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A recurrent neural network based microscopic car following model to predict traffic oscillation

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ABSTRACT

This paper proposes a recurrent neural network based microscopic car following model that is able to accurately capture and predict traffic oscillation. Neural network models have gained increasing popularity in many fields and have been applied in modelling microscopic traffic flow dynamics due to their parameter-free and data-driven nature. We investigate the existing neural network based microscopic car following models, and find out that they are generally accurate in predicting traffic flow dynamics under normal traffic operational conditions. However, they do not maintain accuracy under conditions of traffic oscillation. To bridge this research gap, we first propose four neural network based models and evaluate their applicability to predict traffic oscillation. It is found that, with an appropriate structure and objective function, the recurrent neural network based model has the capability of perfectly re-establishing traffic oscillations and distinguish drivers characteristics. We further compare the proposed model with a classical car following model (Intelligent Driver Model). Based on our case study, the proposed model outperforms the classical car following model in predicting traffic oscillations with different driver characteristics.

1. Introduction

Traffic oscillation, or stop-and-go traffic, has raised many concerns to both transport practitioners and researchers. Its negative impacts include deteriorating highway mobility, increasing safety concerns, excessive fuel consumption and greenhouse gas emissions (Bilbao-Ubillos, 2008; Zheng et al., 2010; Song et al., 2013). Various car-following models have been proposed and improved in order to accurately capture the traffic oscillation. See for example Brackstone and McDonald (1999) and Saifuzzaman and Zheng (2014) for reviews.

On the other hand, machine learning techniques, especially artificial neural networks, have been widely applied in many modelling fields, such as speech recognition (Sak et al., 2014), handwriting recognition (Graves et al., 2009), and self-driving cars (Santana and Hotz, 2016). With the increases in data quantity and computational power, the machine learning approach is more efficient and accurate than ever before. Using machine learning to model car-following behaviours has also been studied intensively (Papathanasopoulou and Antoniou, 2015; He et al., 2015; Aghabayk et al., 2014; Chong et al., 2011,

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2013; Mathew and Ravishankar, 2012; Khodayari et al., 2012; Panwai and Dia, 2007; Jia et al., 2003). Compared with classical car-following modelling approaches, one unique benefit of machine learning is its nonparametric characteristic. Typically, in classical car-following models, one has to calibrate the parameters in the empirical equation to achieve a high level of accuracy. Whereas neural network based models can learn from field data and automatically generate the car-following model without many artificial parameters. They often produce superior results (Aghabayk et al., 2014; Mathew and Ravishankar, 2012; Khodayari et al., 2012; Chong et al., 2011). Unfortunately, these neural network based models have not been tested under oscillating traffic conditions.

Therefore, we implement different neural network architectures under traffic oscillations, and the results indicate that neural network based models can produce highly accurate results when the tests are based on the inputs from field data. However, when being tested based on the inputs from the previous predictions similar to iterative simulation, the test results yield unsatisfactory performance. The results suggest that the unsatisfactory performance is mainly caused by insufficient data inputs and inaccurate measurements.

This paper aims to bridge the gap using a Recurrent Neural Network (RNN) based car-following model. RNNs are a variation of the neural network family, with greater strength in predicting sequential data (Lipton et al., 2015; Mikolov et al., 2010). The car-following behaviours can be treated as a behaviour sequence due to the fact that the order of driving conditions matters when a driver is going to take their next action. For example, an acceleration phase followed by a deceleration phase is different to the reverse. With this strength, an RNN-based model considers not only the local information (such as short-term or immediate traffic condition used in classical car-following models), but also the global information which is a long-term condition stores in a RNN memory. In other words, RNN model takes action more like human in terms of the memory-based decision-making. In the car-following literature, a memory-based car-following model has also been paid attention to due to the driving history is an essential factor in predicting the next action. Treiber and Helbing (2003) address the historical impact by introducing an additional dynamical variable to a classical model. From this perspective, the memory effect does matter regarding developing a more accurate car-following model. Therefore, we develop an RNN-based model to capture car-following behaviours in oscillating scenarios and extended it to non-oscillating cases. The results illustrate that the RNN-based model can successfully predict both oscillating and non-oscillating car-following rules and increase accuracy by learning driver behaviours.

The rest of the paper is organised as follows. Section 2 briefly reviews the literature on traffic oscillation and neural network based car-following models. Section 3 shows the data and the pre-processing method we adopted to regularise data noise. Section 4 compares existing neural network based car-following models under oscillating traffic circumstances, and raises the inaccuracy and other potential issues produced from using these models. At the end of this section, we attempt to fix these issues by proposing a new neural network model that predicts partial gaps. This new model improves the performance but has a shortcoming in handling less informative data. In Section 5, we propose the RNN-based model to further improve modelling capacity in capturing driving behaviours. Section 6 concludes this paper.

2. Literature review

2.1. Oscillation

With the urbanisation of our cities, traffic volume has been increasing continuously. A negative consequence to our daily travel is the notorious phenomenon known as traffic oscillation. The formation and propagation mechanisms of traffic oscillation, also known as stop-and-go traffic, have been intensively investigated during recent years in the literature. A general car-following model may not describe oscillation accurately. Therefore, researchers have proposed or improved upon existing models to better describe and illustrate the oscillating patterns on congested highways.

The measuring and analysing methodologies for traffic oscillation have been developed and extended, which has improved the understanding of the mechanisms of oscillations. The traffic flow on congested highways can be described as three phases including free flow, synchronized flow and wide moving jam. Hence the three-phase traffic theory was proposed to fully explain the nonlinearity of traffic flow on highways (Kerner, 1999, 2012). However, Treiber et al. (2010) discuss the inconsistent use of the term "traffic phases" and show the three-phase traffic theory can be reproduced with simple two-phase models with suitably specified model parameters and a consideration of factors characteristic for real traffic flows. In the term of vehicular speed, Tian et al. (2016) suggests that the standard deviation of speed grows concavely along vehicles in the oscillation, which they find is a universal property of traffic oscillation. Li et al. (2010) propose a frequency spectrum analysis approach that enhanced the measurement of the periodicity and magnitude in a traffic oscillation. The oscillation triggers at the vehicle level, and the propagation features of oscillation, were analysed using the Wavelet Transform (WT) (Zheng et al., 2011a, 2011b), which enables investigation of the oscillation behaviours down to the micro level.

Also, several car-following models have been proposed to capture traffic oscillation. Bando et al. (1998) investigate the properties of congestion and the delay time of car motion using optimal velocity model. Furthermore, the behaviour of each driver differs, especially in a traffic oscillation. An oscillation is more likely to be instigated by an aggressive driver who may maintain a small response time and minimum spacing, which may also lead to capacity drop (Chen et al., 2014). According to this finding, to achieve more accurate car-following simulation, it is necessary to separate drivers depending on their driving behaviours (Chen et al., 2012; Laval and Leclercq, 2010). Laval and Leclercq (2010) introduce an additional parameter η to the