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Agent-based simulation framework for mixed traffic of cars, pedestrians and trams☆

Hideki Fujii*, Hideaki Uchida, Shinobu Yoshimura

The University of Tokyo, 7-3-1 Hongo, Bunkyo, Tokyo 113-8656, Japan

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ABSTRACT

In this paper, we report on the construction of a new framework for simulating mixed traffic consisting of cars, trams, and pedestrians that can be used to support discussions about road management, signal control, and public transit. Specifically, a layered road structure that was designed for car traffic simulations was extended to interact with an existing one-dimensional (1D) car-following model and a two-dimensional (2D) discrete choice model for pedestrians. The car model, pedestrian model, and interaction rules implemented in the proposed framework were verified through simulations involving simple road environments. The resulting simulated values were in near agreement with the empirical data. We then used the proposed framework to assess the impact of a tramway extension plan for a real city. The simulation results showed that the impact of the proposed tramway on existing car traffic would not be serious, and by extension, implied that the proposed framework could help stakeholders decide on expansion scenarios that are satisfactory to both tram users and private car owners.

1. Introduction

Road traffic is a key part of the infrastructure supporting mobility through the transportation of humans and goods. However, at the same time, it is also the cause of various types of urban and environmental issues including traffic jams, accidents, heavy energy consumption, as well as air pollution and global warming due to engine emissions.

Promotion of public transportation usage is among the most effective methods for addressing such issues. Herein, we will focus on the extension of a tramway into a rail station square because the connectivity of public transportation services (such as railways and tramways) is regarded as an index for transportation service accessibility (Scheurer and Porta, 2006; Tahmasseby et al., 2008), and because improved transportation services can suppress excessive public dependency on private cars. However, careful consideration must be taken given the fact that policies aimed at improving tram convenience might impair the use of the private cars that must share the same limited road space available.

Furthermore, since it is very difficult to restore a road environment to a previous condition once it has been changed, it is strongly desirable to accurately estimate the impact of transportation policies quantitatively. This is why simulations have been playing an important role in the field of traffic engineering, and why various types of traffic simulators have been developed and utilized (Kitamura and Kuwahara, 2005; Barceló, 2010). A number of mixed traffic simulation models that can be used to support the validity of novel signal control methods or public transport planning efforts have been proposed in recent years (e.g., Ma et al., 2014; Estrada et al., 2016; Shi et al., 2017), primarily because they can ascertain precise traffic properties at specific road environment locations,

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* Corresponding author.
E-mail address: fujii@sys.t.u-tokyo.ac.jp (H. Fujii).

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especially intersections, as will be described later.

In this paper, we report on our newly constructed multi-agent-based traffic simulator for mixed traffic of cars, pedestrians, and trams. More specifically, we installed a pedestrian and tram agent model into an existing car traffic simulator that we have been developing and set interaction rules among these agents. This simulator was then applied to a case study involving a tramway extension plan in an actual city. Since the extended tramway is designed to cross the intersection in front of the city's central railway station, where car and pedestrian traffic is quite heavy, an accurate simulation that considers interactions between cars, pedestrians, and trams was deemed necessary. Via our simulation, we aimed to deliver objective data to the extension plan stakeholders by providing a quantitative analysis on the impact of the policy on car traffic.

2. Literature review

Car traffic simulation models are generally classified into two categories: macroscopic models based on continuum fluid dynamics and microscopic models in which each vehicle is modeled as a kind of particle. Since traffic phenomena are regarded as a mixture of complex systems produced by numerous human beings who possess intelligence, goals, intentions, as well as individualities, a multi-agent system is useful for describing microscopic car behavior. Microscopic models can be divided according to the representation of road structure in greater detail. In the continuous road model group, a base structure of road space is modeled as a continuous one-dimensional (1D) link. The behavior of car agents is often implemented by applying car-following theories (e.g., Chandler et al., 1958; Bando et al., 1994; Helbing and Tilch, 1998; Treiber et al., 2000; Jiang et al., 2001; Ge et al., 2008; Peng et al., 2011; Tang et al., 2012; Zheng et al., 2012). Most commercial microscopic traffic simulators employ the continuous road model. In the cell-type road model group, road space is discretized by homogeneous cells in which the behavior of car agents is expressed using transition rules such as cellar automata (e.g., Nagel and Schreckenberg, 1992; Fukui and Ishibashi, 1996; Kerner et al., 2002; Tonguz et al., 2009). In a queuing model group, road networks are modeled as queue networks (Gawron, 1998; Agarwal and Lämmel, 2016).

Microscopic models used for pedestrian (or crowd) simulations are classified as well. The social force model (SFM) (Helbing and Molnár, 1995) and centrifugal-force based models (CFM) (Yu et al., 2005; Chraibi et al., 2010), in which pedestrian agents move in two-dimensional (2D) road space, have been successfully used in continuous road model groups. The predictive performance of those models was enhanced by introducing the capability to anticipate pedestrian actions (Asano et al., 2010) and stride adaptation mechanisms (von Sivers and Köster, 2015). A 1D pedestrian model (Yamashita et al., 2013) in which the SFM spatial dimensions are compressed into one, has been applied to evacuation simulations. Furthermore, the discrete choice model (Antonini et al., 2006) is among the continuous road models with discretized decision-making rules for each pedestrian agent. The floor field model (Burstedde et al., 2001) and Muramatsu's lattice-gas-based model (Muramatsu et al., 1999) belong in the group of cell-type road models.

In addition, several researchers have proposed simulation frameworks for mixed traffic of two or more models. For example, Yang et al. (2006) proposed a framework for pedestrian road crossing behavior in Chinese cities in which they determined the criterion used by pedestrians to decide whether start crossing a road after considering vehicle flows. While the model itself was relatively simple, the simulation results (with adjusted parameters) agreed well with the observed values.

Meanwhile, Zeng et al. (2014) modeled pedestrian-vehicles interactions at crosswalks by adding external force to the SFM in order to minimize pedestrian-vehicle collisions. Anvari et al. (2013) used the SFM to model mixed car and pedestrian traffic scenarios by extending the SFM for car dynamics and integrating a car-following model. Huang et al. (2011) also developed a 2D car behavior model based on the SFM and integrated it with the proportional-integral-derivative (PID) control algorithm, while Huynh et al. (2013) extended the SFM to model the behavior of motorcycles, passenger cars, and buses for use in a mixed traffic simulation at a signalized intersection. These SFM-based car models are capable of being naturally integrated with the SFM-based pedestrian models. However, a major disadvantage of existing car traffic simulators based on car-following models is that they are hard to apply to this approach. Furthermore, generally speaking, the computational load of 2D models is much higher than that of 1D models.

Additionally, Crociani and Vizzari (2014) proposed an integrated simulation model by combining a 1D car-following model and a 2D floor field pedestrian model in which they employed a hierarchical road environment structure to exploit the different representations of cars and pedestrians. The specific types of agents are situated in the lower level and comprehensive views of the overall situation are given at the higher level.

Dobler and Lämmel (2013) integrated multi-modal simulation modules to the existing framework of MATSim, which is a large-scale traffic simulation framework based on the queueing model (Charypar et al., 2007). Their integration approach was based on locally replacing simple queue structures with continuous 2D space at sections with higher traffic flows. The behavior rules of agents in the 2D space are based on the SFM.

Finally, Krajzewicz et al. (2014) introduced pedestrian and bicycle agent models into SUMO, which is widely used traffic simulator belonging to the continuous road model group (Krajzewicz et al., 2002), and were able to consider and verify their agents qualitatively, even though the pedestrian and bicycle agents had relatively simple behavior rules by which they move in 1D virtual trajectories.

3. Models in proposed framework

In this research, mixed traffic conditions refer to those in which cars, trams, and pedestrians coexist simultaneously. Simulating such traffic conditions requires agent models for all of those travel modes. Since continuous road models are suitable for simulating the precise behavior of cars, trams, and pedestrian agents, the multi-agent based car-traffic simulator we have been developing (Yoshimura, 2006) was chosen as the basis of this research. The simulator, which is named the Multi-Agent-based Traffic and