Transportation Research Part C 95 (2018) 47–60

Contents lists available at ScienceDirect

Transportation Research Part C

journal homepage: www.elsevier.com/locate/trc

The station-free sharing bike demand forecasting with a deep learning approach and large-scale datasets

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ARTICLE INFO

Keywords:
Sharing mobility
Station-free bike sharing
Travel demand forecasting
Bike sharing
Deep learning
Long short-term memory networks
Big data

ABSTRACT

The station-free sharing bike is a new sharing traffic mode that has been deployed in a large scale in China in the early 2017. Without docking stations, this system allows the sharing bike to be parked in any proper places. This study aimed to develop a dynamic demand forecasting model for station-free bike sharing using the deep learning approach. The spatial and temporal analyses were first conducted to investigate the mobility pattern of the station-free bike sharing. The result indicates the imbalanced spatial and temporal demand of bike sharing trips. The long short-term memory neural networks (LSTM NNs) were then developed to predict the bike sharing trip production and attraction at TAZ for different time intervals, including the 10-min, 15-min, 20-min and 30-min intervals. The validation results suggested that the developed LSTM NNs have reasonable good prediction accuracy in trip productions and attractions for different time intervals. The statistical models and recently developed machine learning methods were also developed to benchmark the LSTM NN. The comparison results suggested that the LSTM NNs provide better prediction accuracy than both conventional statistical models and advanced machine learning methods for different time intervals. The developed LSTM NNs can be used to predict the gap between the inflow and outflow of the sharing bike trips at a TAZ, which provide useful information for rebalancing the sharing bike in the system.

1. Introduction

The sharing bike is a sustainable and environmentally friendly urban traffic mode. During the past decade, the bike sharing system has been widely deployed in numerous cities worldwide. In the early 2017, a new kind of station-free bike sharing has been deployed in a large scale in several cities in China (see Fig. 1). This new station-free bike sharing system is quite different from the conventional bike sharing system. Without any docking stations in this bike sharing system, the bike can be parked in any proper places. As shown in Fig. 1(a), the built-in GPS tracking module allow riders to find and rent nearby bikes by using their smartphone apps. When finding the nearby bikes, riders can unlock the intelligent lock of a bike by scanning the quick response (QR) code printed on the bike body.

Due to the high freedom and conveniences, the station-free bike sharing system has attracted large number of bike riders for commuting trips. It becomes one of the useful solutions for traffic congestions and last-mile problem in urban transportation systems. However, like the conventional bike sharing system, it also suffers from the problem of fluctuating spatial and temporal demand, leading to inefficient bike repositioning and high operating costs in the bike sharing rebalance (Pal and Zhang, 2017). The dynamic

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https://doi.org/10.1016/j.trc.2018.07.013
Received 10 September 2017; Received in revised form 16 July 2018; Accepted 16 July 2018

(a) Station-free bike sharing (b) Bike sharing system with docking station

Fig. 1. Station-free bike sharing and conventional bike sharing with docking stations.

demand forecasting is critical important for rebalancing the sharing bikes in different areas (Liu et al., 2018). This study investigated the mobility pattern of the station-free bike sharing based on the OD matrices data from one of the bike sharing operation companies for several consecutive days. The dynamic demand forecasting models were developed to predict the travel demand in short time.

To improve the performance of bike sharing with docking stations, numerous studies have been conducted to understand the contributory factors affecting the demand of station-based bike sharing in recent years (Beecham and Wood, 2014; Gebhart and Noland, 2014; Zhao et al., 2014, 2015; Fishman et al., 2015; Campbell et al., 2016; El-Assi et al., 2017; Feng and Wang, 2017; Fournier et al., 2017). The current studies on travel demand of station-based bike sharing have generally focused on two major issues, including the investigations of bike sharing travel patterns (Gebhart and Noland, 2014; Beecham and Wood, 2014; Zhao et al., 2015; Fishman et al., 2015; Campbell et al., 2016) and the forecasting of bike sharing trip frequency (Zhao et al., 2014; Fournier et al., 2017; El-Assi et al., 2017; Feng and Wang, 2017). In the studies focused on the first issue, the travel survey and smart card data were used to investigate the travel patterns of station-based bike sharing, including the riders' choice preferences, travel time, trip duration, and trip purpose. For example, Campbell et al. (2016) developed a multinomial logit model to investigate the contributing factors to the choice of sharing bike based on a stated preference survey conducted in the four main urban districts of Beijing. The results suggested that trip distance, temperature, precipitation and poor air quality negatively affect the choice to switch from other transportation mode to sharing bike. Gebhart and Noland (2014) used the hourly weather data to evaluate the effects of weather conditions on the travel patterns of bike sharing. The results indicated that cold temperatures, rain, and high humidity levels reduce both the likelihood of using sharing bike and the duration of trips.

In the studies about the prediction of bike sharing trip frequency, different modeling methods and data were used to identify the contributory factors to the number of bike sharing trips (Zhao et al., 2014; Fournier et al., 2017; El-Assi et al., 2017; Feng and Wang, 2017). Zhao et al. (2014) investigated the effects of urban features and bike sharing system characteristics on daily sharing bike trip frequency. A partial least squares regression model was developed to link the daily trip number with urban population, government expenditure, the number of bike sharing members, the number of sharing bikes and the number of docking stations. El-Assi et al. (2017) evaluated the effects of built environment and weather on bike sharing demand in Toronto. The distributed lag model was used to link the daily station-level bike sharing trip number with land use, built environment and weather conditions. The results showed that road network configuration, bike infrastructure, and temperature significantly affect the bike trip frequency. Fournier et al. (2017) developed a sinusoidal model to predict the pattern of seasonal sharing bicycle demand. The evaluation results showed that the sinusoidal model is capable of estimating monthly average daily sharing bike trip frequency and average annual daily sharing bike trip frequency.

The findings from previous studies provide valuable insights in understanding of the contributing factors to the travel demand of station-based bike sharing. However, to the best of our knowledge, we are unable to find studies that have been conducted to investigate the travel demand of the station-free bike sharing. The dynamic demand forecasting model for station-free bike sharing is important because it provides useful information to develop effective and timely rebalance strategies to increase the operational efficiency of the station-free bike sharing system.

This study aimed to develop a citywide dynamic demand forecast model for station-free bike sharing system using deep learning approach with large-scale trip data. The station-free sharing bike trip data were collected at a citywide scale from one station-free sharing bike operation company. This study has the potential to contribute to the field of sharing bike by: (1) revealing the mobility pattern of the station-free bike sharing at a citywide scale; and (2) using deep learning approach to predict the travel demand of station-free bike sharing for large-scale road network at a citywide scale. So far, the development of station-free sharing bike demand forecast model has not been identified in previous studies. The results of this study have the potential to provide useful information for station-free sharing bike rebalance and to improve the operational efficiency of the station-free bike sharing system.

Recently, deep learning approaches have been increasingly used in different fields of transportation engineering (Jiang et al., 2014; Chen et al., 2017; Liu et al., 2018; Zhang et al., 2018; Wu et al., 2018; Dabiri and Heaslip, 2018; Kanarachos et al., in press). A number of studies have used deep learning approaches for travel demand forecasting, such the passenger demand of on-demand ride service and high-speed rail (Jiang et al., 2014; Chen et al., 2017; Ke et al., 2017). Ke et al. (2017) proposed a novel deep learning approach of convolutional long short-term memory network to forecast short-term passenger demand of on-demand ride service. The