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Aerial observations of moving synchronized flow patterns in over-saturated city traffic

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ABSTRACT

In this work, moving synchronized flow patterns (MSP) in empirical city traffic at signals have been observed which was predicted by Kerner (2013, 2014). The single vehicle data has been obtained through aerial observations. Based on this microscopic data, we have found trajectories for all vehicles together with vehicle speeds as functions of time and space. This has allowed us to find empirical MSPs in oversaturated city traffic as well as to perform microscopic analysis, that revealed the following empirical spatiotemporal features of MSPs:

(i) MSPs emerge upstream of the queue at the signal and then they can propagate through the complete road section, (ii) merging of several MSPs into a single MSP, (iii) dissolving MSPs and (iv) spontaneous emerging of MSPs faraway upstream of the signal, (v) spontaneous emerging of moving queue within an MSP that is far away upstream of the signal. As a base for this work, we used an unmanned aerial vehicle (UAV) to record videos of inner city traffic situations and supervised tracking methods to gather the vehicle trajectories.

1. Introduction

1.1. Moving queues (MQs) in classical theory of city traffic

Traffic at signals have been studied for more than 60 years now. The classical theory has been developed to minimize the average vehicle delay and to optimize the throughput in road networks. It has revealed fundamental findings such as the propagation of moving queues (Dion et al., 2004a, 2004b; Gartner, 1983; Gartner et al., 1991; Gartner and Stamatiadis, 2009; Gazis, 1964; Geroliminis and Skabardonis, 2011; Grafton and Newell, 1967; Hunt et al., 1981; Little, 1966; McShane and Roess, 1990; Michalopoulos et al., 1981, 1980; Morgan and Little, 1964; Newell, 1965, 1960; Robertson, 1969; Robertson et al., 1979; Stephanopoulos et al., 1979; Webster, 1958). In the classical theory of city traffic at the signal, under- and oversaturated traffic are distinguished. In under-saturated traffic at the signal, a vehicle queue built at the signal during the red signal phase dissolves during the green signal phase. Contrarily, in oversaturated traffic, a queue built at the signal during the red signal phase cannot dissolve fully during the green signal phase. As a result, over-saturated city traffic occurs that consists of moving queues (MQs) propagating upstream. MQs propagate upstream of the signal (Dion et al., 2004a, 2004b; Gartner, 1983; Gartner et al., 1991; Gartner and

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Stamatiadis, 2009; Gazis, 1964; Geroliminis and Skabardonis, 2011; Grafton and Newell, 1967; Hunt et al., 1981; Little, 1966; McShane and Roess, 1990; Michalopoulos et al., 1981, 1980; Morgan and Little, 1964; Newell, 1965, 1960; Robertson, 1969; Robertson et al., 1979; Stephanopoulos et al., 1979; Webster, 1958).

1.2. Moving synchronized flow patterns (MSPs) in city traffic

In simulations of oversaturated city traffic at the signal made recently in (Kerner et al., 2013), additionally to MQs, synchronized flow patterns (SP) have been found. The first empirical indication for the existence of SPs in oversaturated city traffic at the signal was found in real measured single vehicle data of probe TomTom vehicles (Kerner et al., 2014a). Moreover, based on traffic simulations Kerner (2011, 2013, 2014) predicted the existence of moving synchronized flow patterns (MSP) at the signal in city traffic. MSPs have been known only for highway traffic (Kerner, 2002, 2004, 2009). An MSP is a moving localized traffic pattern within which synchronized flow is realized. Simulations made in (Kerner and Klenov, 2002, 2003; Kerner et al., 2013, Kerner et al., 2014b), indicate MSPs propagating upstream on a road. However, simulations made in (Kerner and Klenov 2010) show that MSPs can also propagate downstream (in the latter case, the flow rate within an MSP is larger than outside the MSP).

Up to now MSPs could not be observed in empirical city traffic. This is due to the need of almost all single vehicle data for the MSP observations. Through the use of aerial observations made in our empirical study of city traffic, it has been possible to measure trajectories for all vehicles together with vehicle speeds as functions of time and space. This enables the observation and empirical study of MSPs. In this paper, the results obtained from the observations of MSPs in oversaturated city traffic at the signal are presented. In these observations, all MSPs propagate upstream of the signal location.

A detailed empirical study of city traffic is important for the future development of intelligent transportation systems (ITS). In particular, ITS that should perform well in complex conditions occurring in city traffic during rush hours. The understanding of empirical city traffic can be used both for a deeper insight into the performance of any emerging technology in transportation, such as automated driving vehicles (Carvalho et al., 2015; Katrakazas et al., 2015; Kerner, 2016, 2017), traffic control (Feng et al., 2015; He et al., 2015; Khondaker and Kattan, 2015; Płaczek, 2014), dynamic traffic assignment (Dia, 2002; Lin and Chen, 2017), an analysis of the energy efficiency of conventional and electrical vehicles (Hemmerle et al., 2015, 2016; Hermanns et al., 2015) other transportation technologies (HomChaudhuri et al., 2016; Suh et al., 2014) and for the development of simulation tools that are consistent with the empirical features of city traffic. In particular, if features of empirical city traffic are understood, the related knowledge could be used for the development of future controllers of autonomous vehicles that permit a comfortable and safety driving in complex city traffic conditions. Furthermore, if future microscopic simulation tools can reproduce features of MSPs in city traffic, traffic management systems that monitor all vehicle movements at road sections could use predictive simulations to suggest individual driving strategies improving the traffic flow.

1.3. Availability of empirical data for studies of city traffic and the objective of this article

For the empirical studies of city traffic, different measurement data is available: (i) Data from roadside video or loop detectors allows to measure vehicle speeds and traffic flow per lane at one single location. Using detector data, it is possible to find temporal speed drops at the monitored location that indicate synchronized flow. However, it is not possible to resolve *microscopic* spatiotemporal features of traffic patterns based on single detectors. (ii) As shown in (Kerner et al., 2014a), anonymized probe vehicle traces measured by personal navigation devices also offer spatial information. With a mean probe rate of 30 vehicles per hour for two lanes the coverage is enough to show the existence of empirical synchronized flow, especially in combination with detector measurements. Nonetheless, with a coverage of 2–4% and without the distinction of traffic lanes the data is not sufficient to measure spatiotemporal vehicle behaviour and to recognize microscopic patterns. (iii) In a first attempt, we tried to use radar traffic sensors for a complete spatiotemporal reconstruction, however, it showed that due to so called same-speed effects of the radar technology at that time, the measurement quality decreases significantly during the appearance of moving queues (Kaufmann et al., 2016). This approach would have only worked well for the examination of free traffic. (iv) A complete measurement of all trajectories based on aerial observations has been obtained in the classical work by Treiterer (1975) as well as in NGSIM (Alexiadis et al., 2004). However, Treiterer's data is related to highway traffic. In NGSIM data for city traffic at signal no sufficient data either for under- or oversaturated traffic can be found.

For these reasons, we believe that our empirical microscopic study of vehicle trajectories obtained from aerial observations is the first one in which microscopic spatiotemporal features of MSPs have been found. This explains the objective of this paper: With the use of microscopic empirical data we have revealed the following empirical spatiotemporal features of MSPs:

(i) MSPs emerge upstream of the queue at the signal and then they can propagate through the complete road section.
(ii) Merging of several MSPs into a single MSP.
(iii) Dissolving MSPs.
(iv) Spontaneous emerging of MSPs faraway upstream of the signal.
(v) Spontaneous emerging of moving queue within an MSP that is far away upstream of the signal.

In this empirical article, we analyse the gathered data of a 14:30 minutes long aerial video recording. The following sections provide a description of the measurement setup and methodology, the complete spatiotemporal measurement as well as a survey of different empirical inner-city traffic patterns.