Microscopic Estimation of Arterial Vehicle Positions in a Low Penetration Rate Connected Vehicle Environment

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INTRODUCTION

Wireless communication among vehicles and roadside infrastructure, known as connected vehicles, is expected to provide higher-resolution real-time vehicle data, which will allow more efficient traffic monitoring and control. Adoption of connected vehicle technology among the vehicle fleet may be gradual or limited, with many drivers unable or unwilling to transmit their locations. Additionally, many connected vehicle mobility applications do not experience benefits when fewer than 20 percent to 30 percent of roadway vehicles participate.

In an effort to improve the performance of connected vehicle applications at low connected vehicle penetration rates, we propose a novel technique to estimate the positions of non-communicating (unequipped) vehicles based on the behaviors of communicating (equipped) vehicles along a signalized arterial. Unequipped vehicle positions are estimated based on observed gaps in a stopped queue, and the forward movement of these estimated vehicles is simulated microscopically using a commercial traffic simulation software package.

The location estimation algorithm is generic and could be applied to other connected vehicle applications to improve performance at low penetration rates.

BACKGROUND

In a connected vehicle environment, equipped vehicles can share their locations, speeds, headings, and many other data in real time with nearby vehicles and the surrounding infrastructure via wireless communications. This information can be used to improve the performance of various traffic applications, although research has shown that applications are only successful when a minimum percentage of vehicles can participate.

Connected Vehicle Applications and Corresponding Minimum Required Equipped Vehicle Penetration Rates

Application	Minimum Equipped Vehicle Penetration Rate
Traffic signal control	20-30%
Freeway incident detection	20%
Lane-level speed estimation	20%
Arterial performance measurement	10-50%
Queue length estimation	30%

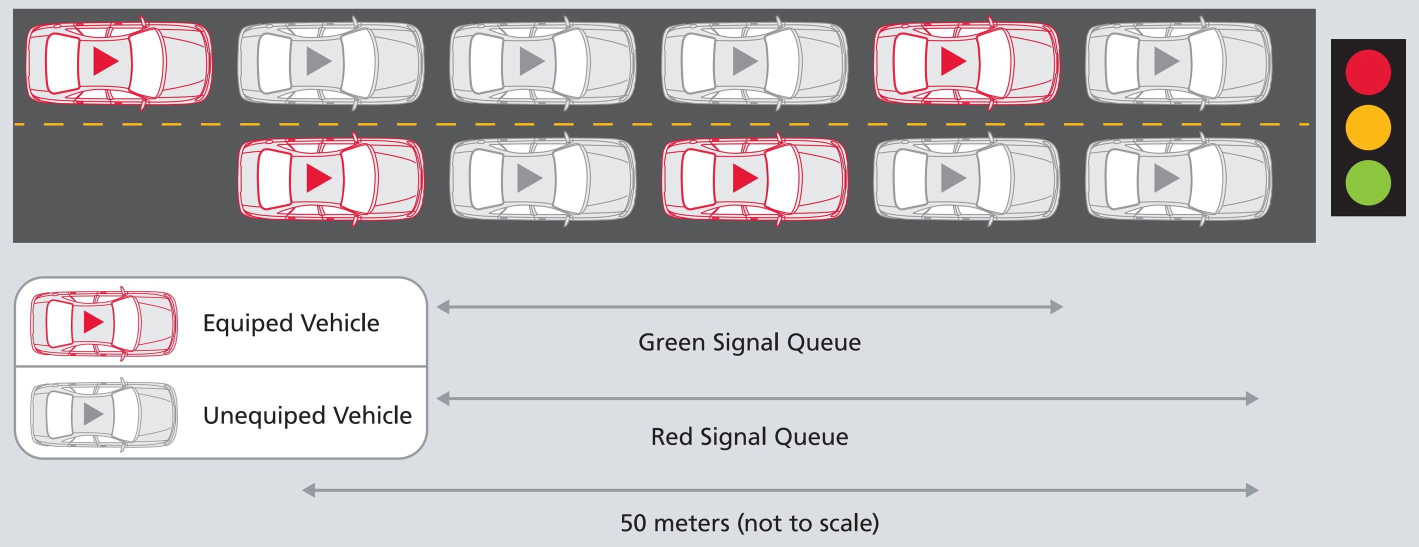
OBJECTIVES

1. Can the locations of some unequipped vehicles be estimated from the behavior of a few equipped vehicles?
2. Can these estimated locations then be used to improve the performance of connected vehicle mobility applications?

PROCEDURE

Step 1: Queue Gap Detection. Find gaps greater than 14.5 meters (Wiedemann model) between stopped vehicles within 50 meters of the stop bar. These gaps suggest the presence of an undetected unequipped vehicle.

Queue Estimation



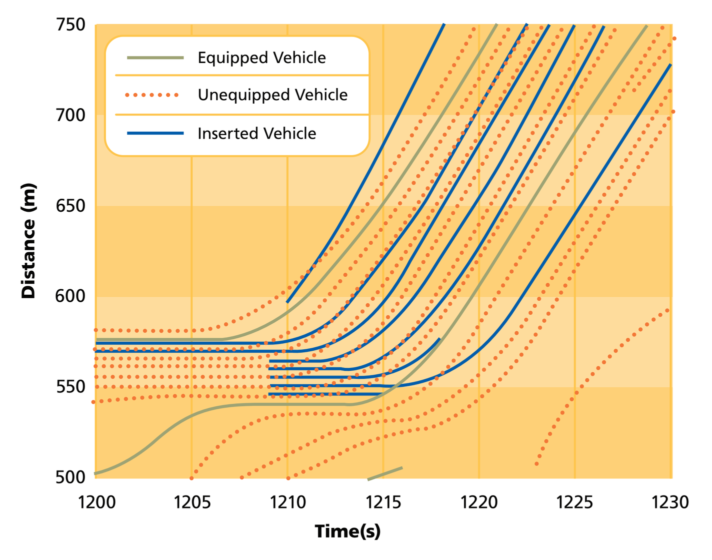
Step 2: Estimate Vehicle Speed and Location. The gaps in the queue are assigned simulated unequipped vehicles (called "inserted vehicles"), with speeds of zero, lengths of 4.75 meters, and gaps of 2.5 meters.

Step 3: Simulate Inserted Vehicle Movements. The movements of inserted vehicles are simulated in a model of the network using microscopic traffic simulation software package VISSIM. Inserted vehicle movements are based on the self-reported trajectories of nearby equipped vehicles. VISSIM's COM interface allows on-the-fly insertion and removal of individual vehicles.

Step 4: Inserted Vehicle Deletion. Inserted vehicles are deleted from the simulation if their position overlaps an equipped vehicle or they reach the end of the network.

EVALUATION

A Sample of Vehicle Trajectories at 15% Equipped Vehicle Penetration Rate on a Single Lane



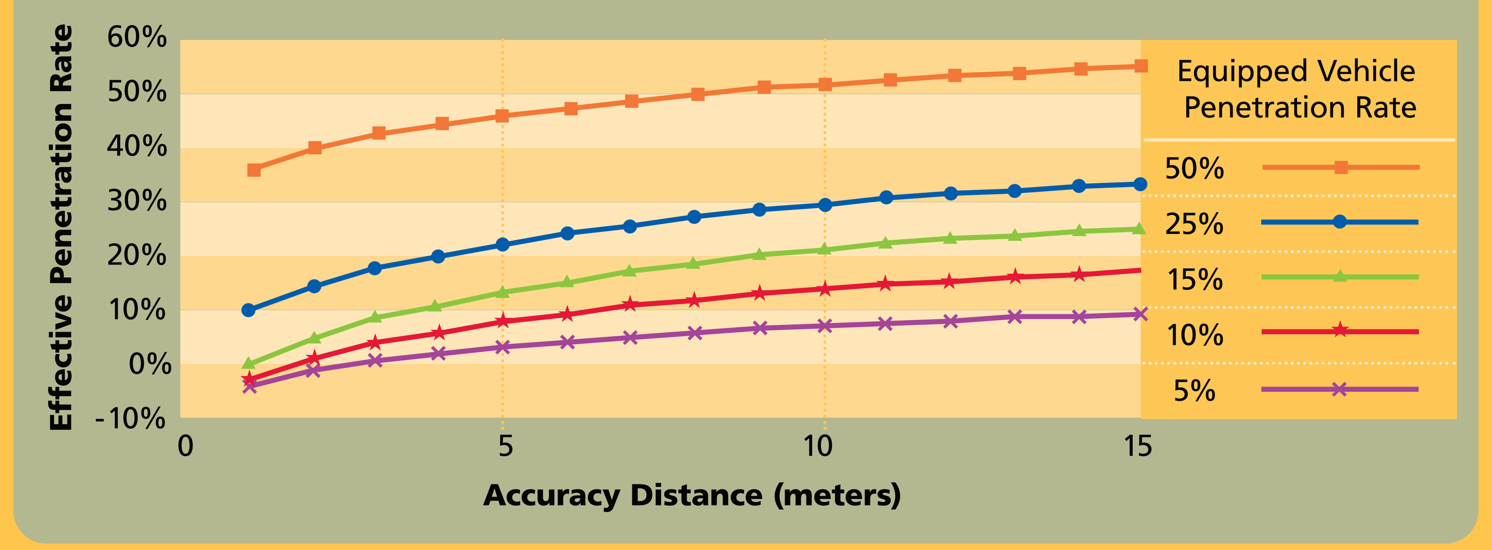
Penetration rate	5%	10%	15%	25%	50%	100%
Number of insertions	1116	1482	1963	2119	2164	1568
Number of equipped vehicles	225	449	673	1126	2260	4515
Average inserted vehicle lifespan *(s)*	74.4	78.9	76.8	72.6	66.4	17.7
Insertions per real vehicle	0.248	0.330	0.438	0.470	0.479	0.347
Insertions per equipped vehicle	4.96	3.30	2.92	1.89	0.96	0.35
Equipped vehicle - seconds per insertion	33.6	47.3	52.5	78.8	155.8	462.3

Effective Penetration Rate

A "correct" insertion has a one-to-one relationship with a nearby unequipped vehicle in the same lane, at the same time, within minimum headway less than the required accuracy distance.

$$PR_{eff} = \frac{\text{No. Equipped Vehicles} + \text{No. Correct Insertions} - \text{No. Incorrect Insertions}}{\text{No. Equipped Vehicles} + \text{No. Unequipped Vehicles}}$$

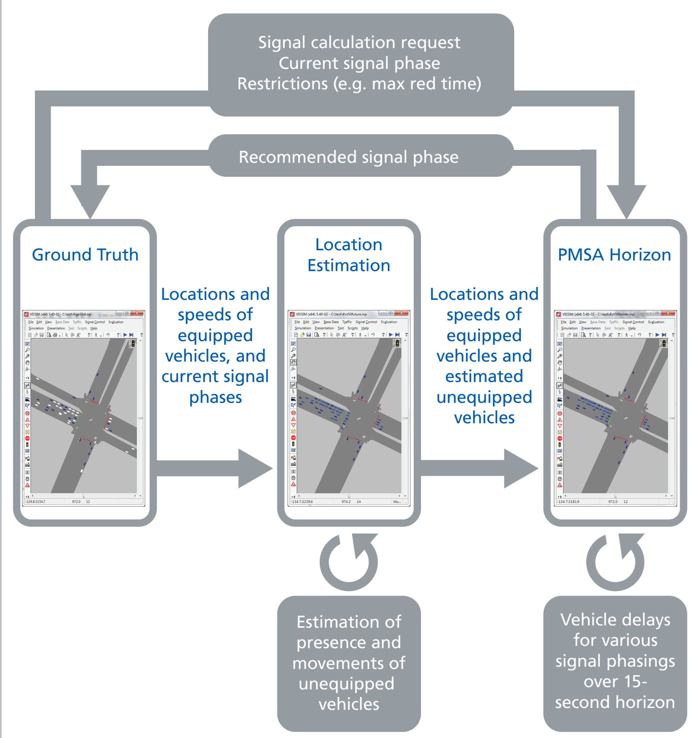
Average Effective Penetration Rate



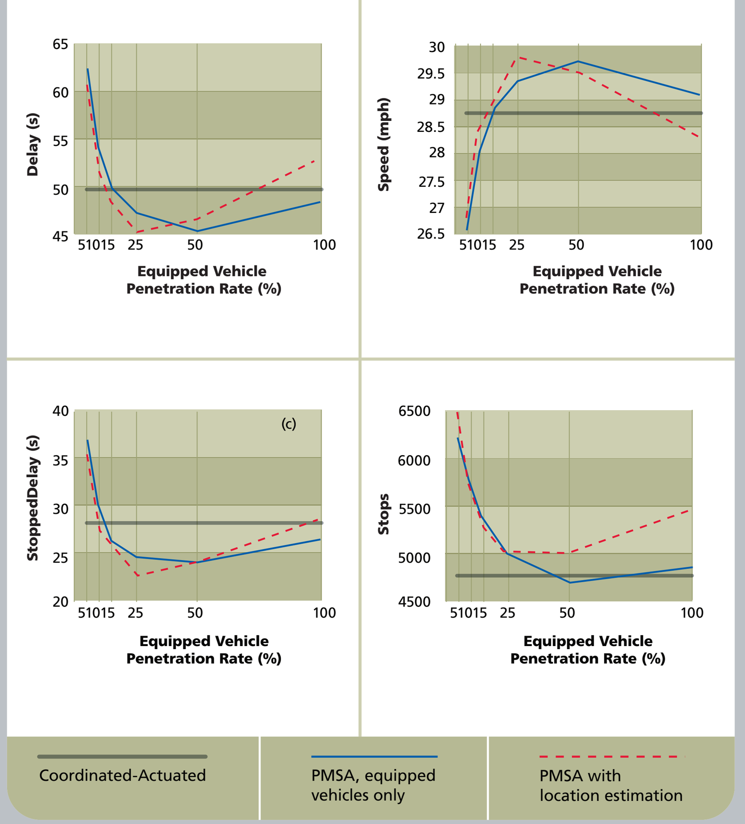
APPLICATION: CONNECTED VEHICLE TRAFFIC SIGNAL CONTROL

To test its effectiveness, the location estimation algorithm was applied to the Predictive Microscopic Simulation Algorithm (PMSA) for traffic signal control.

Flow of Information Among Three Components of Traffic Signal Control Algorithm



Performance of Connected Vehicle Traffic Signal Control (PMSA), With and Without Location Estimation Algorithm



CONCLUSIONS

First attempt to measure the positions of individual unequipped vehicles on arterials without restrictive assumptions.

In simulations, the algorithm made more correct than incorrect estimates of unequipped vehicle positions in the same lane and within 7 meters longitudinally.

Improved the performance of connected-vehicle traffic-signal control strategy at equipped vehicle-penetration rates between 10 percent and 25 percent, with worse performance at 50 percent and higher.

The proposed location estimation technique may prove beneficial to other connected vehicle algorithms, such as queue length estimation for transit signal priority or ramp metering at low penetration rates.

Acknowledgements

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