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Improved vehicle classification from dual-loop detectors in congested traffic

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A B S T R A C T

Vehicle classification is an important traffic parameter for transportation planning and infrastructure management. Length-based vehicle classification from dual loop detectors is among the lowest cost technologies commonly used for collecting these data. Like many vehicle classification technologies, the dual loop approach works well in free flow traffic. Effective vehicle lengths are measured from the quotient of the detector dwell time and vehicle traversal time between the paired loops. This approach implicitly assumes that vehicle acceleration is negligible, but unfortunately at low speeds this assumption is invalid and length-based classification performance degrades in congestion.

To addresses this problem, we seek a solution that relies strictly on the measured effective vehicle length and measured speed. We analytically evaluate the feasible range of true effective vehicle lengths that could underlie a given combination of measured effective vehicle length, measured speed, and unobserved acceleration at a dual loop detector. From this analysis we find that there are small uncertainty zones where the measured length class can differ from the true length class, depending on the unobserved acceleration. In other words, a given combination of measured speed and measured effective vehicle length falling in the uncertainty zones could arise from vehicles with different true length classes. Outside of the uncertainty zones, any error in the measured effective vehicle length due to acceleration will not lead to an error in the measured length class. Thus, by mapping these uncertainty zones, most vehicles can be accurately sorted to a single length class, while the few vehicles that fall within the uncertainty zones are assigned to two or more classes. We find that these uncertainty zones remain small down to about 10 mph and then grow exponentially as speeds drop further.

Using empirical data from stop-and-go traffic at a well-tuned loop detector station the best conventional approach does surprisingly well; however, our new approach does even better, reducing the classification error rate due to acceleration by at least a factor of four relative to the best conventional method. Meanwhile, our approach still assigns over 98% of the vehicles to a single class.

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1. Introduction

Vehicle classification is an important traffic parameter for transportation planning and infrastructure management. Length-based vehicle classification from dual loop detectors is among the lowest cost technologies commonly used for collecting these data. A dual loop detector station typically consists of a pair of loop detectors separated by a known distance in each lane. In conventional practice, speed is the quotient of this known distance between the loop detectors and a given vehicle's measured traversal time between the paired detectors. The product of this speed measurement and the dwell time over one of the detectors is then used to calculate the effective vehicle length (where the effective vehicle length is the sum of the physical vehicle length and the size of the loop's detection zone). Finally, to classify the vehicle, each of these effective vehicle length measurements is then sorted into one of several different length bins, e.g., a three bin scheme might seek to sort passenger vehicles, single unit trucks, and multiple unit trucks into different bins.

Like many vehicle classification technologies, the dual loop approach works well in free flow traffic (Davies and Salter, 1983; Minge et al., 2012; Kim and Coifman, 2013). This approach implicitly assumes that vehicle acceleration is negligible; but unfortunately, at low speeds this assumption is invalid (e.g., Wu and Coifman, in press) and performance degrades significantly in congestion (Davies and Salter, 1983; Wu and Coifman, in press). As a result of this fact, many operating agencies are reluctant to deploy classification stations on roadways where traffic is frequently congested.

To addresses this problem, we seek a solution that relies strictly on the measured effective vehicle length and measured speed. We first use the equations of motion to synthesize hypothetical loop detector data and evaluate the feasible range of true effective vehicle lengths that could underlie a given combination of measured effective vehicle length and measured speed at a dual loop detector as the unobserved acceleration is varied. From this analysis we find that there are small uncertainty zones where the measured length class can differ from the true length class, depending on the unobserved acceleration. In other words, a given combination of measured speed and measured effective vehicle length falling in the uncertainty zones could arise from vehicles with different true length classes. Outside of the uncertainty zones, any error in the measured effective vehicle length due to acceleration will not lead to an error in the measured length class. Thus, by mapping these uncertainty zones, most vehicles can be accurately sorted to a single length class, while the few vehicles that fall within the uncertainty zones are assigned to two or more classes. We find that these uncertainty zones remain small down to about 10 mph and then grow exponentially as speeds drop further. Then using empirical data from stop-and-go traffic we evaluate the performance of this new approach, first via synthetic detector data, and then using data from a real dual loop detector station.

The remainder of this section briefly reviews the conventional dual loop detector effective vehicle length measurement and vehicle classification used in this work. As noted above, this conventional method for measuring effective vehicle length assumes that acceleration is negligible. Section 2 uses the equations of motion to evaluate the impacts of unaccounted for acceleration and complete stops on the conventional effective vehicle length measurement. The section generates synthetic vehicle trajectories and then finds the pairwise combinations of measured effective vehicle length and measured speed from a simulated dual loop detector to identify the uncertainty zones where the unaccounted for acceleration can cause the measured effective vehicle length to result in a different classification than the true effective vehicle length would fall in. Once the uncertainty zones have been established, deviating from conventional practice, measurements that fall in these zones are assigned either two or three possible vehicle classes that correspond to the given uncertainty zone. Section 3 evaluates the performance of the new methodology using empirical data. Finally, this paper closes with a discussion and conclusions in Section 4.

1.1. Effective vehicle length measurement and length classes

Fig. 1 shows the time–space representation of a vehicle passing over a dual loop detector, with the paired loops separated by spacing S (leading edge to leading edge). The loop detector controller records four transition times, denoted t_1 to t_4, as the vehicle enters and leaves the two detection zones. From which the controller then calculates the traversal times from the rising edges, $TT_r = t_3 - t_1$, and falling edges, $TT_f = t_4 - t_2$, which in turn yield two separate measures of speed: $V_r = S/TT_r$ and $V_f = S/TT_f$. Similarly, there are two measures dwell time: over the first detector, $T_u = t_2 - t_1$, and second detector, $T_d = t_4 - t_3$, as shown in the figure. As discussed in Wu and Coifman (in press), in conventional practice there are several different ways of averaging these speeds and dwell times to calculate the effective vehicle length. This earlier work evaluated the various combinations in the presence of accelerations and found the method from Coifman and Cassidy (2002) (denoted CM+ and given by Eq. (1)) proved to be the most robust variant of the conventional method during stop-and-go traffic conditions. Note that the "+" suffix denotes the fact that CM+ is already better than the most commonly used conventional approach, CM, that uses just one pair of the speed and dwell time measurements, as given by Eq. (2). Wu and Coifman found that the length-based classification error rate from CM+ was roughly half that of CM.

$$L_{CM+} = \frac{V_r * T_u + V_f * T_d}{2} \tag{1}$$

$$L_{CM} = V_r * T_u \quad \text{or} \quad L_{CM} = V_f * T_d \tag{2}$$