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# Bayesian inference for vehicle speed and vehicle length using dual-loop detector data

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ABSTRACT

A dual-loop detector consists of two connected single-loop detectors placed several feet apart. Compared with a single-loop detector, it is able to provide more useful information on traffic flow with a higher precision. In this paper we investigate statistical inference for vehicle speed and vehicle length using dual-loop detector data. A Bayesian analysis is performed to combine current observations on traffic flow with prior knowledge, which results in a set of simple formulas for the online estimation of both vehicle speed and vehicle length. As a by-product, vehicle classification is also investigated on the basis of posterior classification probabilities. The computational overhead of updating the estimates is kept to a minimum when new information on traffic flow becomes available. The method is illustrated using real traffic data.



## 1. Introduction

Dual-loop detectors play a crucial role in advanced traffic management systems. They provide estimates of fundamental parameters of traffic flow such as vehicle speed and length. It is therefore essential that the information from a dual-loop detector is analyzed as accurately as possible with a minimum computational cost. The aim of this paper is to draw statistical inference for vehicle speed and length using dual-loop detector data.

In recent years, considerable attention has been paid to single-loop detectors. The data from a single-loop detector are provided at an aggregated level, where traffic volume and occupancy are recorded during pre-determined time intervals (each is typically 20–30 s long). Based on the information from a single-loop detector, space-mean-speed can be calculated under the assumption that effective vehicle length is constant and exogenously available.

In the classical estimation method for single-loop data, the calculated space-mean-speed is used as an estimate of current vehicle speed (see, e.g., Kurkjian et al., 1980; Hazelton, 2004). A serious drawback of the classical method is that only one piece of data, i.e., the current space-mean-speed observation, is used for estimation, and thus the quality of the estimator is poor. This classical approach has been greatly improved in the last decade via a pooling of the information obtained in previous time periods. For instance, Dailey (1999) investigated using the Kalman filter to estimate vehicle speed. Through some approximations he derived a linear observation equation and then applied the Kalman filter to obtain a set of recursive formulas. The approach of using the Kalman filter has also been investigated by Ye et al. (2006) and Bickel et al. (2007). Hazelton (2004) has carried out a full Bayesian analysis in which a Markov chain Monte Carlo (MCMC) approach is incorporated to draw statistical inference. Recently Li (2009) has developed a recursive method for fast estimation of vehicle speed, where the current estimate is updated as a weighted harmonic average of the current space-mean-speed and the previous estimate. It is faster than the MCMC approach of Hazelton (2004) and avoids the linearization made in Dailey's method.

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A dual-loop detector consists of two connected single loops, the upstream loop and the downstream loop. Unlike single-loop detectors however, observations from a dual-loop detector are available on a vehicle-by-vehicle basis. Consequently, a dual-loop detector can provide much more accurate information on traffic flow, such as vehicle speed, vehicle length, and truck volume. However, the currently used estimation method for dual-loop data suffers from the same problem as does the classical method for single-loop detectors: only the current observations are used for estimation. The resulting estimates of vehicle speed and length are very noisy. In addition, no measure of the quality of the estimates, such as standard errors, is provided.

It is surprising that relatively little research has been done on dual-loop detectors. In recent years there have been only a few studies, mainly focusing on the data validation of dual-loop detectors. The signals received by a dual-loop detector consist of a sequence of 0 and 1 digits. In practice, a positive or negative single-digit false will sometimes occur, i.e., a digit of 0 (or 1) is mistakenly input as 1 (or 0). Zhang et al. (2006) developed a robust algorithm to eliminate such erroneous inputs that included a noise filter and a postprocessor to screen out noise, and a matching scheme to pair up on-time pulses. They also considered various checks to test the validity of the data for the calculation of vehicle speed and length. Cheevarunothai et al. (2006) investigated how to enhance the reliability of dual-loop data via removing the sensitivity discrepancy between the two single loops and adjusting their sensitivities to the appropriate level. Coifman and Dhoorjaty (2004) proposed eight detector validation tests for freeway surveillance, where the extracted vehicle information was compared with corresponding pre-set constant thresholds to identify erroneous loop data. The signal validation and improvement in these studies have laid a solid foundation for subsequent data analysis.

In this paper we extend the estimation method for single-loop data developed by Li (2009) to the scenario of dual-loop problems where statistical inference for both vehicle speed and vehicle length is drawn. We perform Bayesian analysis to pool the information obtained previously with the current observations to improve the estimates of vehicle speed and length. As in Li (2009) for single-loop detectors, the Bayesian analysis results in a set of simple formulas that are analytically pleasing. As a by-product, vehicle classification is also investigated by comparing the posterior classification probabilities that a vehicle falls into different vehicle classes. The developed method incurs a minimum computational cost, and can easily be implemented in practice.

This paper is structured as follows. Section 2 is devoted to the problem formulation. A statistical model for dual-loop data is developed in Section 3. Then Bayesian analysis is performed to estimate the vehicle speed and length in Section 4. To illustrate the proposed method, numerical examples are examined in Section 5. Finally, concluding remarks are offered in Section 6. All proofs are given in the Appendix.

## 2. Problem formulation

### 2.1. Notation

Consider a dual-loop detector that consists of two connected single-loops, an upstream loop and a downstream loop, as illustrated in Fig. 1. In practice, the sensitivity region of a single loop may differ from the area defined by its physical boundary (Hazelton, 2004; Cheevarunothai et al., 2006). Let

- $M$ be the distance between the leading edge of the upstream loop's sensitivity region and the leading edge of the downstream loop's sensitivity region;
- $L_d$ be the length of the sensitivity region of the downstream loop.

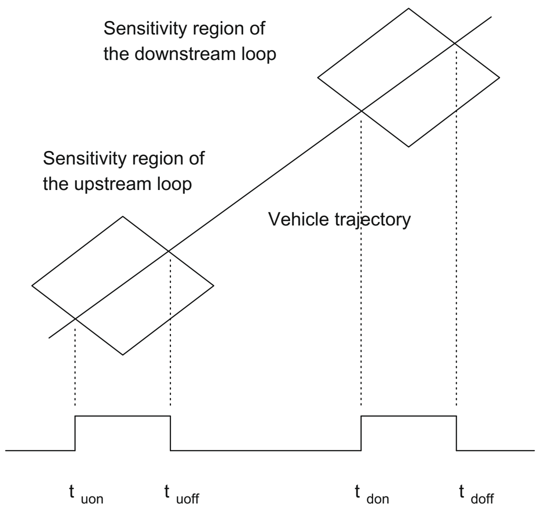


**Fig. 1.** An illustration of a dual-loop detector.