Microscopic Estimation of Freeway Vehicle Positions from the Behaviors of Probe Vehicles

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ABSTRACT

The modern passenger vehicle is an incredibly sophisticated machine, with computer monitoring and control of most of its functions, including speed, acceleration, heading, and GPS-enabled position. Vehicles are beginning to communicate these data wirelessly to other vehicles and to roadside equipment. These communicating "probe" vehicles will drastically impact the way traffic is managed, allowing for more responsive traffic signals, more comprehensive traffic information, and more accurate travel time prediction. Research suggests that to begin experiencing these benefits, at least 20% of vehicles must act as probes, with benefits increasing with higher participation rates. Because of bandwidth limitations of and slow rollout of the technology, only a portion of vehicles on the roadway will be able to act as probes. Fortunately, the behavior of these probe vehicles may suggest the locations of nearby non-probe vehicles, thereby artificially augmenting the penetration rate and generating greater benefits. We propose an algorithm to predict the location of non-communicating vehicles based on the behaviors of nearby probe vehicles. By employing driver behavior models and rolling estimation techniques, the algorithm is able to predict the locations of 30% of vehicles with 9-meter accuracy when only 10% of vehicles are communicating, theoretically leading to immediate improvements in many probe vehicle applications.

Background

A modern vehicle is able to determine its position, speed, and heading from in-vehicle sensors. In the near future, some vehicles will be able to wirelessly transmit these data to nearby vehicles and roadside infrastructure. These vehicles will act as probes providing valuable information on roadway performance, and researchers continue to develop new applications using this data to improve safety and mobility of the roadway.

Application	Minimum probe vehicles needed
Traffic signal control	20-30%
Freeway incident detection	20%
Lane-level speed estimation	20%
Arterial performance measurement	10-50%

Figure 1: Vehicle probe applications and minimum penetration rates

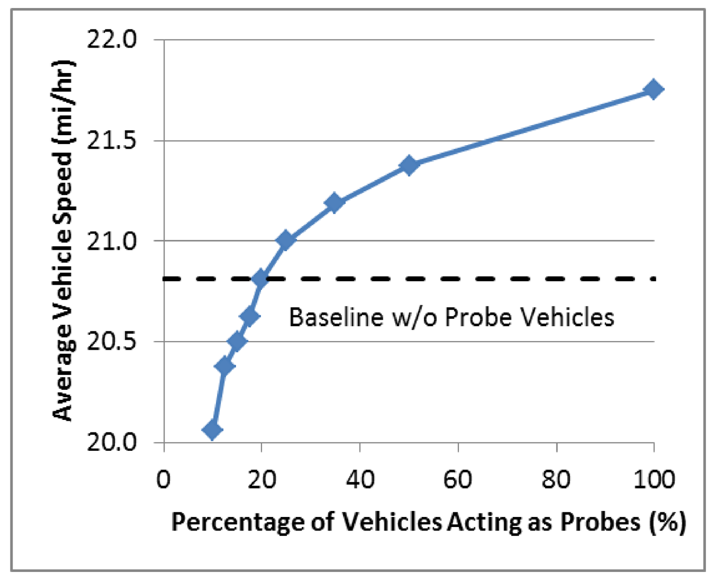


Figure 2: Traffic signal control speed improvements using probe vehicles

Due to bandwidth limitations of cellular, and a slow rollout of alternative communications technologies in vehicles, only a portion of vehicles will be able to act as probes. The new applications that use probe vehicle data, however, require between 10 and 50% penetration rate to experience benefits, as shown in Figure 1.

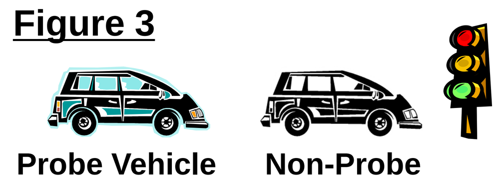
As expected, higher penetration rates also produce greater benefits, even beyond the minimum required penetration rate, as shown in Figure 2.

More vehicle probes = better performance

Estimating Vehicle Positions

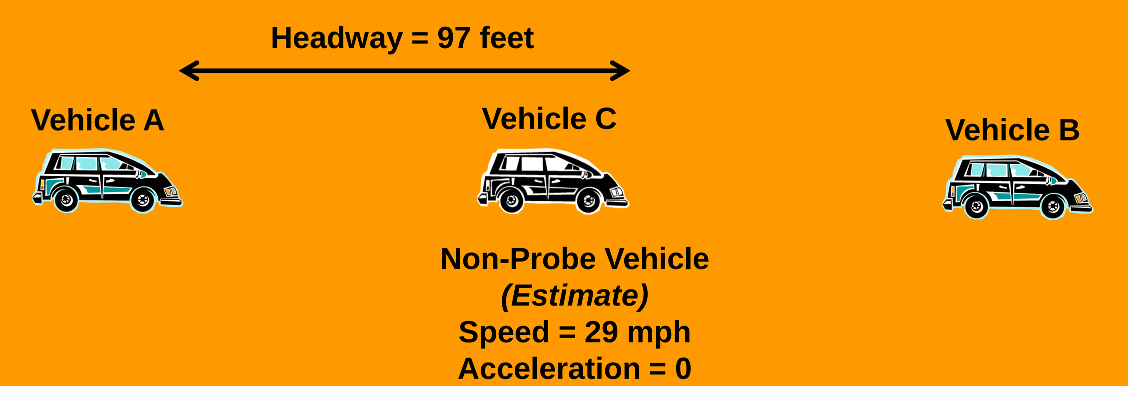
The behavior of probe vehicles can suggest the presence of non-probe vehicles. Consider vehicles stopped at a signal in Figure 3. The probe vehicle doesn't pull forward *as expected*, suggesting a non-probe vehicle directly ahead.

Figure 3

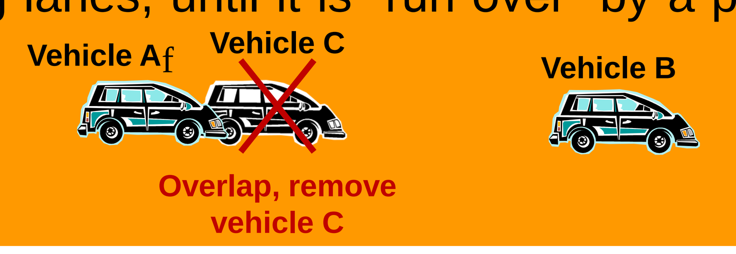


This becomes more complicated on freeways. In this example, Vehicle A is not accelerating as a well-known driver behavior model predicts it should, and is probably reacting to an unseen, non-probe vehicle.

This non-probe vehicle, "Vehicle C" is inserted at an empirically determined speed, and a headway based on Vehicle A's behavior and the driver behavior model.



The inserted vehicle drives according to the driver behavior model, never switching lanes, until it is "run over" by a probe vehicle and deleted.



Evaluation

This algorithm was testing using field recorded vehicle trajectories from a freeway in Los Angeles, California. Figure 8 shows densities.

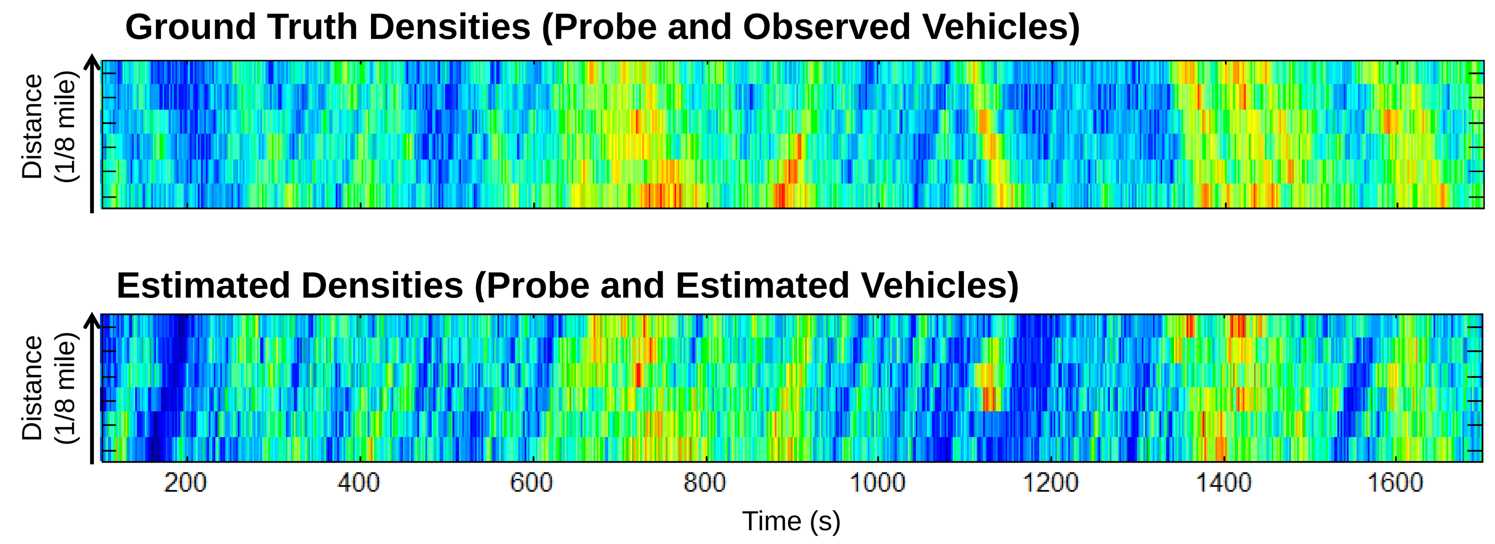


Figure 8: Densities of the estimated vehicle positions vs. the observed data with 25% of vehicles acting as probes.

To discourage over-guessing, each estimate outside the required accuracy range negates an estimate within the accuracy range. Figure 9 shows the new "effective" penetration rate, based on the original probe penetration rate and the desired accuracy. The algorithm is able to replicate a 30% penetration rate at much lower actual penetration rates, as summarized in Figure 10.

Figure 9

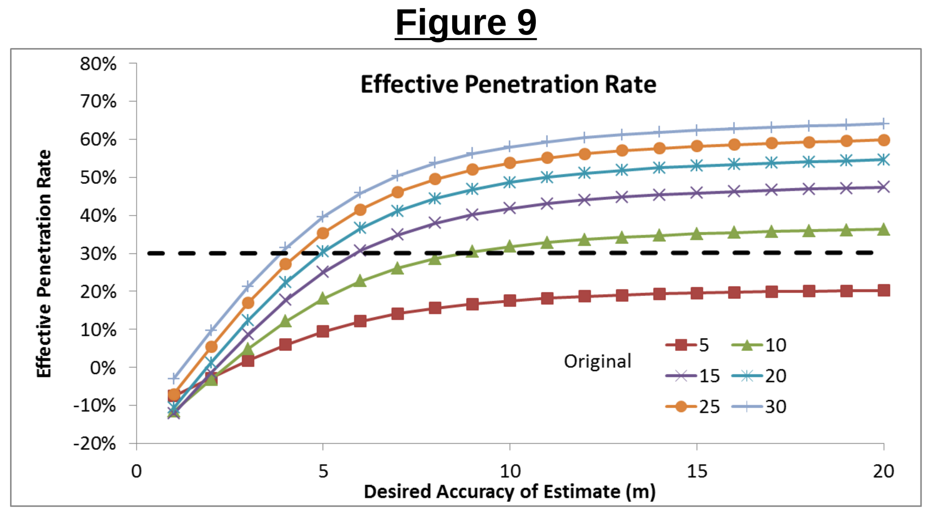


Figure 10

Original Penetration Rate	Min Accuracy Level to Reach 30% Effective Penetration Rate
5%	N/A
10%	9 meters
15%	6 meters
20%	5 meters
25%	5 meters
30%	4 meters

Conclusions

By post-processing wireless vehicle data as demonstrated through this research, current and future transportation systems that use wireless vehicle data will experience greater benefits, and sooner than without. The techniques developed here have the potential to reduce emissions, travel time, and fuel consumption by improving the performance of probe vehicle applications.