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Macroscopic Traffic Dynamics with Heterogeneous Route Patterns

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Abstract

This paper investigates at an aggregated (macroscopic) scale the effects of route patterns on a road network. Four main variables are considered: the production, the mean speed, the outflow and the mean travel distance. First, a simple network with heterogeneous travel distances between origins and destinations is studied by simulation. It appears that the mean travel distance is not only very sensitive to the changes in the origin-destination (OD) matrix but also to the internal traffic conditions within the network. When this distance is assumed constant as usual in the literature, significant errors may appear when estimating the outflow at the network perimeter. The OD matrix also modifies the shape of the macroscopic fundamental diagram (MFD) to a lesser extend. Second, a new modelling framework is proposed to account for multiple macroscopic routes within reservoirs (spatial aggregates of road network) in the context of MFD simulation. In contrast to existing works, partial accumulations are defined per route and traffic waves are tracked at this level. This leads to a better representation of wave propagation between the reservoir frontiers. A Godunov scheme is combined to a HLL Riemann approximate solver in order to derive the model numerical solutions. The accuracy of the resulting scheme is assessed for several simple cases. The new framework is similar to some multiclass models that have been elaborated in the context of link traffic dynamics.

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Keywords: network fundamental diagram; macroscopic fundamental diagram; traffic dynamics; travel production; mean travel distance; mean spatial speed; route choices; macroscopic traffic simulation; macroscopic origin-destination.

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1. Introduction

Mitigating congestion in large-scale cities remains a large challenge for traffic managers. Classically, traffic management systems in an urban context resort to optimizing traffic signals and route guidance. Efficient management schemes exist for traffic management at local and intermediate urban scales, e.g. SCOOT (Hunt *et al.*, 1983), SCATS (Lowrie, 1982) and TUC (Kouvelas *et al.*, 2011) but they hardly face the complexity of large urban areas. Recently, innovative strategies have been introduced based on perimeter flow control for urban sub-regions. For example, the city of Zürich (Switzerland) has implemented a control access strategy (Züritraffic) to maintain a sufficient level of service in the inner center. The implemented control scheme corresponds to pre-determined signal settings at the perimeter that are applied depending on the feedback from loops within the region. Such a strategy is appealing because it permits to revisit traffic signal control for urban networks by introducing a two-layer approach. The first level is a perimeter and boundary flow control that mitigates the level of congestion between different regions in order to improve the system efficiency at an aggregate level. The second layer corresponds to classical local traffic controls that smooth traffic movements within the regions.

A powerful tool to investigate aggregate traffic behavior is the concept of Macroscopic Fundamental Diagram (MFD). This concept provides for network regions a well-defined relation between space-mean flow and density (or vehicle accumulation). The idea of an MFD belongs to Godfrey (1969) and similar approaches were introduced later by Herman and Prigogine (1979), Mahmassani *et al.* (1984, 1987) and Daganzo (2007). The verification of its existence with dynamic features has been firstly realized using loops data from downtown Yokohama (Geroliminis and Daganzo, 2007; 2008). This concept has already been utilized to numerically experiment simple perimeter flow control policies in homogeneous networks (Daganzo, 2007; Keyvan-Ekbatani *et al.*, 2012; Geroliminis *et al.*, 2013; Aboudolas and Geroliminis, 2013; Knoop and Hoogendoorn, 2014; 2015). Most of the papers use the MFD concept to simulate the dynamic evolution of the vehicle accumulation within the reservoirs. This corresponds to a new class of traffic simulators that work with an aggregate description of the urban network but keep a dynamic description of congestion spreading.

Despite the recent findings for the existence of MFD with low scatter, such curves cannot be a universal law because network topology, origin-destination matrix and route choices might affect the shape and scatter under different cases. For example, (Geroliminis and Sun, 2011; Mazloumian *et al.*, 2010; Knoop *et al.*, 2013) have identified that the uneven spatial distributions of vehicle density in the network lead to traffic states that are well below the upper bound of an MFD and much too scattered to line along an MFD. (Leclercq and Geroliminis, 2013) has also shown that flow distributions associated to driver route choices may influence the MFD shape for a simple parallel network. It then appears that the demand pattern and the route allocation within a reservoir modify the overall performance of an urban network. A key element is that non-Manhattan network topology with unbalanced origin-destination tables and route choices clearly lead to non-homogeneous network loadings. Notably, traffic flows between the different parts of the reservoir perimeter may be unevenly distributed. A first solution to circumvent this drawback and to resort again to well-defined MFD is network partitioning (Ji and Geroliminis, 2012). In each sub-reservoir, traffic conditions may then be homogenous enough to exhibit a MFD. However, this does not solve all the problems because travel distances within sub-reservoirs can remain highly distributed depending on the reservoir shape and the entry and exit points for vehicles.

This paper proposes to investigate the relations between route patterns within a network and the related aggregate traffic dynamics. The main contributions are twofold: first, simulation results on an idealized and simple network provide insights on how main aggregated traffic variables are influenced by the external demand (OD matrix) and the internal traffic conditions. A particular attention is paid to the mean travel distance. It appears that this variable is far from constant when a large set of different and heterogeneous network loadings is considered. Second, a new aggregate dynamic traffic model will be proposed. This model splits the reservoir perimeter into different macroscopic origins and destinations in order to define aggregate internal routes. Thus, the travel distance is no longer uniform but can be defined for each internal route. This provides an insightful framework to monitor the heterogeneities due to route patterns within a reservoir without requiring to track traffic conditions in all network links. Furthermore, the model can more easily handle changes in the MFD due to the changes in the OD. This should pave the way to more accurate aggregate simulators and a better account for heterogeneous network loadings.