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?

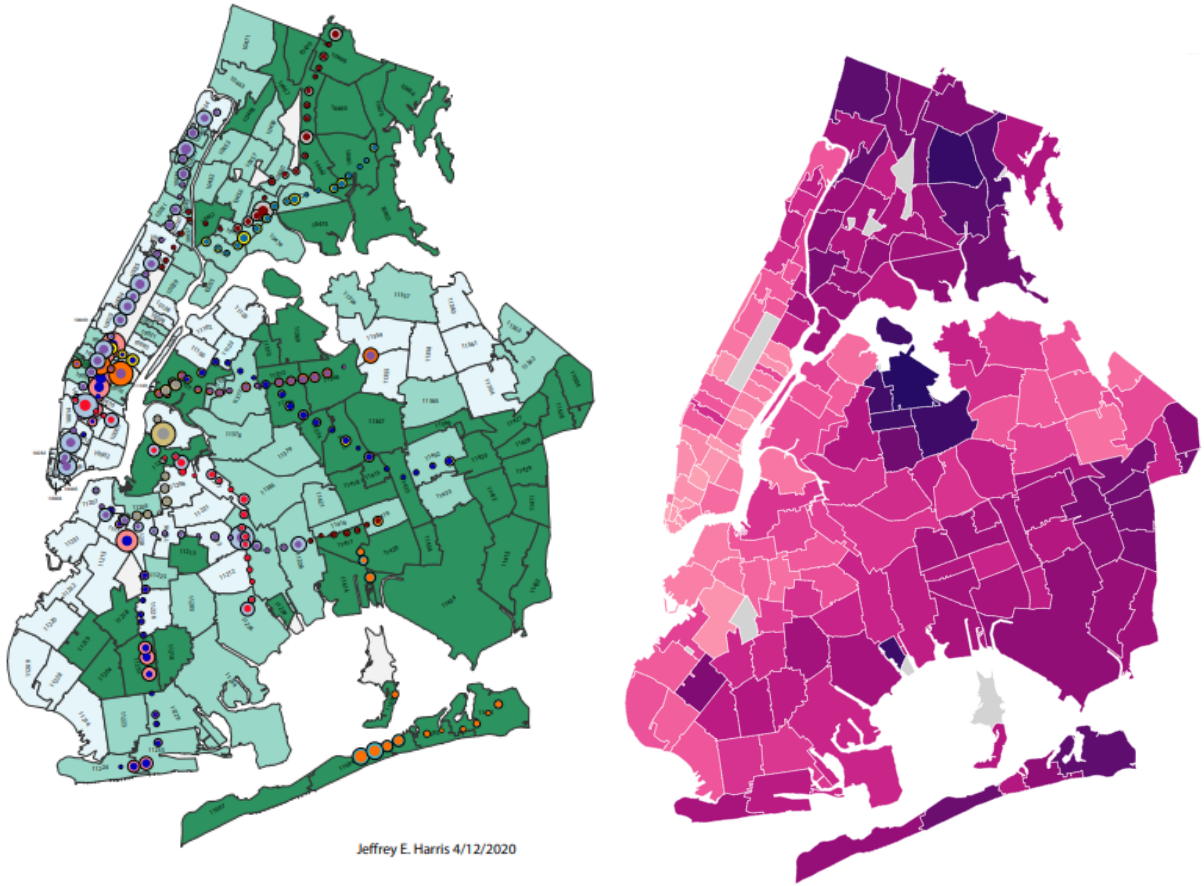
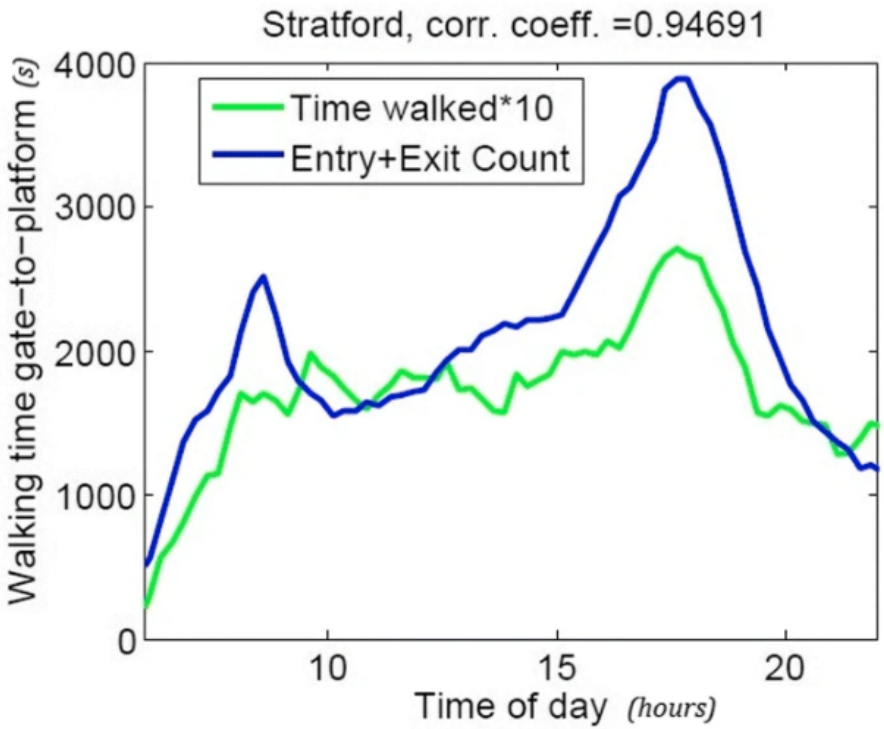
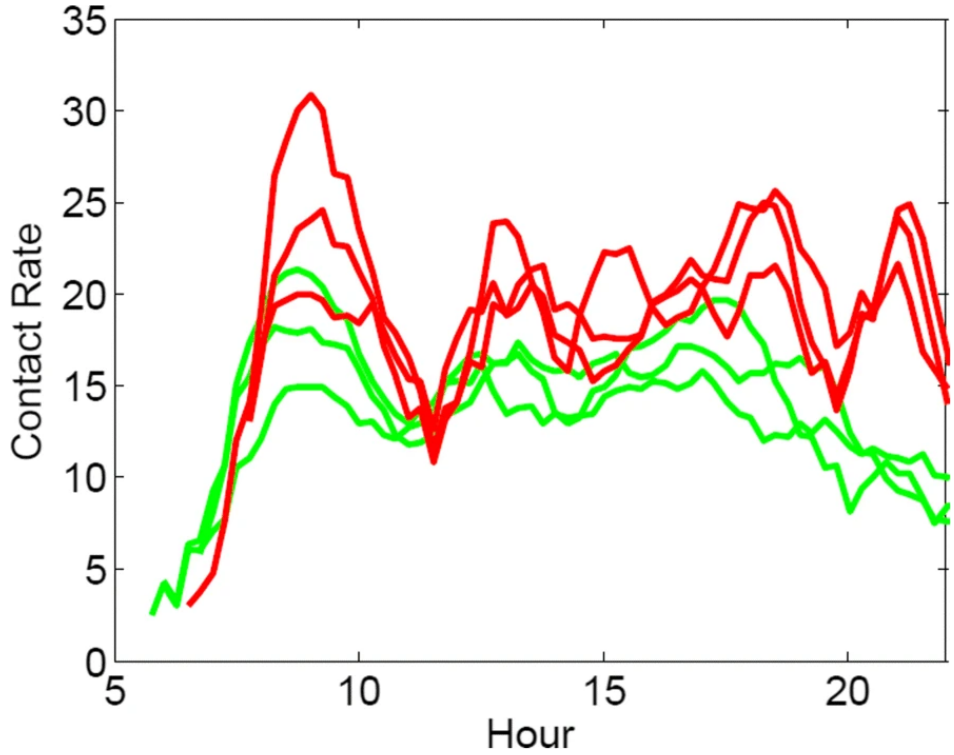


Figure: Left: Case Rate And Subway On April 12, 2020 [**?**]
Right: NYC COVID Case Rate As Of June 23, 2020 [**?**]

Prior Research (London Underground)

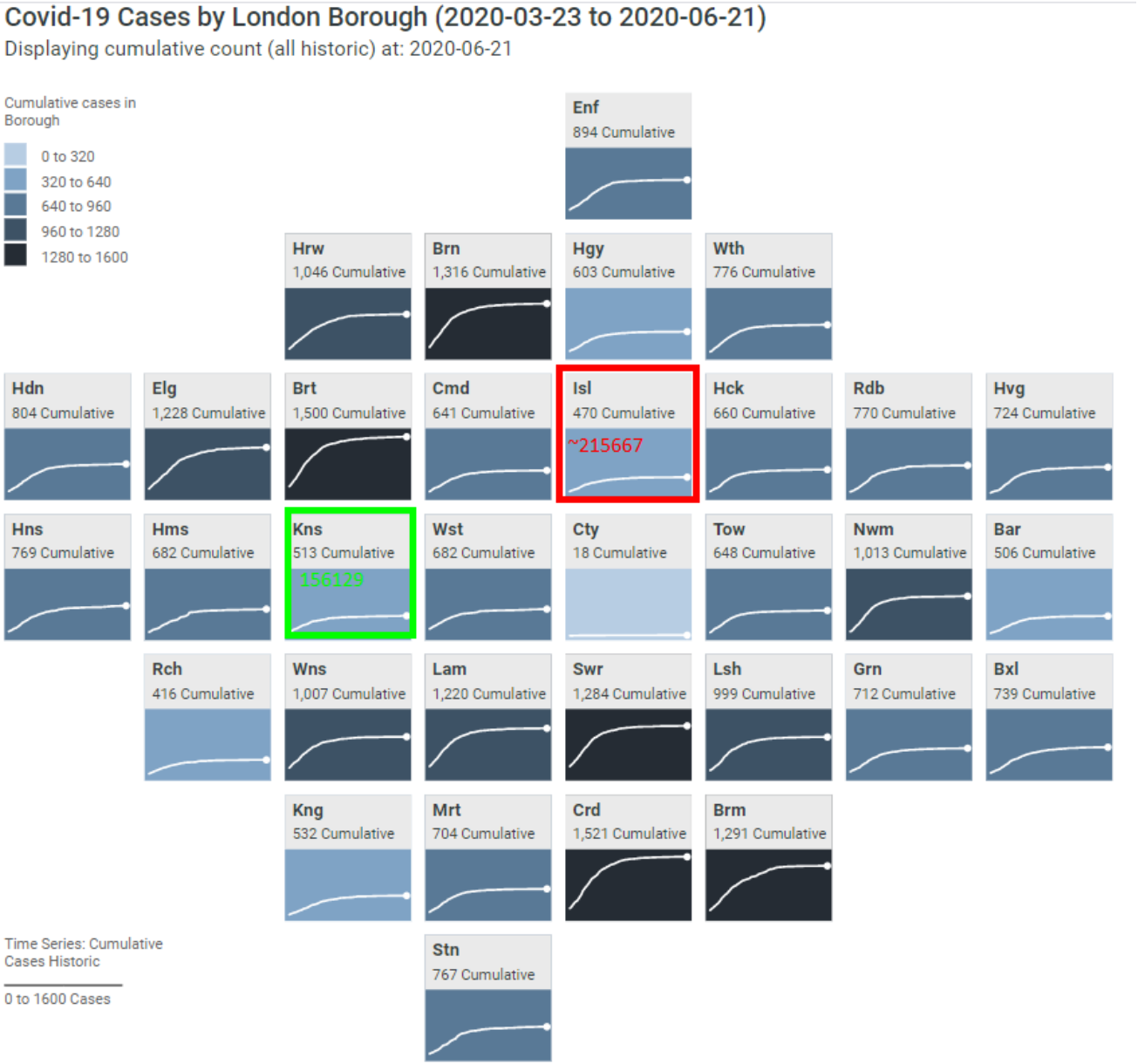
Data: Oyster (Card), CASA (Timetable), PHE Data (Demographics)





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. [**?**]

COVID in London



Speaker's Remark:

Prior Research (Singapore Buses)

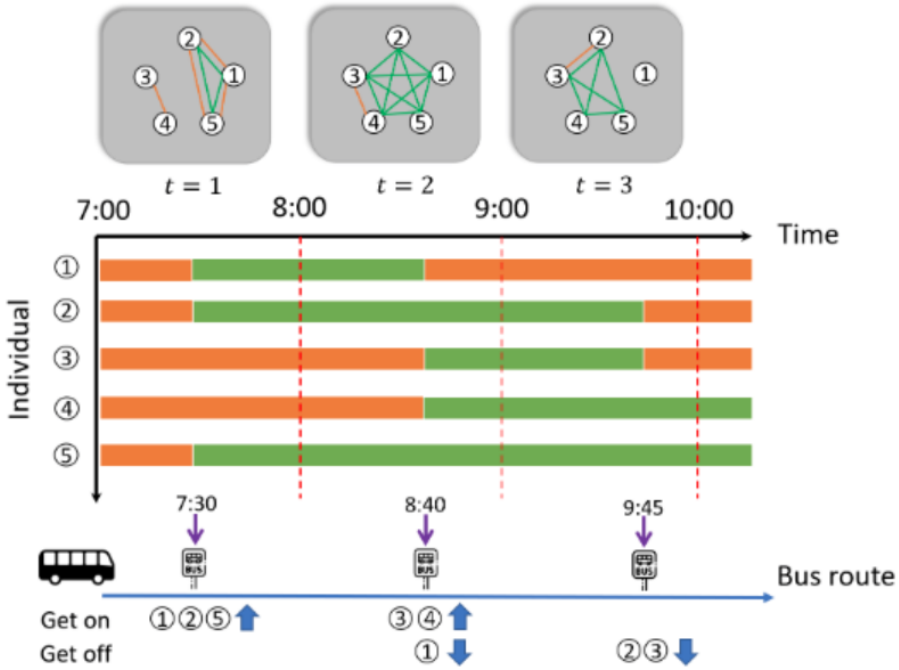
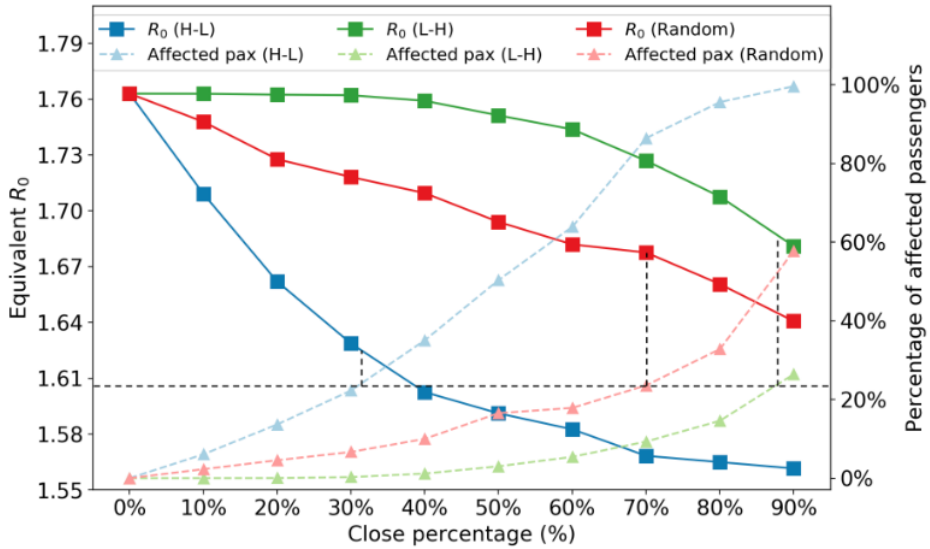


Figure 1: Network representation of a five-passenger system

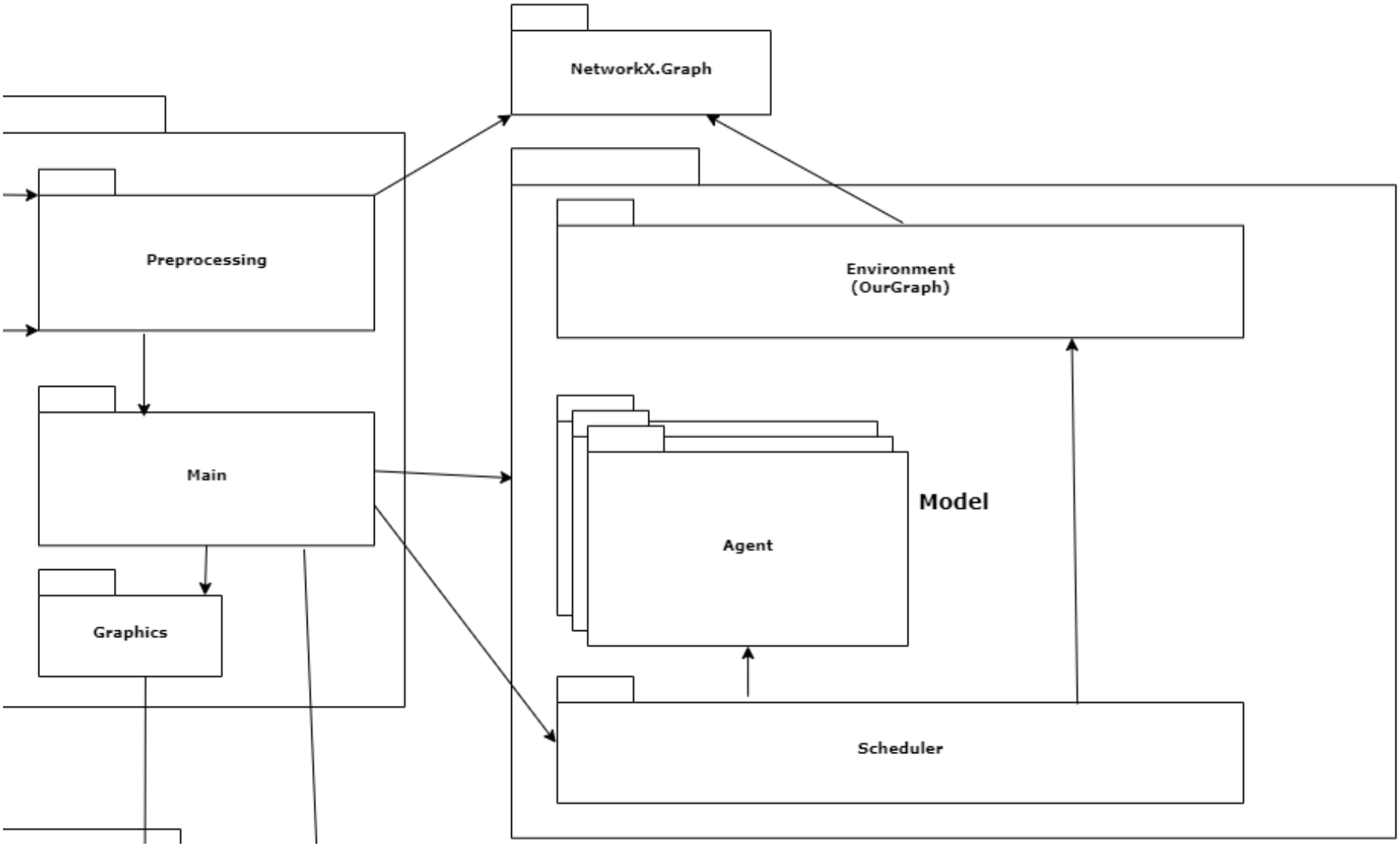


The direct contact in trains is, however, difficult to obtain from smart card data because the transactions are recorded at the station level [**?**]

Speaker's note:

- We show these things not to embarrass ourselves, but the depth of research available even just looking at one system. - List some other research

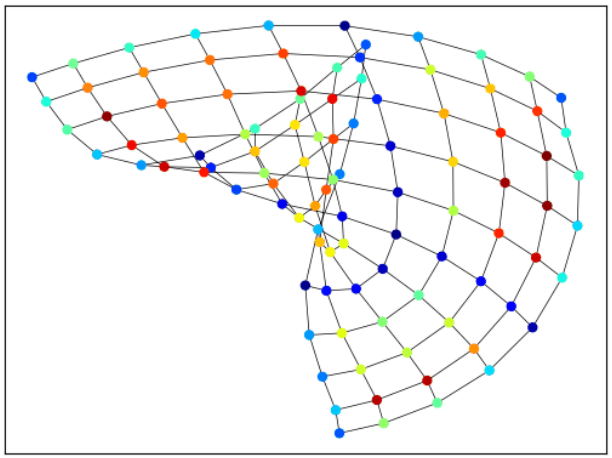
ABM Framework

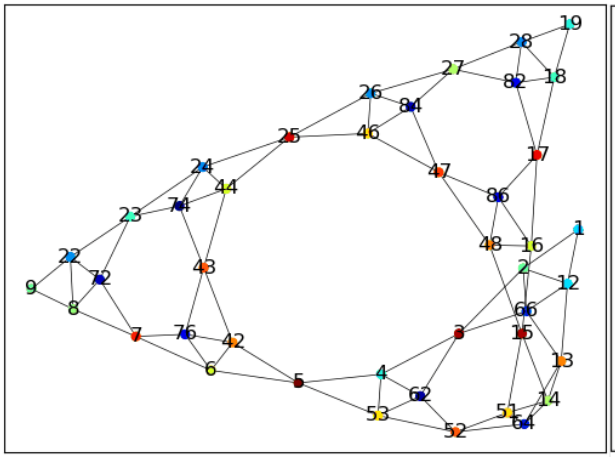


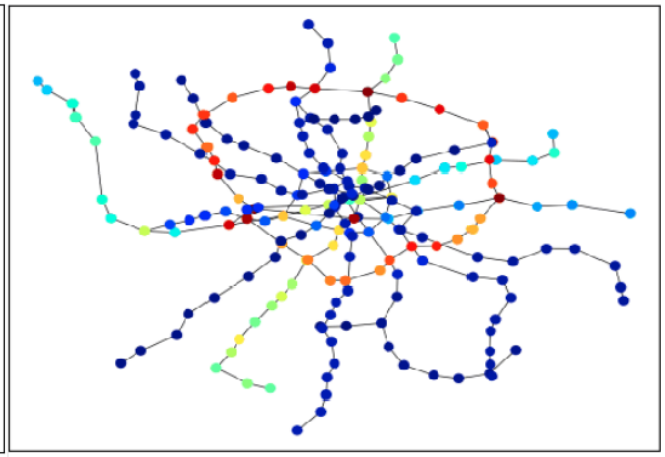
Components: Python, MESA, Networkx

Base Classes: Transportation Model, SEIR Agent

Simple Geometries







- Grid
- Sierpinski's Triangle
- Moscow

World Airline Network (Passenger Flow)

Disease spread faster inside a country. Why? Data Source (openflights, articles) World Airline Network Methods (ABM)

World Airline Network (Passenger Flow)

Madrid Commuter Trains (Central Hubs)

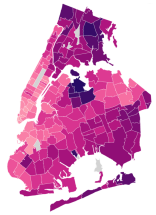
How important are central transportation hubs to disease spread? Data Source (madrid renfe gtfs)

Madrid Commuter Trains (Central Hubs)

Methods (ABM)

Results (Madrid)

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 [**?**]*

- 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

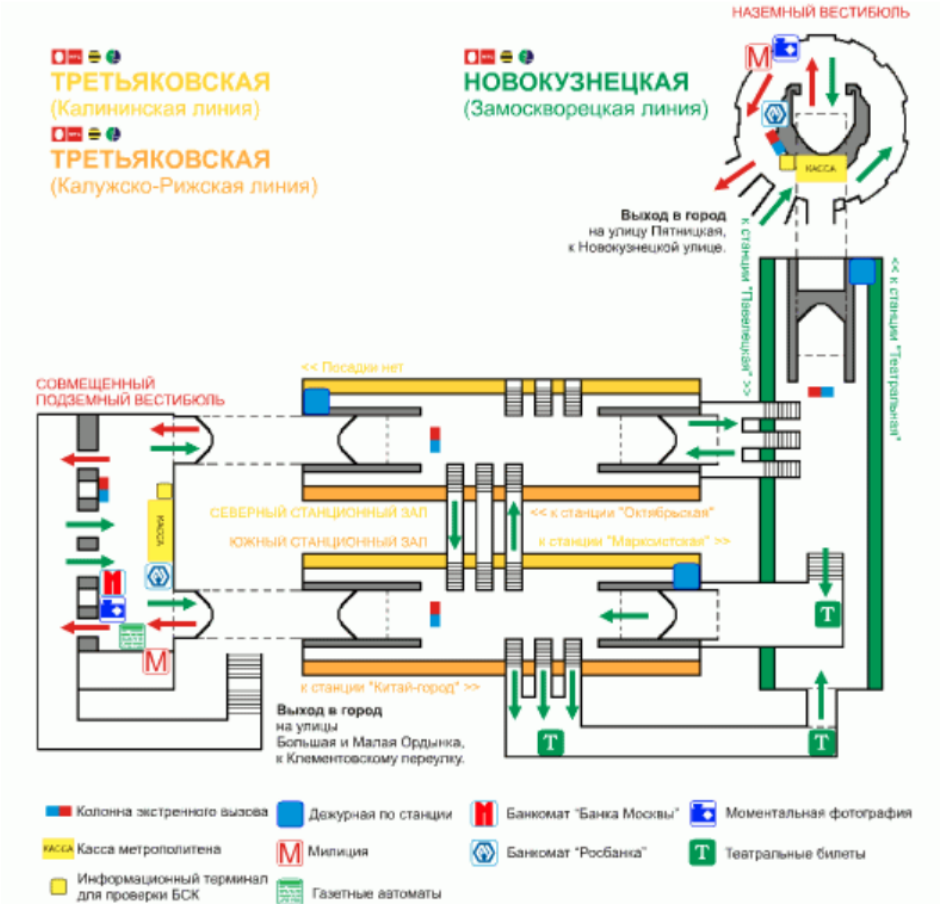


Figure: Floor Plan of Novokuznetskaya Metro Station [**?**]

NYC Subway Data

Stations, Map, Turnstiles (GTFS not considered)

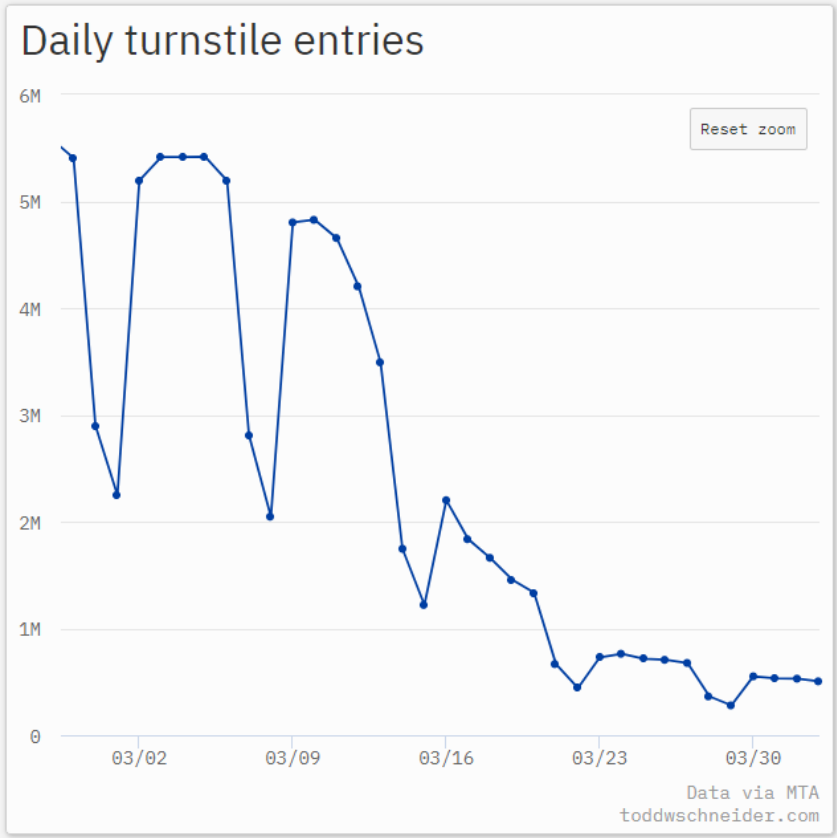


Figure: NYC Subway daily turnstile entries for March 2020 [**?**]

```
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

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

Subway Agent - SEIR Agent with additional exposure based on location.
Subway Graph - Nodes $\propto$ Stations, Edges $\propto$ **Lines, Complex**, Route Lookup.

NYC Model Parameters, Hyper-parameters

Default SEIR Rates: $\beta, \alpha, \gamma = 1.75, 0.20, 0.50$
Countermeasures: Isolation, Recommendation, Awareness: $= 5000, 500, 500$
Defiance: 10% Local, 25% Global
Global Exposure: 0.7
Commute Time: Squared shortest path from Grand Central or Times Square

Compartmental Modeling Results (NYC)

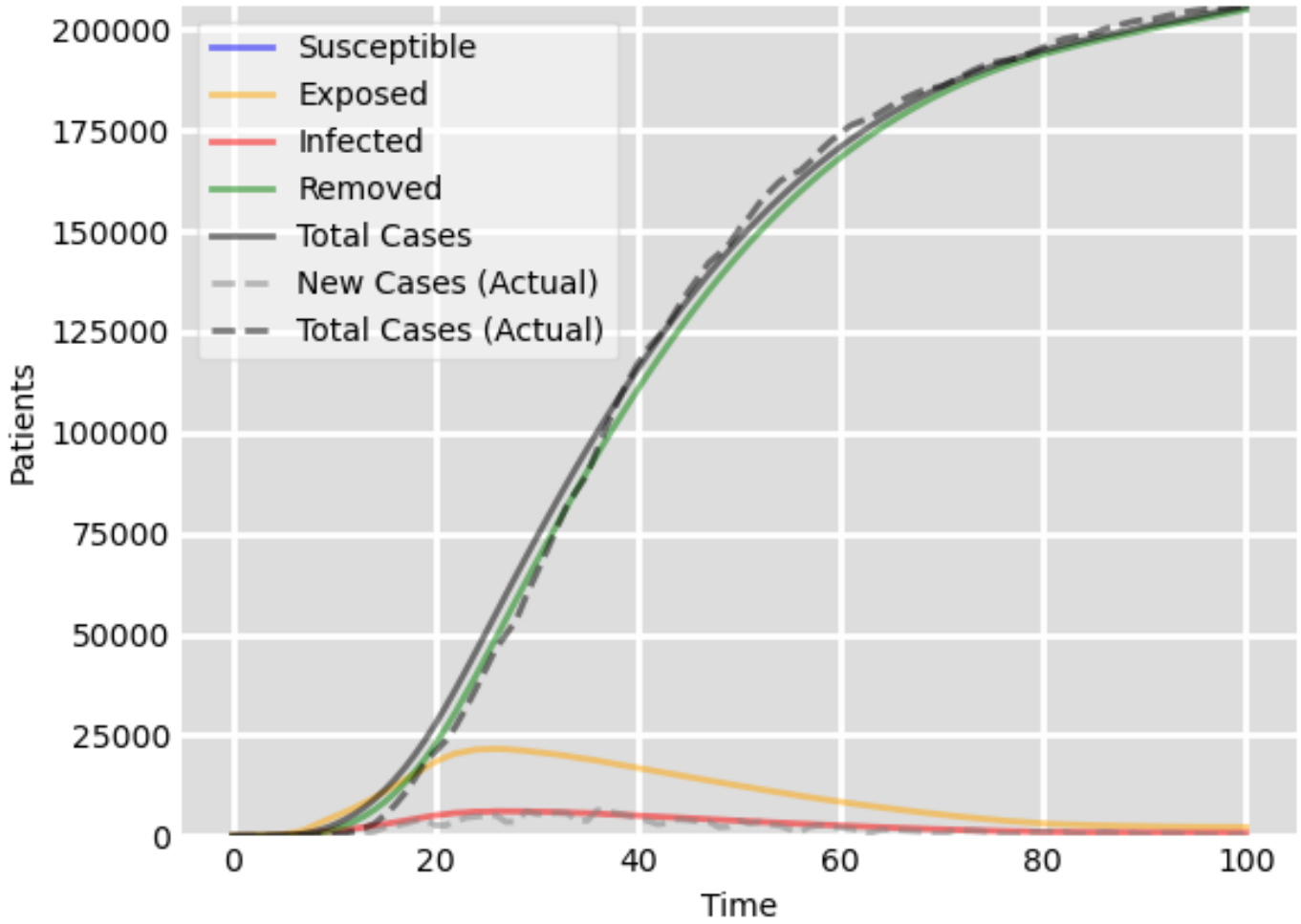
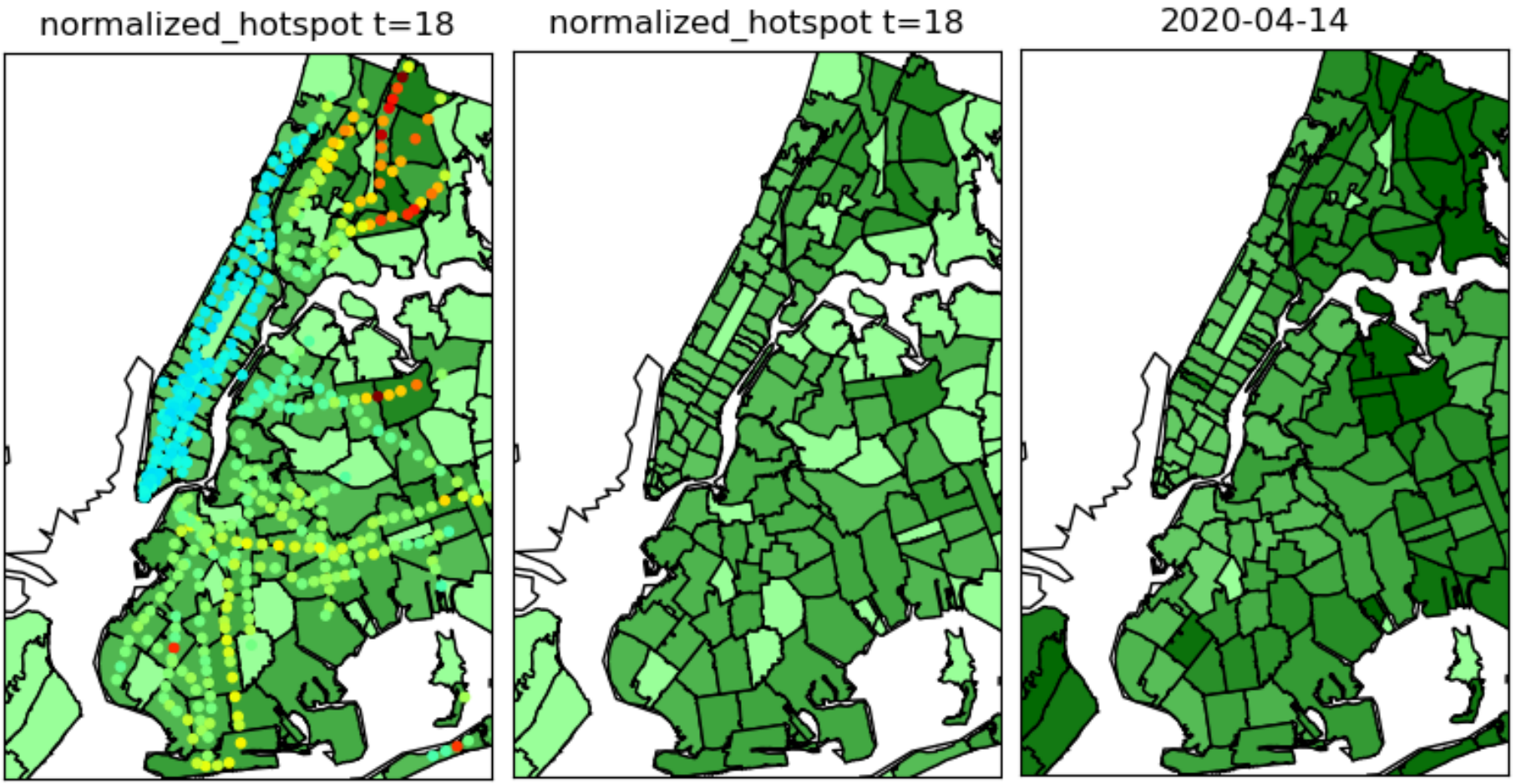


Figure: SEIR Fitting to NYC Case Total. *MAPE* ($t \geq 30$)*: 0.0145*

Results by MODZCTA (NYC)



New York City Timelapse

Discussion

All models are wrong!

- Passenger Flow
- Outer suburbs phenomenon exists
- Simple GDP/capita data
- Erase some of these stupid parameters

Conclusions

- Determining passenger flow is a difficult problem for all transportation networks at all granularities.
-
-

Credits, Links, References

Frank Acquaye - WAN, Passenger Flow
Ho Lum Cheung - NYC, Organization, Research, Testing
Dimas Muñoz-Montesinos - Madrid, Hotspots
Elie Wanko - Theory, Consulting
github link references used in slides