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Modeling the effect of electric vehicle adoption on pedestrian traffic safety: An agent-based approach

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ABSTRACT

When operated at low speeds, electric and hybrid vehicles have created pedestrian safety concerns in congested areas of various city centers, because these vehicles have relatively silent engines compared to those of internal combustion engine vehicles, resulting in safety issues for pedestrians and cyclists due to the lack of engine noise to warn them of an oncoming electric or hybrid vehicle. However, the driver behavior characteristics have also been considered in many studies, and the high end-prices of electric vehicles indicate that electric vehicle drivers tend to have a higher prosperity index and are more likely to receive a better education, making them more alert while driving and more likely to obey traffic rules. In this paper, the positive and negative factors associated with electric vehicle adoption and the subsequent effects on pedestrian traffic safety are investigated using an agent-based modeling approach, in which a traffic micro-simulation of a real intersection is simulated in 3D using AnyLogic software. First, the interacting agents and dynamic parameters are defined in the agent-based model. Next, a 3D intersection environment is created to integrate the agent-based model into a visual simulation, where the simulation records the number of near-crashes occurring in certain pedestrian crossings throughout the virtual time duration of a year. A sensitivity analysis is also carried out with 9000 subsequent simulations performed in a supercomputer to account for the variation in dynamic parameters (ambient sound level, vehicle sound level, and ambient illumination). According to the analysis, electric vehicles have a 30% higher pedestrian traffic safety risk than internal combustion engine vehicles under high ambient sound levels. At low ambient sound levels, however, electric vehicles have only a 10% higher safety risk for pedestrians. Low levels of ambient illumination also increase the number of pedestrians involved in near-crashes for both electric vehicles and combustion engine vehicles.

1. Introduction

The U.S. Department of Transportation has declared pedestrians to be the top-priority roadway agents in terms of traffic safety (NHTSA, 2010), as statistics have shown that traffic accidents involving pedestrians have become a major traffic safety concern. In 2014, there were 4884 pedestrian fatalities and 65,000 injuries from a total of 44,820 fatal traffic crashes. Pedestrians are even more likely to be involved in traffic crashes in urban areas (78% of total pedestrian fatalities) and under low-light conditions (72% of total

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pedestrian fatalities) (NHTSA, 2016). With the current increasing trend in hybrid/electric vehicle adoptions, regarding concerns have increased due to the silent engines and low sound levels of such vehicles, which non-motorists (pedestrians, bicyclists, skaters, etc.) cannot rely on as easily to warn of approaching vehicles in the urban areas. The National Highway Transportation Safety Agency (NHTSA) has therefore called these cars "quieter cars" in a 2009 report, which concluded that hybrid electric vehicles (HEVs) are two times more likely to be involved in a pedestrian crash than internal combustion engine vehicles (ICEVs) (Hanna, 2009). This report, however, was updated in 2011 with more extensive data by adding crash files reported to the state database in recent years. According to the report, accident rates are highly dependent on vehicle speed, maneuvering, and location, but the largest difference between the involvement rates of HEVs and ICEVs in pedestrian crashes (the former being 22% greater than the latter) is observed when the average vehicle speed is less than 35 mph, during low-speed maneuvers, and when pedestrians are on the roadway (Wu and Austin, 2010). The NHTSA has also performed another extensive study on quieter cars posing a safety risk for blind pedestrians. This second study included two phases of research. The first phase studied the determination of overall sound levels and general spectral content for a selection of hybrid-electric and internal combustion vehicles under different operating conditions, as well as the evaluation of detectability for low and high ambient sound levels (Garay-Vega et al., 2010). The second phase proposed potential specifications for vehicle sound levels to be used in HEVs, including adding a synthetic vehicle sound (Hastings et al., 2011). The solution of placing a synthetic sound source into silent vehicle has been extensively studied recently. For instance, in a technology research study, the Japanese electric vehicle manufacturer Nissan developed a synthetic sound system called VSP (Vehicle Sound for Pedestrians), which emits a synthetic sound to satisfy three key concerns: to provide detectability for pedestrians, to provide silence for drivers, and to maintain a quiet environment for the neighborhood as a whole (Tabata et al., 2010).

There are many factors affecting pedestrian traffic safety, including the relative illumination of the traffic environment, pedestrian and driver behaviors, vehicle technology, vehicle and ambient sound levels, vehicle traffic density, traffic flow speed, traffic signage, and other applicable factors. Some of these factors can be linked to the adopted vehicle type by making correlations with driver behavior as well as pedestrian perception. Since EV drivers are at a higher economic level and are therefore more likely to have received a better education, they demonstrate more careful traffic behavior (Shinar, 2007). Additionally, higher internal car noise increases drivers' risk-taking propensity (Horswill and Coster, 2002). On the other hand, the relative silence of the average EV's engine will make it less detectable by oncoming pedestrians and therefore more likely to be involved in collisions. Since EV adoption therefore has both positive and negative impacts on the pedestrian's traffic safety, the overall resultant effect can be investigated with an agent-based modeling approach. Agent-based modeling (ABM) is a new approach to computational modeling that simulates dynamic systems with various interacting agents. ABM has gained significant attention over the past 10 years, during which time the systems that have needed to be analyzed and modeled have become more complex in terms of the different interdependencies involved. ABM is particularly useful when there are interacting agents and factors that simultaneously affect each other, and is now being applied to topics such as market analysis, organizational decision-making, energy analysis, air traffic control, etc. For instance, Noori and Tatari (2016) used an agent-based model for regional market penetration projections of EVs, and discovered that government subsidies play a vital role in EV market adoption. Similarly, Shafiei et al. (2012) developed a multi-agent environment to predict the market share of EVs in Iceland. and concluded that successful EV market penetration occurs in scenarios with low gasoline prices, or with a combination of medium-level gasoline prices and constant EV price only when supporting policies such as tax exemptions are available. The ABM approach has been also recently used in transportation modeling, such as in a recent study that modeled the dynamic route choice behavior of individual drivers under the influence of real time traffic information (Dia, 2002). Using a similar approach, Waraich and Axhausen (2012) developed an agent-based parking choice model in their study to investigate the overall effects of parking capacity and pricing on parking-oriented transportation policies. Another study simulated electric vehicle driver behavior in road transport and electric power networks (Marmaras et al., 2017).

The traffic flow on pedestrianized streets was analytically studied by many researchers. Daganzo and Knoop (2016) provided analytical formulae predicting the capacity and macroscopic fundamental diagram (MFD) of pedestrianized streets. According to study, free-flow speed on the pedestrianized street declines proportionately with the pedestrian flow and capacity declines by an amount proportional to the square root of the pedestrian flow. In another study, Zeng et al. (2014). carried out pedestrian behavior analysis at signalized intersection through a microscopic simulation model that employs a social force theory. The study concludes that the microsimulation model enables visually representing the pedestrian crossing behavior in the real world Crociani and Vizzari (2014) modeled the interaction between vehicles and pedestrians in an area of a zebra crossing. By providing simple pedestrian crossing scenarios in an agent based environment, the study showed the mutual perception of pedestrian and vehicles cooperating to avoid accidents. Lobjois and Cavallo (2009) examined the road crossing decisions by the age and gender factors. According to study, the gender doesn't have obvious effect and age factor showed that the young group had a greater number of tight fits and missed fewer opportunities on the crossing task. Similarly Dommes et al. (2012) investigated age related differences for the street crossing behavior. Gorrini et al. (2016) conducted an empirical study to model the pedestrian-vehicle interaction on urban unsignalized intersections. Another pedestrian crossing behavior model was developed for Chinese cities where the pedestrians' road crossing behavior is different than the pedestrian behavior in European countries. Yang et al. (2006) classified pedestrians into two types: law-obeying ones and opportunistic ones. The model has shown the high rate of pedestrians' red light running characteristics in Chinese cities. This study also provides a vehicle pedestrian interaction in pedestrian crossings and measures the difference between conventional and electric vehicles. A traffic micro-simulation is carried out using a powerful multi-method 3D simulation environment called AnyLogic (AnyLogic: Multimethod Simulation Software, 2016). AnyLogic is a unique tool that combines the System Dynamics, Discrete Event, and Agent-Based modeling methods into one model development environment, allowing the AnyLogic software to provide a great deal of flexibility with its built-in Java capabilities, as all of the complex agent behavior in the simulation can therefore be modeled with Java coding. A model developed in AnyLogic is fully mapped into Java code and, having been linked with