Macroscopic traffic state estimation: Why automated vehicles should keep track of the flow relative to their trajectories

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1 Introduction

Traffic State Estimation (TSE) is an important element in traffic operations and planning (Seo et al., 2017). In TSE, we want to estimate the macroscopic traffic flow variables flow q, density k and speed u throughout the road network. More concisely, traffic can be described based on three dimensions (Makigami et al., 1971), that is, space x, time t and the cumulative flow (or cumulative vehicle number) N. The derivatives of N to space and time respectively provide q and k, which combined yield u. Therefore, it suffices to known N over space-time to have all three macroscopic traffic flow variables.

Traffic sensing data plays a crucial role in TSE. Historical data allows us to understand traffic flow and develop models to describe traffic flow behavior over space-time, e.g., the LWR-model (Lighthill & Whitham, 1955), (Richards, 1956). Real-time data provide observations of traffic variables with specific spatial/temporal characteristics. In a model-driven estimation approach we can combine these different types of information to estimate the traffic state.

Researchers have investigated the use of different data-types for TSE. The most studied data-types are road-side detectors, e.g., Wang & Papageorgiou (2005), and probes, e.g., Nanthawichit et al. (2003), Herrera & Bayen (2010). Following the trend of increasing vehicle automation, researchers are studying the opportunity to use new types of vehicle-based sensing data. For instance, Seo & Kusakabe (2015) propose to use spacing (headway) observations and Florin & Olariu (2017) propose to use automated vehicles as moving-observes which observe overtaking.

The sensing and processing equipment in automated vehicles is used to collect a wide range of data-types valuable for its own driving task, e.g., headway data (Seo & Kusakabe, 2015). Furthermore, it may be used to collect other data-types which are valuable for other tasks such as TSE, e.g., overtaking data (Florin & Olariu, 2017). For each individual or combination of data-types, we may develop different TSE methodologies. This means that there are still many options to explore in TSE. However, we cannot and do not want to explore each individual option. Instead, we want to study which traffic sensing data should be collected by the automated vehicles and how these data can be used in TSE. In contrast to other studies, we make a conscious choice for the data-type with respect to the other options.

We argue that automated (or sensor-equipped) vehicles should serve as moving-observers which record the flow relative to their position over time. This variable describes the change in cumulative flow, i.e., ΔN, over a line in space-time (the vehicle trajectory). Road-side sensing equipment, e.g., detectors or cameras, can also record ΔN over a line in space-time (fixed location over time). We consider the use of sensing data from road-side and moving-observers in a model-based TSE approach. Our analysis demonstrates that differences in spatial/temporal characteristics between moving-observers and between moving-observers and road-side observers are valuable in TSE. This helps us to estimate ΔN over the full space-time domain, limit the errors in information and allows us to effectively deal with remaining errors when fusing (assimilating) all information.

To discuss the strengths and weaknesses of using automated vehicles as moving observers, the following approach is taken. Based on literature, we explain the initial choice for the sensing data and estimation approach. Next, we expose three important elements in TSE and how these are influenced by our traffic sensing data. To gain a better insight in the effect of the spatial/temporal data characteristics we provide examples for each of the three elements. This allows us to relate the spatial/temporal characteristics of road-side and moving observers to their value in TSE.

This approach may be unconventional for TSE estimations, however, it allows us to discuss the importance data characteristics on different elements of TSE. Alternatively, we would have to design a full methodology for each element and test it in a restrictive case study. This would lead to multiple independent articles, thereby making it difficult for readers to get the bigger picture. Nevertheless, this article should serve as the basis the explore each element in detail in future research.

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