

Planes, Trains, and Afflictions

Agent-based modeling for the spread of disease through transportation networks

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Motivation

Why were certain areas of NYC more affected by COVID-19?

How were the subways involved?

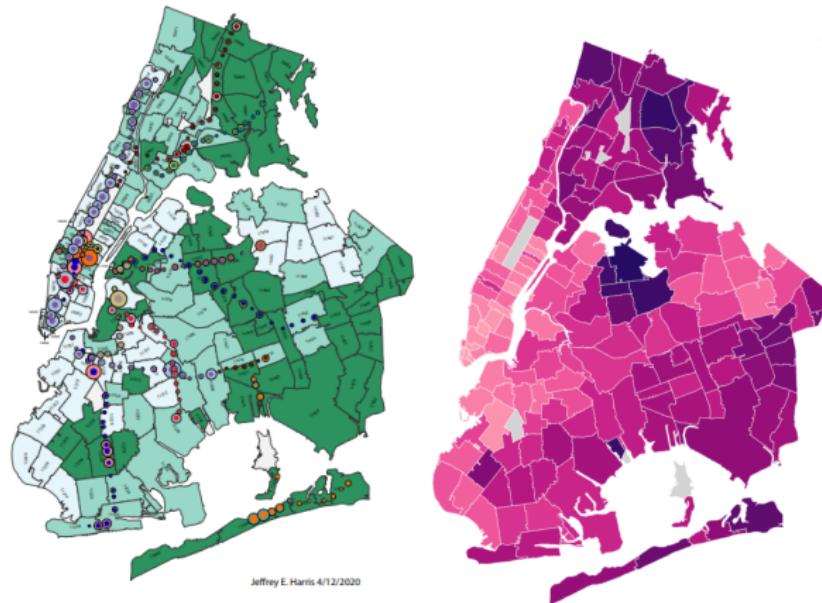
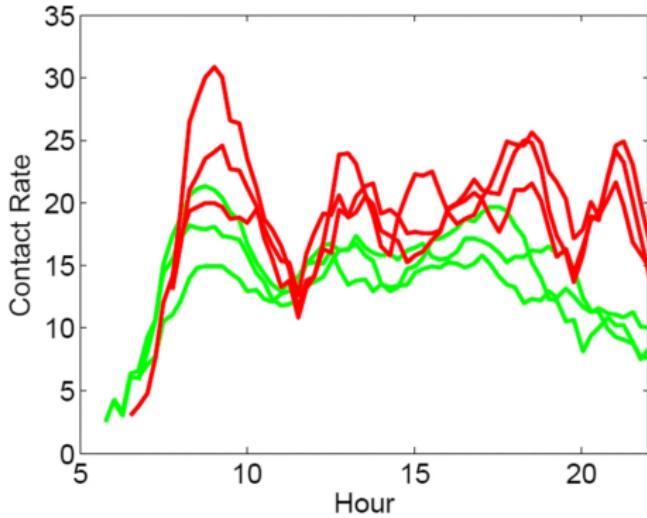
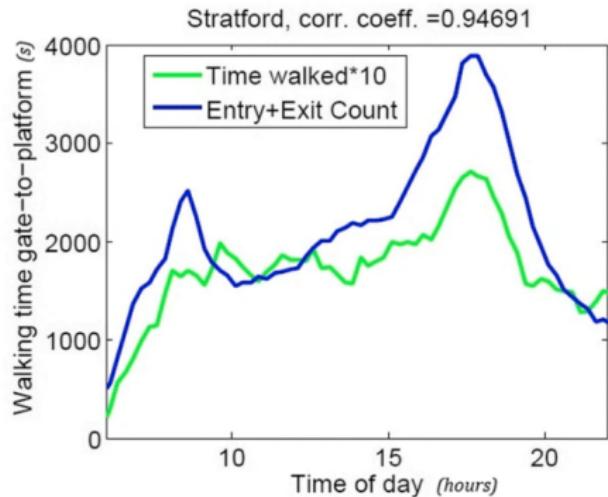


Figure: Left: Case Rate And Subway On April 12, 2020 [1]

Right: NYC COVID Case Rate As Of June 23, 2020 [2]

Prior Research (London Underground)

Data: Oyster (Card), CASA (Timetable), PHE Data (Demographics)



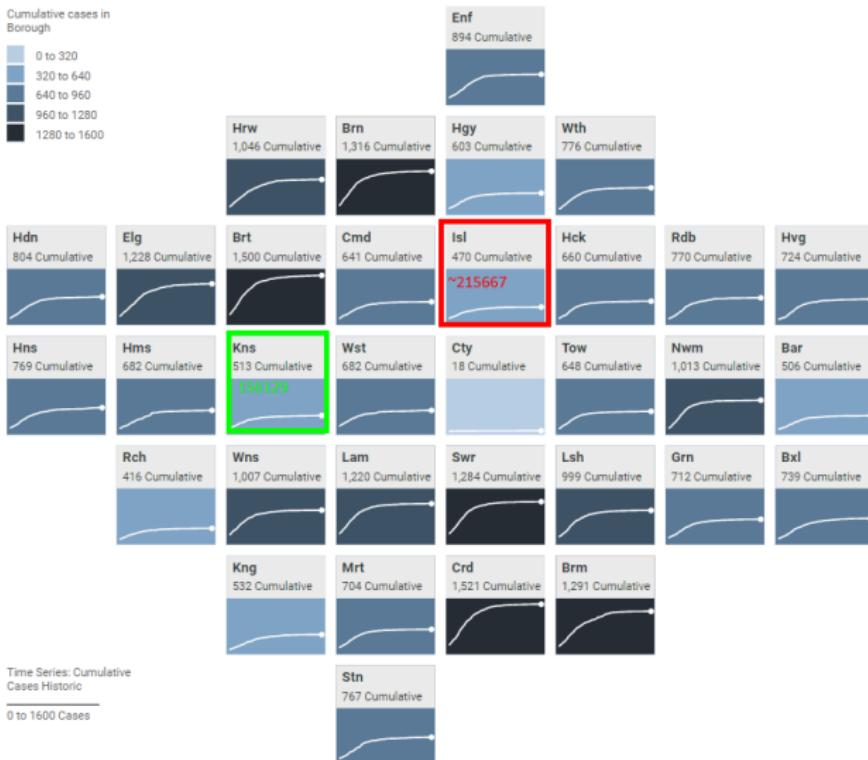
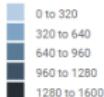
Results show a correlation between the use of the underground and ILI cases in London, specifically they show that higher numbers of ILI cases arise in those boroughs where the population spend more time in the Underground and/or incur in a higher number of contacts when travelling. [3]

COVID in London

Covid-19 Cases by London Borough (2020-03-23 to 2020-06-21)

Displaying cumulative count (all historic) at: 2020-06-21

Cumulative cases in
Borough



Source: <https://coronavirus.data.gov.uk/> - Note: Data for most recent 5 days may be incomplete.

Graphic by GLA City Intelligence | London Squared Format by After The Flood



Prior Research (Singapore Buses)

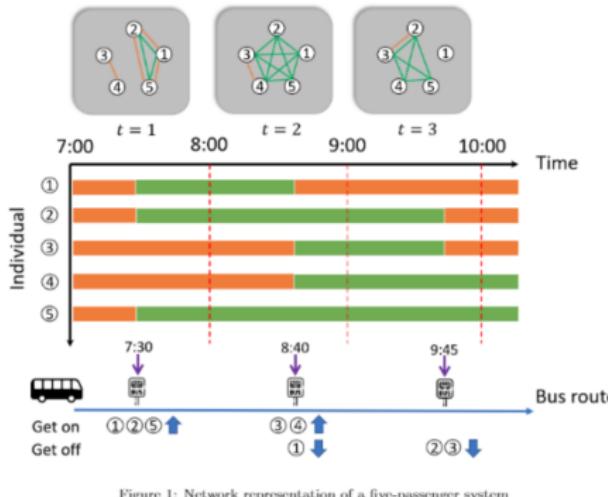
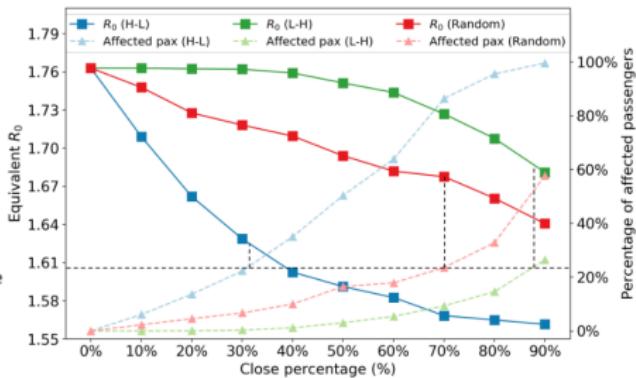
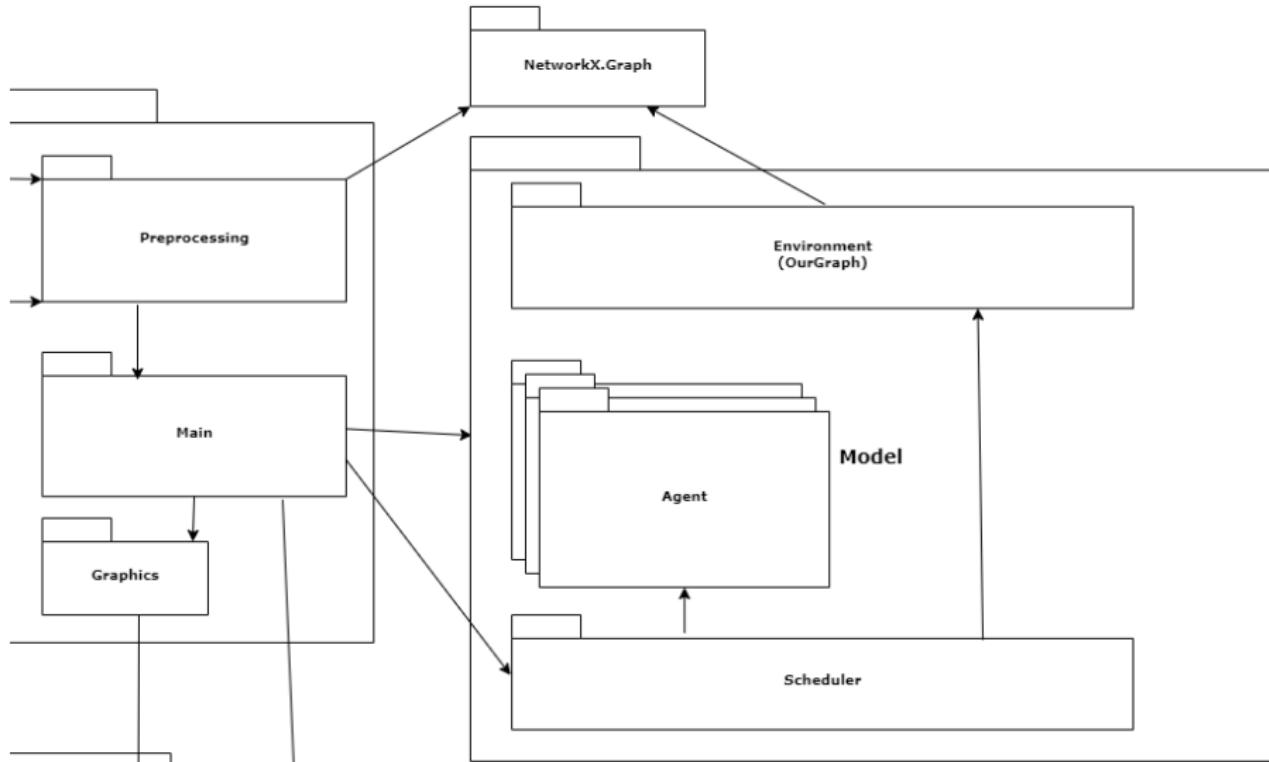


Figure 1: Network representation of a five-passenger system



The direct contact in trains is, however, difficult to obtain from smart card data because the transactions are recorded at the station level [4]

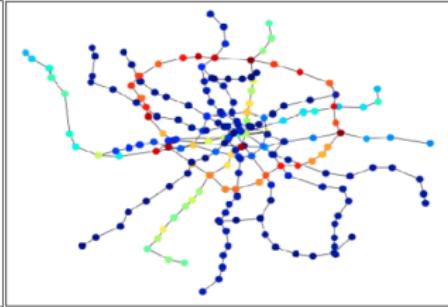
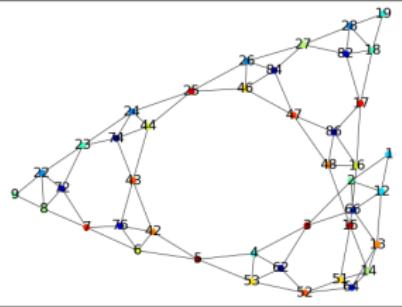
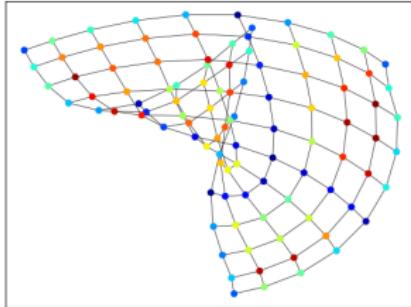
ABM Framework



Components: Python, MESA, Networkx

Base Classes: Transportation Model, SEIR Agent

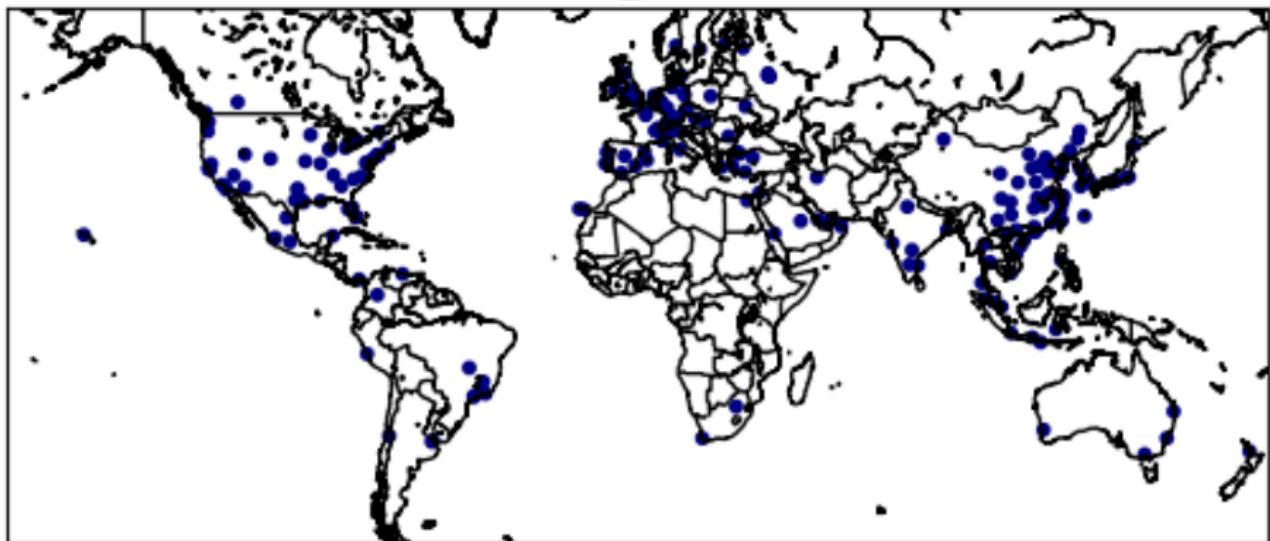
Simple Geometries



- Grid
- Sierpinski's Triangle
- Moscow

World Airline Network (Passenger Flow)

- Investigate similarities and differences with subways
- Make framework more robust



World Airline Network (Passenger Flow)

Main Idea: Detailed route data can help model spread of diseases.

- Regional / Domestic / EU Domestic / International Airports
- Regional / Domestic / EU Domestic / International Air Routes

Problem: This data not widely available. Solutions [5]:

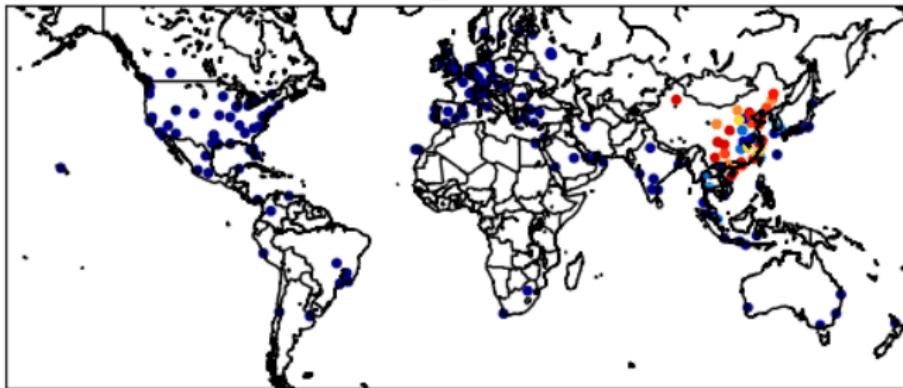
- ① Commercial Providers
- ② Open Data
- ③ Statistical Modeling

World Airline Network (Passenger Flow)

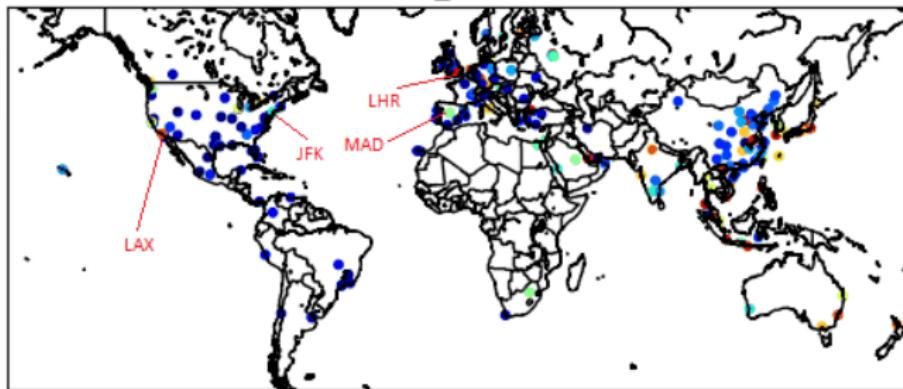
- List of Airports - OpenFlights [6]
 - List of Air Routes - OpenFlights [6]
 - Airport Passenger Flow Numbers - [7]
 - Top Air Routes [8]
 - Other Air Routes
- ① Process airports, air routes
 - ② Add all known passenger flow numbers
 - ③ Add all known airport and air route labels
 - ④ Classify remaining airports and air routes
 - ⑤ Interpolate missing air route data

World Airline Network Visualization (gif)

normalized_hotspot t=62



normalized_hotspot t=79



Madrid Commuter Trains (Central Hubs)

How important are central transportation hubs to disease spread?

Data Sources:

- Madrid Renfe GTFS: <https://crtm.maps.arcgis.com/home/item.html?id=1a25440bf66f499bae2657ec7fb40144>
- Madrid Renfe Turnstile data: <https://data renfe com/dataset/volumen-de-viajeros-por-franja-horaria-madrid>

Madrid Commuter Trains

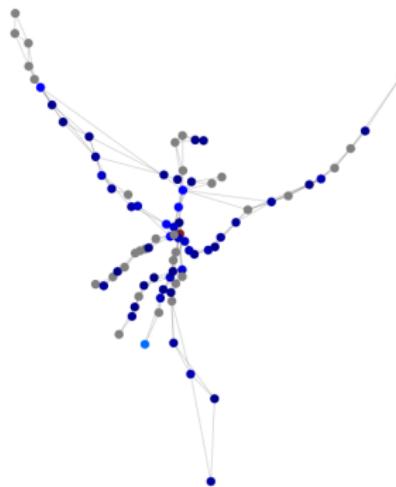


Figure: Madrid Cercanías map 2020 (urban trains)

Madrid Commuter Trains

Method: Agent Based Model (ABM)

Agents: Passengers

Flow based on weights w which depend on the turnstiles data: *in-weight* and *out-weight* (incoming and outcoming passengers respectively).

Madrid Commuter Trains - Passengers flow

At each time step t ...

N passengers join the network randomly:

- ① Join at a random time.
- ② Origin station depending on the *in-weight*.
- ③ Platform choice based on the weight of the next platforms.
- ④ The passengers wait on the platform until a train arrives.

Passengers who are in a train:

- Leave the network (destination arrival) depending on the *out-weight* of the station.
- Leave the train and go to another platform depending on the weights of each platform.

Madrid Commuter Trains - Parameters

In order to simulate the spread of an infection:

- Passengers (in a day): 500,000.
- Infected passengers: 50,000 (10% of them).
- Infection probability: 0.005.

On average, an infected passenger will infect 5.04 other people.

Madrid Commuter Trains - Results



Figure: Top 10 stations with most infections

Madrid Commuter Trains - Results

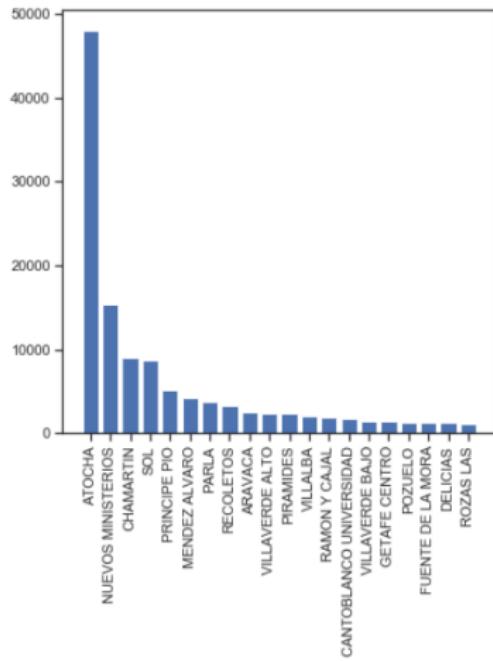


Figure: Top 20 stations with most infections

Madrid Commuter Trains - Results

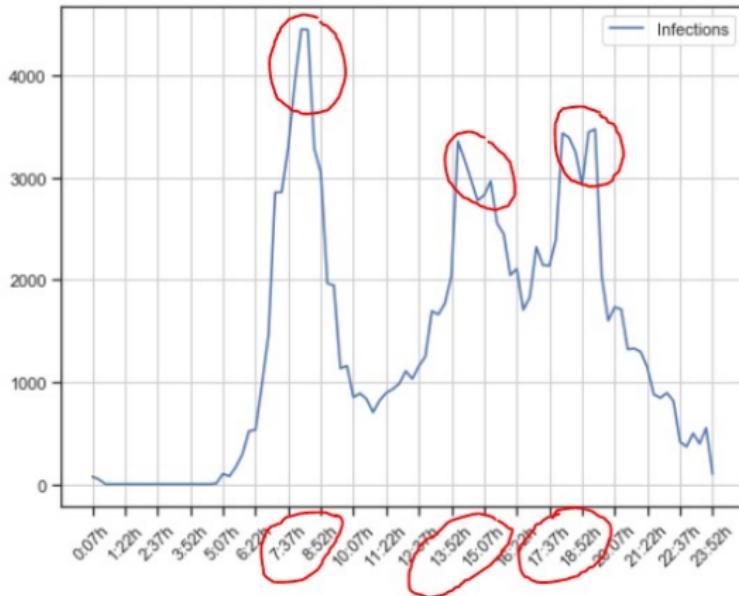


Figure: Infections in the whole network during a day.

Madrid Commuter Trains - Results

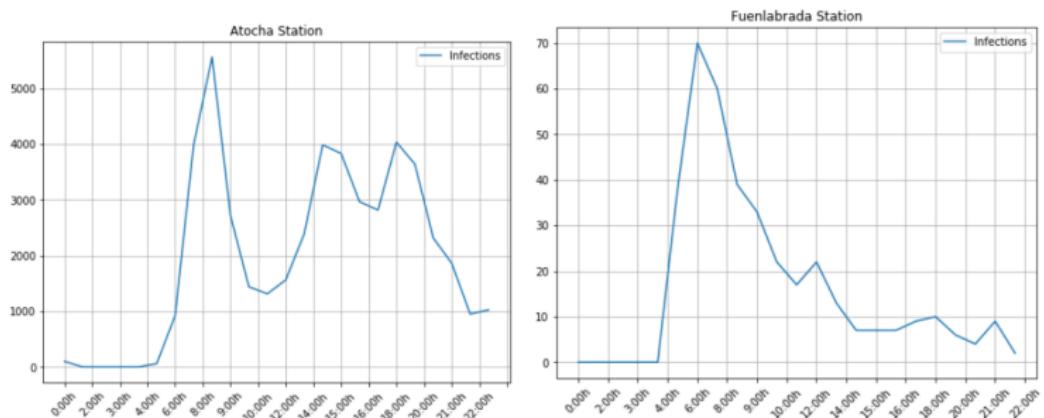


Figure: Infections in a central hub (left) and a station in a suburb (right).



NYC Demographics And COVID Timeline

NYC residents working in Manhattan primarily travel by subway. This is also true for residents of the Bronx, Brooklyn, and Queens [9]

- March 9 - Mayor holds press conference and notes that there have been 16 confirmed cases. (106 cases)
- March 12 - Mayor declares a local state of emergency. (687 cases)
- March 15 - Schools officially close. (2,986 cases)

Borough - A geographical region. NYC has 5 boroughs.

MODZCTA - Modified Zip Code Tabulation Areas. \propto postal codes.

Subway Systems

Complex, Station, Line, Route

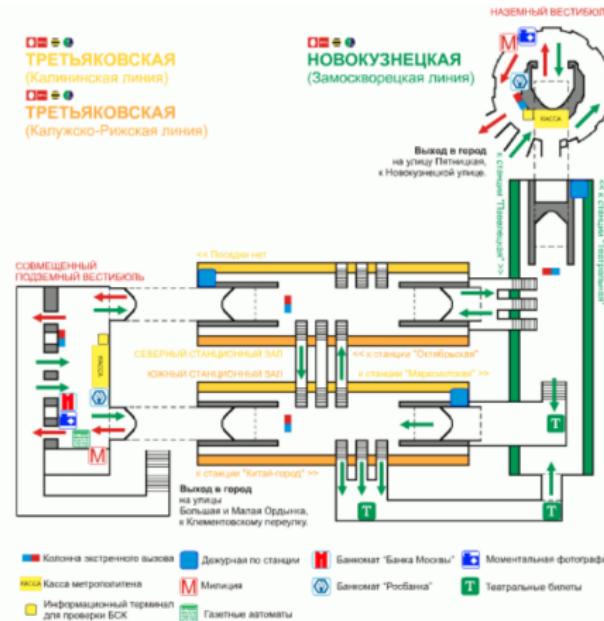


Figure: Floor Plan of Novokuznetskaya Metro Station [10]

NYC Subway Data

Stations, Map, Turnstiles (GTFS not considered)

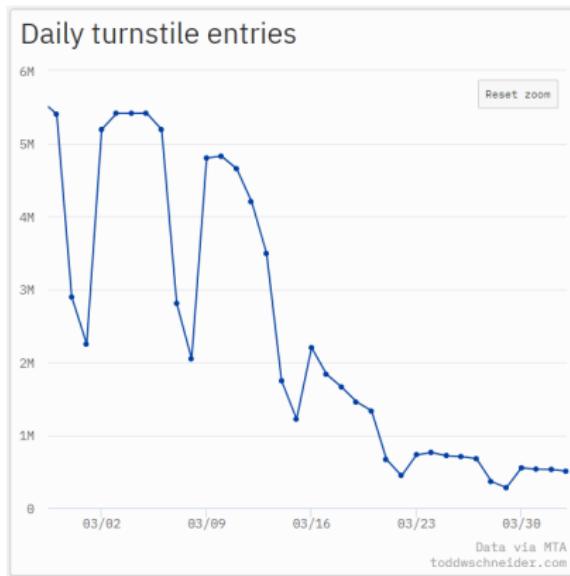


Figure: NYC Subway daily turnstile entries for March 2020 [11]

167,167,A32,IND,8th Av - Fulton St,W 4 St,M,A C E...

167,167,D20,IND,6th Av - Culver,W 4 St,M,B D F M...

NYC Subway Modeling

Algorithm 1 Simulation of Disease Spread on Subways

```
1: for  $i = 1; i < TIMESPAN; i++$  do
2:   Check conditions ( $i$ , number of infected) to see if we should deploy
      COUNTERMEASURES
3:   for Station in SubwayModel.Environment.Nodes do
4:     Calculate 'Local Exposure' from infected and commute time.
5:     Calculate 'Route Exposure' from infected on the same route.
6:     Calculate 'General Exposure' due to city-wide infected.
7:     Update 'Exposure' at station based on above conditions
8:   end for
9:   for Agent in SubwayNetwork.Agents do
10:    Get 'Exposure' At Location
11:    Get City-wide COUNTERMEASURES
12:    Get Percentage of commuters
13:    Calculate SEIR beta and gamma based on conditions
14:    Update SEIR numbers
15:  end for
16: end for
```

Subway Agent - SEIR Agent with additional exposure based on location.

Subway Environment (Graph) - Nodes \propto Stations, Edges \propto Lines, Complex



NYC Model Parameters, Hyper-parameters

	Contact Rate (β)	Latent Rate (α)	Removal Rate (γ)	Start Trigger
Default	1.75	0.2	0.5	$t = 0$
Isolation Modifier	0.25	1	2	$I > 5000$
Recommendation Modifier	0.67	1	1.5	$I > 500$
Awareness Modifier	1 to 0.25	1	1	$I > 500$

Other Parameters: Global Exposure, Defiance, Commuter Ratio By Station, Awareness Increase Rate, Borough Commuting Modifier...

Compartmental Modeling Results (NYC)

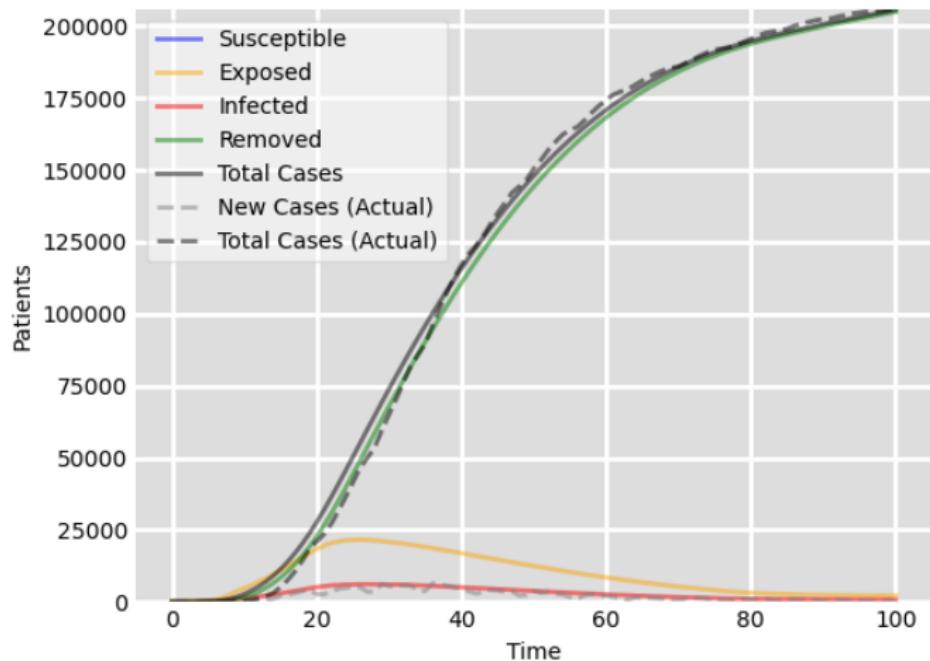
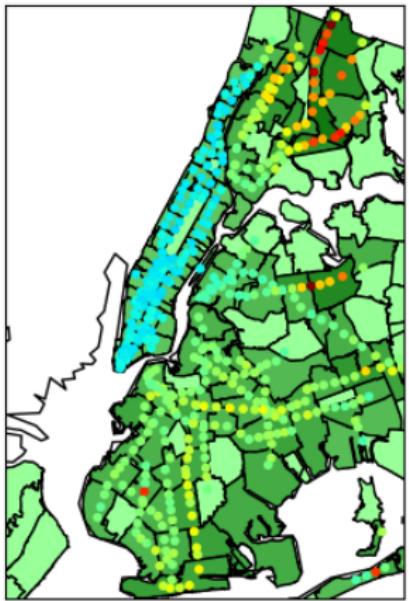


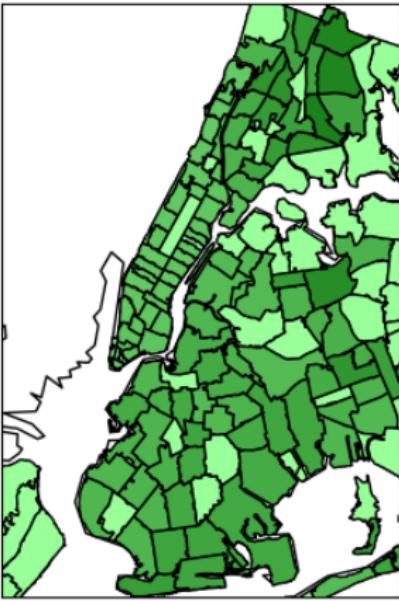
Figure: SEIR Fitting to NYC Case Total. $MAPE(t \geq 30)$: 0.0145

Results by MODZCTA (NYC)

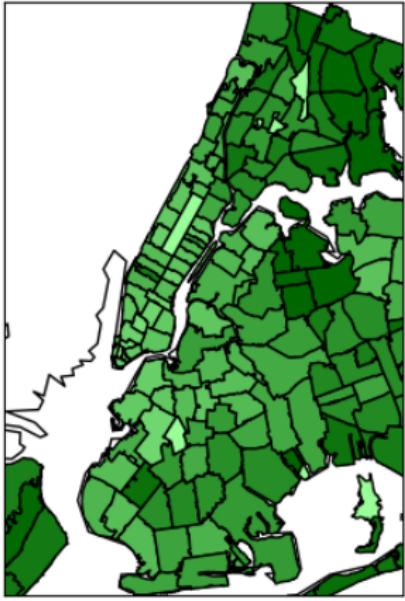
normalized_hotspot t=18



normalized_hotspot t=18



2020-04-14



Scale(0 - 0.11 infections/person, 0 - 0.11 infections/person, 0 - 0.20 cumulative cases/person)

$MAPE (t \geq 32, \text{Stations} \geq 1 = 0.311)$

New York City Timelapse

Discussion

- More granular passenger flow and population data.
- New York City is not a closed system.
- Control for population density, income, and other factors.
- Simplify away the feature bloat

Conclusions

All models are wrong, but some are useful -George Box

- Determining passenger flow is a difficult problem for all transportation networks at all granularities.
- Rush hour and hubs contribute strongly to disease propagation
- Commute time is correlated to prevalence of ILIs
- Subway routes are correlated to prevalence of ILIs

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Frank Acquaye - WAN, Passenger Flow

Ho Lum Cheung - NYC, Organization, Research, Testing

Dimas Muñoz-Montesinos - Madrid, Hotspots

Elie Wanko - Theory, Consulting

[Project on Github](#)

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