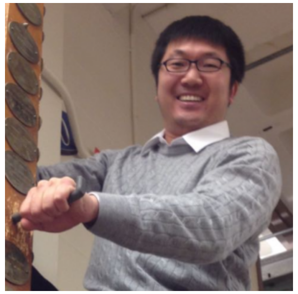
Predictive Real-time Traffic Management in Large-Scale Networks Using Model-based AI


Weiran Yao


Zemian Ke


Bin Gui


Wei Ma


Sean Qian

Smart Mobility Decisions with ML/AI

Smart Mobility Decisions with ML/AI

Transportation systems are often characterized by complex multiscale multiphysics between heterogeneous travelers and network flow dynamics. Massive non-recurrent data collected over the years is likely noisy, biased, spatially and temporally sparse, siloed by its own sensing system, and not well exploited yet. Predicting those non-recurrent and out-of-distribution traffic impacts to inform decisions with a sufficient lead time is notoriously difficult. Mobility Data Analytics Center aims to integrate the **predictive power**, **interpretability** and **domain knowledge** of **physics-based network flow models** with **machine learning** to: (1) reveal the behavior information for both passenger transportation and freight transportation; (2) serve as a key instrument for managing transportation systems, and (3) target a range of users including legislators, transportation planners, travelers and private companies.

- **ML+Traffic Simulation** is the optimal choice for informing smart mobility decisions

Project 1: Real-Time Predictive Traffic Management

Challenges of Incident-Induced Congestion Management

- Late response time
  - Lack of real-time and advance awareness of road conditions. Traffic operators often react after receiving complaints.
  - Overhead from verification of incidents and determination of signal plans.
- Excessive workload
  - Traffic operators need to gather and analyze incident information from multiple directives (cameras and travel information platforms)
- What decisions to make?
  - We know there is an incident, so what? What to do? Turn predictive data to decisions.

Our Solution: We build a **predictive incident plan recommendation system** which notifies the optimal signal timing plans in real time under incidents **30 minutes ahead**

Method

We decompose the recommendation task into two subtask models in hierarchy -- **traffic predictor** and **signal plan associator**.

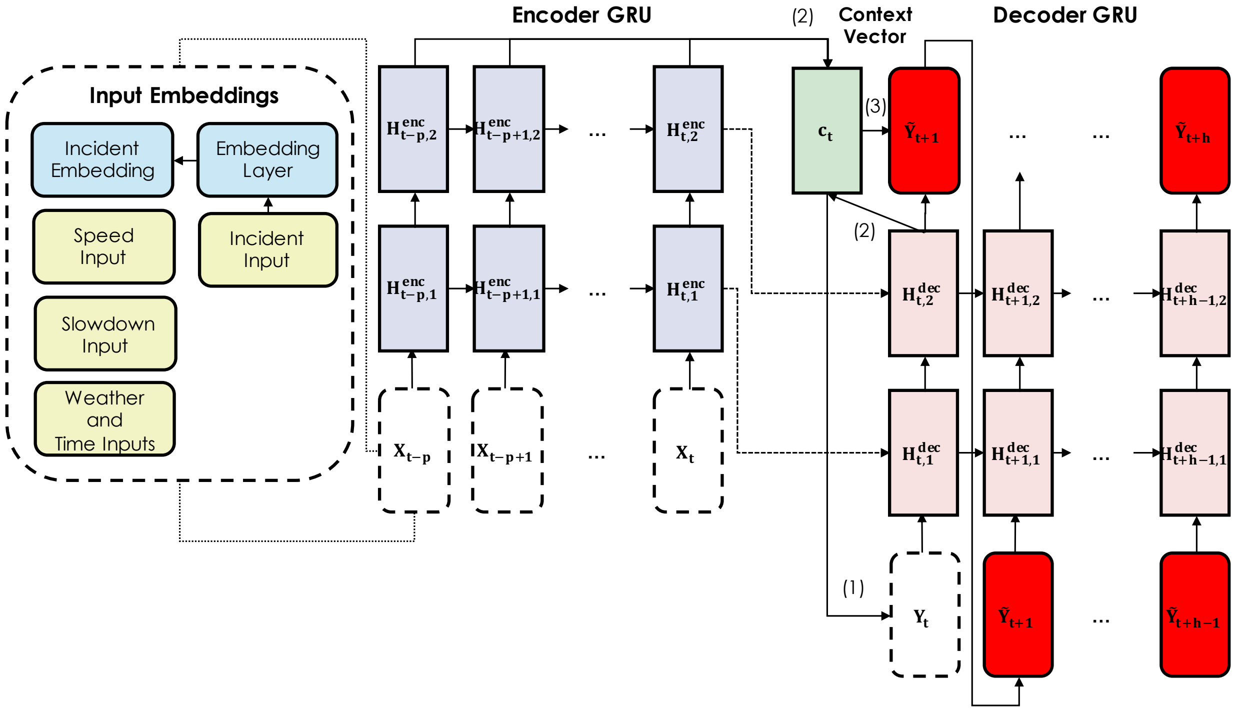
Machine Learning + Domain Knowledge

- Leverage the imbalance between abundant road conditions and few Y engagement records
    - Sequential Deep Learning for Traffic Prediction for each road segment 30 min ahead.
    - Develop optimal signal timing plans for typical nonrecurrent traffic conditions using VISUM Traffic Simulation
    - Design incident plan triggering conditions by associating engaged records with real-time traffic conditions

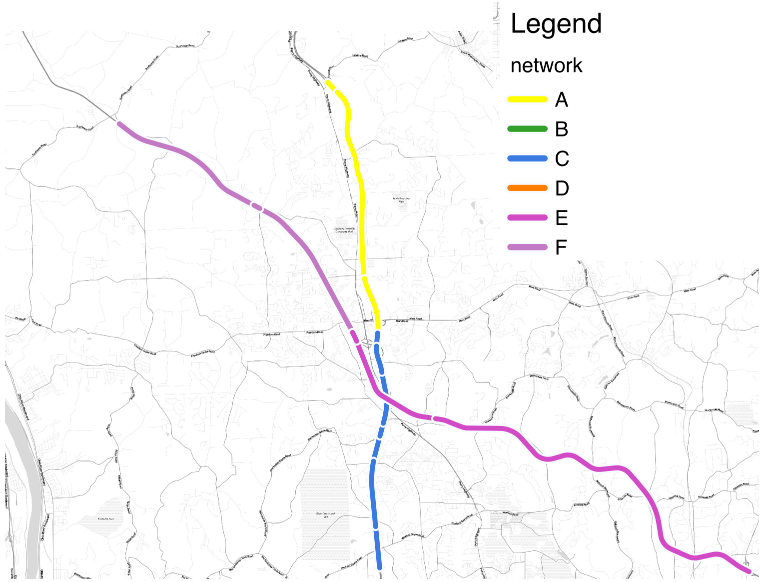
Traffic Predictor: Model Architecture

Model Architecture: Encoder-decoder GRU with Bi-Linear Attention:

- Inputs: Speed, incident, weather and temporal features
- Outputs: Speed predictions on target segments with forecasting horizon from 5 min – 30 min.



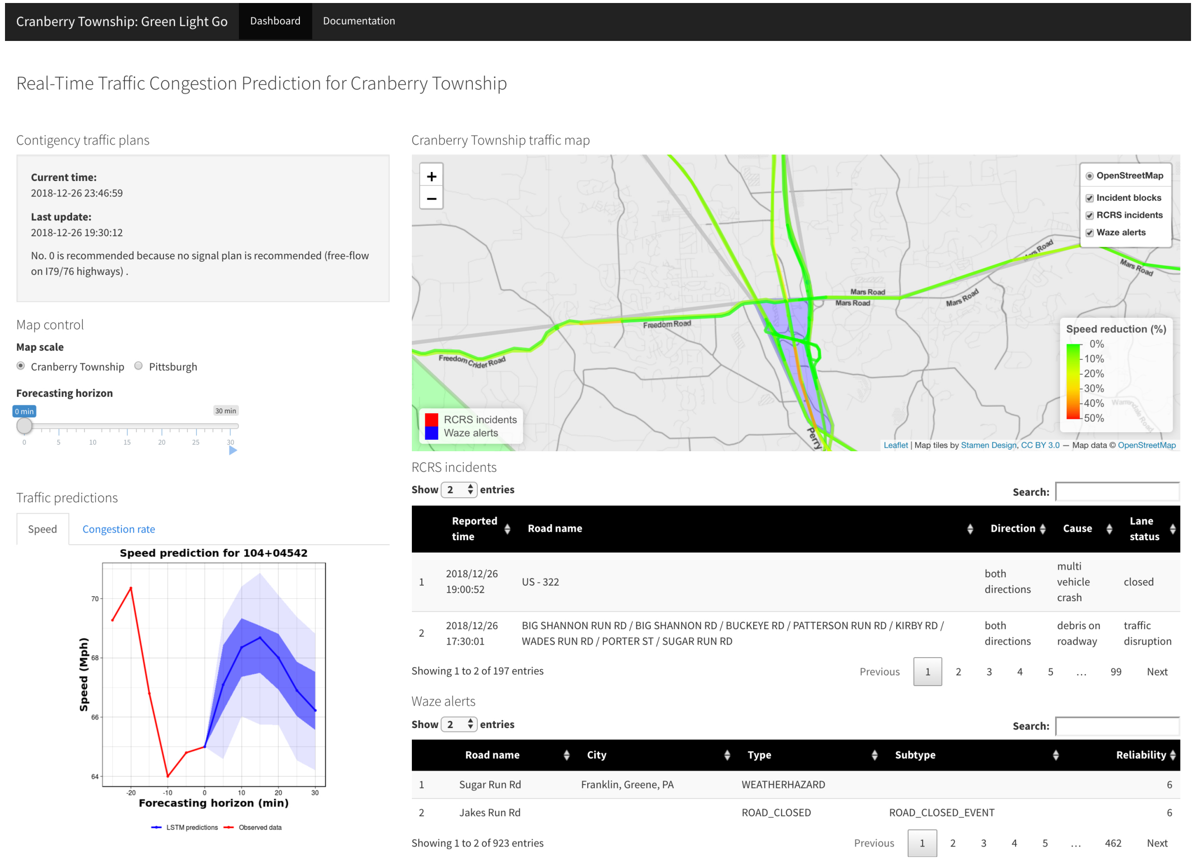
Rule-based Incident Plan Recommendation



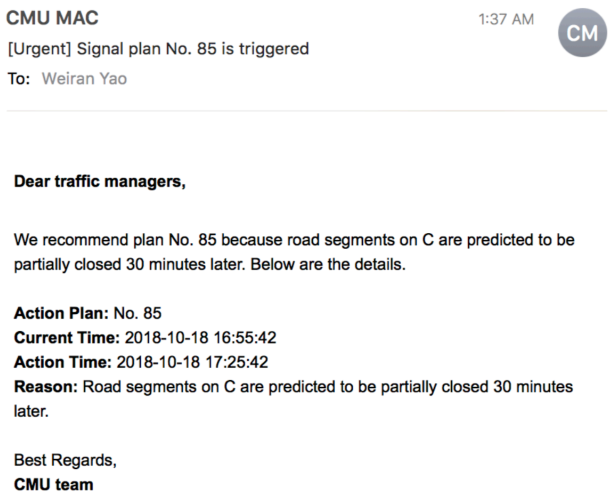
	Full Closure
81 (AM) 82 (PM)	(A) I-79 Southbound
83 (AM) 84 (PM)	(B) I-79 Northbound
	Partial Closure
85 (AM)	(C) I-79 Southbound
86 (MID/PM)	(D) I-79 Northbound
87 (MID/PM)	(E) I-76 (PA Turnpike) Eastbound
88 (MID/PM)	(F) I-76 (PA Turnpike) Westbound

- **Step 1:** Create Incident Signal Timing Plans for Typical Incident Scenarios (from Cranberry Township)
  - PTV VISUM traffic simulation
  - VISUM tuned with historical data.
  - Determine specific plan with network coordination cycle time
- **Step 2:** Determine the triggering conditions by associating the triggered signal plans by traffic operators with real-time traffic conditions
  - Speed <= threshold
  - TTI >= threshold
  - Other rules

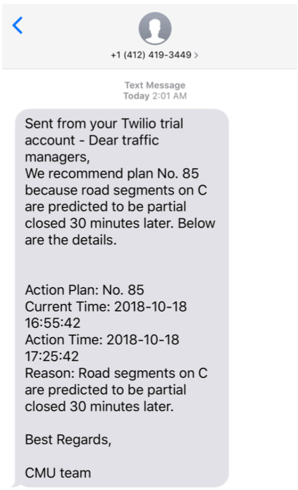
System Deployment



- <u>24/7 monitoring & decision making</u>
- <u>Automating</u> the process for TMC
- Email/message notification

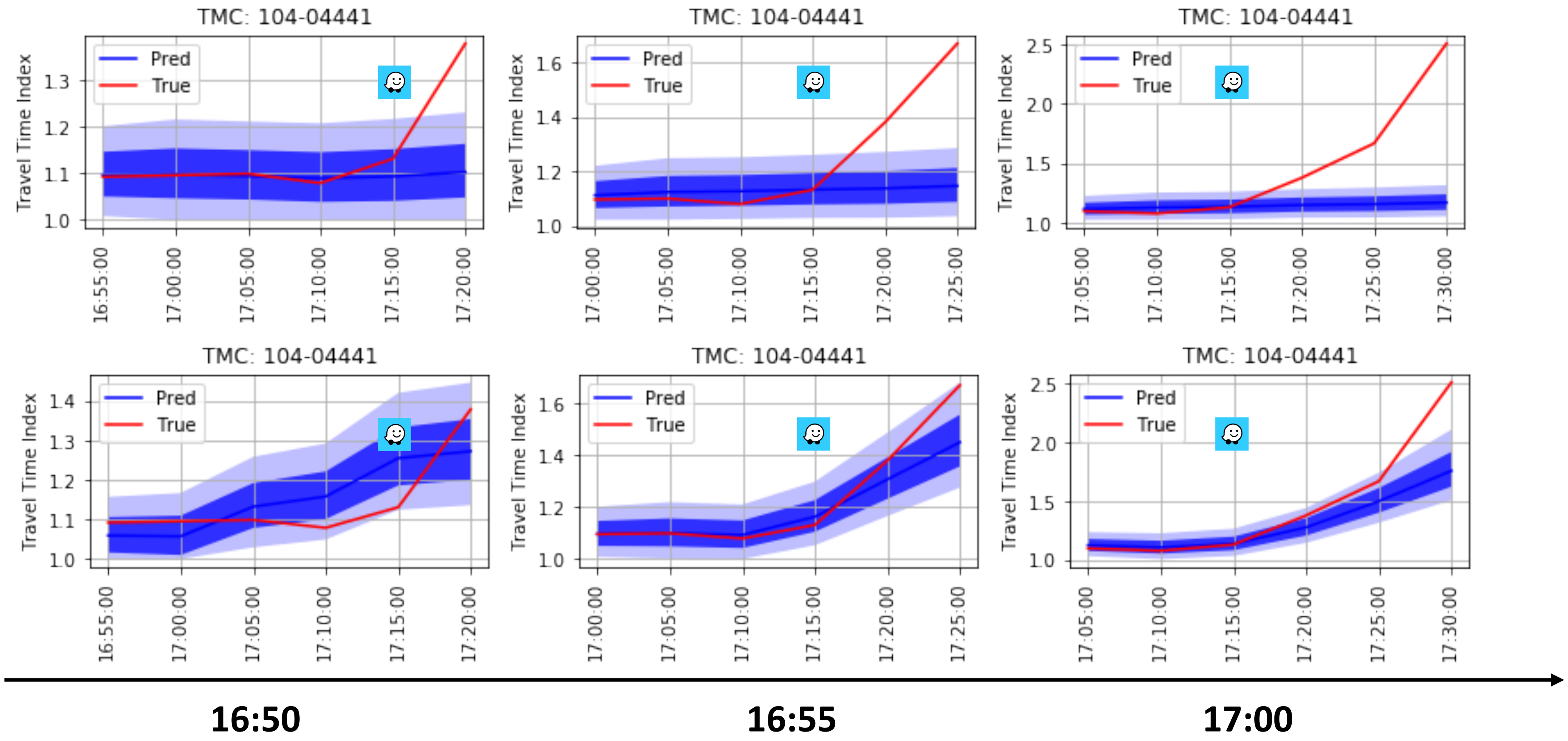


(a) Email notification sample.



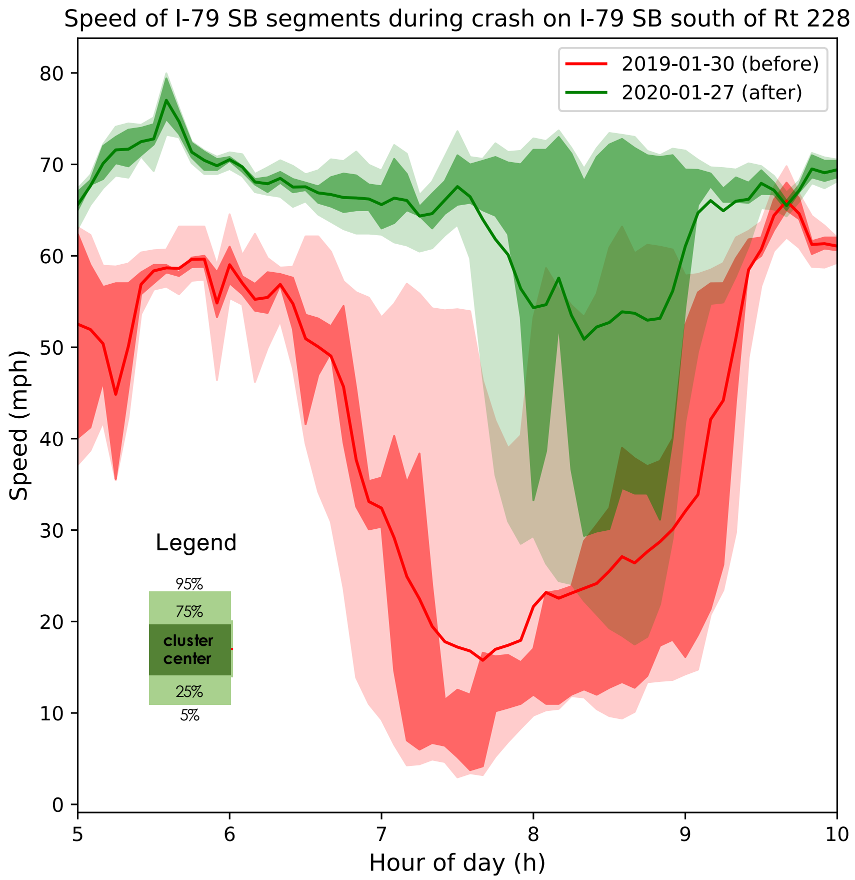
(b) Text notification sample.

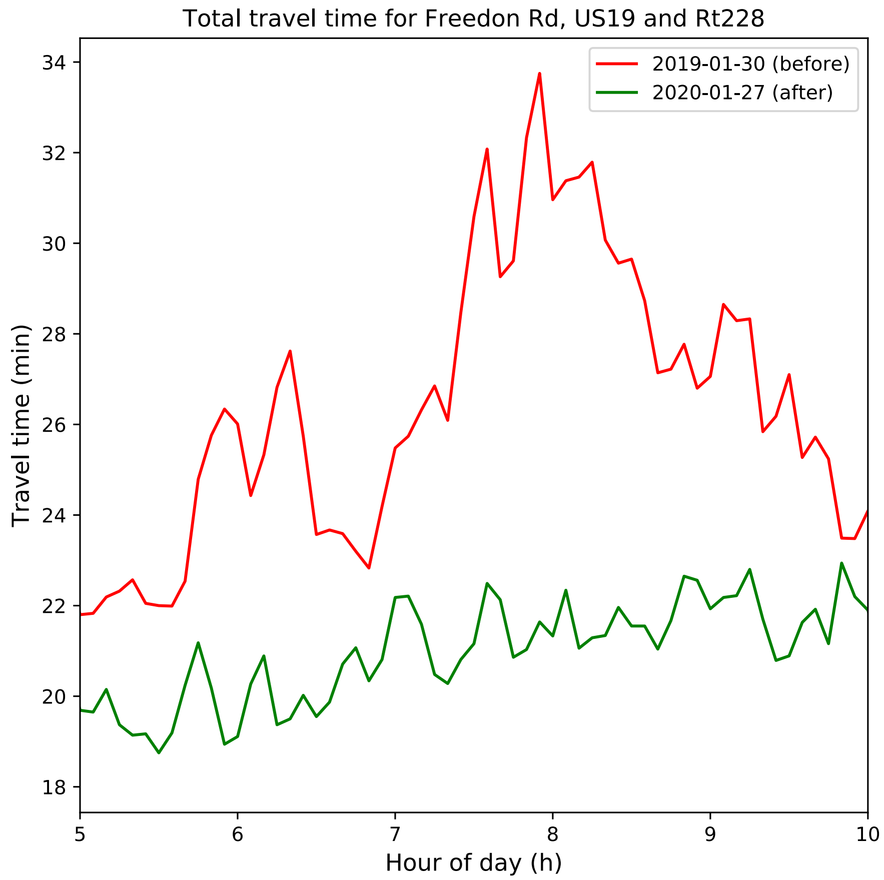
Incident Timeline on 03/05/2019



- Incident reported by Waze at **03/05/2019 17:15**

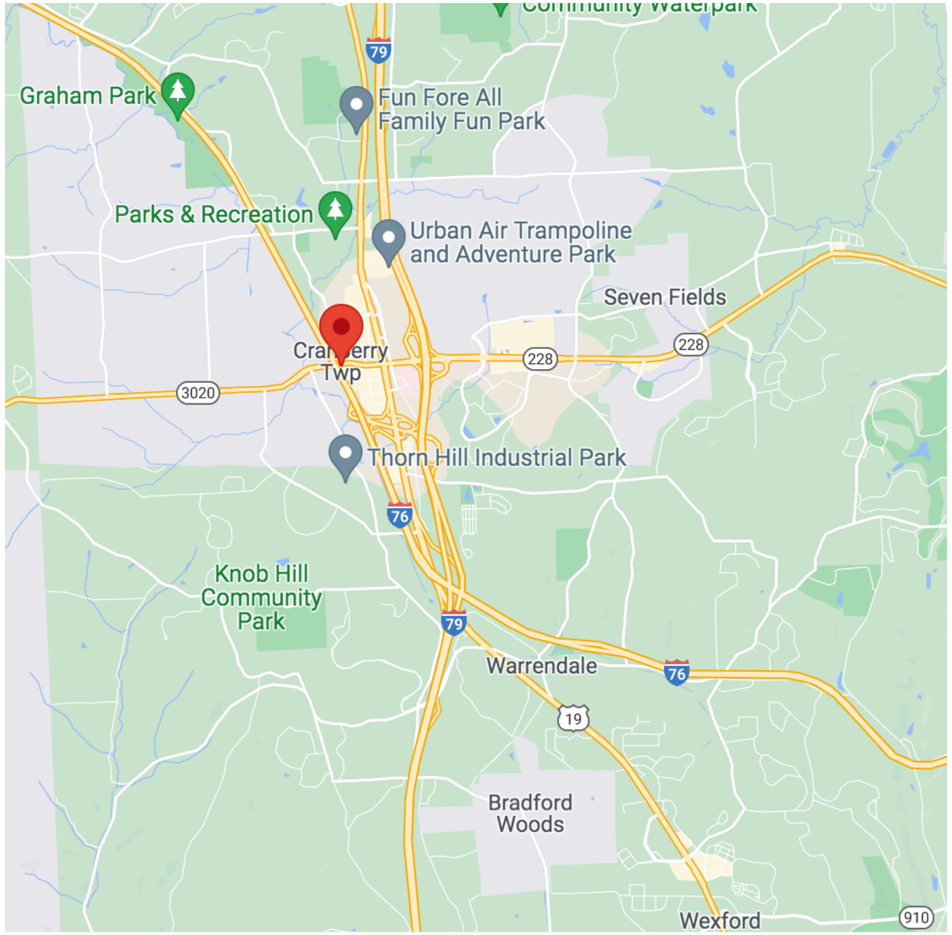
Before-and-after Analysis of Congestion Management in Cranberry Township



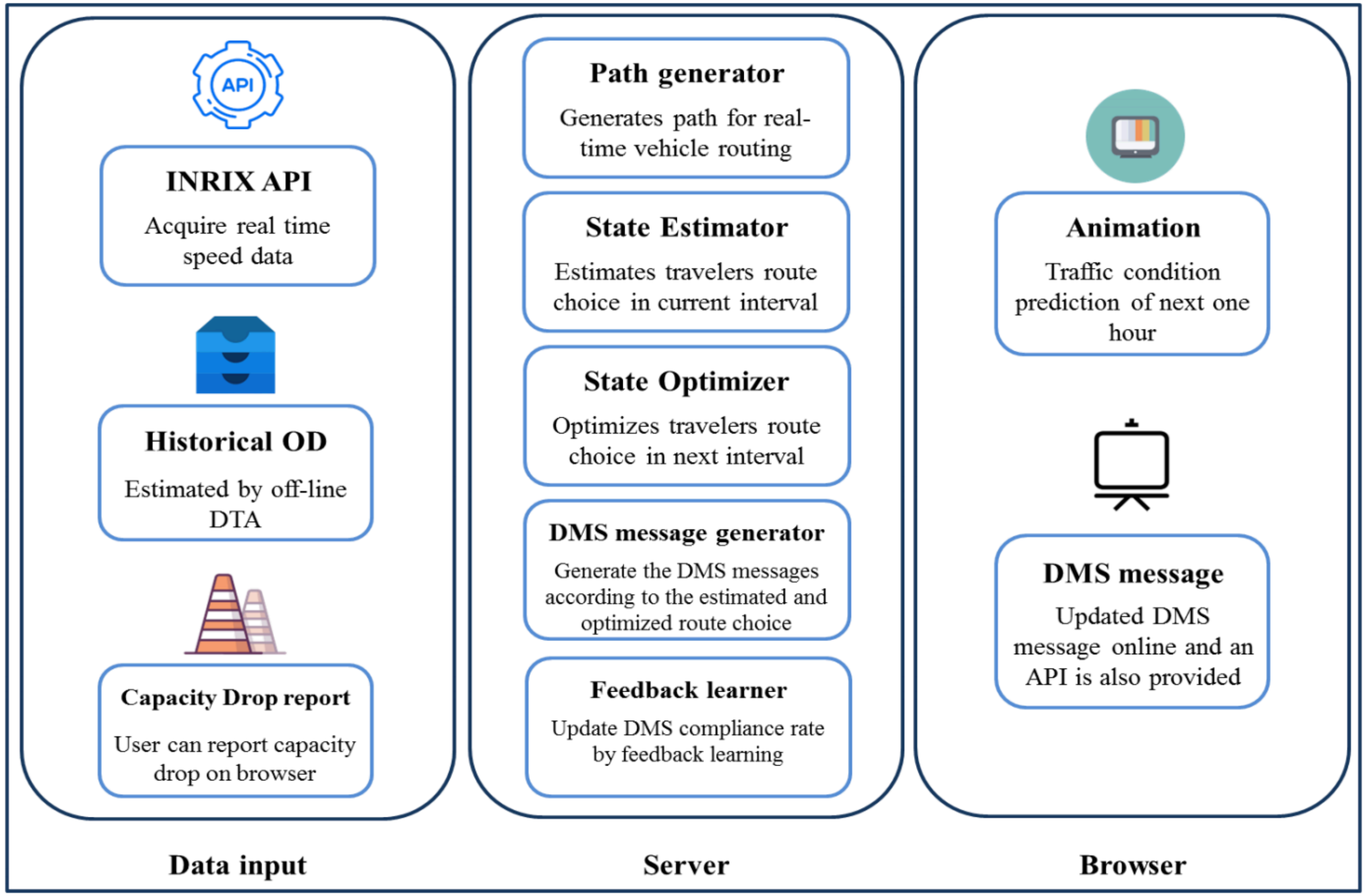


Summary

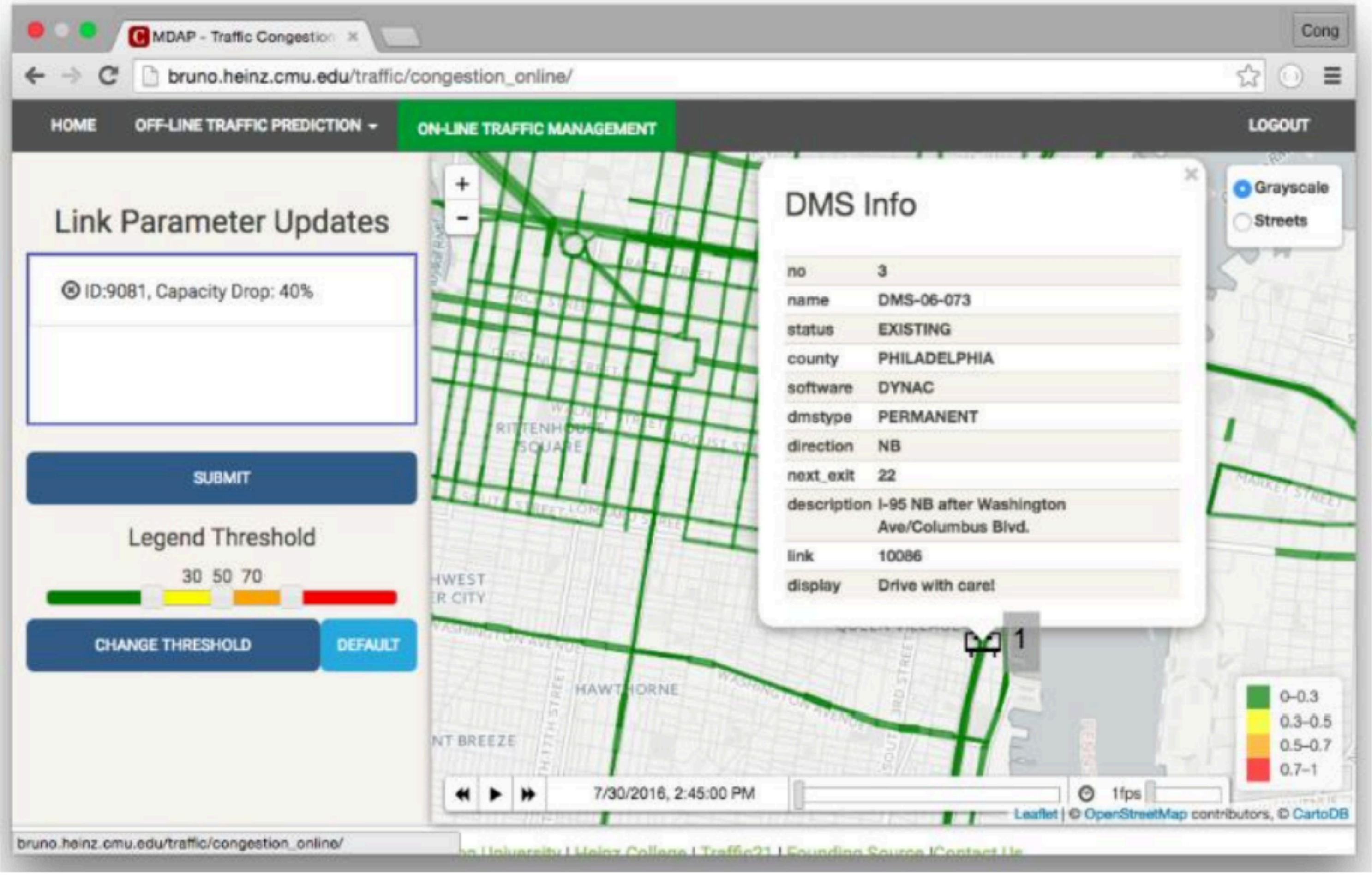
- Deployed at Cranberry Township
  - Detect traffic anomalies and recommend optimal signal timing 30 minutes ahead by email
  - Can be 15-25min ahead of Waze reports
  - Field trials confirm that incident signal timings can be engaged 15-50 minutes earlier than without this system
  - Reduce delay by 60% under an incident on I-79SB during AM peak



Project 2: Philadelphia Region Real-Time Traffic Management



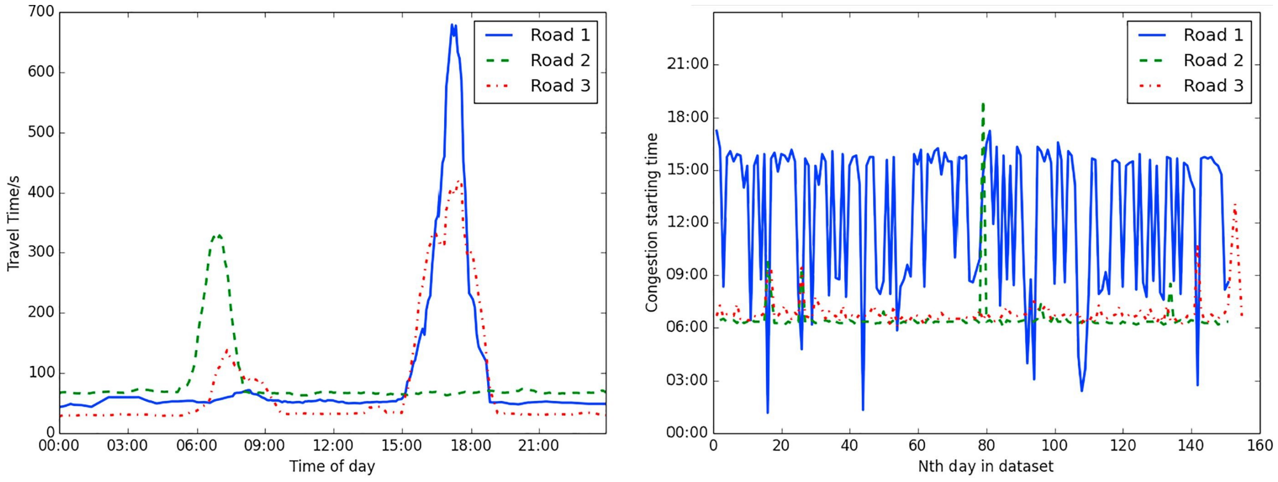
Interactive Dashboard for What-If DMS Decisions



Project 3: Next-Day Morning Traffic Prediction

- **Definition:** Predict morning traffic before early morning or even earlier
- **Background:** 13% of the population commute before 6 am; 4.4 % by 5 am (American Community Survey, 2015)
- **Motivation:** To provide **travel information**, traffic prediction of morning rush hour traffic before early morning (e.g. 5 am) is needed; Determine the pretimed signal plans for the next day

- **Challenge:** However, **real-time** and **historical traffic** are **not helpful:**



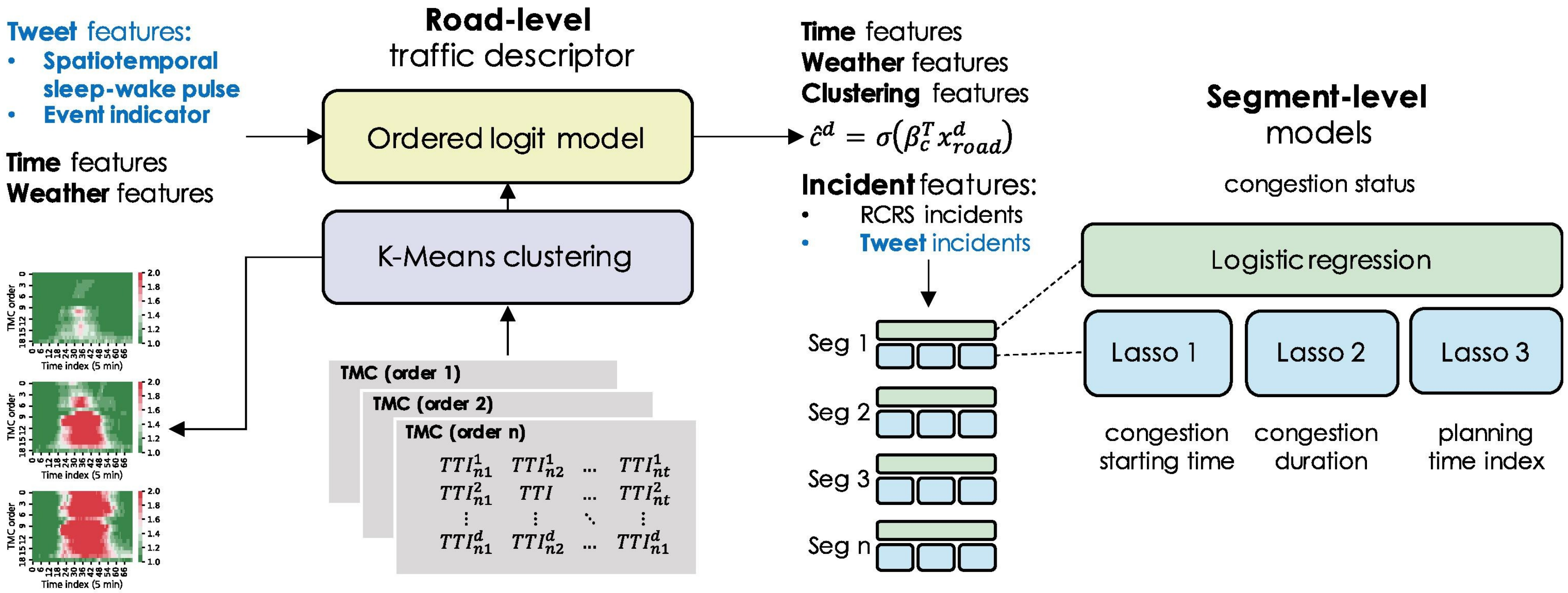
(a) (b)

Opportunities

- **Travel demand** on each day (departure time, mode, etc.) may be explained by commuters' activities at midnight or early in the morning;
- The rise of social media and analytics offer new tools to **sensing crowd activities** during late night and early morning;

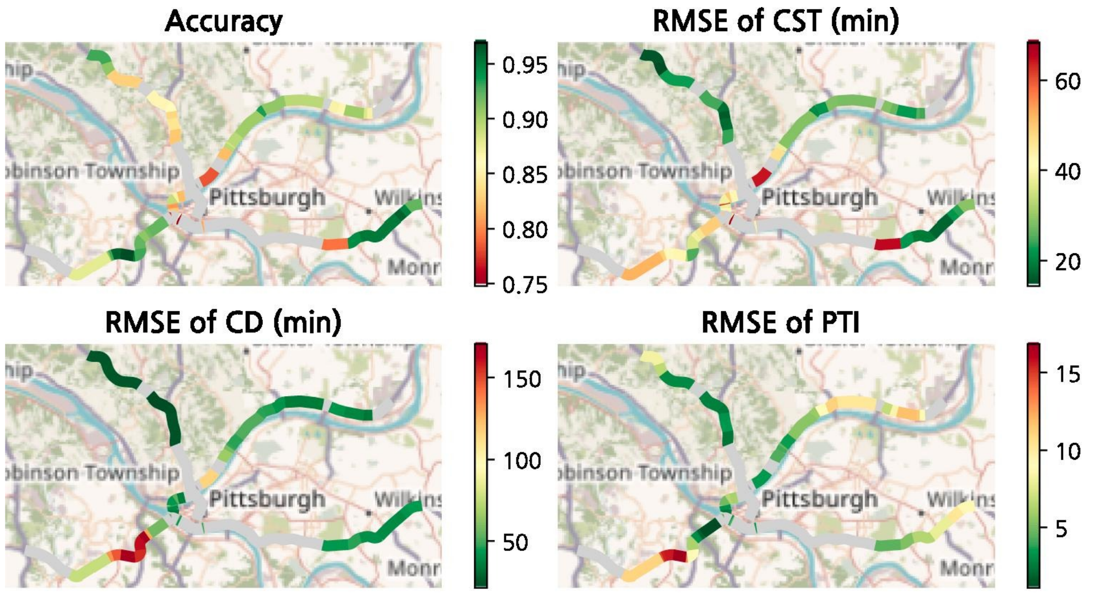
Location of Tweets Oct.23-Nov.30 2012. (Leetaru, et al., 2013)

Tweet2traffic Clustered Model Architecture

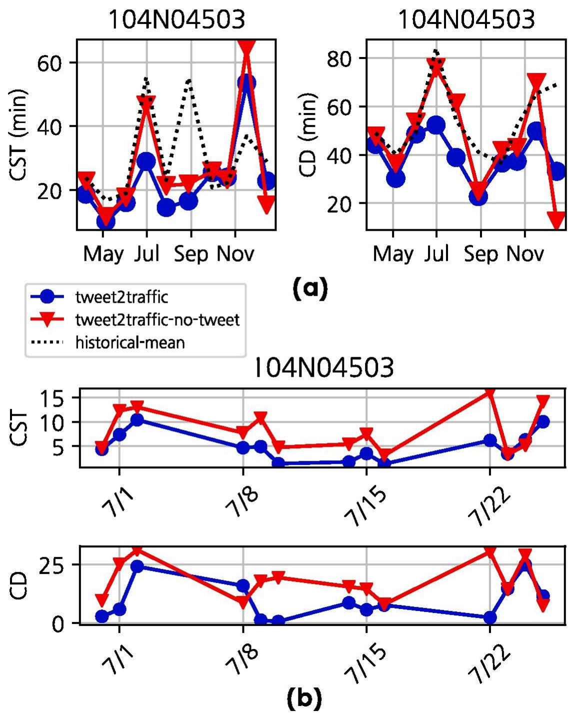


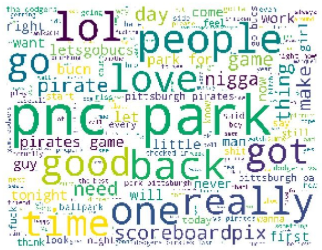
- **Road-level descriptor:** Orderd logit regression trained to predict ordered road traffic cluster index. **Segment-level classifier:** Logistic regression is trained for each segment with descriptor feature included.
- **Segment-level regressor:** LASSO trained for each segment for predicting congestion starting time and duration with **descriptor feature** included.

Experiment Results



(a) Morning traffic prediction error by road segment.





(e)

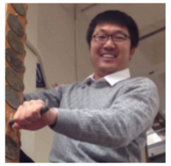
(f)

- Tweet information collected **by the midnight** before is sufficient to make good prediction for next-day morning traffic

Takeaways

- Three featured projects that incorporate ML/AI with domain knowledge (network flow models, traffic simulation, etc.) are presented to achieve two main goals:
  - (1) To predict non-recurrent traffic conditions in large-scale networks ahead
  - (2) To proactively recommend operational management strategies in real-time.
- Field trials and experiment results show that coupling traffic prediction and operational strategies can give traffic operators a significant time window to access the conditions and respond appropriately.
- Multi-source large-scale data such as social media data can help sensing crowd activities related to traffic operation when normal traffic sensors are not available, such as during late night and early morning


Prof. Sean Qian
Director


Dr. Bin Gui
Postdoctoral Researcher

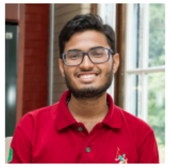

Matthew Battifarano
PhD Candidate


Weiran Yao
PhD Candidate


Rick Grahn
PhD Candidate


Zemian Ke
PhD Student


Pengji Zhang
PhD Candidate


Arnav Choudhry
PhD Candidate


Pablo Guarda
PhD Student


Radhika Katti
PhD Student


Daryn Lee
PhD Student


Jiachao Liu
PhD Student

CONTACT US

http://mac.heinz.cmu.edu/

MAC
Mobility Data Analytics Center
Carnegie Mellon University

Director: Sean Qian

Hamburg Hall 3044, **Carnegie Mellon University**
4800 Forbes Ave, Pittsburgh, PA, 15213
Email: seanqian@cmu.edu