Clustering of fundamental traffic relations for capacity estimation

Ellen F. Grumert\textsuperscript{a,b}, David Gundlegård\textsuperscript{b}

\textsuperscript{a}Swedish National Road and Transport Research Institute (VTI), SE-581 95 Linköping, Sweden
\textsuperscript{b}Linköping University, Department of Science and Technology, SE-601 74 Norrköping, Sweden

Abstract

Capacity estimation at bottleneck locations along urban motorways are of importance for control purposes. If the capacity is known, the control strategy can be designed to not exceed capacity, or at least prolong the time until exceeding the capacity and thereby entering congested traffic conditions. In this study we show how the probability distribution of capacity can be estimated using automatic identification of traffic breakdowns and clustering methods.

\textcopyright{} 2020

Peer-review under responsibility of the scientific committee of the 23rd EURO Working Group on Transportation Meeting.

Keywords: Capacity estimation; Fundamental diagram; Clustering;

1. Introduction

Traffic congestion contributes to large costs for the society in terms of delays, especially on urban motorways that experience large traffic flows due to daily commuting. The most frequently observed congestion is recurrent congestion, which is the result of traffic demand exceeding the capacity of a bottleneck, e.g. on- or off-ramps or lane-drops. At the transition from non-congested to congested traffic conditions, frequent accelerations/decelerations and lane-changing is reducing the capacity at the bottleneck, resulting in the well-known capacity drop (Srivastava and Geroliminis, 2013). Hence, it is of great importance to reduce the number of times the demand is too high to be served by the bottleneck. By applying a control strategy in such a way that the traffic flow never exceeds the capacity, a traffic breakdown can be delayed or even avoided. To achieve an optimal design of the control strategy, knowledge of traffic flow characteristics, especially capacity, is required. Today, many of the urban motorways are equipped with densely placed sensors with short data collection intervals. This data is a useful resource to identify and analyze the characteristics of traffic flows and estimate the capacity in a more systematic way. However, as stated in Kondyli et al. (2017) the capacity is known to vary, even at one specific bottleneck for similar traffic conditions, and it is therefore desirable to group days and sensors with similar traffic characteristics in order to reduce the variance in capacity before it is estimated. In this paper, we propose a methodology for estimating the distribution of capacity for clusters with

\textsuperscript{*} Corresponding author. Tel.: +46-766-324-342.

E-mail address: ellen.grumert@vti.se
similar speed-flow relations. The methodology consist of the following steps: (1) an automated process to identify breakdowns resulting in recurrent congestion, (2) a clustering method to cluster breakdown days and locations with similar speed-flow relations, and (3) a statistical approach for estimating the capacity distribution for each cluster.

2. Methodology

A breakdown is defined as the transition from non-congested to congested traffic. This phenomenon can be identified in data by observing piece-wise linear trends in the cumulative number of vehicle arrivals and the cumulative density (Cassidy, 1998). The discontinuities between the linear trends is representing the transitions between two traffic states. When congestion occur, the density is increasing at the same time as the traffic flow is decreasing. Hence, as stated by Soriguera et al. (2017) a breakdown is detected by a sudden increase in the slope of the cumulative density together with a decrease in the slope of the cumulative count of the number of vehicles. We use an automated process for identification of these sudden changes in the curves to be able to handle a large data set with many breakdowns.

With sensor data for a long time period, the observations might contain large variations in capacity. To reduce the variability of the estimated capacity, the fundamental relations can be clustered before estimation. As a result, a number of explanatory variables, such as location or type of day, can be identified. There are numerous studies on clustering techniques for traffic data, but focus is often on either speed or flow and not the fundamental relation speed-flow (Gu et al., 2016). Exceptions are Kianfar and Edara (2013) with focus on identifying congested and non-congested flows, Azimi and Zhang (2010) identifying service levels and Gu et al. (2016) using a parametric approach with a triangular fundamental diagram. In this paper we use a non-parametric approach focusing on capacity estimation.

The capacity can be estimated by calibrating the fundamental diagram using observations of the fundamental relations of speed-flow, see e.g. Dervisoglu et al. (2009) and Knoop and Daamen (2017). However, since the capacity is known to vary also at similar traffic conditions and for the same locations, it is estimated as a probability function rather than a static value, similar to the work by Brilon et al. (2005).

3. Case study and results

The proposed methodology is evaluated using one year of empirical observations of speed and flow from an urban motorway stretch south of Stockholm, Sweden. The 15 km long road stretch consists of homogeneous road sections with two or three lanes and three on-and off-ramp locations. The speed and flow observations are collected from a total of 116 densely located sensors (150-300 meter spacing) in both southbound and northbound direction and averaged over one-minute periods. The proposed methodology is analyzed by investigating the estimated distribution of capacity without clustering to the estimated distribution of capacity with different ways of clustering speed and flow relations. Possible explanatory variables that affect the shape of the fundamental relations are also identified.

References