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A methodology for signal timing estimation based on low frequency floating car data: Analysis of needed sample sizes and influencing factors

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Abstract

The objective of this paper is to analyze the estimation quality of a staged methodology, that allows the estimation of signal timing information like cycle length, green and red time intervals for time-dependent fixed-time controlled and actuated intersections based on low-frequency and sparse floating car data (FCD). The paper exemplifies, based on simulated dataset, the estimation approach, which assumes as a principle condition the daily repetition of similar signal plans, whereby identical daytime and workday periods are aggregated to reach a sufficient trajectory density. The established concept utilizes efficiently small amounts of FCD trajectories that cover typical sampling intervals between 15-45 seconds. The introduced approach considers three processing stages. Firstly, map matching, data decomposition and stop line estimation are required. Secondly, trajectories' stop line crossing times are calculated, whereby crossing times of all trajectories are iteratively projected by the application of a modulo operation into the time scale of potential cycle lengths. A statistical data analysis is carried out to estimate cycle lengths and daytime slices with similar signal program patterns. Finally, the last stage of the used approach considers the precise estimation of red and green time intervals based on a histogram analysis. The paper conclusively analyzes the signal program estimation quality considering different degrees of saturation and trajectory sample sizes.

Keywords: FCD, Floating Car Data, signal timing estimation, low frequency

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1 Introduction

Stops at traffic lights significantly influence the road network capacity and impact the emissions of motorized traffic strongly. Increasing traffic demand urge infrastructure operators as well as the automotive industry to act. On the one side minimizing stops and hence reducing delays and emissions in road networks could be achieved by the optimization of traffic lights (Pohlmann et al., 2010). On the other side drivers could also contribute to emission reduction while driving with foresight and using the advice of a Green Light Optimized Speed Advisory (GLOSA) (Eckhoff et al., 2013). Assistance concepts like GLOSA or even simpler automatic start/stop functions need a reliable estimate of signal switching times at signalized intersections. Actual methodologies focus on the processing of signal switching data provided by centralized traffic control systems. Other approaches are based on the processing of local traffic signal data in combination with a bilateral short range communication between vehicle and infrastructure to transmit forecasted switching information (Barthauer et al., 2014; Braun et al., 2009). This concept requires large investments which are hardly financeable by road authorities. During the recent years the increasing availability of floating car data (FCD) caused by the popular use of modern smartphone navigation software offers a promising data source to estimate signal timing information like cycle length and green/red time interval based on this ubiquitous data source.

Until now there has not been much research focusing on signal timing estimation that considers temporary sparse probe vehicle data, so called low-frequency FCD, supplied typically by commercial data providers (Axer et al., 2015; Fayazi et al., 2015; Liu et al., 2012). Therefore, further effort is needed to investigate the capabilities of signal timing estimation by taking into account low-frequency FCD with low penetration rates. This paper is connected to research from (Axer et al., 2016; Axer et al., 2015) that provides an offline-approach to estimate signal timing information for periodic signal controlled intersections, based on a sparse historical low frequency floating car dataset. The used methodology for signal timing and phase estimation will be exemplified in detail, taking into account data samples from a microsimulation model. Furthermore, the usage of a microsimulation allows later an analysis of the estimation quality and important influencing factors.

2 Related work

The problem of the estimation of signal timing and phase information based on vehicle trajectory data has been analyzed under consideration of different data requirements and methodical approaches (Fayazi et al., 2015; Kerper et al., 2012; Liu et al., 2012). Until now methods introduced have in common, that they are using FCD with relatively high penetration rates and/or high sampling frequencies. The main characteristics of sparsity and density differ strongly from typical data situations being available in European cities.

Kerper et al. (2012) performed a first feasibility study for fixed-time controlled intersections using only simulated FCD with a high sampling frequency of 1 Hz and also a high penetration rate that differs from typical commercial FCD. The basic principle lies in the determination of green time interval beginnings by observing the acceleration process of vehicles in relation to their stop line distance. Cycle length information gets continuously calculated based on the time difference of consecutive green time interval beginnings. To be able to determine the cycle length online, the algorithm needs at least two qualified trajectories during a time period of a constant signal program. Green and red times get calculated for each cycle by the analysis of crossing and stopping times of each vehicle. This process requires typically a very dense data source.

Fayazi et al. (2015) developed referring to Kerper et al. (2012) an approach using low-frequency but high periodic trajectories provided by a bus transit system in San Francisco. The study considers the combined data of two high frequently used bus routes which allowed the collection of 4289