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An extended car-following model with consideration of the electric vehicle's driving range

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HIGHLIGHTS

- This paper proposed an electric vehicle's following model.
- The effects of the driving range on each vehicle's speed are studied.
- The effects of the driving range on each vehicle's headway are studied.

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ABSTRACT

In this paper, we propose a car-following model to explore the influences of the electric vehicle's driving range on the driving behavior under four traffic situations. The numerical results illustrate that the electric vehicle's behavior of exchanging battery at the charge station can destroy the stability of traffic flow and produce some prominent jams, and that the influences are related to the electric vehicle's driving range, i.e., the shorter the driving range is, the greater the effects are.

1. Introduction

To date, traffic pollution has been one serious social problem, which has attracted researchers to explore various models to study the vehicle's fuel consumption and exhaust emissions [1–3]. The models developed in Refs. [1–3] can reduce the exhaust emissions and fuel consumption, but the exhaust emissions cannot completely be eliminated since each traditional vehicle should consume fuel. To reduce the traffic pollution or completely eliminate the exhaust emissions, engineers recently designed the electric vehicle without exhaust emissions [4–6]. Because the electric vehicle can completely eliminate the exhaust emissions, it has been a potential traffic tool. Thus, researchers have recently begun to study the electric vehicle's energy consumption [7–9] and micro driving behavior [10], but the "range anxiety" (i.e., the distance that each electric vehicle can run is limited) is one fatal drawback of the electric vehicle [11], so the electric vehicle has not widely been used and little efforts have been made to study the effects of the electric vehicle's driving range on its driving behavior. In this paper, we introduce the driving range into the car-following model and propose an extended car-following model to investigate the impacts of the electric vehicle's driving range on each vehicle's micro driving behavior from the numerical perspective.

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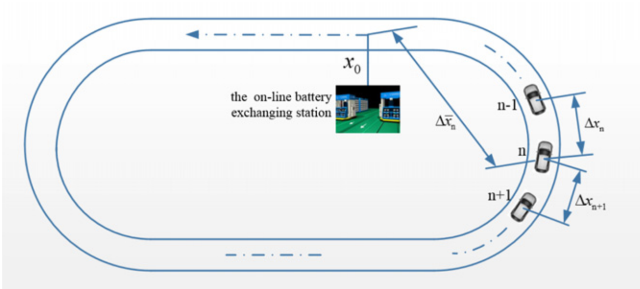

Fig. 1. The scheme of the car-following model for electric vehicles on a ring road with an on-line charging station.

2. Model

To investigate the complex traffic phenomena, researchers proposed traffic models [12–52], which can roughly be classified into the dynamics models and the car-following models. The existing car-following models on the single-lane road can be formulated as follows:

$$\frac{dv_n}{dt} = f(v_n, \Delta x_n, \Delta v_n, \ldots), \quad (1)$$

where v_n, Δx_n, Δv_n are the nth vehicle's speed, headway and relative speed, respectively; f is the nth vehicle's stimulus function determined by the speed, headway, relative speed and other related factors. If f is defined as a different expression, we can obtain different car-following models (e.g., the FVD (full velocity difference) model [14]), where the FVD model can be defined as follows:

$$\frac{dv_n}{dt} = \alpha\left(V\left(\Delta x_n\right) - v_n\right) + \lambda_1 \Delta v_n, \quad (2)$$

where α, λ_1 are two reaction coefficients; $V(\Delta x_n)$ is the optimal velocity. However, the FVD model cannot reproduce the influences of interruption factor (e.g., accident) on traffic flow since it does not consider this factor. Thus, Tang et al. [23] proposed a car-following model with consideration of the traffic interruption probability, i.e.,

$$\frac{dv_n(t)}{dt} = \alpha[V(\Delta x_n) - v_n] + \lambda_1(1 - p_{n-1})\Delta v_n + \lambda_2 p_{n-1}(-v_n), \quad (3)$$

where λ_2 is a reaction coefficient, p_{n-1} is the probability that the $(n-1)$th vehicle is interrupted.

However, the above models cannot completely describe the electric vehicle's driving behavior because they do not consider the driving range of the electric vehicle. Like the traditional vehicle's driving behavior, the electric vehicle's driving behavior can be influenced by some interruption factors (e.g., the charging station, exchanging battery, etc.), which shows that the model [23] can be used to investigate the electric vehicle driving behavior as long as we extend it based on the electric vehicle's properties.

Before extending the model [23], we should here give the following assumptions:

(1) The drivers are homogeneous.
(2) The electric vehicle's and traditional vehicle's driving behaviors are the same when the electric vehicle need not exchange its battery at the on-line charging station.
(3) The number of vehicles is N and the electric vehicle's proportion is r.
(4) When an electric vehicle's electricity does not satisfy the demand, it will choose to exchange its battery at the online charge station and does not choose to charge its battery since the charge time is much longer than the time of exchanging battery.
(5) The road is a single-lane ring without ramp.
(6) There is an on-line charge station on the ring, where its position is x_0 (see Fig. 1). In addition, only a vehicle can be serviced at the station every time.
(7) Each electric vehicle's driving range is D_R.
(8) The condition whether each electric vehicle exchanges its battery at the charge station depends on the remaining electricity of its battery, i.e., if an electric vehicle's driving range is relatively long at the charge station, the probability that the vehicle need exchange its battery is relatively low. If an electric vehicle's driving range is N circles, it need only exchange its battery for one time between 1st and Nth circle and can run N circles after it exchanges its battery.
(9) The time that each driver exchanges the battery is T_0.
(10) Each vehicle's initial headway is Δx_0, the nth vehicle's position is x_n.