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Project Title

Knowledge-Based Machine Learning for Freeway COVID-19 Traffic Impact Analysis and Traffic Incident Management

University

North Dakota State University
University of Utah

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Research Needs

Since the early March of 2020, the COVID-19 pandemic has placed significant impacts to the traffic across the U.S. due to the quarantine rules of many states and the "work-from-home" style of many residents. Weekday VMT traffic pattern changed from typical two-peak pattern (morning peak followed by a drop and then afternoon peak) to a gradually increasing to one afternoon peak [1]. One of the reasons for the changes is that home-based work reduces the early morning travel needs and provides people the new flexibility for mid-day in-person errands. Beside the commute traffic pattern changes, some researcher also observed the sharp increase in on-demand delivery and e-commerce [2]. Hence, at the early stage of the pandemic, a great reduction in traffic demands has been observed on transportation networks. Later on, with the process of re-opening local businesses, schools, etc., and the decrease in daily COVID confirmed cases, traffic demands have been gradually increased over time especially with express delivery truck traffic and have even been recovered to the same level as before COVID pandemic in some states currently [3]. It is clear to see that traffic pattern, traffic demands, and duration alter with COVID status. Therefore, there is a critical research need of studying the impact of COVID on traffic patterns and analyzing the relationship among traffic demand patterns, daily confirmed cases/deaths, state policies, public perceptions, etc. Such research results will be valuable to

responsive agencies such as state DOTs to better understand the long-term impacts of COVID on transportation and get prepared for near-future traffic demand patterns (e.g., during the late stage of the pandemic or the post-pandemic period).

Besides the study of COVID's impact on mobility, the investigation of its impacts on traffic safety is also worthy of investigation. This research will first examine the change of traffic crash frequency and severity truck-related and non-truck related crashes after the start of the pandemic. Then, an effective model, based on the principle of newly invented knowledge-based machine learning, will be developed to predict the traffic impact of traffic incidents and advance traffic incident management (TIM). In practice, TIM systems include coordinated efforts among multi-disciplinary teams to detect, respond to, and clear traffic incidents and restore traffic flows as soon as possible. A typical TIM system may involve several steps [4]: (1) an incident is detected by various sources such as patrol units, police, drivers' report, CCTV, etc., and is reported to the management center; (2) an incident response unit is immediately dispatched to the incident sites and related data are collected to predict the incident duration; (3) a model is implemented to predict the incident impact to traffic and the additional delay due to the non-recurrent congestion, according to the predicted incident duration; (4) based on the traffic impact assessment, the decision on whether a detour/diverting operation is necessary is made; and (5) up-to-date traffic information and the detour plan are provided to the drivers. Hence, it can be noted that the second and third steps would require research efforts in model development. Considering the incident duration prediction (the second step) has been widely discussed in the literature, this research will particularly focus on the model development for incident traffic impact prediction (the third step).

Research Objectives

Recognizing the aforementioned research needs, this research selects the freeway networks in Salt Lake City, Utah for case study including data collection and model development. Specifically, the following objectives are expected to be achieved with the completion of this research project:

1. Conduct statistical analysis to understand the impact of COVID-19 pandemic on transportation mobility patterns;
2. Develop prediction models to forecast the traffic demand patterns in the near future (e.g., during the late stage of pandemic or post-pandemic periods);
3. Leverage the newly invented knowledge-based machine learning to predict the impacts of traffic incidents on traffic efficiency;
4. Advance TIM systems and help make decisions on whether a detour/divert operation is necessary after the occurrence of traffic incidents.

To ensure the success of this research project, this collaborative research will be carried out by researchers at both North Dakota State University (NDSU) and University of Utah (UU), where the team has extensive research experiences in transportation data analytics, machine learning, traffic operation, and traffic safety.

Research Methods

The proposed research includes several key steps, such as literature review, data collection, model development, TIM system design, and performance evaluation. Therefore, appropriate research methods are essential to support the work in the model development.

This research will produce two core models. The first model aims to quantify the correlations between freeway traffic demand patterns by type and other social factors related to COVID-19 for predicting the near-future demand patterns. The model will be formulated with an innovative data-driven approach that integrates machine learning with graph theory [5]. More specifically, the graph theory will specify the spatial and temporal correlations among traffic volumes at different locations of the freeway network and during different times of the year. Machine learning (e.g., random forest and XGBoost) will model the impact of other social factors, such as COVID-19 daily cases, etc., on the traffic volumes.

The second model is expected to be capable of capturing the change in traffic patterns during nonrecurrent congestions caused by traffic incidents. Despite a large body of studies in the literature utilized machine learning to model the fluctuations of traffic flow, their model performances highly rely on the quantity and quality of training data. Hence, those existing methods may not apply to this research due to limited traffic data are available for nonrecurrent congestion scenarios. To fill this research gap, this research will leverage the newly invented knowledge-based machine learning concept [6] to fuse classical traffic flow models with machine learning. Compared with traditional pure machine learning, such knowledge-based methods can be superior in dealing with those nonrecurrent events. More specifically, a set of models grounded on the physics guided deep neural network and physics regularized Gaussian process will be developed for this research.

Expected Outcomes

At the end of this project, the proposed research is expected to provide a better understanding of the COVID-19's impact on transportation and help agencies such as state DOTs make more efficient decisions for TIM. The following outcomes will be produced by this research:

1. Literature review of COVID impact on transportation in other states;
2. Document to illustrate the correlations between COVID related social factors and transportation mobility/safety performances;
3. Graph theory empowered machine learning model for predicting freeway mobility patterns in the near-future;
4. Knowledge-based machine learning framework to integrate the classical traffic flow model into machine learning technique;
5. Advanced TIM systems that is capable of predicting the traffic incident impact to traffic on the freeway networks; and
6. Final project report, journal publications, and conference presentations which summarize all findings.

Relevance to Strategic Goals

Safety – Improve public health and safety by reducing transportation-related fatalities and injuries.

This research focuses on the study of COVID-19 impacts on freeway traffic safety and the advancement of TIM systems. Salty Lake City, Utah will be selected as the study site, a set of safety models will be developed to predict freeway safety performances under various conditions. This research will assist in improving public safety and reducing transportation-related fatalities and injuries.

Livable Communities – Foster livable communities by integrating transportation policies, plans, and investments with coordinated housing and economic development policies to increase transportation choices and access to transportation services for all.

With a better understanding of COVID-19 impacts on transportation mobility, the outcomes of this research can potentially support the long-term urban planning strategic goals during the post-pandemic periods. The resulted data can also be used to facilitate economic related studies.

Educational Benefits

This project will directly fund one Ph.D. students from Department of Civil and Environmental Engineering at University of Utah. Females and students from underrepresented groups will also be encouraged to participate in the project. The student will be responsible for conducting the research activities under the supervision of the PIs. He or she will also lead the writing of peer-reviewed journal and conference articles resulting from this project. The research outcomes will directly support his/her dissertation work as well. In addition, we will foster the integration of research and teaching in transportation engineering. Students enrolled in the following courses will directly benefit from this research: Transportation Engineering (CVEEN 3520), Optimization in Transportation (CVEEN 5920/6920), Smart City & Infrastructure (CVEEN 5920), Highway Planning and Logistics (TL 882).

Technology Transfer

This research will deliver several machine learning-based models to provide state DOTs, such as NDDOT and UDOT, a better understanding of the impact of COVID-19 on both transportation mobility and safety. The research results will also help them get prepared to the further transportation demands at the late stage of pandemic and in post-pandemic periods. Moreover, the capability of the proposed model in predicting traffic impact caused by freeway traffic incidents can greatly advance the current TIM systems by providing better detour/divert operations. PIs at both NDSU and UU have been working closely with the traffic safety division/office of NDDOT and UDOT through previous project efforts. The research results will be delivered to them. Also, a safety-related UDOT project is used as the cost share of this research, the Co-PI Yang will bring the Technical Advisory Committee (TAC) of that UDOT project to provide feedbacks to this research.

Potential audiences of this research would include traffic engineers, traffic safety agencies, transportation asset managers, transportation planners, and policy decision-makers. The following agencies, offices, and committees are those most likely to implement the research results:

- North Dakota Department of Transportation
- Utah Department of Transportation
- FHWA Office of Safety and Office of Planning
- TRB Standing Committee on Disaster Response and Emergency Evacuation, Safety Data, Analysis and Evaluation, Highway Safety Performance, Traffic Monitoring, Artificial Intelligence, etc.

The research outcomes will also be published on peer-reviewed journals and conferences such as traffic injury prevention, accident analysis and prevention, transportation research part C, ASCE Journal of transportation engineering, and Transportation Research Board Annual Meeting.

Work Plan

The proposed research work will take from June 1, 2021 to December 31, 2022 (1 year and 7 months) to complete. Research tasks are listed as follows:

Task 1: Literature review: this research will review existing studies that study the COVID impacts to transportation mobility and safety and examine the capability of knowledge-based machine learning models including both physics guided/informed neural network and physics regularized Gaussian process.

Task 2: Data collection: the research team will collect traffic volumes, traffic safety records, social-economic information, COVID related data, etc., in both North Dakota and Utah.

Task 3: Data Analysis: the research team will conduct correlation analysis to understand how COVID-19 impacts the transportation mobility and safety in both North Dakota and Utah.

Task 4: Traffic demand prediction: the research team will integrate graph theory and machine learning to predict the future traffic volumes on the freeway network selected in Utah.

Task 5: Knowledge-based machine learning development: this research will leverage both physics guided/informed neural network and physics regularized Gaussian process to model the freeway traffic states during nonrecurrent congestions.

Task 6: TIM advancement: the model from Task 5 will be utilized to study the traffic incident impact and help make better TIM decisions in detour/divert operations.

Task 7: Reporting: the research team will prepare the final project reports.

Project Cost

Total Project Costs:	$337,686.41
MPC Funds Requested:	$168,843.00
Matching Funds:	$168,843.41
Source of Matching Funds:	North Dakota State University; $66,275.41 University of Utah; $52,568.00 Utah Department of Transportation; $50,000.00

References

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[3] Glaeser, Edward L., Caitlin S. Gorback, and Stephen J. Redding. How much does COVID-19 increase with mobility? Evidence from New York and four other US cities. No. w27519. National Bureau of Economic Research, 2020.

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