Deep Learning-Based Algorithms in Solving Traffic Jam in Smart Transportation

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Abstract: With the increase in the number of private cars, people's travel has become more convenient. However, currently artificial intelligence has not played a particularly significant role in solving traffic congestion. Traffic congestion has lots of disadvantage: it can increase people's commuting time; it can increase travel costs and so on. This article aims at providing an overview of some possible ways in predicting traffic flow, ranging from machine-learning based method to deep learning methods, which give a feasible scheme for the traffic system to moderate the traffic light time and better smooth the traffic flow. In the discussion part, the article analysis that machine-learning based methods still have shortcomings in terms of interpretability and adaptability. In the future, the predicting method will be improved by adapting SHapley Additive exPlanations and domain adaptation. Also, computational speed also needs to be taken into account, with the use of parallel computing. The author proposes a framework that focuses on parallel computing. This article provides a good overview of the field of predicting traffic flow.

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1 INTRODUCTION

With the rapid development of Internet of Things (IOT), transportation facilities in the city are connected to the traffic network, giving rise to the concept of smart transportation. Smart transportation is considered a general term that encompasses route optimization, parking, street lighting, accident prevention and detection, road anomalies, and infrastructure applications (Zantalis, 2019). Some apps e.g. Gaode in the field of transportation, it can help users optimize the route to destination. They can easily obtain the location information of a certain vehicle and predict the time it will take to reach a certain station by installing mobile devices on public transportation. Meanwhile, the increase in the number of cars puts pressure on traffic system. In the urban area, it is often easy to encounter traffic congestion at intersections due to excessive traffic flow or accidents. Traffic jams are detrimental to people's lives in many aspects. It takes more time for people to wait and consumes more gasoline. Thus, how to solve traffic congestion in a better way is what needs to be considered.

Artificial intelligence technology includes data excavation and intelligent algorithms, which means that it can search for useful information through its internal algorithm and can solve certain types of issues. In real situation, collecting information on vehicles can be regarded as data excavation, while getting a solution for traffic jams is what the artificial algorithm can do. Therefore, artificial intelligence can be well integrated with intelligent transportation, especially, the prediction of traffic flow.

In the aspect of predicting the traffic flow through artificial intelligence, many researchers have carried out some relative works. In early research, researchers employed mathematical statistics or traditional machine learning method to build traffic flow prediction model. For example, Wang upgraded the Cellular Automata model suitable for describing the spread of traffic congestion by taking certain set called "Squeezing to change lanes" into consideration (Wang, 2010). Castro et al. utilized the advantages of online learning methods to predict traffic flow under different conditions, and thus proposed a supervised statistical learning technique called Online Regression Support Vector Machine (Castro-Neto, 2009). However, the conventional machine learning

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method has various disadvantages. Traditional machine learning method requires people to establish eigenvalues and has a significant workload in identifying feature values. Moreover, it is impossible to exhaustively list all the characteristics. With the appearance of neural network, deep learning can find out the rules without establishing eigenvalues for them. Thus, researchers tried using deep learning to tackle the prediction issue. Liang et al. improved the accuracy of predicting urban traffic flow through deep learning, specifically the Spatio-Temporal Relation Network (STRN), which consists of Convolutional Neural Network (CNN) (Liang, 2021). Mao et al. established a platform based on Spark and Hadoop to achieve real-time monitoring of urban traffic flow. This platform also has some other functions, such as the ability to analyze specific types (Mao, 2022). Due to the rapid development of this field and its importance, it is necessary to make a comprehensive overview of this direction.

The rest of the paper is constructed as follows. In Section 2, The article will provide a thorough explanation of the procedures used by others in their workflow, such as traditional machine learning method and Artificial Neural Network (ANN). In section 3, the author will discuss shortcomings of current researches and future development directions. Finally, section 4 sums up the paper.

2 METHOD

2.1 Framework of Machine Learning-Based Methods in Predicting Traffic Flow

Machine learning process for traffic flow prediction shown in Figure 1 can be loosely broken down into six steps. The first step is data collection, which obtains various kind of information e.g. weather, historical traffic flow, time, holidays, events. Then, in the data preprocessing progress, data will experience steps like cleaning, normalization for the reason that different data are of different importance for predicting traffic flow forecasts, and there might be some abnormal values. This step aims at enhancing the quality of data. In the next step, a model that can predict the traffic flow is constructed, consisting of suitable algorithms. Algorithms such as Random Forest, K-NN are prevailing in traditional machine learning. In the fourth step, when the model is trained, whose parameters is dynamically moderating in order to get a more precise prediction value of the traffic flow. In the fifth step, when the model is well trained, it will be accessed by some index like some metrics to figure out whether the model's parameter or algorithm need changing or not. Finally, the model can be deployed and help police visualize where traffic jam will take place. The section left describes the details of model building and training.

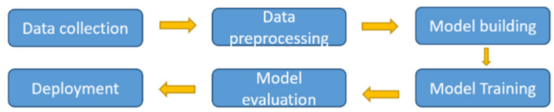

Figure 1: The workflow of machine learning-based methods in predicting traffic flow (Photo/ Picture credit: Original).

2.2 Machine Learning Algorithms

2.2.1 Random Forest-Based Prediction

When it comes to model building and training progress, Chen et al. proposed Random Forest Prediction model shown in Figure 2 for traffic flow prediction (Chen, 2018). Random Forest is a combined algorithm that uses multiple tree learners for classification and regression prediction. The sample to be classified is denoted as Xt=Xt1, Xt2, Xt3, where Xt1, Xt2, and Xt3 are mapped to the predicted traffic flow, velocity, and occupancy of target section in the upcoming period. Icons of different shapes and colors represent distinct traffic situations (Chen, 2018). When a sample to be classified is given, each decision tree calculates the percentage of different classes in the training sample at the leaf node where the sample falls to determine the classification result of the sample (Zhou, 2019). Finally, the classification results from all the decision trees are collected and voted. The one which has the highest number of votes is the prediction of the traffic state.

Figure 2: The framework of Random Forest Prediction Model for traffic flow prediction (Photo/Picture credit: Original).

2.2.2 K-Nearest Neighbour Classification (K-NN)

K-NN shown in Figure 3 is another algorithm that can be applied to build the model. K-NN requires 5 elements: Complete historical datasets, state vector, distant standard, K nearest neighbour matching and prediction algorithm (Cover, 1967). The first step is to construct a historical database from data that has been preprocessed. The historical database needs to be large enough and has representative data. The second step is to define the state vector. Next, select a distance metric criterion. Then, search for K neighbours of the current vector and put it into prediction algorithm to get a prediction result. The prediction algorithm can be divided into 2 parts: arithmetic mean prediction algorithm and weighted prediction algorithm (Lin, 2015).

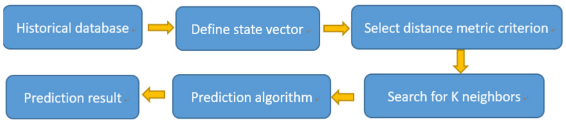

Figure 3: The framework of K-NN for traffic flow prediction (Photo/Picture credit: Original).

2.3 Deep Learning Methods

What the framework of deep learning methods look like is quite similar to that of the machine learning methods. However, since deep learning can extract abstract features and learn automatically in the model building progress, it is better than classical machine learning.

2.3.1 Convolutional Neural Network

CNN is characterized by its deep feedforward neural network that utilizes convolutional computation and deep structure (Qiu, 2022). Ma et al. migrate the application of CNN to the field of traffic forecasting shown in Figure 4. In the data preprocessing process, the traffic flow is transformed into graph. There are 2 main steps in the model building process. Firstly, images that have spatiotemporal characteristics and are produced by traffic network are the main resource of the model input (Ma, 2017). Secondly, both the convolutional layer and pooling layers, which are two of the most crucial components of the CNN model, extract features from the input and integrate with each other at the same time (Ma, 2017). Finally, through a fully connected layer, vectors representing features are transformed into model outputs (Ma, 2017).

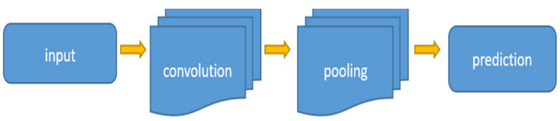

Figure 4: The framework of CNN for traffic flow prediction (Photo/Picture credit: Original).

2.3.2 Spatio-Temporal Relation Network (STRN)

STRN shown in Figure 5 is another model that can predict traffic flow precisely (Liang, 2021). This model collects traffic flow at different times and selects key time steps. Then, it preprocesses the data by dividing the data into three categories: closeness, period and trend. These three categories are processed in a convolutional layer. Also, external factors like weather, POI&RN are preprocessed through Meta Learner. Then, all of the preprocessed data are sent to the backbone network and the GloNet for model learning.

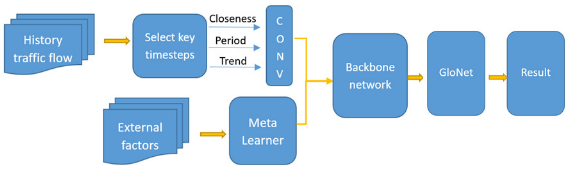

Figure 5: The framework of STRN for traffic flow prediction (Photo/Picture credit: Original).

3 DISCUSSIONS

Although significant progress has been achieved in this field, the deep learning-based model has some drawbacks. The interpretability of deep learning is relatively poor. It can provide people a prediction result, but it is challenging for people to understand why it gets such a result. Especially when error occurs in prediction, people have no way to find out the reason. Also, the applicability needs to be further improved. In previous researches, the prediction models are used in certain roads or areas. If the circumstance changes, for example, the prediction model needs to be applied in a more complicated situation, it may cause error. Furthermore, although currently there have been many traffic flow prediction models, their computing speed is very important since it need to predict the real-time traffic flow.

There are some ways that can be considered to tackle the issues above in the future. Firstly, the SHapley Additive exPlanations (SHAP) can compensate for the shortcomings of poor interpretability because it can quantify the contribution of each factor to the prediction results and help understand the decision process of the model. The Domain Adaptation can tackle the applicability issue through feature-based and instance-based approach. Finally, it is possible to take parallel computing into consideration to solve the computing speed problem.

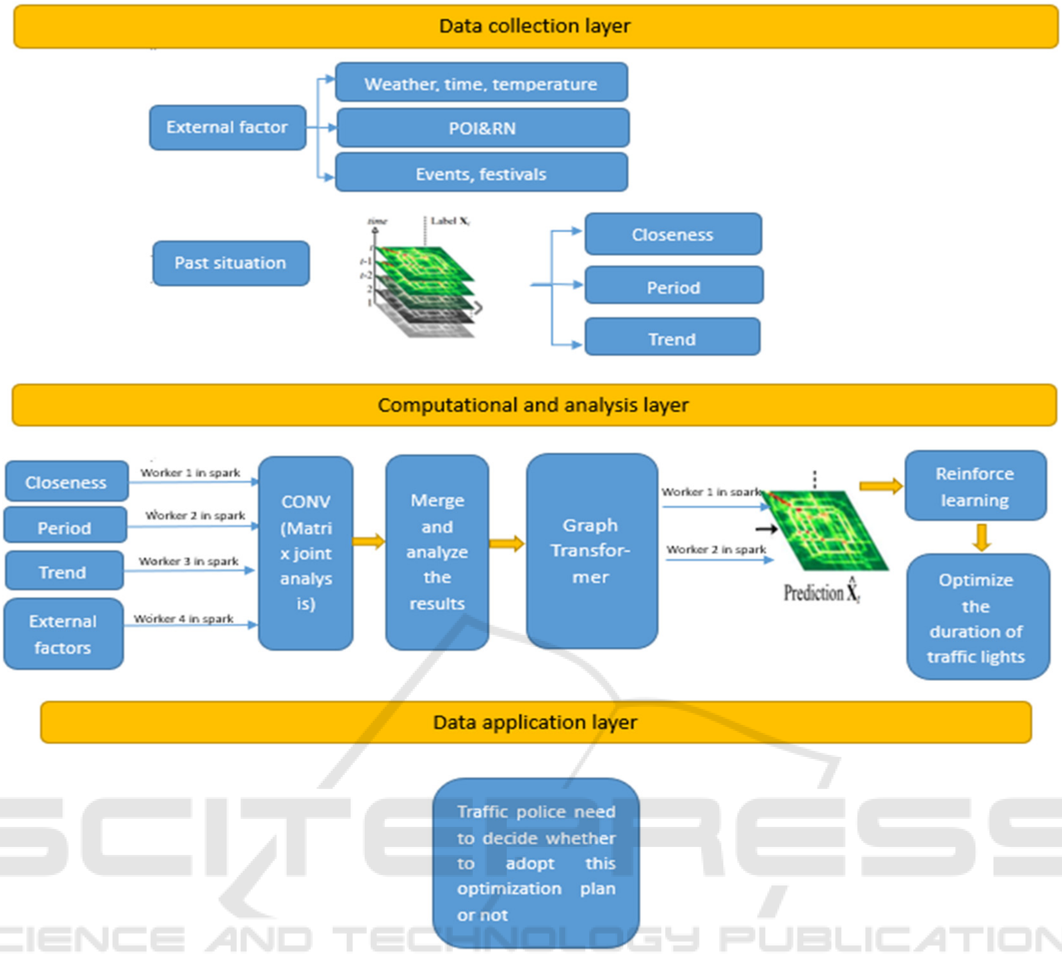

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Figure 6: The potential framework in the future (Photo/Picture credit: Original).

A possible framework shown in Figure 6 is proposed in this study. The model can be splited into three layers. The first layer is data collection layer, then comes the computational and analysis layer and the last layer is the application layer. In the first layer, it is required to collect external factors and past situation and preprocess them. Then, in the computational and analysis layer, since external factors, closeness, period, and trend can be considered independent of each other, parallel computing is feasible for them. These four factors are placed on the four computing nodes of Spark for parallel computation and processed through convolutional layers. However, there are many redundant and irrelevant information in the obtained four processing results. Therefore, matrix joint analysis can be applied to capture key features and extract effective information for these four results. Input the results into Graph Transformer for parallel computing, while in the previous research it will be processed and analyzed by Backbone Network and Glonet, but this method is difficult to parallelize. Next, by using reinforcement learning models with the goal of minimizing congestion, the optimized future traffic light duration is obtained. The last layer is the application layer, it depends on whether the transportation department adopts this optimization plan.

4 CONCLUSIONS

In this work, the article provided a review of machine learning in traffic flow prediction. It summarizes some traditional machine-based methods and deep learning methods in predicting traffic flow. The methods of this research include Random Forest, K-NN, CNN and STRN. Through the discussion and analysis, currently the machine-learning method still has some disadvantages such as interpretability, applicability and computing speed. This article has some drawbacks because some classic models are out of consideration. In the future, further study plans to carry out a more comprehensive job and incorporate more algorithms related to traffic flow prediction into the system.

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