Technologies for Safe & Efficient Transportation

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Data-driven Network Models for Analyzing Multi-modal Transportation Systems

Final Research Report

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Problem Statement

In this project, a data-driven network model for analyzing multi-modal transportation systems on large-scale networks is proposed. This model is applicable to large-scale regional networks with private car travels and freight truck travels. We firstly proposed a solution method for dynamic traffic demand estimation for cars and trucks using real-world traffic measurements data including traffic volume count and traffic flow speed. Then an evaluation framework for multi-modal traffic systems with cars and trucks is developed based on large-scale multi-modal traffic simulation. With carefully calibrated traffic demand, our multi-modal traffic simulation can accurately simulate the dynamic network conditions. Various kinds of traffic impact events, traffic planning, traffic management and traffic operation strategies can then be evaluated and tested in the simulation framework to help with decision making in the multi-modal transportation systems.

Recent years have witnessed a great change in the urban transportation system. Transportation networks have become unprecedentedly complicated and inter-connected with the involvement of not only standard personal vehicles but also trucks, and automated and connected vehicles. In real traffic flow, cars and trucks have different attributes including free-flow speed, capacities, critical and jam densities, and thus asymmetric effects on each other while propagating in the networks. Recent years have also witnessed tremendous traffic data by cars and trucks. How to make best use of those data for multi-class network models is unclear. Also, how to effectively manage the transportation system and improve the network efficiency under the multi-modal setting presents a big challenge to public agencies.

As an indispensable component of dynamic transportation network models, the dynamic traffic demand plays a key role in transportation planning and management. It reveals the overall network-level congestion in a region. Policymakers can understand the departure patterns and daily routines of multi-class vehicles through the day-to-day traffic demand. the dynamic traffic demand of cars and trucks also helps the policymakers understand the impact of each vehicle class to the roads, and hence the management and regulation policy for a specific vehicle class can be studied. To our best knowledge, studies to understand and estimate the dynamic traffic demand of multiple vehicle classes including cars and trucks are lacking. In view of this, this study presents a data-driven solution method for dynamic traffic demand estimation with multi-class vehicles on large scale networks. The demand estimation for cars and trucks is then served as one input of our simulation-evaluation framework for multi-modal traffic systems, where different traffic impact events, traffic planning, traffic management and traffic operation strategies can be conveniently and thoroughly tested.

Approach

Step 1. A data-driven method for multi-modal dynamic traffic demand estimation. We firstly proposed a solution framework for dynamic traffic demand estimation for cars and trucks using real-world traffic measurements data. The proposed framework formulates the multi-modal dynamic traffic demand estimation problem and codes it into a computational graph (see Figure 1) with the real-world traffic measurement data as the input data layer. Then the problem is efficiently solved with a novel forward-backward algorithm on the computational graph. The computational graph can be evaluated on multi-core CPUs or Graphics Processing Units (GPUs), and hence the proposed multi-modal dynamic traffic demand estimation method is computational efficient and can be applied to large-scale networks.

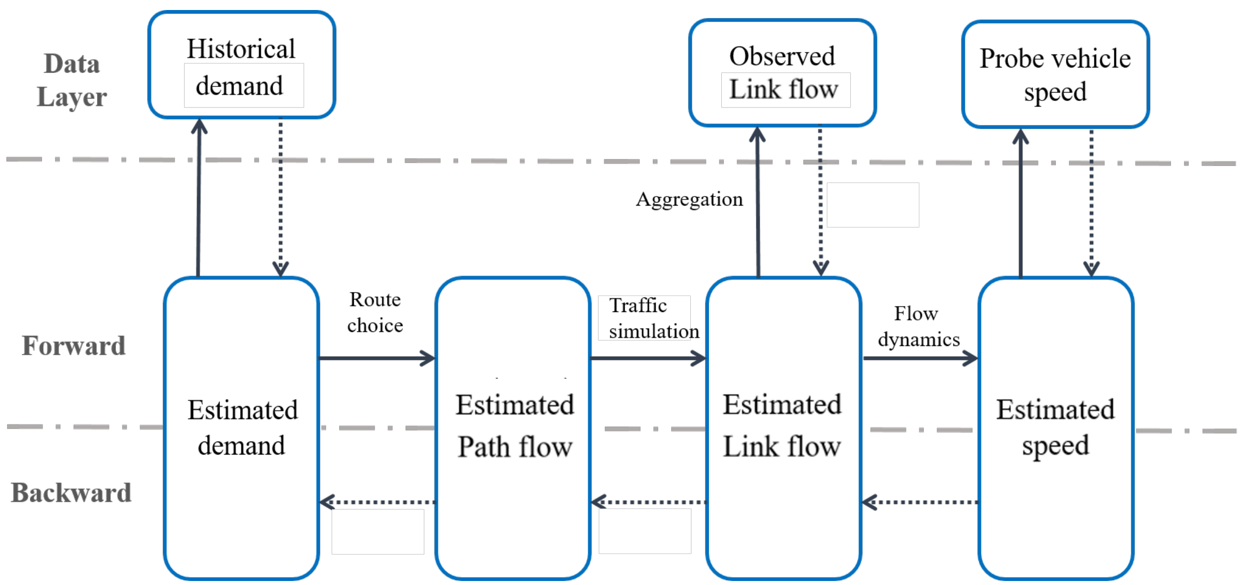

Figure 1. The computational graph of our data-driven framework of multi-modal dynamic traffic demand estimation.

The real-world traffic measurement data used in this study include traffic volume count data and traffic flow speed data. The historical traffic volume count measurements are provided by the Pennsylvania Department of Transportation (PennDOT). The data are collected annually for some selected locations on the Pennsylvania state routes, for each hour of the day and for one day of the year. The car traffic volume counts and truck traffic volume counts are collected separately. The traffic speed data (probe vehicle speed data) is from FHWA covering most highways and major roads in the US, also with car speed and truck speed measured separately. A direct visualization of samples of traffic volume data and traffic speed data used in this study is presented in Figure 2.

Traffic volume count **Traffic speed**

Figure 2. Visualizations of traffic volume data and traffic speed data used in this study.

Step 2. A simulation and evaluation framework for traffic impact analysis. The demand estimation for cars and trucks is then served as one of the inputs of our simulation-evaluation framework for multi-modal traffic systems, where different traffic impact events, traffic planning, traffic management and traffic operation strategies can be conveniently tested. The whole simulation-evaluation process is shown in Figure 3 below.

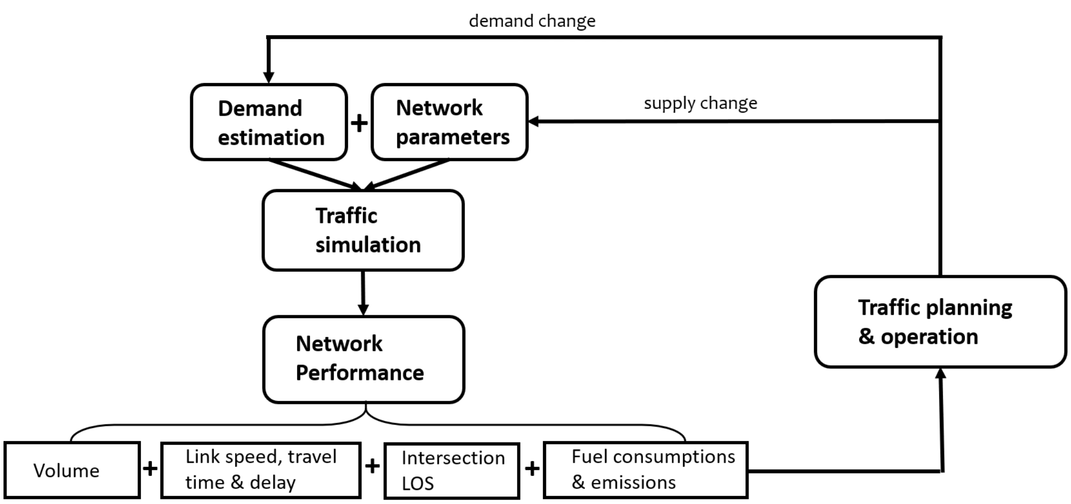

Figure 3. The simulation-evaluation framework developed in this study.

Findings

The proposed framework is examined on a real-world network in the southwestern Pennsylvania. It is a large-scale network for the Pittsburgh metropolitan area (see Figure 4). The network covers the ten counties of southwestern Pennsylvania region, with the Pittsburgh city in the center. In the network, there are around 2.57 million people and 7,112 square miles area.

The network itself consists of 16,100 road links, 6,297 intersections and 80,089 origin-destination pairs.

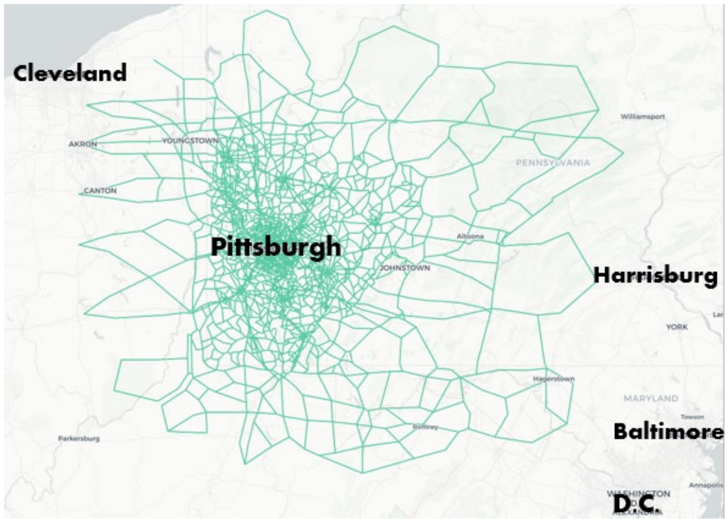

Figure 4. The southwestern Pennsylvania transportation network used in experiments.

1. Results of multi-modal dynamic traffic demand estimation. After demand estimation, the traffic demand is used to run the traffic simulation. The comparisons between the observed and simulated traffic flow volume are presented in Figure 5. The R-squares between the observed and simulated traffic volume are 0.52 and 0.50 for cars and trucks, respectively. This shows a good match between the true network conditions and simulated conditions, as well as a good performance of our traffic demand estimation method.

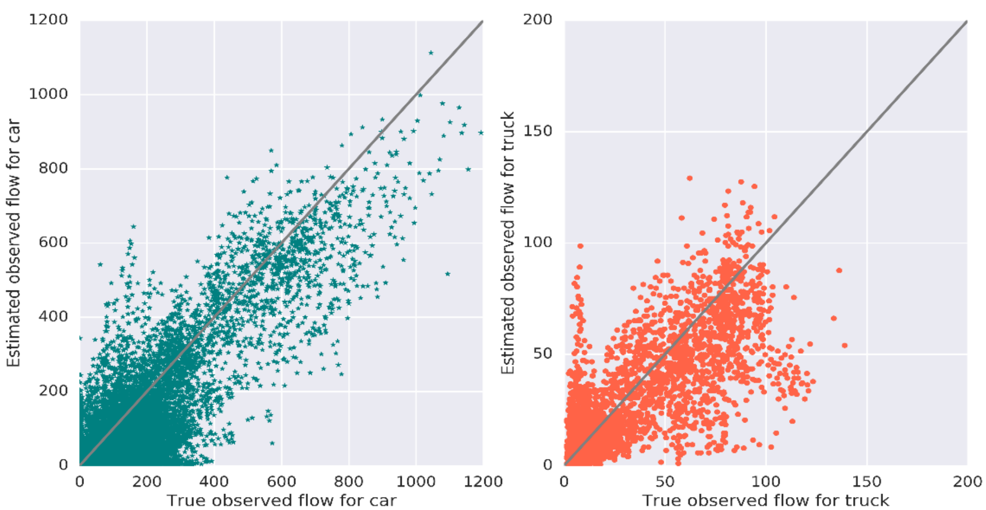

Figure 5. The comparison between observed traffic volume and simulated traffic volume. (Left: result for cars. Right: result for trucks.)

2. Results of simulation-based traffic impact analysis and policy evaluation. The simulation-based evaluation framework and its real-world applications is shown in Figure 6. After demand estimation, we can run simulation with different traffic impact events and traffic planning and operation strategies, for example road closures, incidents, development projects, etc. The simulation will provide us the change of various traffic network conditions including traffic volume, travel time/speed, travel delays, emissions and energy consumptions, pavement deterioration. Etc. All these metrics can provide decision making support for users including legislators, transportation planners, engineers, researchers, travelers and private companies, in order to improve the overall multi-modal transportation system efficiency.

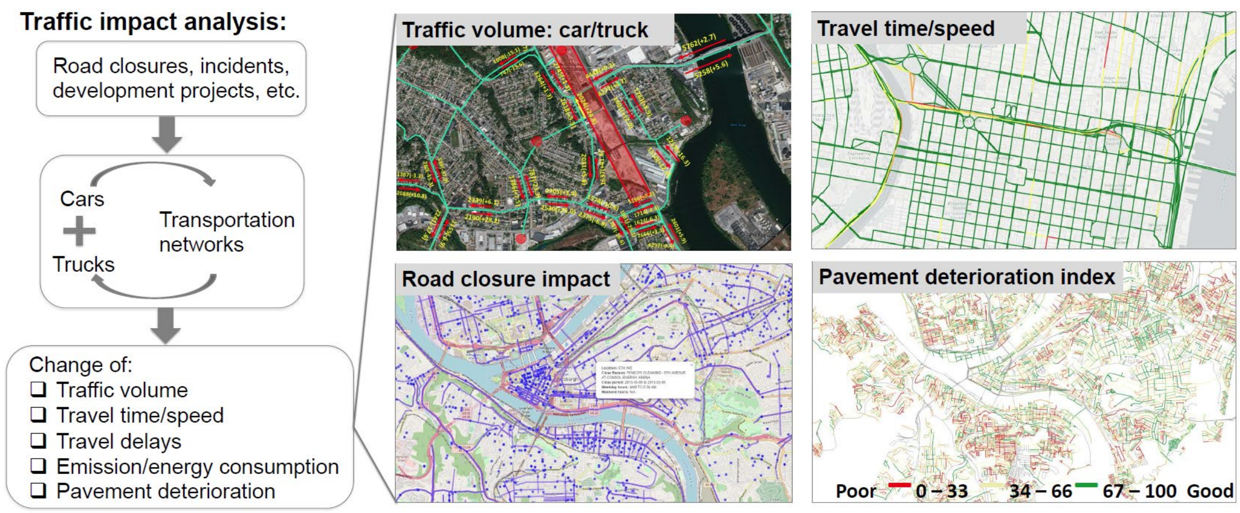

Figure 6. The simulation-based evaluation framework and its real-world applications.

Conclusion

Transportation networks have become unprecedentedly complicated and inter-connected with the involvement of not only standard personal vehicles but also trucks, and automated and connected vehicles. Recent years have also witnessed tremendous traffic data collected by traditional or emerging data acquisition methods. How to make best use of those data for multi-class network models and how to effectively manage the transportation system and improve the network efficiency under the multi-modal setting presents a big challenge to public agencies. In this project, we proposed a data-driven network model for analyzing multi-modal transportation systems on large-scale networks. This model is applicable to large-scale regional networks with private car travels and freight truck travels. We firstly proposed a solution method for dynamic traffic demand estimation for cars and trucks using real-world traffic measurements data including traffic volume count and traffic flow speed. Then an evaluation framework for multi-modal traffic systems with cars and trucks is developed based on large-scale multi-modal traffic simulation. With carefully calibrated traffic demand, our multi-modal traffic simulation can accurately simulate the dynamic network conditions. Various kinds of traffic impact events, traffic planning, traffic management and traffic operation strategies can then be evaluated and tested in the simulation framework to help with decision making in the multi-modal transportation systems. Experiment on a large-scale multi-modal transportation network in southwestern Pennsylvania shows our traffic demand estimation method has good performance and our simulation-evaluation framework is useful in traffic impact analysis and traffic management decision making process.