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Short-term prediction of border crossing time and traffic volume for commercial trucks: A case study for the Ambassador Bridge

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ABSTRACT

Short-term forecasting of traffic characteristics, such as traffic flow, speed, travel time, and queue length, has gained considerable attention from transportation researchers and practitioners over past three decades. While past studies primarily focused on traffic characteristics on freeways or urban arterials this study places particular emphasis on modeling the crossing time over one of the busiest US–Canada bridges, the Ambassador Bridge. Using a month-long volume data from Remote Traffic Microwave Sensors and a yearlong Global Positioning System data for crossing time two sets of ANN models are designed, trained, and validated to perform short-term predictions of (1) the volume of trucks crossing the Ambassador Bridge and (2) the time it takes for the trucks to cross the bridge from one side to the other. The prediction of crossing time is contingent on truck volume on the bridge and therefore separate ANN models were trained to predict the volume. A multilayer feedforward neural network with backpropagation approach was used to train the ANN models. Predicted crossing times from the ANNs have a high correlation with the observed values. Evaluation indicators further confirmed the high forecasting capability of the trained ANN models. The ANN models from this study could be used for short-term forecasting of crossing time that would support operations of ITS technologies.

1. Introduction

Short-term forecasting of traffic characteristics, such as traffic flow, speed, travel time, and queue length, has gained considerable attention from transportation researchers and practitioners over past three decades (Chen and Rakha, 2014; Lin et al., 2014a; Qi and Ishak, 2014; Vlahogianni et al., 2014; Zhang et al., 2014). The primary goal of the forecasting is to feed predicted information into Intelligent Transportation Systems (ITS). ITS, for instance – Advanced Traveller Information Systems (ATMS) and Advanced Traffic Management Systems (ATMS), provide advanced information to travellers, about traffic conditions or scheduling for a trip. These systems are also used to post travel time and/or expected delays via on-route variable message signs (VMS). Quick processing of real-time data that is fed into VMS has been possible with the progression

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achieved in computational power and the availability of more sophisticated methodologies (Fei et al., 2011; Vlahogianni et al., 2005).

A broad array of methods was used in past research to model real-time traffic data to perform short-term predictions (e.g. 10 min). These methods could be classified as parametric, nonparametric methods or hybrid of both. Parametric methods include autoregressive integrated moving average (ARIMA) based models (Chandra and Al-Deek, 2009; Smith et al., 2002; Vlahogianni et al., 2004; Wang and Papageorgiou, 2007; Williams and Hoel, 2003). On the other hand, nonparametric data driven approaches include a variety of Artificial Neural Network (ANN) models, nearest neighbor nonparametric regression, simulation models, Bayesian models, and Support Vector Regression (SVR) (Fei et al., 2011; Lin et al., 2014a; Smith et al., 2002; Vlahogianni et al., 2005). Hybrid integration models that make use of fuzzy logic and genetic algorithms were also used in past studies (Dimitriou et al., 2008; Ishak and Alecsandru, 2004).

Although there are ample research on short-term forecasting of traffic flow, travel time, and/or speed, most of the existing efforts focused on freeways or urban arterials. In comparison, little has been done to model traffic conditions at border crossings (Huang and Sadek, 2009; Lin et al., 2014a). Typically, cross-border flows are different from those observed on major road arterials. In North America, the increased security and inspection procedures in aftermath of the attacks of 9/11 have emphasized the importance of researching land border facilities and their performance (Anderson, 2012; Anderson et al., 2014). In this paper, we focus on the analysis of border traffic volume and crossing times at the Ambassador Bridge, which connects Windsor, Ontario to Detroit, Michigan. The Ambassador Bridge stands as one of the busiest Canada–US crossings as it handles over 26% of the total Canada–US trade (Anderson, 2012).

ANN models (per traffic direction) were designed, trained, and validated to perform short-term predictions of (1) the volume of trucks crossing the Ambassador Bridge and (2) the time it takes for the trucks to cross the bridge from one side to the other. A multilayer feedforward neural network with backpropagation approach was used to train the ANN models. The training of the first set of models is based on a one month worth of Remote Traffic Microwave Sensors (RTMS) data pertaining to trucks crossing the bridge from Canada to the US and vice versa during the months of May and June in 2015. On the other hand, Global Positioning System (GPS) data from a large sample of Canadian trucks that crossed the bridge during a yearlong period (September 2012–August 2013) were employed to model the crossing times on the bridge. To our knowledge, no previous study utilized the type of detailed data employed in this research to develop short-term predictive models of traffic volumes and crossing times for a land border crossing.

The remainder of this paper is organized as follows: the next section provides an overview of the existing efforts that have been performed to forecast traffic characteristics at border crossings. Section three highlights the importance of the Ambassador Bridge and the size of daily truck traffic it handles. It also describes the datasets used in the performed analysis. Section four presents the ANN approach used in the modeling of the data. It also highlights the evaluation indicators employed to validate the trained networks. Section five reports the results and discusses the performance of the developed ANN models. Finally, the last section provides a conclusion to our study.

2. Forecasting traffic characteristics on border crossings

To our knowledge, there is only one attempt in the past that paid particular attention to forecasting traffic flow on a border crossing. In that study, Lin et al. (2014a) used an innovative approach entitled "Enhanced Spinning Network" to forecast hourly traffic volumes at the Peace Bridge that connects Niagara Falls, Canada and Buffalo, US. The method builds on an original method known as the Spinning Network (SPN) algorithm, which was first proposed by Huang and Sadek (2009). According to the authors, an SPN algorithm attempts to mimic how the human memory works to remember information to come up with an exact answer.

Typically, the process of remembering something specific is based on retrieving fragments of information that would be stored in different layers of memory. These layers could be represented by concentric rings in which rings with larger radii represent distant memory in the mind. At first, an individual spends time spinning through the elements of her fragmented and distant memory to piece out meaningful information by comparing the various fragments. Once meaningful information is pieced together, it is placed in a more recent context (i.e. passed to a smaller ring) and compared to the memory fragments found in that recent layer to piece together further meaningful details. Joined information is then passed to a more recent context and so forth until the individual is able to paint a full picture about what she needs to remember.

The enhanced SPN used in Lin et al. (2014a) extends the original SPN by using the Dynamic Time Warping (DTW) algorithm. It is argued that the DTW is more suitable for time series analysis since it provides the optimal pairing of the elements of two time series sequences. The advantage of the DTW is its ability to perform a comprehensive comparison of all the elements of two time series sequences to pair elements that have a more similar pattern. The performance of the enhanced SPN was compared to the outcome obtained from three other methods which included the original SPN, SARIMA (Seasonal-ARIMA) model, and SVR model. Hourly crossing volumes during 2009 and 2010 on the Peace Bridge were used to compare the predicting accuracy of the four approaches. Hourly volumes were predicted for five distinct periods: Mondays through Thursdays, Fridays, weekends, holidays, and game days. The Mean Absolute Percentage Error (MAPE) was used to compare the results. It was found that the DTW-SPN outperformed all other approaches except for game days where SVR performed slightly better.

A handful of studies have been conducted in the past to predict the delays of land border crossings (Khan, 2010; Lin and Lin, 2001; Lin et al., 2014b; Paselk and Mannering, 1994). Paselk and Mannering (1994) used a hazard duration model to study the determinants of border delays at the US–Canada border crossing between Washington State and the province