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# Car-following behavior with instantaneous driver–vehicle reaction delay: A neural-network-based methodology

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ABSTRACT

Reaction delay of the driver–vehicle unit varies greatly according to driver–vehicle characteristics and traffic conditions, and is an indispensable factor for modeling vehicle movements. In this study, by defining the time interval between the relative speed and acceleration, the gap and speed observed from real traffic as driver–vehicle reaction delay, a neural network for instantaneous reaction delay is built. Incorporating the reaction delay network into a neural-network-based car-following model, movements of nine vehicles which follow each other are simulated. Simulation results show that the models with instantaneous reaction delay apparently outperform the models with fixed reaction delay. In addition, the model with short fixed reaction delay makes the vehicles follow each other more closely than the vehicles in real traffic do, and collisions occur in the model with long fixed reaction delay, which also illustrates the necessity of taking into account instantaneous reaction delay in microscopic traffic simulation. Besides, for future reference, the calibrated weights and biases in the proposed methodology are presented in Appendix.



## 1. Introduction

Due to the ability of capturing the complexity of traffic systems, traffic simulation has become one of the most used approaches for traffic planning, traffic design and traffic management. A wide variety of traffic simulation software is currently available on the market and is utilized by thousands of consultants, researchers and public agencies (Barceló, 2010; Bloomberg and Dale, 2000; Hidas, 2005; Takahashi et al., 2002; Wu et al., 2003; Yang and Koutsopoulos, 1996). With the popularity of traffic simulation, the car-following and lane-changing models, two of the most significant components in traffic simulation, have naturally attracted a lot of attention from traffic researchers (Brackstone and McDonald, 1999; Gipps, 1986; Hidas, 2002; Panwai and Dia, 2005; Toledo, 2007; Zheng et al., 2012a). A number of models have been proposed in the past decades to describe such driving behavior more realistically and accurately.

The concept of car following was first proposed by Reuschel (1950) and Pipes (1953), which assumed that the following vehicle controls its behavior with respect to the preceding vehicle in the same lane. Thereafter, considerable car-following models were developed to mimic this behavior more consistently with real traffic. In Gipps (1981), equations of motion were accepted to describe driver's acceleration and deceleration behavior. According to stimulus and response relationship, Gazis et al. (1961) proposed a widely studied car-following model. Kikuchi and Chakroborty (1992) built a car-following model based on fuzzy logic theory. In addition, Nagel and Schreckenberg (1992) presented a typical cellular automata model to simulate vehicle movements. And, the model formulation in Bham and Benekohal (2004) adopted the concept of cellular automata and car-following models. Besides, neural networks were also used to model car-following behavior (Panwai and Dia,

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2007). Based on discrete choice theory, drivers' acceleration and deceleration decisions were evaluated (Zheng et al., 2012b,c).

Reaction delay is a common characteristic of humans in operation and control, such as driving a car. The operational coefficients and delay characteristics of humans can vary rapidly because of changes in factors such as task demands, motivation, workload and fatigue. As mentioned above, research on car-following models historically has focused on exploration of different modeling frameworks and variables that affect this behavior. Recently, researchers have recognized that reaction delay of each driver is an indispensable factor for the identification of car-following models since it affects traffic dynamics not only in a microscopic way but also macroscopically (Ma and Andréasson, 2006). However, due to that the estimation of variations in reaction delay is almost impossible in classic paradigms, in the abovementioned car-following models reaction delay was all assumed to be fixed. Besides, in previous studies the delay within the mechanical system of a vehicle was usually neglected. In fact, the time that a vehicle takes to respond to a request (decelerating, accelerating, steering) depends greatly on the vehicle and roadway conditions, and is different for different types of vehicles (motorcycle, car, heavy vehicle). For modeling vehicle movements more realistically, vehicle reaction delay should also be considered.

As an effort to circumvent the limitations to modeling vehicle movements, by defining the time interval between the relative speed and acceleration observed in real traffic as reaction delay, Khodayari et al. (2012) proposed a neural-network-based car-following model which can take instantaneous driver–vehicle reaction delay into consideration. Although based on their method for some vehicles driver–vehicle reaction delay can be clearly identified, an explicit reaction delay model was not presented in the research, which completely limits the applicability of the method in simulation.

In this study, the driver–vehicle reaction delay is specified by the time interval not only between the relative speed and acceleration but also between the gap and speed of the vehicle. A neural network for instantaneous reaction delay is trained by observed delay samples and then compared with a previous piecewise linear reaction delay model. Comparison results show that the neural network delay model is more realistic than the piecewise linear model. Incorporating the reaction delay network into a neural-network-based car-following model, movements of nine vehicles which follow each other are simulated. Simulation results demonstrate that the models with instantaneous driver–vehicle reaction delay clearly outperform the models with fixed reaction delay. Furthermore, the model with short fixed reaction delay makes the simulated vehicles follow each other more closely than the observed vehicles do, and collisions happen in the model with long fixed reaction delay, which also indicates that taking instantaneous reaction delay into account is essential for modeling vehicle movements.

The paper is composed of five sections. Data sets used in this study are briefly introduced in the subsequent section, followed by the description of the neural-network-based methodology. In Section 4, the proposed methodology is thoroughly validated. The last section is devoted to the conclusions.

## 2. Data sets

The data used in this study were collected on a segment of U.S. Highway 101 in Los Angeles, California, by using eight video cameras that were mounted on a high story building. The study site is 640 m long and covers an on-ramp and an off-ramp. There are five mainline lanes throughout the study site and an auxiliary lane is present through a portion of the corridor between the on-ramp and the off-ramp. The data sets were provided by Cambridge Systematic Incorporation for Federal Highway Administration as a part of the Next Generation Simulation (NGSIM) program. Detailed information about observed vehicles, (vehicle type and size, lane ID, two-dimension position, speed and acceleration) was extracted from video data, together with information about the preceding and following vehicles.

Data reflecting congested traffic conditions in morning peak periods were collected during 7:50 am and 8:35 am on June 15, 2005. Traffic composition and traffic flow characteristics are listed in Table 1. In addition, the data were collected in clear weather, good visibility, and dry pavement conditions. A detailed analysis of the data and the data processing methodology is presented in NGSIM U.S. 101 Data Analysis Report (Cambridge Systematics Inc., 2005).

Besides, in order to alleviate the noise in the data (Punzo et al., 2011), the moving-average filter for a duration of 1 s is applied to all vehicle trajectories before data analysis in this study.

## 3. The neural-network-based methodology

The methodology is based on two models, the reaction delay model and the car-following model. As displayed in Fig. 1, according to traffic conditions (speed, gap, relative speed, etc.) at time *t*, the reaction delay model is used to estimate the time

**Table 1**
Traffic composition and traffic flow characteristics.

| Number of automobiles | Number of heavy vehicles | Number of motorcycles |
|---|---|---|
| 5919 (97.0%) | 137 (2.2%) | 45 (0.7%) |
| Flow rate (veh/h) | Average speed (km/h) | Density (veh/km) |
| 8077 | 35.0 | 231 |