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An Express Management System With Graph Recurrent Neural Network for Estimated Time of Arrival

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ABSTRACT

Estimated Time of Arrival (ETA) is a crucial task in the logistics and transportation industry, aiding businesses and individuals in optimizing time management and improving operational efficiency. This study proposes a novel Graph Recurrent Neural Network (GRNN) model that integrates external factor data. The model first employs a Multilayer Perceptron (MLP)-based external factor data embedding layer to categorize and combine influencing factors into a vector representation. A Graph Recurrent Neural Network, combining Long Short-Term Memory (LSTM) and GNN models, is then used to predict ETA based on historical data. The model undergoes both offline and online evaluation experiments. Specifically, the offline experiments demonstrate a 5.3% reduction in RMSE on the BikeNYC dataset and a 6.1% reduction on the DidiShenzhen dataset, compared to baseline models. Online evaluation using Baidu Maps data further validates the model's effectiveness in real-time scenarios. These results underscore the model's potential in improving ETA predictions for urban traffic systems.

KEYWORDS

Estimated Time of Arrival, GRNN, LSTM, GNN, Baidu Maps, Online Evaluation, Offline Evaluation

INTRODUCTION

Estimated time of arrival (ETA) is an important task in the logistics and transportation industry (El Makhloufi, 202; López & Lozano, 2022; Tsolaki et al., 2022). It can help businesses and individuals better plan and manage their time, thereby improving efficiency and accuracy. For example, logistics companies can use ETA to predict the arrival time of goods to better schedule transportation and distribution. In the transportation sector, ETA can help people better plan their trips to avoid congestion and delays. As the logistics (Liu et al., 2023) and transportation (Li et al., 2021) industries grow and globalization rapidly and increase in size and complexity, the accuracy of ETAs subsequently becomes more and more important (Zhang et al., 2025). Overall, the accuracy of ETA forecasting

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tasks becomes very important for both organizations and individuals. It helps them to plan and manage their time better, thus increasing efficiency and accuracy.

Recent studies have shown that graph neural network (GNN) models have higher performance in modeling road traffic and other aspects (Jiang & Luo, 2022). It has been found that the reason why GNN models perform well in ETA tasks is that they can model traffic conditions by learning the connectivity structure of the road network (Jin et al., 2023). In 2021, the DeepMind team collaborated with Google Maps to successfully improve the real-time ETA accuracy of Google Maps in major cities such as Berlin, Tokyo, and Sydney by up to 50% using GNNs (Derrow-Pinion et al., 2021). To achieve this goal globally, DeepMind used GNNs to perform spatiotemporal reasoning by adding relationship learning biases to the model, thereby modeling the connectivity of the real-world road network (Huang et al., 2025). After the roads are sliced into multiple road networks, the road network is divided into several super sections, which refer to several adjacent sections affected by each other's traffic flow. Then, the local road network are viewed as a graph, where each road segment corresponds to a node, and the edges connecting two road segments (nodes) are either on the same road or connected through an intersection. These mechanisms enable GNNs to utilize the connectivity structure of the road network more efficiently.

Currently, there is a continuous emergence of GNN predictive models in the fields of transportation and logistics. The following are five commonly used GNN predictive models:

- Spatio-Temporal Graph Convolutional Network (ST-GCN; Yu et al., 2017): ST-GCN is based on the concept of GNN and integrates spatiotemporal information. By performing convolution operations on spatiotemporal graphs, it effectively captures the spatiotemporal dependencies in transportation or logistics systems. ST-GCN excels in traffic flow prediction, accurately capturing the complex spatiotemporal dynamics in urban transportation networks, thereby enhancing predictive performance in transportation systems.
- Adaptive Spatial-Temporal Graph Convolutional Network (ASTGCN; Chen et al., 2023): ASTGCN introduces an adaptive mechanism, adjusting to different spatiotemporal dependencies by considering dynamic weights of neighboring nodes. This adaptability allows the model to flexibly accommodate complex transportation or logistics systems. ASTGCN performs exceptionally well in handling irregular and dynamic traffic networks, enhancing its modeling capabilities for complex urban traffic patterns.
- Trajectory Graph Neural Network (TrajGNN; Cao et al., 2021): TrajGNN focuses on modeling trajectory data, representing trajectory data as nodes in a graph and leveraging GNN to learn relationships between trajectories. This approach aids in considering interactions between individual trajectories during the prediction process. TrajGNN excels in modeling complex interactions between individual trajectories and is applicable to predicting trajectories of pedestrians or vehicles.
- Diffusion Convolutional Recurrent Neural Network (DCRNN; Li et al., 2017): DCRNN combines convolution and recurrent neural networks, modeling traffic networks as diffusion processes in spatial dimensions to learn traffic flow relationships between nodes. DCRNN excels in capturing long-term spatiotemporal dependencies in traffic networks and is suitable for accurate long-term predictions of traffic flows.
- Graph WaveNet (Wu et al., 2019): Graph WaveNet is based on the WaveNet model and introduces graph convolution operations to adapt to graph structures. It captures spatiotemporal dependencies between nodes through layer-wise convolution operations. Graph WaveNet is suitable for capturing dynamically changing graph structures, exhibiting strong generalization capabilities for complex spatiotemporal predictions in transportation and logistics systems.

To further enhance the accuracy of ETA tasks, this study proposes a novel graph recurrent neural network (GRNN) model (Qiao et al., 2020) integrating external factor data. The model initially

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