Epidemiology of the Airways:

Using World Airplane Flight Paths to Simulate the Spread of Disease

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How can we control the spread of disease?

2.86 Billion

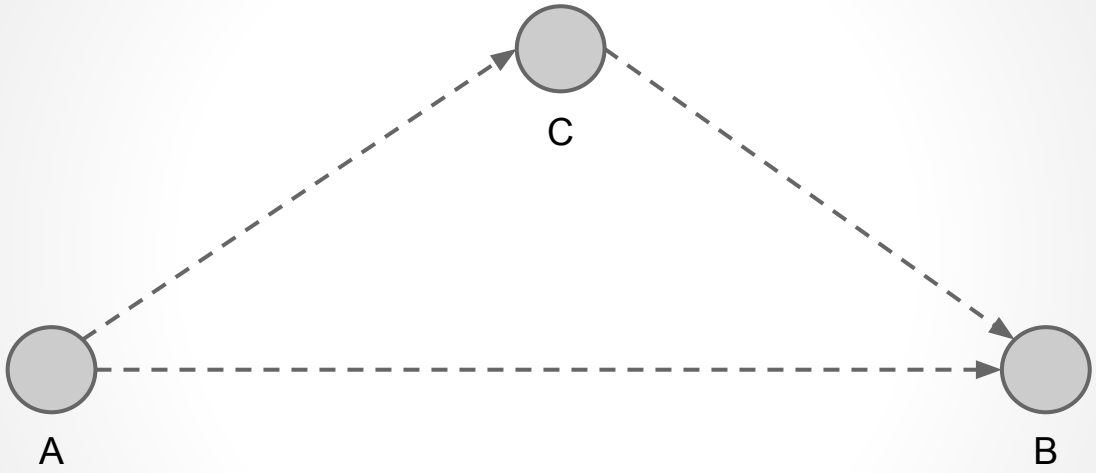
Airline passengers worldwide per year

Data for 2013 according to The World Bank

7.85 Million

Airline passengers worldwide per *day*

Data for 2013 according to The World Bank


C
A
B

7,662

Airports

Data for 2014 according to openflights.org

68,819

Airline routes

Data for 2014 according to openflights.org

"Pandemics will move as rapidly as the vectors that transport the pathogen. In the case of human infectious diseases, transmission via ships has been replaced almost completely by air traffic."

Entry & Exit Screening Procedures, Gaber et al. (2009)

What did we learn from SARS?

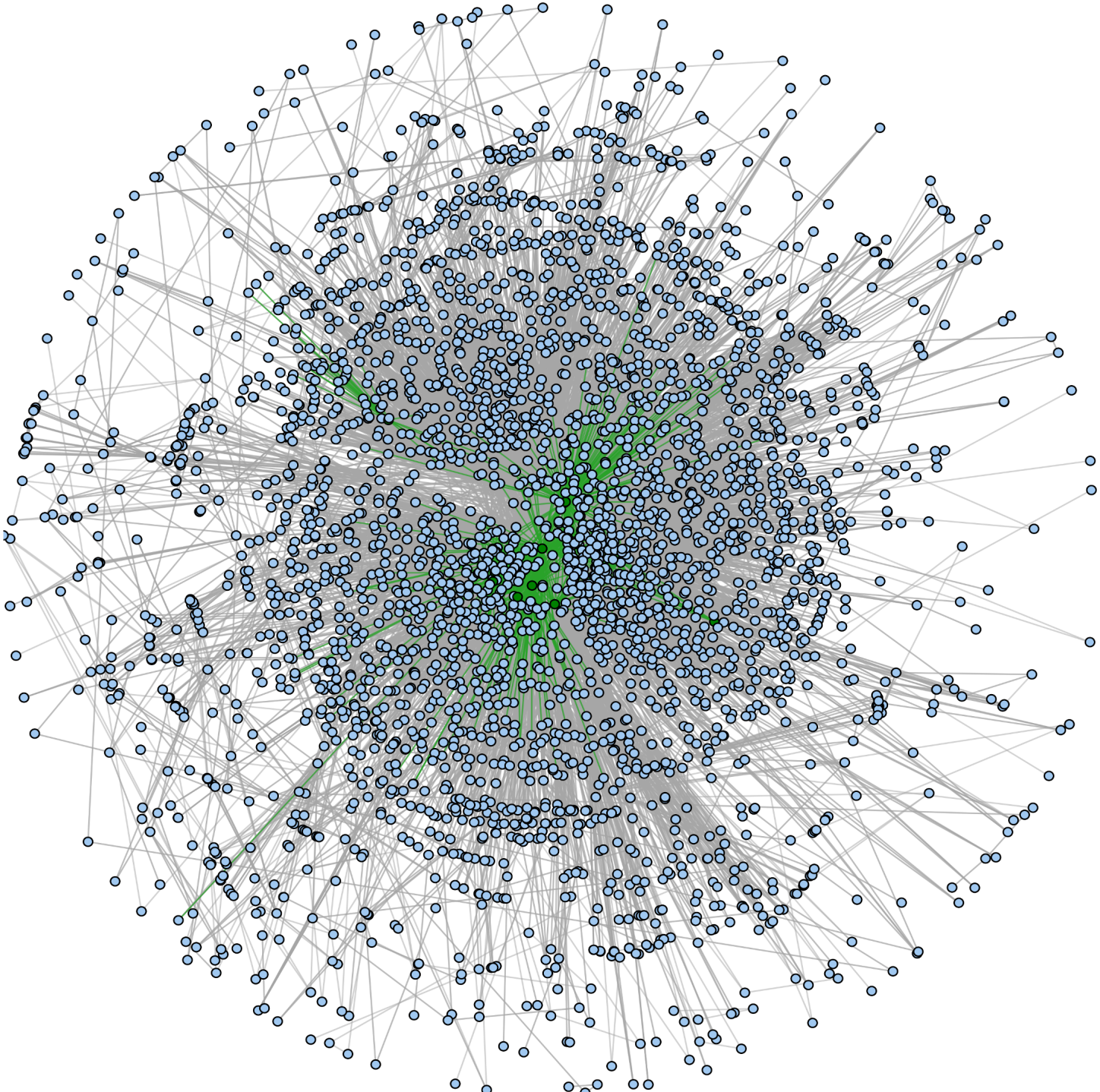
- WHO implemented quarantine strategies after the outbreak had spread.
  - Did not have a preexisting plan that provided specific instructions regarding method of transmission.
- Unprepared for a pandemic of *any* scale.
  - Universal experience.

How can we control the spread of disease?

Screen Passengers for Disease

Close Airports

Cancel Flights



Modifications to the Network

Removed redundant routes

Removed airports without commercial flights

Selected the largest component of the network

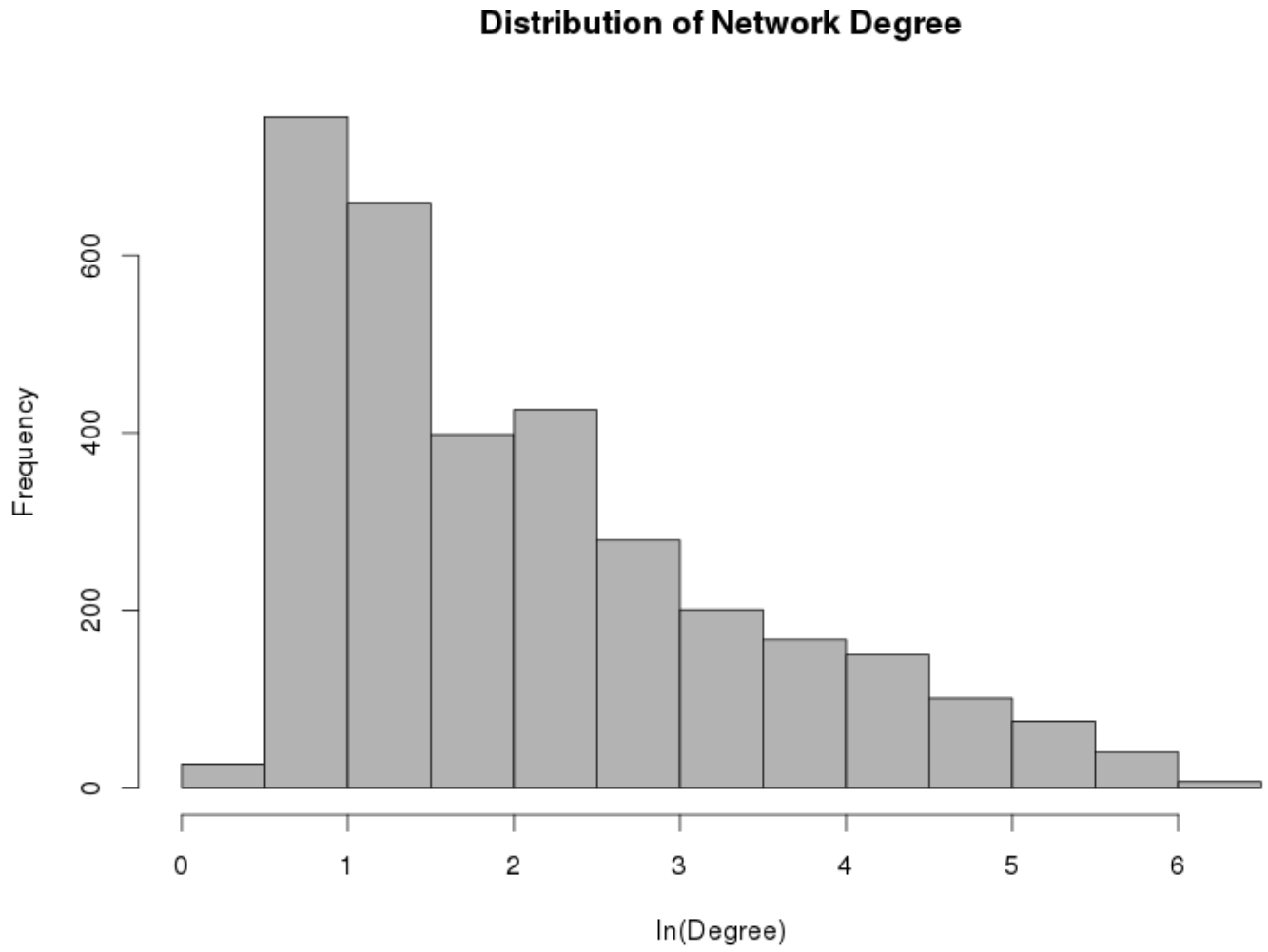
Properties of the Network Model

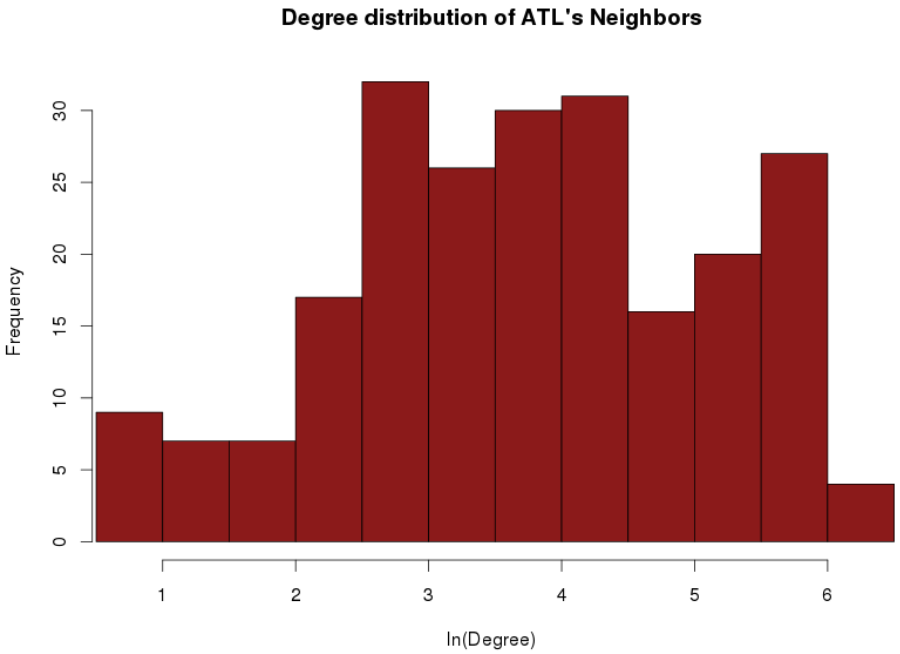
3,286 connected airports

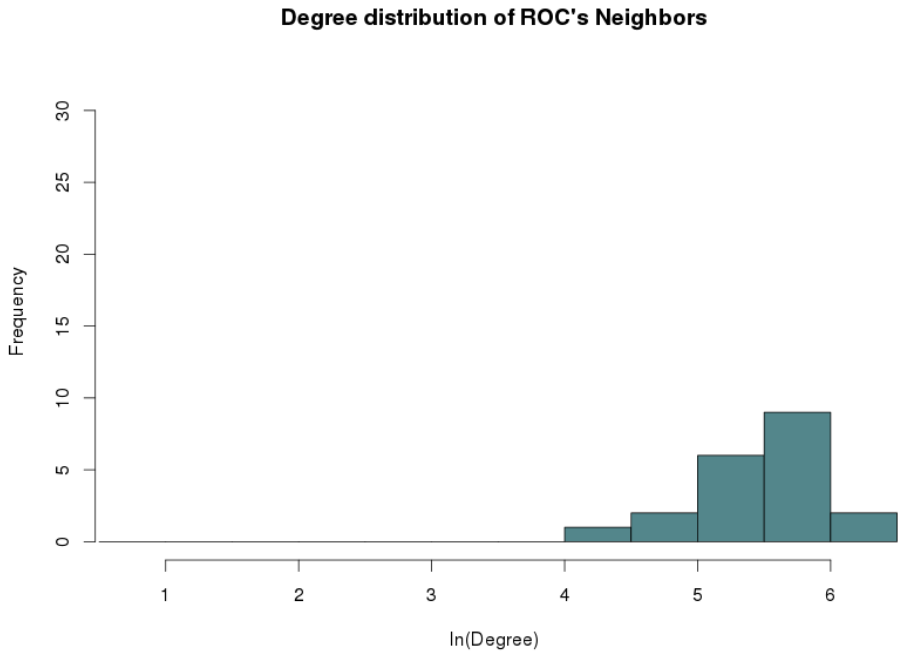
39,429 flights

Longest path has 11 stops

Network re-calculates traffic based on cancellations

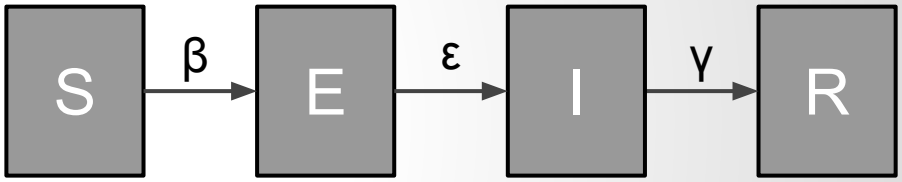

Distribution of Network Degree
Frequency
0
200
400
600
0
1
2
3
4
5
6
ln(Degree)


Degree distribution of ATL's Neighbors
Frequency
0
5
10
15
20
25
30
1
2
3
4
5
6
ln(Degree)

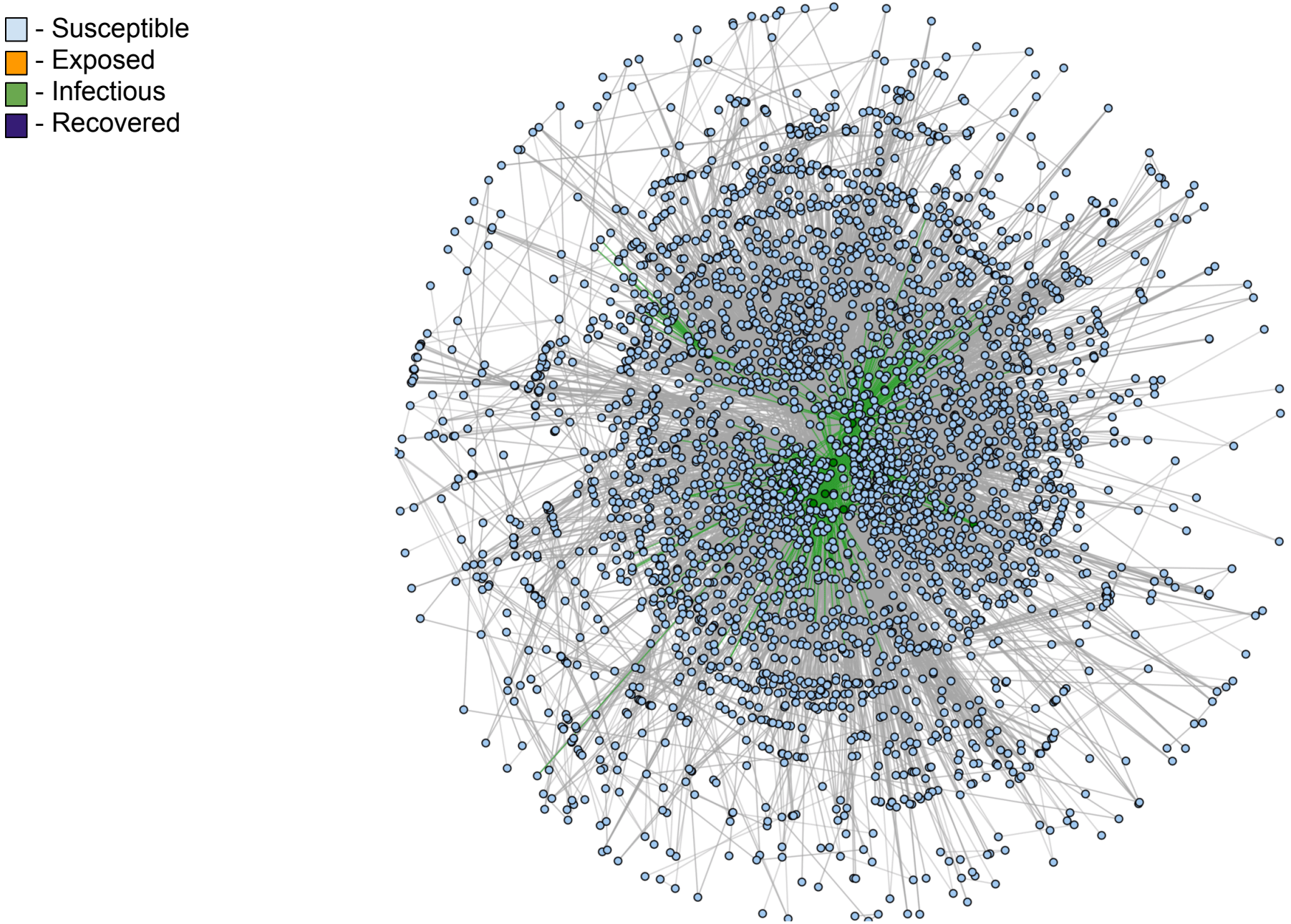

Degree distribution of ROC's Neighbors
Frequency
0
5
10
15
20
25
30
1
2
3
4
5
6
ln(Degree)

Disease in our Network Model

- Airports are used as proxies for individuals
  - Transient passengers infect airport staff, who can then infect other passengers.
- Infectious individuals travel along routes.
  - Each route has a probability of carrying infectious individuals.



β: The probability of being exposed
ε: Incubation rate
γ: Recovery rate


- Susceptible
- Exposed
- Infectious
- Recovered

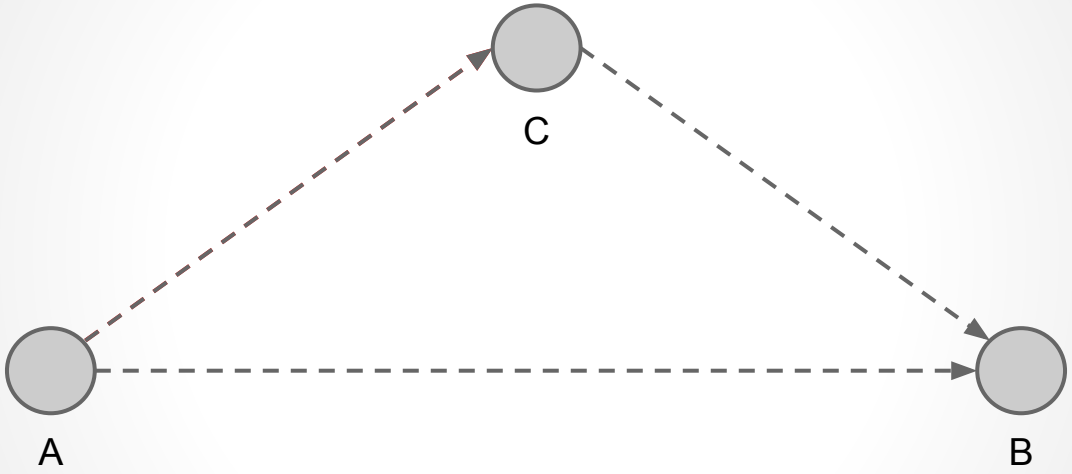
Strategies for Cancellation

Random

Betweenness Centrality

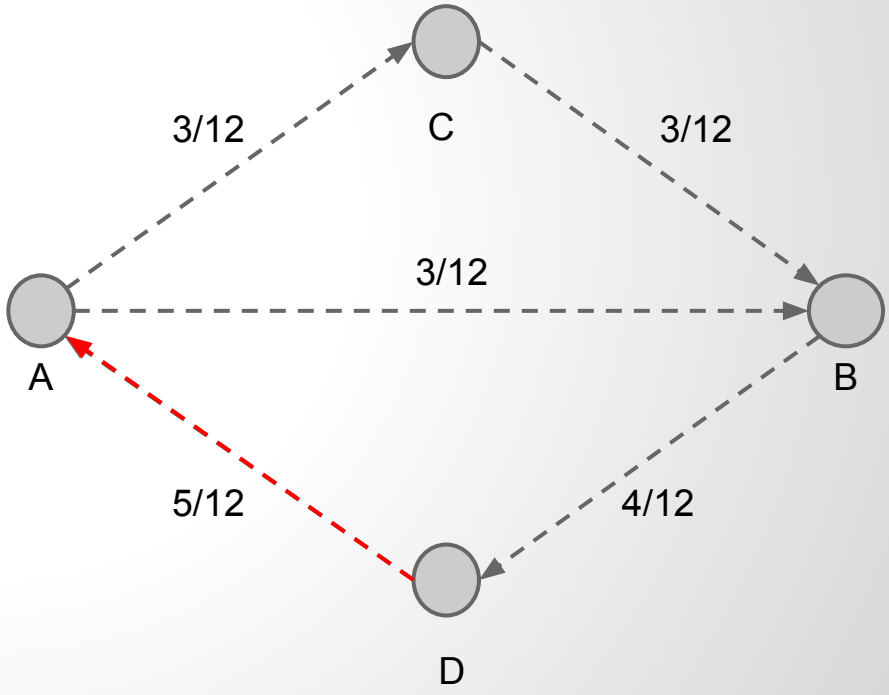
Clustering Coefficient

Random Cancellation



Betweenness Centrality Based Cancellation

- Cancel flights that have a high edge betweenness centrality.
- *The proportion of all shortest routes from all airports to all others that utilize a particular route.*



Betweenness centrality lets us cancel flights based on importance.

Sample Betweenness Routes

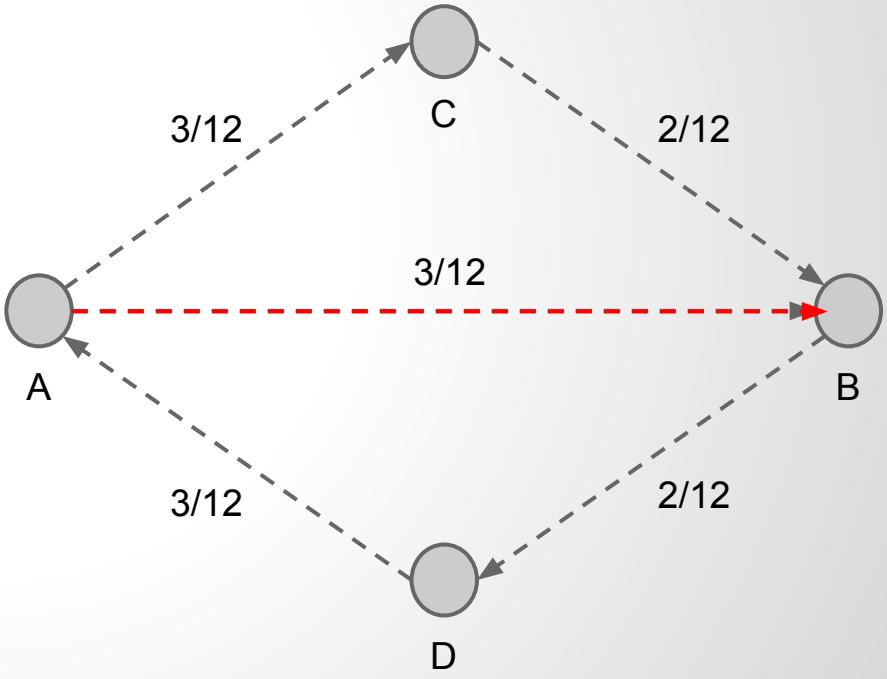
Sydney Airport TO San Francisco International

Narita International TO Hartsfield-Jackson Atlanta International

Newcastle Airport TO Canberra International

Clustering Coefficient Based Cancellation

- Cancel flights based on the summation of the clustering coefficient of the departure and arrival airport.
- *The number of realized routes for an airport's neighbors over the number of possible routes between all airports*



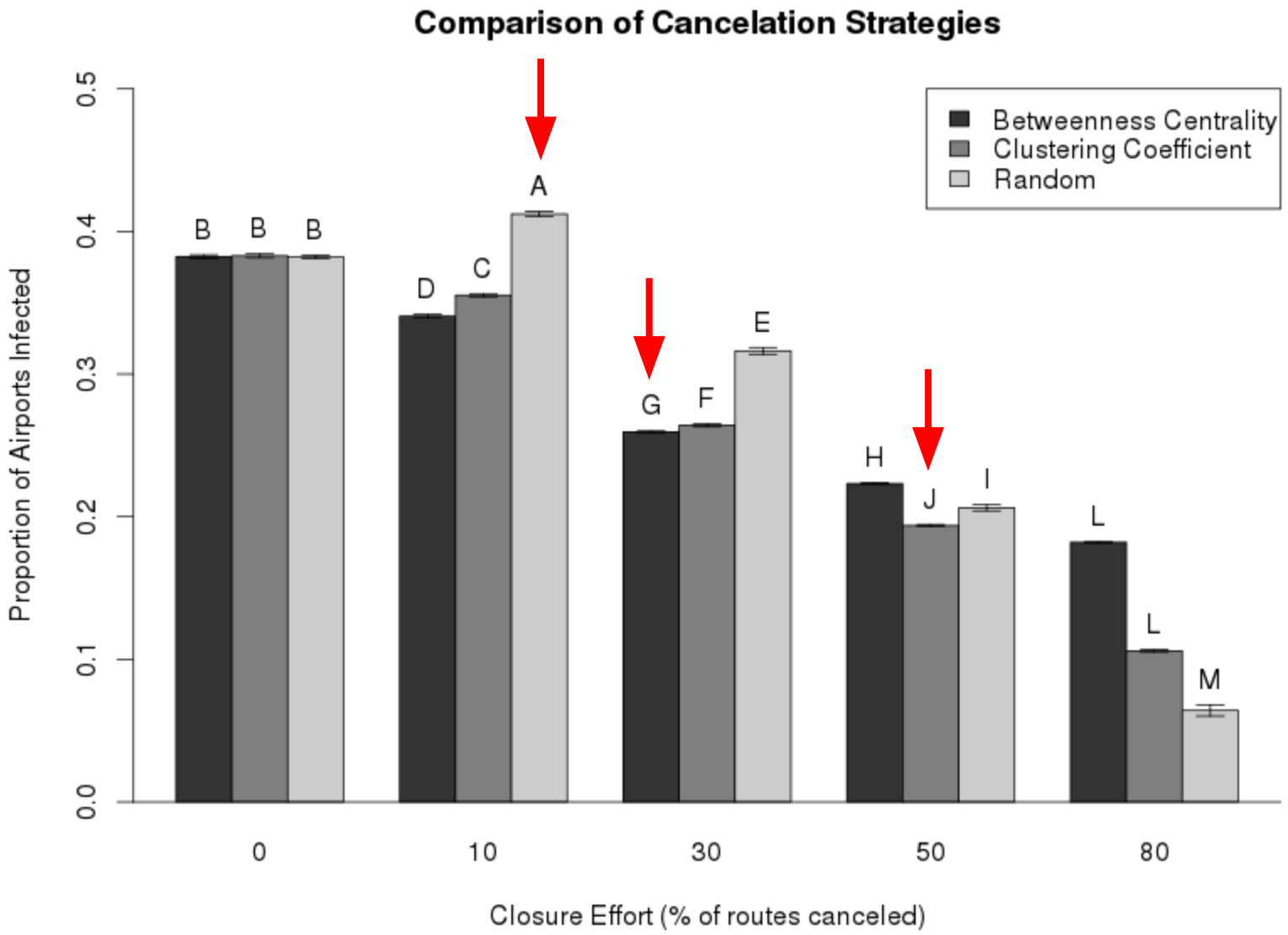
Clustering coefficient lets us cancel flights between highly connected airports in local clusters.

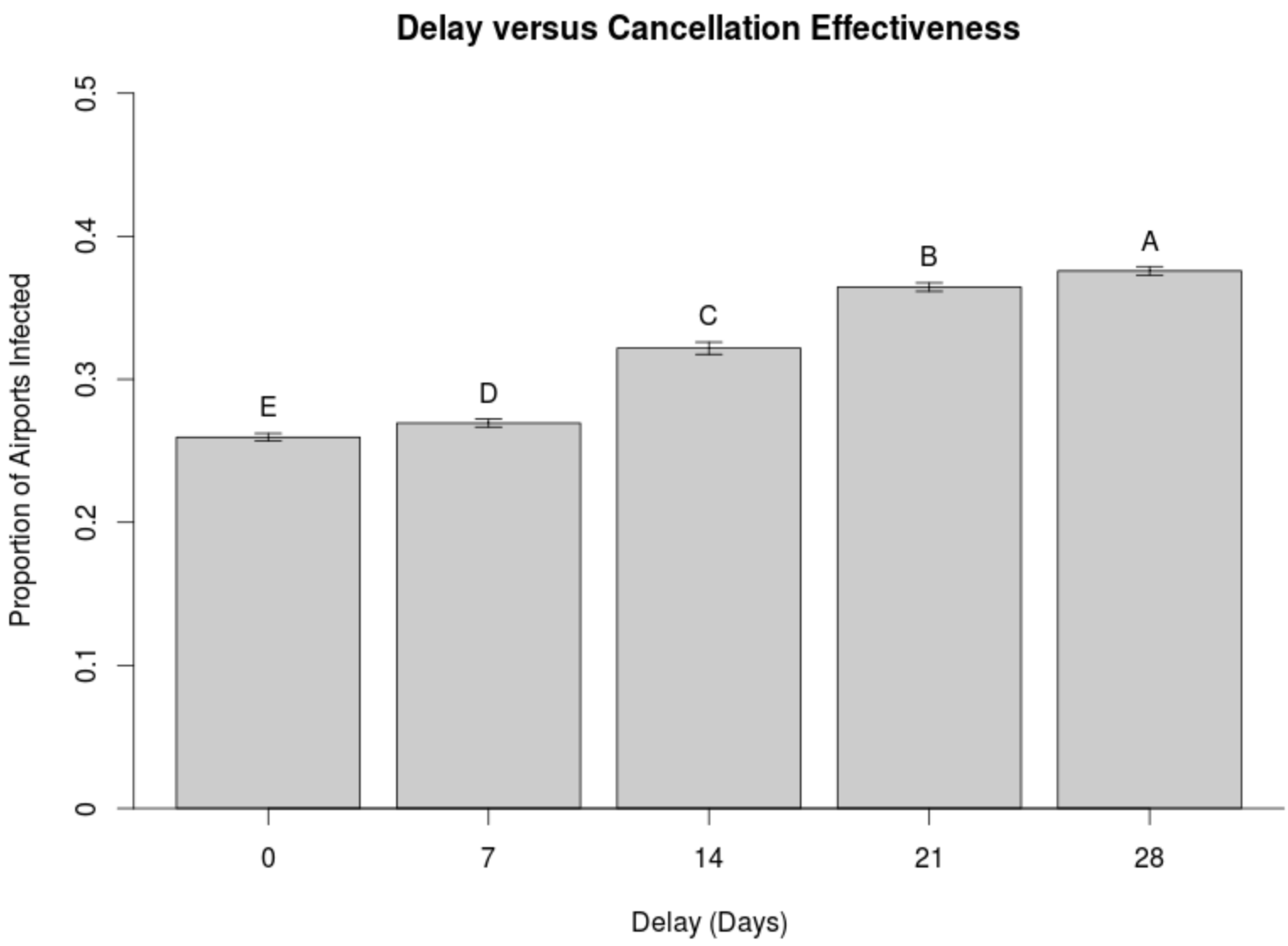
Sample Clustering Routes

Buffalo International TO Raleigh-Durham International

Richmond International TO Cincinnati International

Greater Rochester International TO Baltimore Washington International


Comparison of Cancelation Strategies
Betweenness Centrality
Clustering Coefficient
Random
Proportion of Airports Infected
0.0
0.1
0.2
0.3
0.4
0.5
B
B
B
D
C
A
G
F
E
H
J
I
L
L
M
0
10
30
50
80
Closure Effort (% of routes canceled)


Delay versus Cancellation Effectiveness
Proportion of Airports Infected
0
0.1
0.2
0.3
0.4
0.5
E
D
C
B
A
0
7
14
21
28
Delay (Days)

What do our results tell us?

Clustering coefficient and Betweenness Centrality are effective metrics when preventing infections by canceling flights.

Inappropriate closures may facilitate the spread of infectious disease

Timely detection of infection is very important for cancellation success.

Acknowledgements

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Works Cited

1. Amaral LAN, Scala A, Barthelemy M, Stanley HE. 2000 *Classes of small-world networks*. *Proc. Nat. Acad. Sci.* 97;21. DOI: doi: 10.1073/pnas.20032719.
2. Amaral LAN, Guimera R. 2004 *Modeling the world-wide airport network. Eur. Phys. J B*. 38, 381-385. DOI: 10.1140 /epjb/e2004-00131-0.
3. Marcelino J, Kaiser M. 2012 *Critical paths in a metapopulation model of H1N1: Efficiently delaying influenza spreading through flight cancellation. PLoS Curr.* April 23. DOI: 10.1371/4f8c9a2e1fca8.
4. Garber W, Goetsch U, Diel R, Doerr HW, Gottschalk R. 2009 *Screening for Infectious Diseases at International Airports: The Frankfurt Model*. *Aviat Space Environ Med* 80:595-600.
5. Gaber, Walter, Udo Goetsch, Roland Diel, Hans W. Doerr, and René Gottschalk. "Screening for Infectious Diseases at International Airports: The Frankfurt Model." *Aviation, Space, and Environmental Medicine* 80.7 (2009): 595-600. Web.