# Estimating the effects of temporary bottlenecks on the capacity of urban arterial: An MFD-approach

Sasan Amini*, Gabriel Tilg

*Chair of Traffic Engineering and Control, Technical University of Munich*

**Corresponding author: sasan.amini@tum.de*

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## 1. Introduction

With the growing urbanization, congestion in urban areas is a topic of increasing concern. Traffic congestion frustrate drivers, increase air pollution and interrupt economic productivity. The severity of the problem increases in case of non-recurring congestion caused by incidents, adverse weather condition, work zones, etc. Such conditions are characterised as *unexpected*, and therefore, surprise both the road users and traffic operators and put the reliability of the entire transport system at high risk. Thus, it is crucial to identify them and implement proper control measures to mitigate their negative impacts.

Most of the existing incident detection algorithms rely on the fundamental diagram (FD) of traffic flow theory such as Krause et al. (1996). However, such methods are applicable only on uninterrupted traffic flows and fail to capture the dynamics of interrupted traffic flow on urban roads. The recent findings of Geroliminis and Daganzo Geroliminis et al. (2007); Geroliminis and Daganzo (2008) which show the existence of macroscopic fundamental diagram (MFD) on urban roads has encouraged researchers to explain complex phenomena in urban networks. Studies have shown that the MFD for homogeneous urban regions is insensitive to small changes in demand and depends on network topology and control parameters such as block length and signal control configurations Ramezani et al. (2015); Zhang et al. (2013). This property makes the MFD an ideal tool for development of traffic control measures which has been used for a number of applications such as controlling traffic through gating Keyvan-Ekbatani et al. (2012); Haddad and Shraiber (2014). Generally, the existing methods for estimating the MFD can be categorized in two general groups: first, experimental i.e. simulation and empirical observations Geroliminis and Daganzo (2008) and second, analytical approaches which are based on the method of cuts Daganzo and Geroliminis (2008) derived from the variational theory of kinematic waves Daganzo (2005a,b). These methods have been applied on both homogeneous and stochastic corridors with homogeneous stream of cars. Extended works have also considered moving bottlenecks i.e. the impact of buses and bus stops Castrillon and Laval (2017); Xie et al.

(2013) as well as double-parked trucks for short periods of time Chiabaut (2015). The results reveal a considerable impact on the MFD at maximal capacity which can be similar to the impact of *short blocks* on the network. Other studies have shown the possibility to identify anomalies in a network from the shape of the MFD from empirical observations. For example, Tsubota et al. (2014) have observed that a local accident has been captured in the regional MFD in term of reduction in the network capacity and unusual scatter near capacity. However, to the best knowledge of the authors, there has been no explicit attempts made to analyze the effects of the duration of temporary bottlenecks on arterials with the MFD and to model it analytically. The methodology to achieve the study goal is discussed below.

## 2. Methodology

The recent work of Chiabaut (2015) which refines the methodology proposed by Leclercq and Geroliminis (2013) provides an accurate analytical method to estimate the MFD on multimodal arterial taking into account local capacity reductions. In this paper, this work is extended to estimate the MFD for any location and duration of the bottleneck. The following formula defines an MFD on an arterial:

$$q = min_v(R(V) + kV : V \in [-w, u]) \tag{1}$$

where q and k are the average flow (veh/h) and the average density (veh/km) respectively, u and w are the free-flow speed and backward wave speed (m/s). Please note that all the links are assumed to have a triangular FD. The value of R(V) can be derived from the variational theory. It refers to the maximum average flow at which the traffic can overtake a moving observer with a constant speed V. R(V)+kV defines a "cut" on the (q,k) plane where the MFD is the lower boundary of any possible cuts. In order to find R(V) the time-space diagram is discretized to obtain variational graph on which a moving observer can travel. Since the moving observer starts at the end of the red phase and can only travel with u or -w, a graph composed of all possible paths is sufficient to accurately estimate R(V) for a wide range of V. This will lead to solve the equation (1) and consequently estimate the MFD of the considered arterial even in cases of heterogeneous corridors. Since all the paths in variational graph have the same initial and final point, the associated R(V) corresponds to the least-cost between the points:

$$R(V) = min_p[1/T_p \int_{s \in P} r(v_s)ds] \tag{2}$$

Where r(v) is the passing rate of an observer travelling with speed v, P is the set of all possible paths with average speed V and $T_p$ is the travel time of observer traversing the arterial with speed V. Figure 1 illustrates the impact of a random temporary local bottleneck on the variational graph.

## 3. Simulation Study

In order to evaluate the accuracy of the estimated MFD of the analytical method a two lane arterial with different block lengths has been modelled in microscopic simulation tool

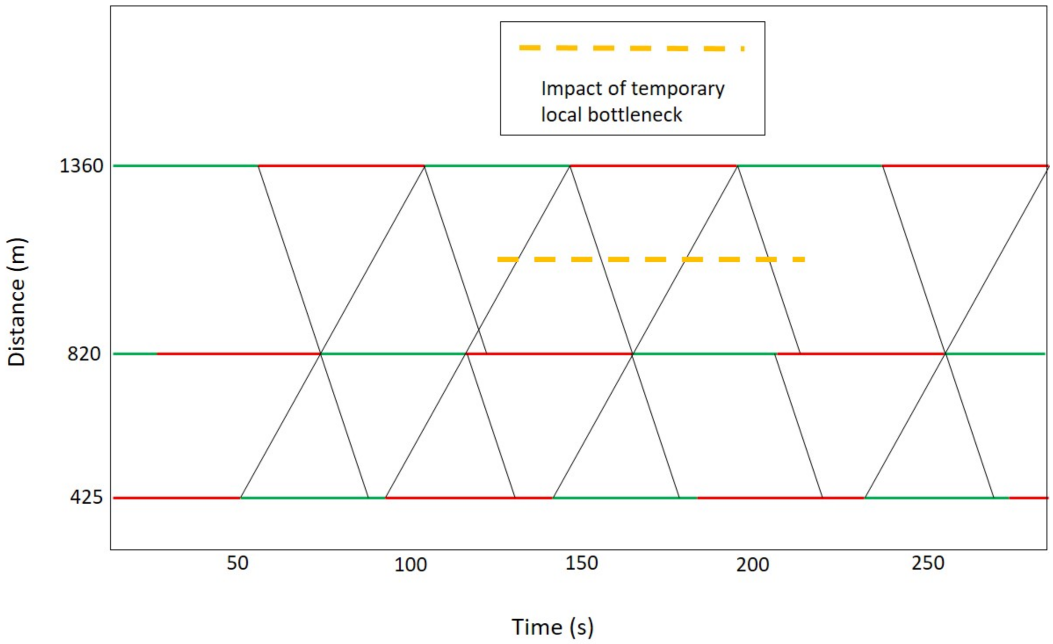


Figure 1: The variational graph with a temporary local bottleneck upstream the third intersection

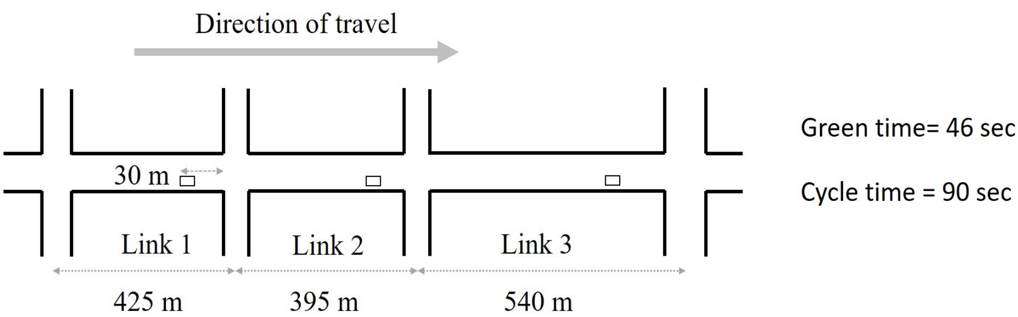


Figure 2: The schematic layout of the modelled arterial with three signalized intersections

SUMO Krajzewicz et al. (2012). Figure 2 depicts the schematic of the studied arterial. The simulation is modelled for six hours with varying demand every 15 minutes ranging from 60 veh/h to 2000 veh/h. In addition, the arterial has a coordinated signal plan with a green time and cycle time of 46s and 90s for all the three intersections. Three different scenarios are studied: a base scenario where no lane closure is considered, a short-term blockage of right lane 150 meters upstream of the last intersection for the duration of 45 minutes during the peak-demand, and finally a long-term blockage of the same lane but for the duration of four hours including peak-demand. Each lane is equipped with a virtual loop detector positioned at 30 meters upstream of the stop line.

## 4. Preliminary Results

By extending the existing analytical method to estimate the MFD on arterial this paper investigates the impact two different incidents on the performance of an arterial. The first results of the simulation (see Figure 3) are in line with the findings of others works Castrillon and Laval (2017); Chiabaut (2015). As expected the base scenario stays in undersaturated state with a capacity of almost 1000 veh/h. The short and long blockage reduce the capacity to 830 and 790 veh/h respectively. In addition, a slight shift on the linear part of the MFD could be observed which corresponds to inefficiency of the signal coordination after the occurrence of the bottleneck. In reality, an adaptive signal control may avoid such reduction of performance by adjusting the offsets. It is important to mention that if the lane closure happens during low demand, it is likely that a very slight deviation from the linear part of the MFD will occur which may not be easily categorized as a bottleneck. Therefore, considering travel time measurements and speed-density relationships will provide a broader overview of the situation which will be considered in the continuation of the work.

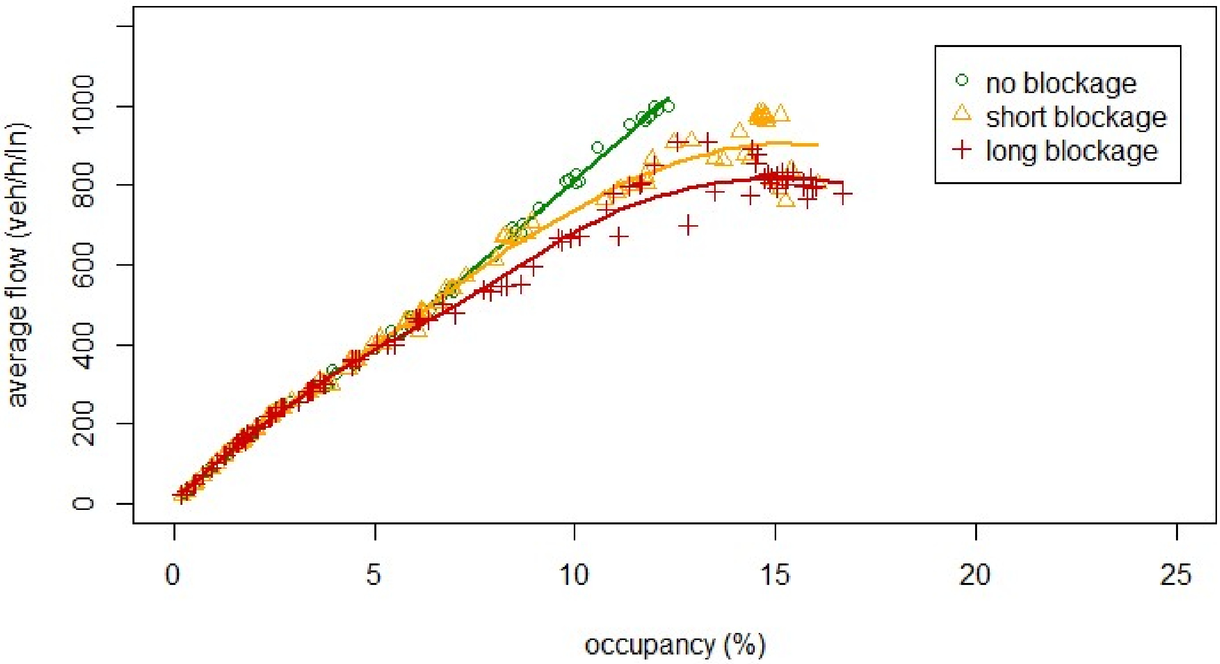


Figure 3: The impact of bottleneck on MFD from the simulation

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