

MODELING ACCELERATION BEHAVIOR IN A CONNECTED ENVIRONMENT

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INTRODUCTION

Connected Vehicles technology will provide drivers information on the presence and behavior of other drivers in their vicinity. This information is intended to help drivers make safe and reliable decisions. It will also affect drivers' strategic and operational decisions, with the most impact on the operational decisions including acceleration choice. From the modeling stand point, however, capturing the effects of this additional information on drivers' decisions is a challenging task and requires a more thorough understanding of humans' decision-making processes.

Acceleration behavior has been studied extensively in the literature, and several models with varying levels of complexity have been introduced to capture the underlying processes. Unfortunately, most of these models are designed to capture driving behavior in the absence of communications. Their modeling capabilities are even more limited in a mixed environment where only a portion of the vehicles are equipped with the essential communication tools. This additional information motivates different behaviors in this mixed environment. The addition of autonomous vehicles could further contribute to the complexity in this environment. This paper is intended to introduce an acceleration framework to capture the impacts of this additional information on driving behavior. Accordingly, different acceleration models with different assumptions are utilized for regular, connected, and autonomous vehicles.

ACCELERATION FRAMEWORK

This section provides an overview of the acceleration framework with a brief description of the acceleration models.

Modeling Vehicles with No Communication Capability

The drivers of these vehicles receive no information from other vehicles nor from the traffic management center (TMC). They only get information from road signs (both VMS and conventional signs). They also have a rough perception of other drivers' behavior in their vicinity. Moreover, their acceleration behavior has a probabilistic nature and they are uncertain about other drivers' future behavior. This uncertainty may result in crash occurrence.

In general, drivers are seeking to travel at a desired speed while avoiding crashes. Avoiding crashes is an extremely important factor in drivers' decision making because of its severe consequences. Hamdar et al. (1) presented an acceleration model that avoids (most) crashes by specifying behavioral mechanism. An extension to this model was presented by Talebpour et al. (2), who recognized that drivers have different perceptions under congested versus uncongested regimes. Accordingly, they introduced two utility functions, one for modeling driver behavior in

congested regimes and one for modeling driver behavior in uncongested regimes. At each evaluation stage, based on drivers' perception of their surrounding traffic condition, drivers employ the corresponding value functions to evaluate the gains from the chosen acceleration. They introduced a binary probabilistic regime selection mechanism into the evaluation stage where drivers use the resulting utility to evaluate each acceleration value. Note that this study adopted Talebpour et al.'s acceleration framework to model car-following behavior in the absence of communication.

Modeling Communication-Ready Vehicles

These vehicles are expected to have the capability of sending/receiving information to/from other vehicles and infrastructure based equipment. Assuming reliable connectivity in the vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications networks, each vehicle will receive information about other vehicles in this network. The driver also receives real-time updates about the TMC decisions (e.g., real-time changes in speed limit). However, this information may not be available at all times and locations, and drivers' behavior may change according to the amount of information they receive. Accordingly, four scenarios can be defined: Active/Inactive Vehicle-to-Vehicle Communications and Active/Inactive Vehicle-to-Infrastructure Communications.

Active Vehicle-to-Vehicle Communications

Considering the flow of information in this V2V/V2I communications network, drivers are certain about other drivers' behaviors. Moreover, they are aware of driving environment, road condition, and weather condition downstream of their current location. Therefore, a deterministic acceleration modeling framework is suitable for modeling this environment. This paper utilizes Intelligent Driver Model (IDM) (3) to model this connected environment. While capturing different congestion dynamics, this model provides greater realism than most of the deterministic acceleration modeling frameworks.

Inactive Vehicle-to-Vehicle Communications

In this driving environment, no active communication exists between vehicles. In case that V2I communications are unavailable, drivers' only sources of information are road signs and their perception of surrounding traffic condition. Drivers' behavior in this case can be modeled similar to the case that vehicles have no communication capability. In the presence of V2I communications, drivers directly receive information about the TMC decisions. Drivers' behavior in this case can be modeled similar to the case that vehicles have active V2I communications.

Active Vehicle-to-Infrastructure Communications

From the TMC point of view, active V2I communications will provide a basis to detect individual vehicle trajectories which can be used as high precision input data to traffic control algorithms. From the driver's standpoint, V2I communications do not directly influence the drivers' acceleration choice. Therefore, the acceleration modeling approach under active V2I communications depends on the availability of V2V communications. However, active V2I communications will provide real-time information about the TMC decisions (e.g. speed limit update in a speed harmonization system) which aim to improve safety and mobility.

Inactive Vehicle-to-Infrastructure Communications

In this driving environment, no direct communication exists between vehicles and the TMC. Without V2V communications, drivers' only sources of information are road signs and their perception of surrounding traffic condition. Drivers' behavior in this case can be modeled similar to the case that vehicles have no communication capability. In the presence of V2V communications, drivers may receive information about the TMC decisions from other vehicles (if at least one vehicle in the V2V communications network receives information from the TMC). Drivers' behavior in this case can be modeled similar to the case that vehicles have active V2I communications.

Modeling Autonomous Vehicles

Considering the ability of autonomous vehicles to constantly monitor other vehicles in their vicinity, an autonomous vehicle is certain about other drivers' behavior. Moreover, these vehicles can react instantaneously to any changes in the driving environment. Therefore, a deterministic acceleration modeling framework with reaction time set to zero is suitable for modeling this environment. This paper utilizes the Intelligent Driver Model (IDM) (3) to model autonomous vehicles.

PRELIMINARY RESULTS

The preliminary simulations targeted a four-lane highway on the eastbound direction of I-290 near Chicago, IL (see Figure 1). This 3.5-mile long segment has 4 on-ramps and 3 off-ramps each with different characteristics and different merging length. An example of simulation results are presented in Figure 2. This figure reveals the impact of market penetration rate on mobility. In this figure, it is assumed that reaction time of drivers will decrease by 50% in the presence of V2V communications. Note that V2I communications are inactive in this example. Based on this figure, higher penetration rate of connected vehicles results in higher breakdown flow (compare 2000 veh/hr at %0 penetration rate to 2500 veh/hr at %50 penetration rate) and density (compare 28 veh/km at %0 penetration rate to 38 veh/km at %50 penetration rate). Moreover, the scatter in the fundamental diagram decreases as the number of connected vehicles increases and at %100 penetration rate, the breakdown is completely eliminated. Therefore, it can be concluded that the efficiency of the highway increases as the number of connected vehicles increases.

CONCLUSION

This paper presents a framework to model drivers' acceleration behavior in the presence of Connected Vehicles technology and autonomous vehicles. Accordingly, different scenarios of active/inactive V2V/V2I communications are considered and appropriate acceleration models are selected to simulate driving behavior under these scenarios. The final paper will include a note on the calibration of the presented framework as well as a comprehensive analysis of the impact of Connected Vehicles technology and autonomous vehicles on mobility. Main contributions of this paper are:

- 1- Present an acceleration framework to simulate driving behavior in a connected environment, and
- 2- Through simulation and sensitivity analysis, quantify and analyze the impact of Connected Vehicles technology and autonomous vehicles on the efficiency of a simple roadway segment.

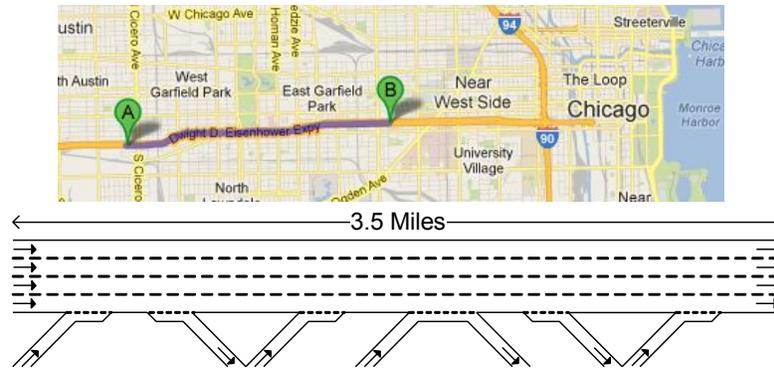


FIGURE 1 Characterization of the Selected Segment in Chicago, IL

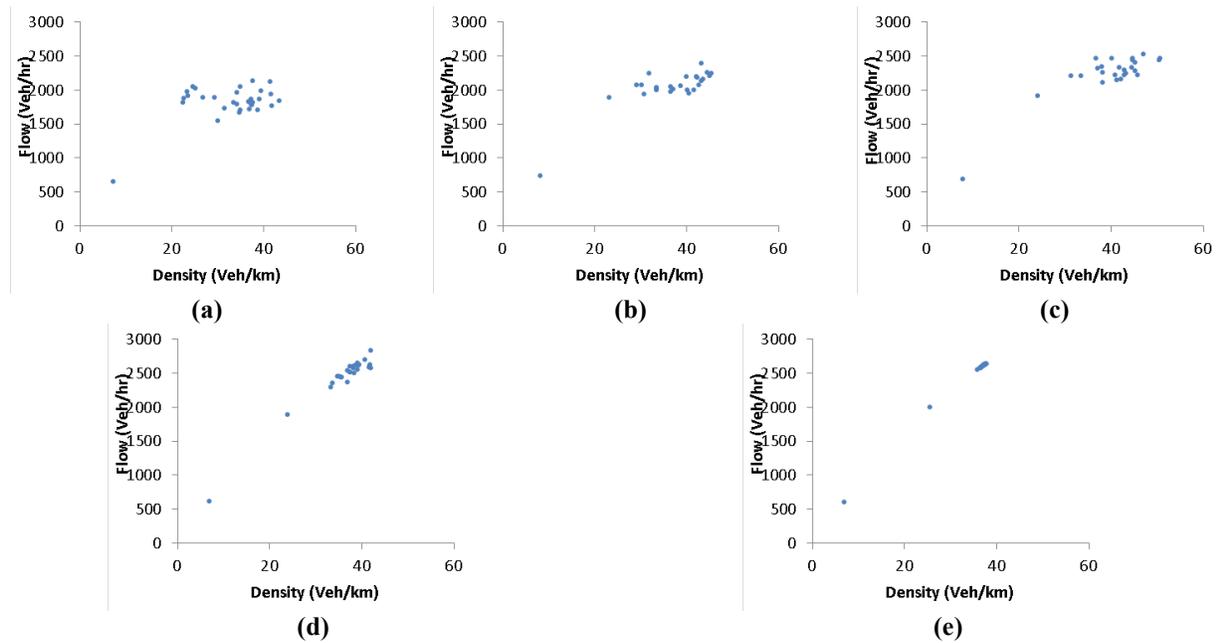


FIGURE 2 Flow-Density graph for different market penetration rates, (a) %0, (b) %25, (c) %50, (d) %75, and (e) %100.

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