based on an M/D/1 queuing model that overestimates delays or queue lengths under unsaturated conditions.

However, the here derived approach can be extended to following conditions without losing generality: a) non-Markovian input process; b) temporal oversaturation; b) piecewise stationarity; and d) actuated and coordinated signals.

## 2.1 Queuing Model at Signalized Intersections

In order to estimate the capacity and traffic state at traffic systems, Measures of Effectiveness (MOE) for the corresponding queuing systems have to be collected. For the traffic performance analysis at signalized intersections, delay and queue length are the most common MOEs. For calculating the queue length or delay at signalized intersections, the capacity and the characteristics of the queuing system must be known. Thus, the capacity $C$ and the characteristics at signalized intersections have to be estimated in advance. However, it is not an easy issue to measure the capacity and the queuing characteristics in the reality.

The queue length and delay at signalized intersections can be estimated according to the stochastic input (demand $q$) and output (capacity $C$) process. At signalized intersections, the queue length at end of green time $N_{GE}$ is the most crucial parameter. The value of $N_{GE}$ can be directly measured at end of green time. Once this parameter $N_{GE}$ is known, the corresponding delay and queue length at other stage of cycle time (e.g. end of red time or end of back-of-queue) can be calculated according existing mathematical models (cf. Wu, 1996). Another parameter which describes the characteristics of