Using Data to Understand the Effects of Transportation on the Spread of COVID-19 as a Propagator and a Control Mechanism

2028738, 2028946

PI Philip E. Paré, Purdue University & PI Raphael Stern, University of Minnesota

RAPID, FY2020

Principal Research Investigators

- *Philip E. Paré, Purdue University*
- *Raphael Stern, University of Minnesota*

Community Partners

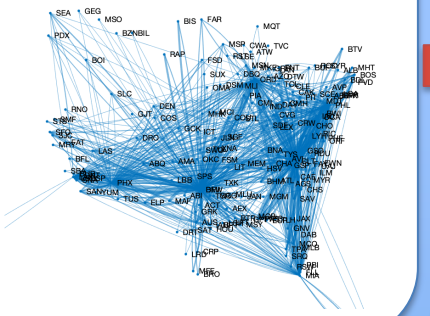
- *Due to the structure of the RAPID grant, we did not have any community partners*
- *A follow-up IRG proposal has been submitted to the NSF S&CC Program with multiple stakeholders:*
  - *Champaign Urbana Public Health District (CUPHD)*
  - *Xpenn Consultants*

PURDUE UNIVERSITY | School of Electrical and Computer Engineering

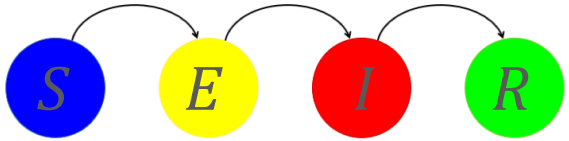
UNIVERSITY OF MINNESOTA Driven to Discover℠

Project Overview

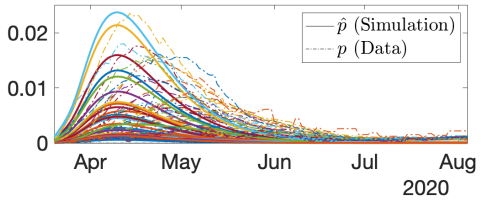
Collect travel data



Model virus evolution



Predict virus spread to allow risk-informed network control



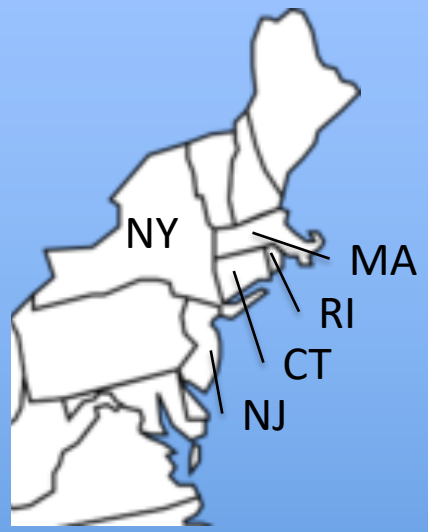
Project Vision

- COVID-19 is spread through human contact and across transportation networks
- Understanding the spread of COVID-19 requires collecting high-resolution data of human travel behavior
- Can extend viral spread models to incorporate travel data
- Use viral spread models and travel data to construct network control strategies to slow the spread of the pandemic

Processed data available for download: M. Shang, J. Pham, D. Vrabac, B. Butler, **P. E. Paré**, and **R. Stern**, "Air travel data during the COVID-19 pandemic in the United States," http://hdl.handle.net/11299/217208, November, 2020.

Project Overview

Use-Inspired Research



Northeastern United States

We consider the spread of COVID-19 through five states, New York (NY), New Jersey (NJ), Massachusetts (MA), Rhode Island (RI), and Connecticut (CT), in the Northeastern US from March through August, 2020, and consider how the underlying air transportation network between the cities in the five-state region propagated the virus.

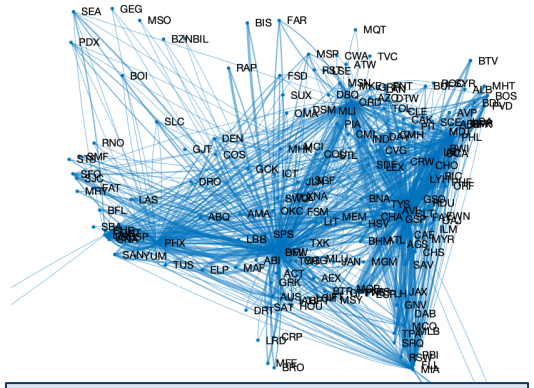
Fundamental Research Contributions

- Compiled travel dataset that contains every flight in the US for the first several months of the COVID-19 pandemic
- Extended traditional viral spread model to incorporate transportation
- Published work in peer-reviewed conferences and journals:

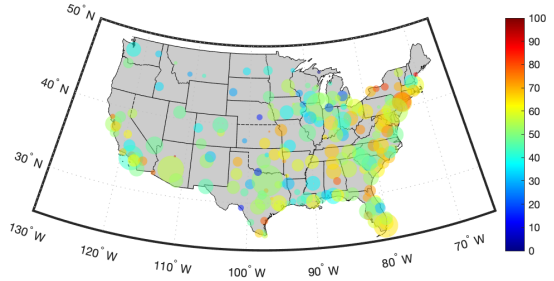
1. D. Vrabac, M. Shang, B. Butler, J. Pham, **R. Stern**, and **P. E. Paré**, "Capturing the Effects of Transportation on the Spread of COVID-19 with a Multi-Networked SEIR Model," *IEEE Control System Letters* (accepted for presentation at *2021 American Control Conference*), to appear, 2021.
2. **P. E. Paré**, C. L. Beck, and T. Başar, "Modeling, estimation, and analysis of epidemics over networks: An overview," *Annual Reviews in Control: Special Issue on Systems and Control Research Efforts Against COVID-19 and Future Pandemics*, Vol. 50, pg. 345-360, 2020.
3. Z. Liu and **R. Stern**, "Quantifying the Traffic Impacts of the COVID-19 Shutdown," *Journal of Transportation Engineering, Part A: Systems,* 145(5), 04021014, 2021.
4. M. W. Levin, M. Shang, and **R. Stern**, "Effects of short-term travel on COVID-19 spread: A novel SEIR model and case study in Minnesota," *PLoS One*, 16(1), e0245919, 2021.
5. B. Butler, C. Zhang, **R. Stern**, and **P. E. Paré**, "Modeling Epidemic Processes Over a Networked SEIR System Using Population Flow," under review for the *IEEE Conference on Decision and Control*, 2021.

Project Update

Flight Data Collection

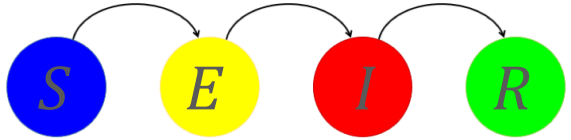


Flights on one day in July, 2020



Reduction in flights by airport

Model Proposal



$$s_i^{k+1} = s_i^k - h\, s_i^k\, \iota_i^k$$

$$e_i^{k+1} = e_i^k + h\, s_i^k \iota_i^k - h\sigma_i\, e_i^k$$

$$p_i^{k+1} = p_i^k + h(\sigma_i\, e_i^k - \gamma_i\, p_i^k)$$

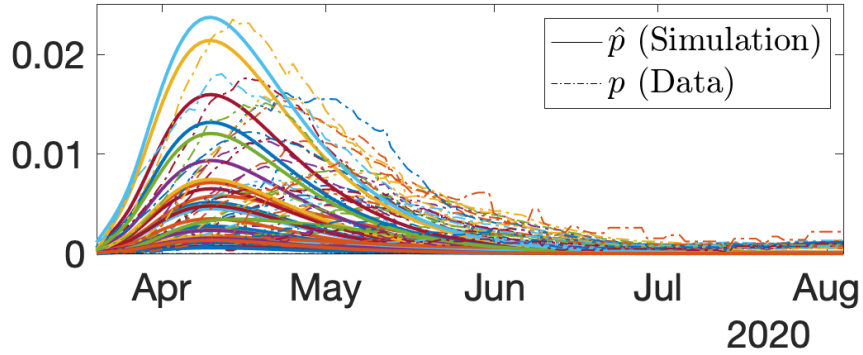
$$r_i^{k+1} = r_i^k + h\gamma_i\, p_i^k$$

where

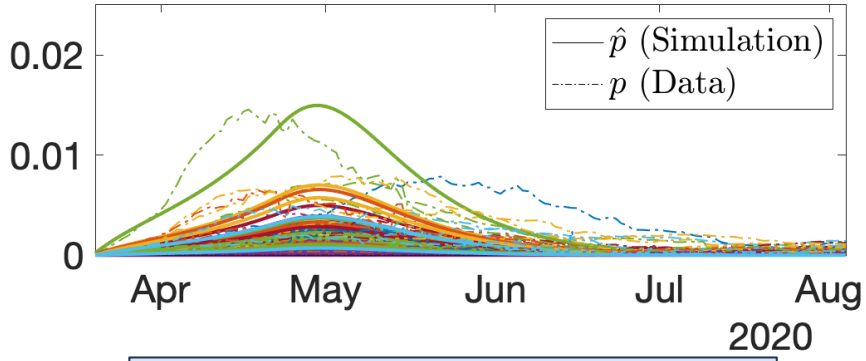
$$\iota_i^k = \sum_{l \in \mathcal{L}} \left(\beta_i^{e,l} \sum_{j \in \mathcal{N}_i^l} a_{ij}^l e_j^k + \beta_i^{p,l} \sum_{j \in \mathcal{N}_i^l} a_{ij}^l p_j^k \right)$$

with $\mathcal{L}$ representing the set of transportation networks

COVID-19 Data & Model Fitting



Urban counties with flights, inter- and intra-county connections



Rural counties with flights, inter- and intra-county connections

Project Evolution

Transportation data collection

- Early efforts focused on scraping seat map data from flights on a daily basis to estimate flight load factors (number of filled seats) before seat maps were deleted from airline websites
- As the pandemic continued, flight volume increased, resulting in too many flights to manually scrape load factor data

Adaptation

- Data collection shifted to scraping all flight activity and load factor was estimated from other surrogate measures

Covid-19 Data Corruption

- Given biased sampling, delays, and other inconsistencies, using COVID-19 testing data was much more difficult than expected

Adaptation

- As a result, we have begun to develop algorithms to estimate the underlying epidemic states from testing data that account for these issues

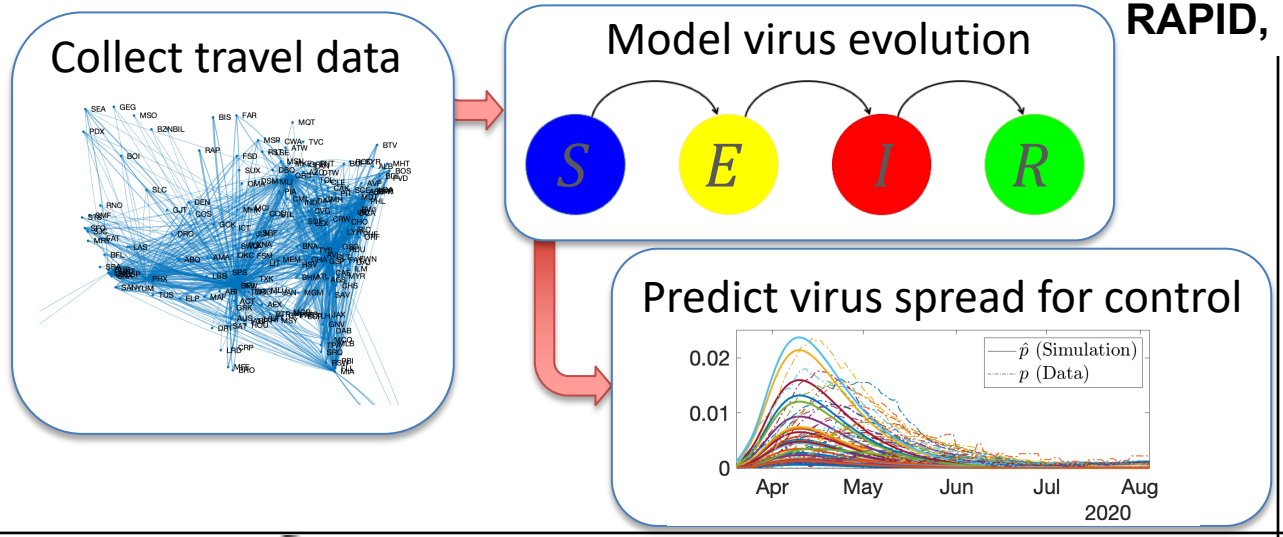
Thank you!

Using Data to Understand the Effects of Transportation on the Spread of COVID-19 as a Propagator and a Control Mechanism

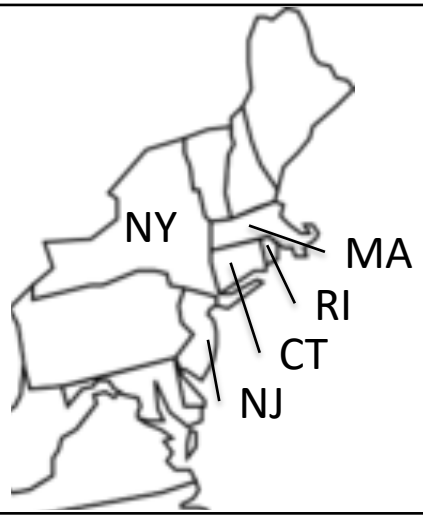
2028738, 2028946

PI Philip E. Paré, Purdue University & PI Raphael Stern, University of Minnesota

RAPID, FY2020



- COVID-19 is spread through human contact and spread across transportation networks
- Understanding the spread of COVID-19 requires collecting high-resolution data of human travel behavior
- Can update viral spread models to incorporate travel data
- Use viral spread models and travel data to construct network control strategies to slow the spread of the pandemic



Use-Inspired Research

We consider the spread of COVID-19 in five states: New York (NY), New Jersey (NJ), Massachusetts (MA), Rhode Island (RI), and Connecticut (CT), from March through August, 2020, using the underlying air transportation network to understand the virus propagation.

Fundamental Research Contributions

- Compiled travel dataset that contains every flight in the US for the first several months of the COVID-19 pandemic
- Extended traditional viral spread model to incorporate transportation
- Five published works in peer-reviewed conferences and journals