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Spatio-Temporal Congestion Patterns in Urban Traffic Networks

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Abstract

Traffic congestion in urban areas is a big issue for cities around the world. Thus, studying congestion and respective counter measures is of high importance for the increasing urbanization of society. Congestion analysis and forecast is most of the times done either on a link-wise network or on a network-wide level. Though, due to bottlenecks in the infrastructure and similar commuting patterns by road users, usually the same parts of an urban traffic network get congested. The idea is to observe and investigate primarily these most vulnerable parts of the network, which are denoted as congestion clusters, as they are crucial to both, drivers and operators. A methodology for determining congestion clusters is described, which provides a significant amount of flexibility to be able to meet different needs for different applications or cities. Based on a five months set of Floating Car (FC) data, the suggested methodology is tested. First analyses are conducted to understand up to which degree these clusters are able to represent the congestion level of the entire network. Besides, correlations between the clusters are investigated on a statistical basis and conclusions are drawn. The results provide a basis for potential traffic estimation and forecast systems.

Keywords: Probe data, network clustering, congestion analysis, traffic estimation, traffic prediction

1 Introduction

For traveller information systems as well as traffic control, it is fundamental to know where traffic jams occur and, in best case, to have reliable forecasts concerning their future development. Otherwise, neither can road users be informed adequately, nor can effective traffic management measures be executed to dissolve congestion.

However, monitoring an entire traffic network and providing forecasts for any possible location is very costly and, since significant parts of the network are never congested, also not necessary. This is also the fundamental motivation for the proposed approach: Start with identifying areas in which connected pockets of congestion typically emerge and reside, and then analyse primarily them instead

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of the whole road network. These congestion-prone areas will from here on be denoted as congestion clusters. The hope is that congestion clusters can be understood as "neuralgic points" of the network. As such, they are most relevant to drivers and traffic management and possibly allow drawing conclusions on the traffic status of the whole network.

The paper is structured as follows: First, an overview on literature concerning urban traffic analysis and forecast will be provided. Then, the Floating Car (FC) data that are used to identify congestion clusters and the data preparation process are described. In a next step, it is explained which properties congestion clusters should show and how they can be computed algorithmically. Finally, a case study is executed. Munich (Germany) and its suburbs are used as test site for a five months period. The sensitivity of the cluster computation methodology on its input parameters is discussed. Then, the congestion in the clusters is analysed. First focus is laid on the typical congestion starts and ends, and second, the correlation between pairs of clusters is determined.

2 Related Work

Traffic forecasts provide valuable information for traveller as well as traffic management and control. With the rapid spread of mobile sensors the availability of traffic data increased dramatically and new method are developed that apply this type of data to problems such as traffic estimation and prediction (Corrado de Fabritiis, 2008), (Herring, Abbeel, Hofleitner, & Bayen, 2010). Short-term traffic prediction has been subject of many works. In (Vlahogianni, Karlaftis, & Golias, 2014) there is a detailed review of current approaches. Usually the methods are classified into parametric and non-parametric approaches. Parametric approaches define a model and fit the parameters of the model to the data. Non-Parametric approaches on the other hand have a flexible structure and a variable number of parameters. (Lippi, Bertini, & Frasconi, 2013) (Karlaftis & Vlahogianni, 2011) present comparisons of different methods and their accuracy in traffic forecasting. In (Vlahogianni, Karlaftis, & Golias, 2014) 10 mayor challenges for upcoming research are pointed out. One is to focus on network level spatio-temporal approaches. In the past year several works regarding that have been published. To mention a few, (Min & Wynter, 2011) apply a multivariate spatial-temporal autoregressive model on a sample network with different road categories. (Kamarianakis & Prastacos, 2005) model the traffic flow in space and time using a Space-Time Autoregressive Integrated Moving Average (STARIMA) model. (Yue & Yeh, 2008) analyse the spatio-temporal characteristics of flow on highways. (Cheng, Haworth, & Wang, 2012) compute correlations between links in the London traffic network in order to analyse required model complexities for models such as STARIMA. Most of the literature is based on small to medium sized networks that model dependencies between road links. For bigger networks, the computational expense increases dramatically to compute the correlations between all links. In order to deal with the computational costs, Neighbourhood Selection Techniques (STN) haven been developed. (Gao, Sun, & Shi, 2011) apply a graphical Lasso approach. (Haworth & Cheng, 2014) give a comparison about different techniques. However, those are still based on a link level approach. Road networks of bigger cities consist of a huge number of links. Furthermore, the traffic state at each time and each segment is often perturbed by nonlinear dynamics. Therefore, another approach is to analyse a traffic network from a macroscopic perspective. (Ji & Geroliminis, 2012) (Ji, Luo, & Geroliminis, 2014) partition a road network into clusters with similar properties in order to (1) determine a macroscopic fundamental diagram and (2) to observe congestion propagation in urban networks. The present work combines both approaches, which, to our knowledge, has not been done yet. First a network is partitioned into frequently congested clusters, followed by a spatio-temporal congestion analysis between the clusters. The aim is to show that the resulting clusters that simplify the complex network allow computing congestion estimations and predictions in a road network.

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