# Making Connections: An Analysis of US Commercial Aviation Networks

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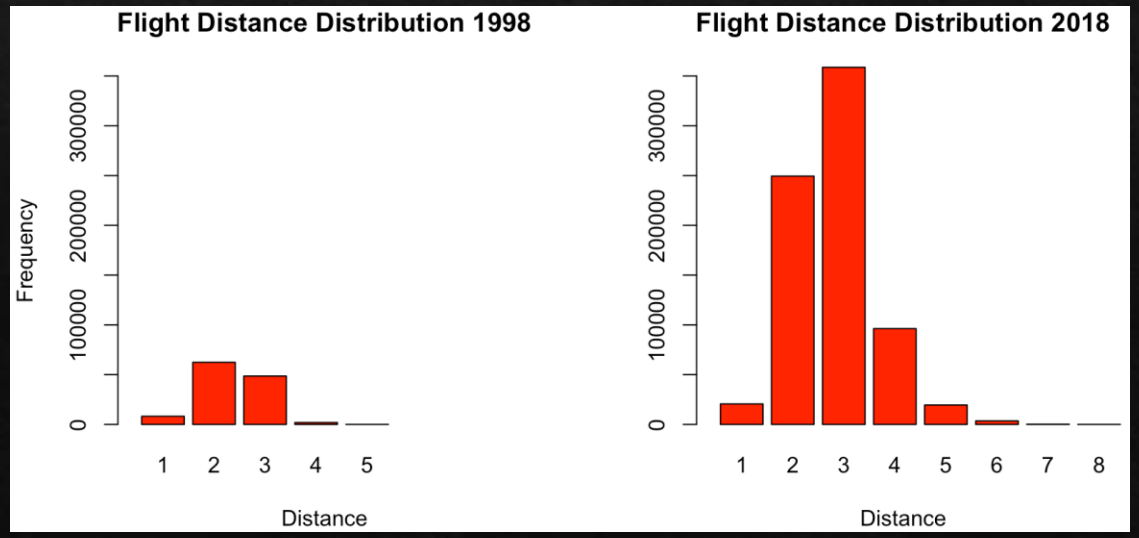
Continental US Aviation in 1998

Continental US Aviation in 2018

Note: Node size is the scaled degree. Edge width and color hue are scaled to number of flights between edges, with thicker lines and darker hues for higher weights.

# *Overview of Total Network*

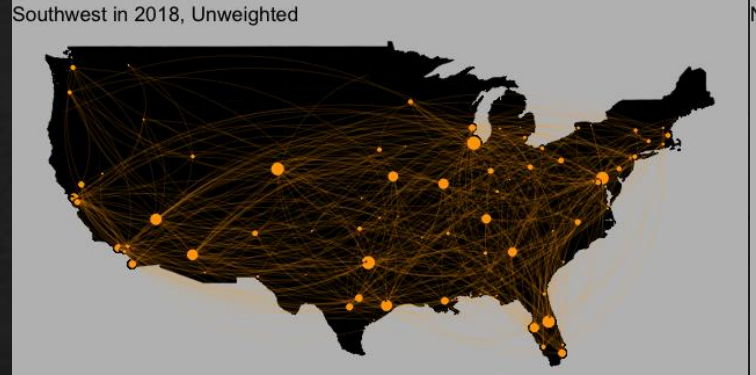
| Metric | 1998 | 2018 |
|---|---|---|
| Unweighted Average Betweenness | 619.4 | 2,700.0 |
| Unweighted Average Degree | 74.7 | 76.6 |
| Unweighted Diameter | 7 | 9 |
| Weighted Average Betweenness | 969.7 | 3,416.3 |
| Weighted Average Degree (Strength) | 35,261.7 | 13,667.0 |
| Number of Airports (Vertices) | 410 | 1,246 |
| Number of Legs (Edges) | 15,323 | 47,716 |
| Number of Flights (Weight) | 7,228,654 | 8,514,517 |
| Number of Passengers | 575,354,256 | 787,782,842 |

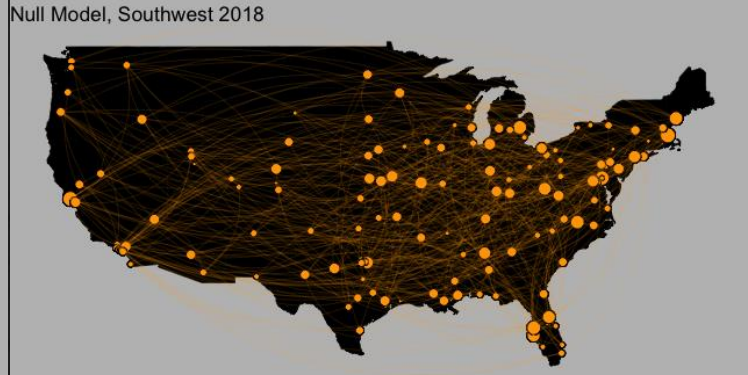


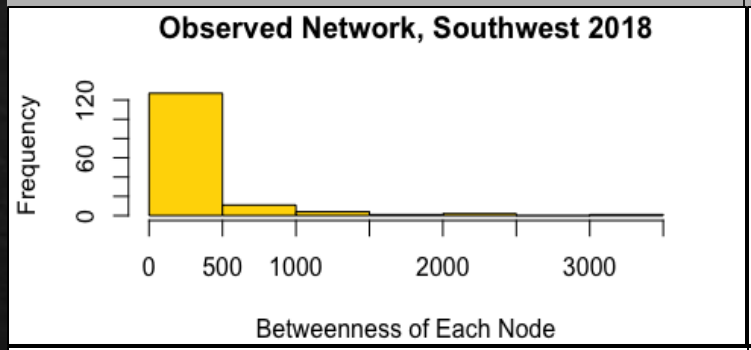
# A Tale of Two Airlines

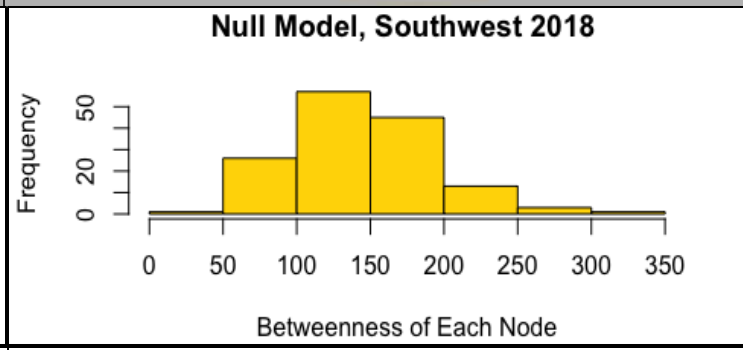
- From 1998 to 2018, Southwest's network nearly tripled the number of nodes, maintained the same average degree, and increased the average betweenness.
- In the same time, Delta's number of nodes and average betweenness both increased by ~44% while the degree increased by 25%.
- When we compared 2018 networks for Delta and Southwest to null models, its clear the observed networks are more centralized than the null model, with a long tail containing a high number of central nodes.
- Delta clearly exhibits this pattern more extremely than Southwest, suggesting Southwest is a flatter network while Delta relies on fewer, larger hubs. An example is Atlanta, a major Delta hub with a betweenness score of 16,812.

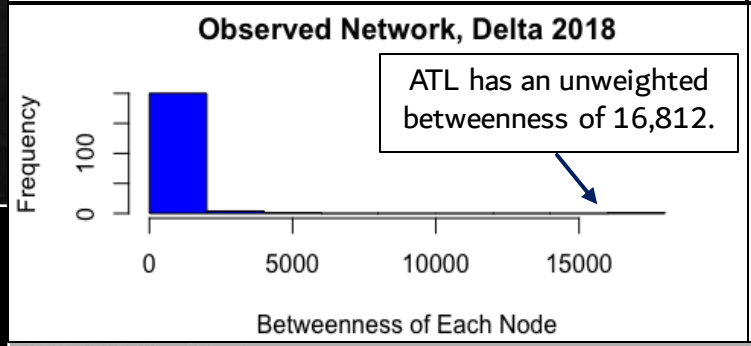
| (measurements are from an unweighted graph) | Number of Nodes | Observed Average Degree | Observed Average Between-ness | Null Model Average Degree | Null Model Average Between-ness |
|---|---|---|---|---|---|
| **Southwest 1998** | 52 | 31.8 | 41.7 | 32.6 | 35.9 |
| **Southwest 2018** | 138 | 35.34 | 201.9 | 34.8 | 144 |
| **Delta 1998** | 131 | 24.9 | 159.1 | 24.7 | 172.3 |
| **Delta 2018** | 187 | 31.3 | 231.1 | 30.9 | 249 |

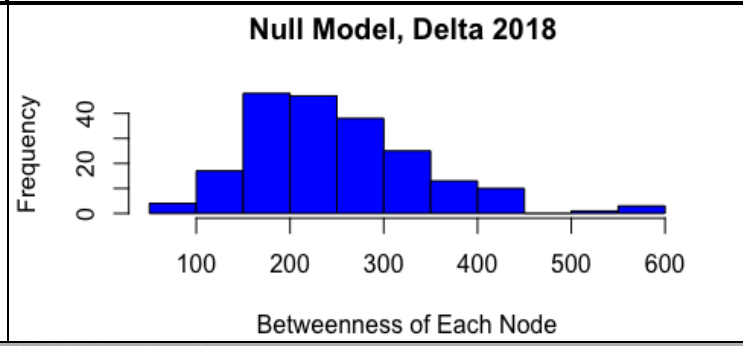


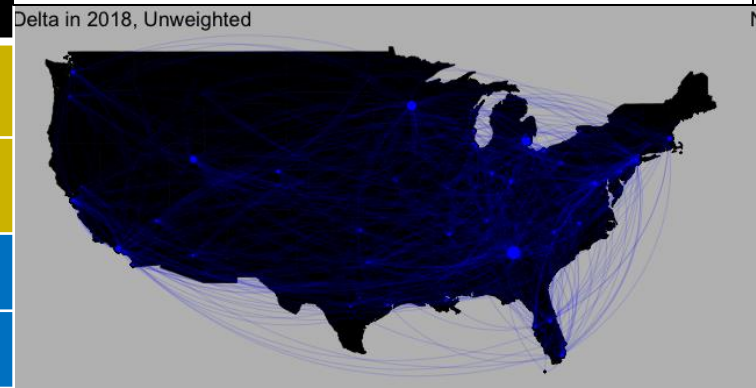



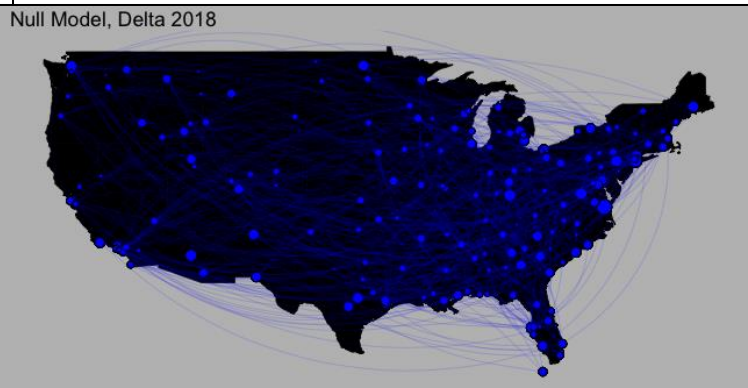



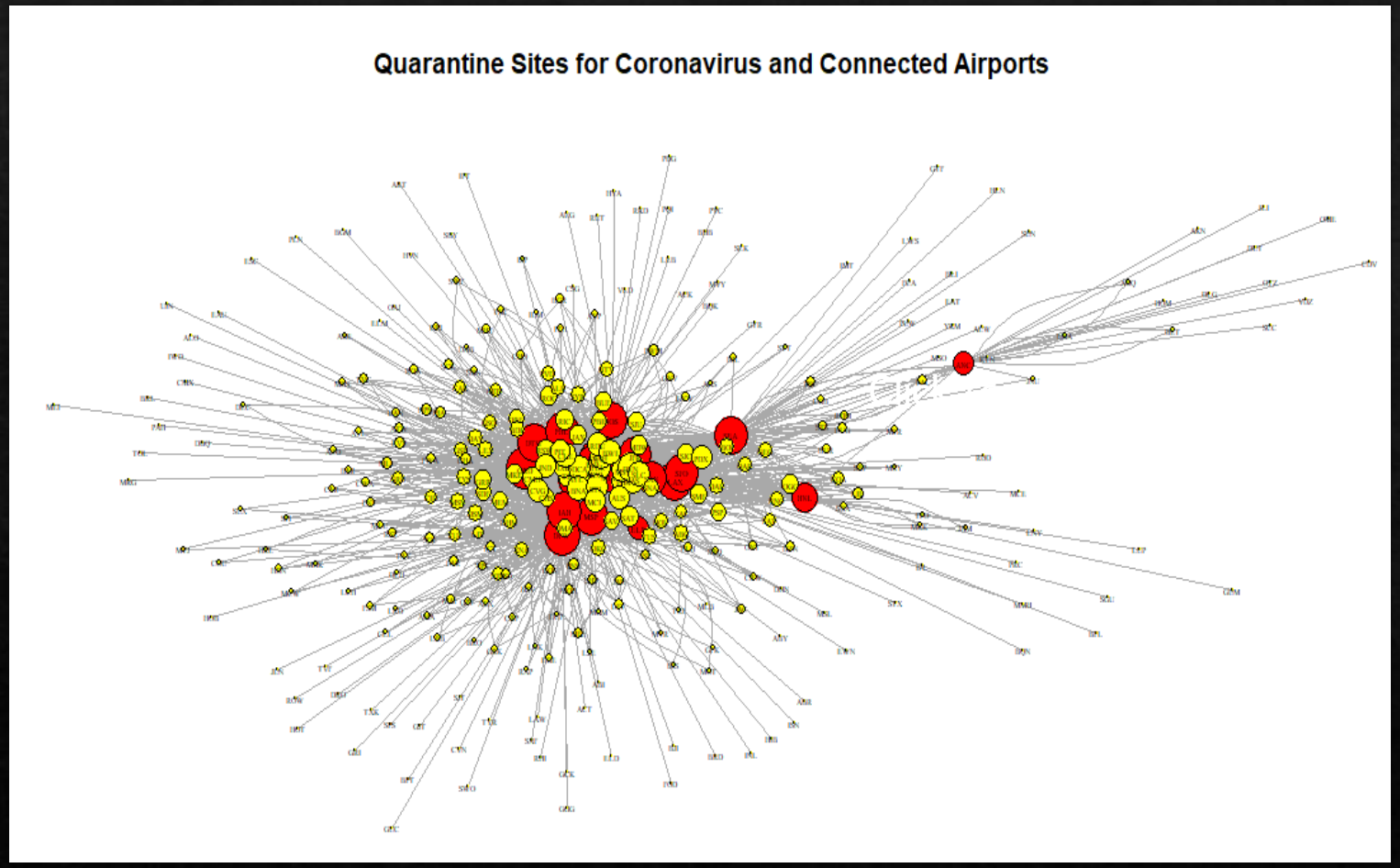



# *Coronavirus Impact on Air Networks*




- 19 airports were designated as quarantine stations by the CDC
- From these 19 airports (excluding Puerto Rico), **298** new airports can be reached in one connection at least once per day
- These 19 airports constitute 7 of the top 10 (13/20) busiest airports in terms of daily departures and 5 of the top 10 (13/20) busiest airports in terms of departing passenger volume
- 68% of passengers traveling domestically in the US will start or end a flight at one of these 19 airports daily
- 65% of all daily domestic flights originated or ended at one of these 19 airports
- This represented 761,000 departing passengers and 7,500 departing flights per day in 02/2018

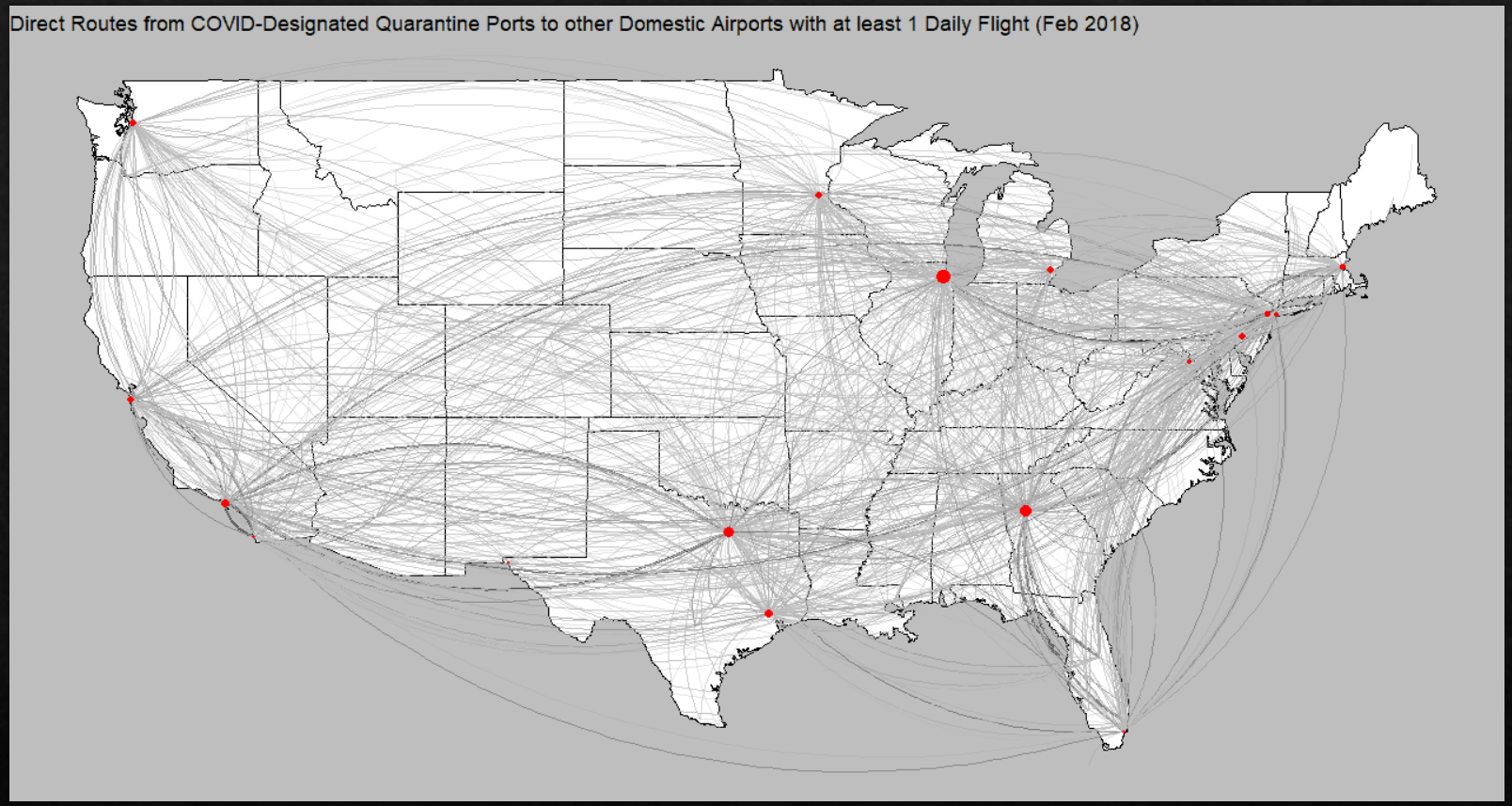
Node size is the log of the degree.
Red Nodes are Screening Airports
Yellow Nodes are within one connection of screening airports
Layout = LGL

*All figures are specific to 02/2018

# Coronavirus Screening Network Metrics

| | All 2018 Flights | All 2018 Flights WITHOUT Screening Airports | To/From Covid-Screening Airports (All 2018) |
|---|---|---|---|
| Degree Centrality (Strength) | 17,495.84 | 6,272.25 | 19,849.05 |
| Diameter | 8 | 8 | 4 |
| Mean Distance | 2.81 | 2.90 | 2.35 |
| Betwteeness | 1776.49 | 1743.66 | 701.22 |
| # Nodes | 901 | 874 | 518 |
| # Edges | 41,541 | 24,918 | 16,623 |
| Total # Flights | 7,881,877 | 2,740,974 | 5,140,903 |

*Numbers are for weighted network with US Territories removed




January 17: Screenings at JFK, LAX, and SFO for passengers from Wuhan, China

January 21: Add screenings at ATL and ORD for passengers from Wuhan.

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# *Appendix*

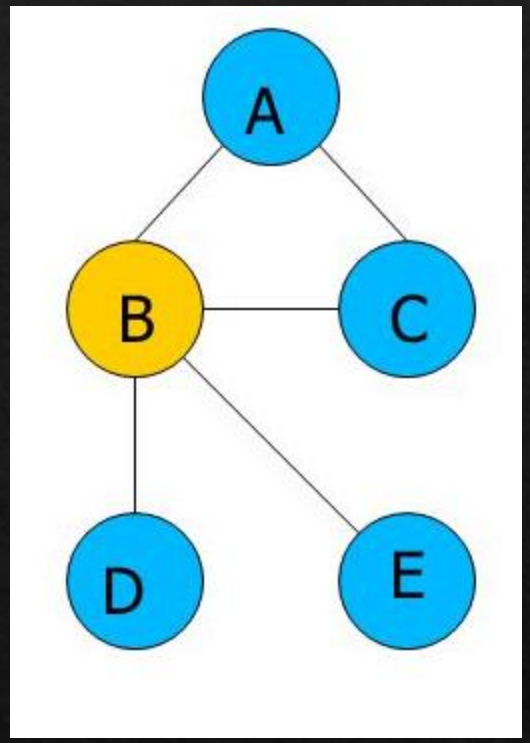
# *Data Source*

- All flight data is from the Bureau of Transportation Statistics, T-100 Domestic Segment (All Carries) table, located here:
  - https://www.transtats.bts.gov/DL_SelectFields.asp?Table_ID=311
- Data is provided monthly, and annual data from 2018 and 1998 was collected with the following fields:
  - `DepScheduled, DepPerformed, Seats, Passengers, Distance, AirTime, UniqueCarrier, UniqueCarrierName, Carrier, OriginAirportID, Origin, OriginCityName, OriginState, DestAirportID, Dest, DestCityName, DestState, DestAirportID, AircratGroup, AircraftType, Month`
- Data was grouped by `Origin, OriginCityName, Dest, DestCityName, UniqueCarrier`, filtered for `SEATS > 0`, and `Passengers` set to `SUM(Passengers)` and `Flights` set to `SUM(DepPerformed)`

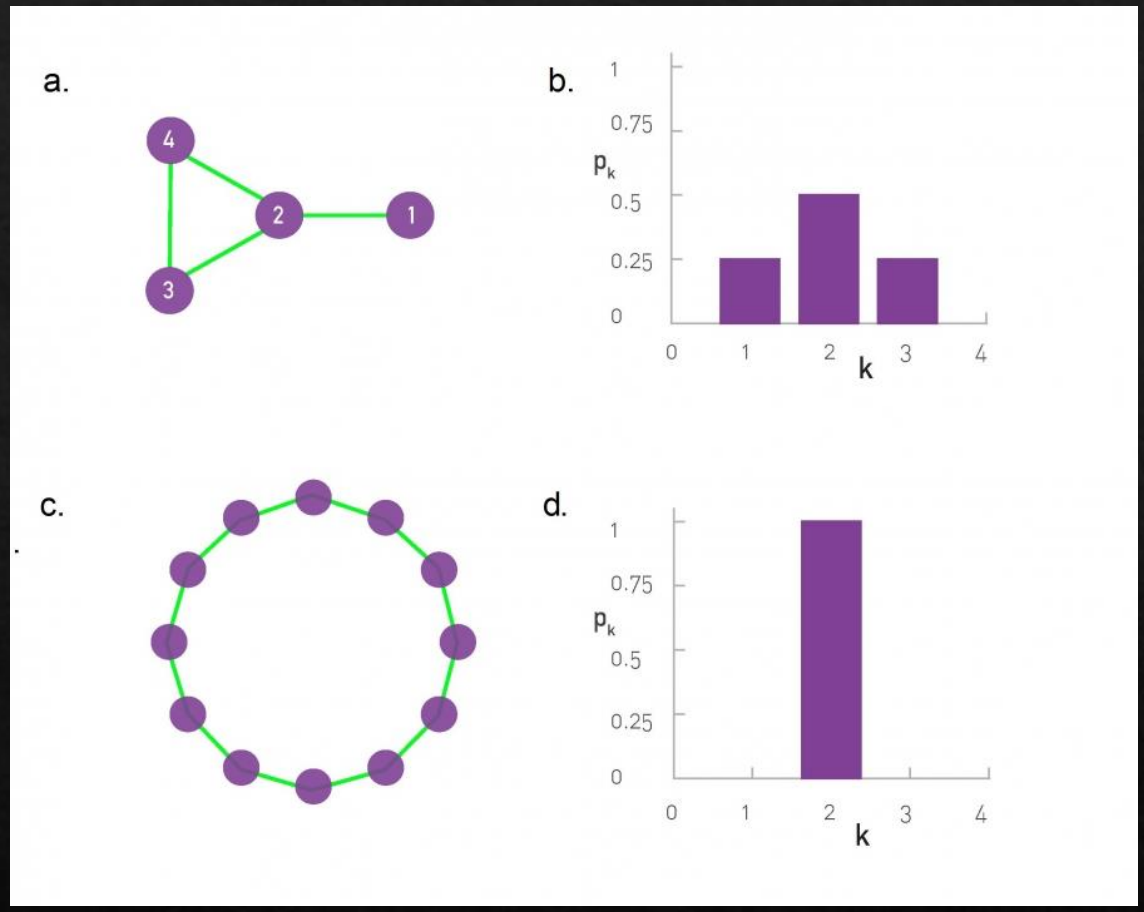
# *igraph Network Measures*

- Betweenness:
  - `betweenness()` - defined by the number of geodesics (shortest paths) going through a vertex
- Mean Distance:
  - `mean_distance()` - calculates the average path length in a graph, by calculating the shortest paths between all pairs of vertices (both ways for directed graphs)
  - This function does not consider edge weights
- Distance histogram:
  - `distance_table()` – calculates a histogram, by calculating the shortest path length between each pair of vertices
  - For directed graphs both directions are considered, so every pair of vertices appears twice in the histogram.
- Diameter:
  - `diameter()` - the length of the longest geodesic (shortest possible line between two nodes)
  - Optional positive weight vector for calculating weighted distances. If the graph has a `weight` edge attribute, then this is used by default
- Degree centrality:
  - `centr_degree()` - centralize a graph according to the degrees of vertices
  - `centr_degree(g)$res` – the node-level centrality scores
  - `Strength()` - Summing the edge weights of the adjacent edges for each vertex. This is the weighted degree
- Random Network
  - `Sample_gnp()` - Generate random graphs according to the G(n,p) Erdos-Renyi model

# Betweenness and Degree

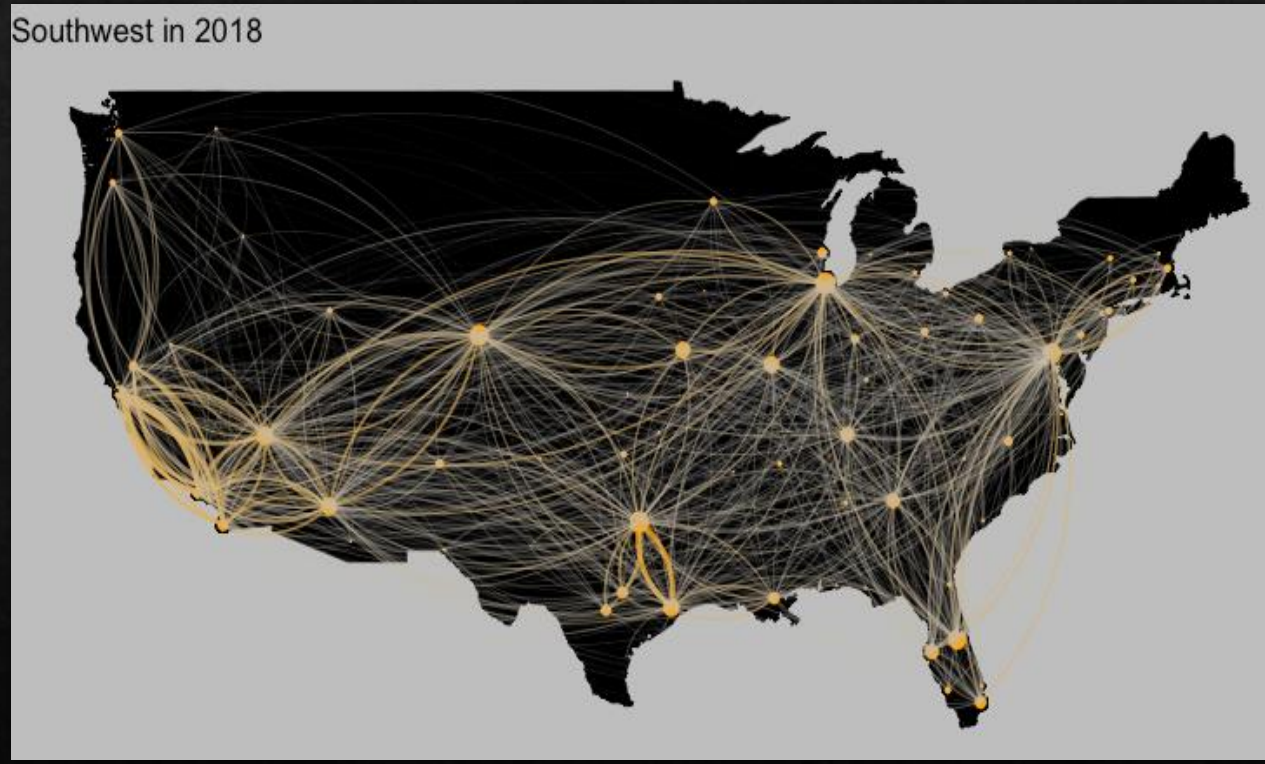



- The shortest paths are AB, AC, ABD, ABE, BC, BD, BE, CBD, CBE, DBE
- Five of those paths (ABD, ABE CBD, CBE, DBE) transit through B.
- B has a betweenness score of 5.




a.For the network in (a) with $N = 4$ the degree distribution is shown in (b).
b.We have $p_1 = 1/4$ (one of the four nodes has degree $k_1 1 = 1$), $p_2 = 1/2$ (two nodes have $k_3 = k_4 = 2$), and $p_3 = 1/4$ (as $k_2 = 3$). As we lack nodes with degree $k \rangle 3$, $p_k = 0$ for any $k \rangle 3$.
c.A one dimensional lattice for which each node has the same degree $k = 2$.
d.The degree distribution of (c) is a Kronecker's delta function, $p_k = \delta(k - 2)$.

# *Cases of Delta and Southwest Growth/Dynamics with Weighted Graphs*

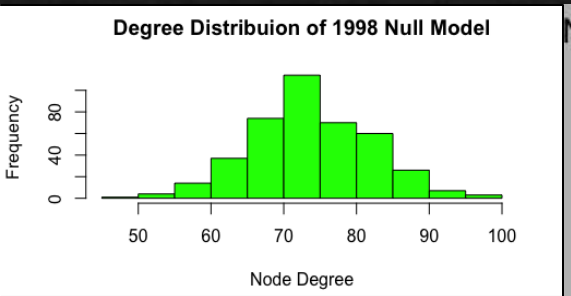
# *Null Model Generation*

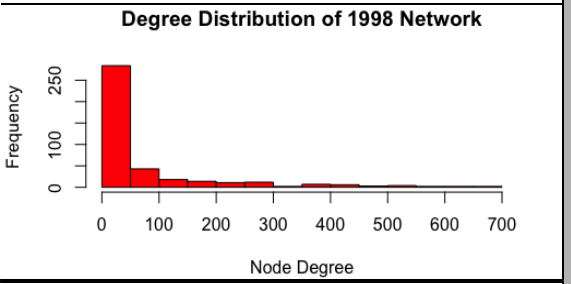
- For a given network, we created a null model by first identifying the number of vertices and the number of edges. From there, we can determine the probability of an edge occurring in a network.
- We used the igraph function sample_gnp() in R to generate our random graph. This function uses the random network model first defined by Gilbert and referred to as *G( N, p).*
- The *G*(*N*, *p*) model fixes the probability *p* that two nodes are connected and the *G*(*N*, *L*)) model fixes the total number of links *L*.
- When needed, we also simulated 1000 random graphs and took their average to build our null model.

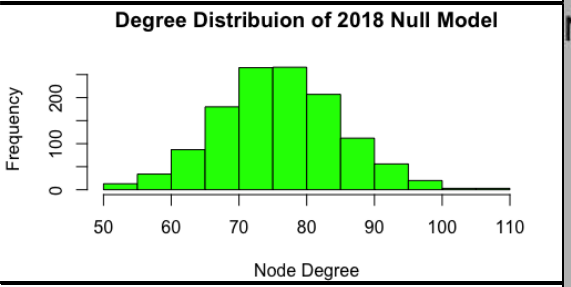
```
# get random network params
 numb_edges <- length(E(g))
 numb_vertices <-length(V(g))
p_edges <- (numb_edges/(numb_vertices*(numb_vertices-1)))


 # make random network
  rand_g <- sample_gnp(n=numb_vertices, p=p_edges, directed=TRUE) %>%
  set_vertex_attr("label", value = V(g)
 V(rand_g)$name <- V(g)$name # name random network vertices same as original graphs
```

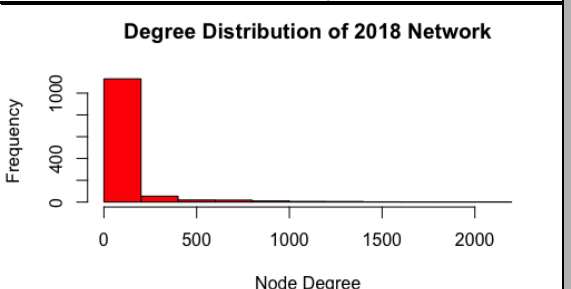
# *Null Models vs. Unweighted Networks*

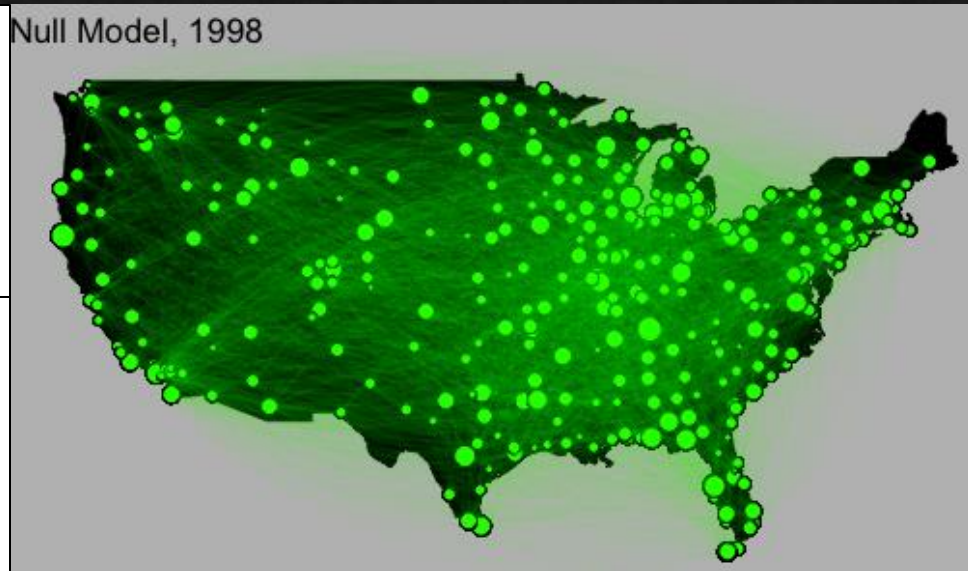
| Metric | 1998 | 2018 | Metric | 1998 | 2018 |
|---|---|---|---|---|---|
| Null Model Average Betweenness | 383.7 | 1576.5 | Observed Average Betweenness | 619.4 | 2,700.0 |
| Null Model Average Degree | 74.6 | 76.8 | Observed Average Degree | 74.7 | 76.6 |
| Null Model Mean Distance | 1.9 | 2.3 | Observed Mean Distance | 2.6 | 3.3 |
| Null Model Diameter | 3 | 3 | Observed Diameter | 7 | 9 |

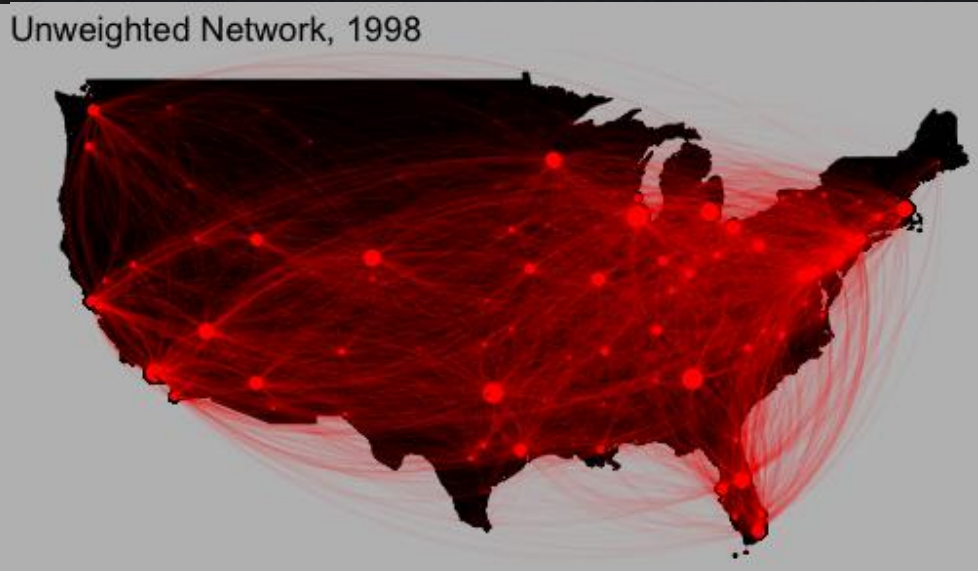


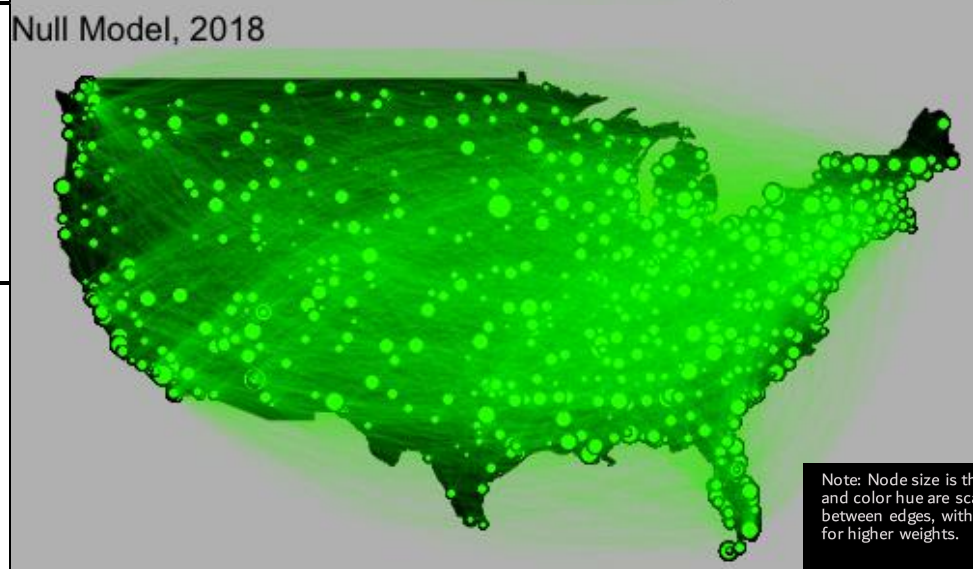



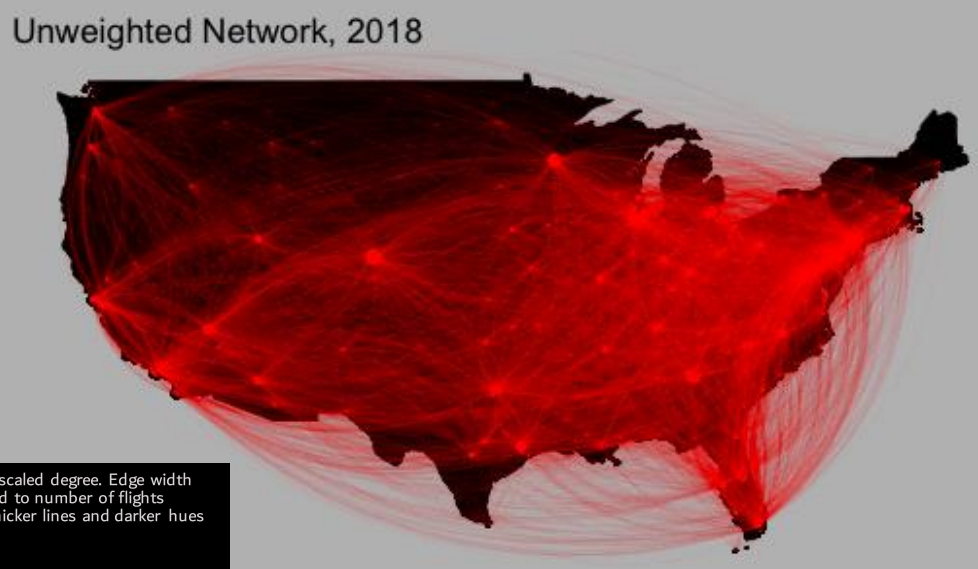

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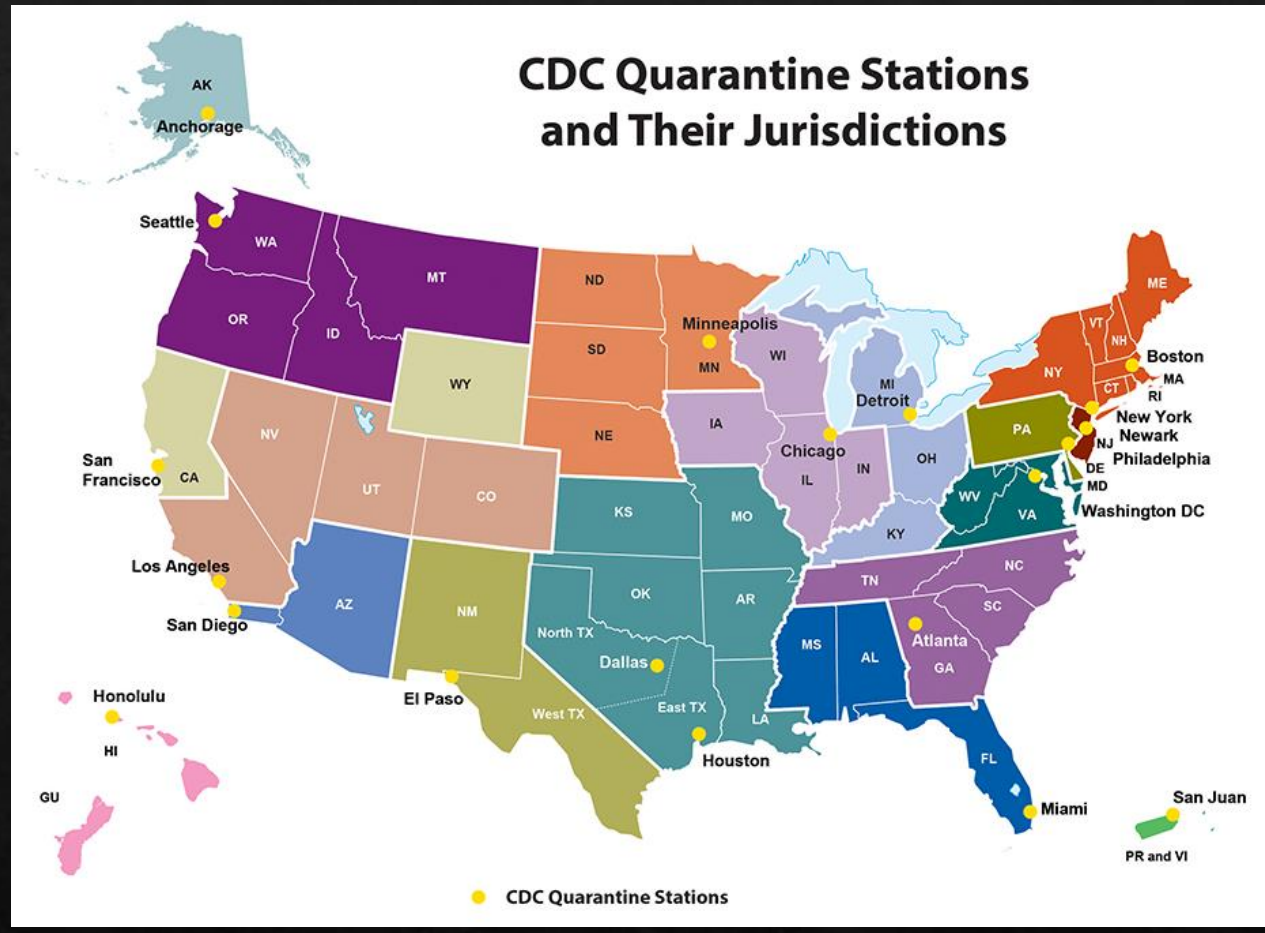
# Coronavirus Screening at US Airports

- The administration followed CDC's existing plan to use 20 widely-used ports of entry as quarantine stations, including many of the America's busiest airports.

- However, this plan may not have considered particular traits of COVID-19, including that patients can remain asymptomatic for many days while still spreading the disease. CDC Director assesses as many as 25% of infected are asymptomatic but can still spread disease (1 April).

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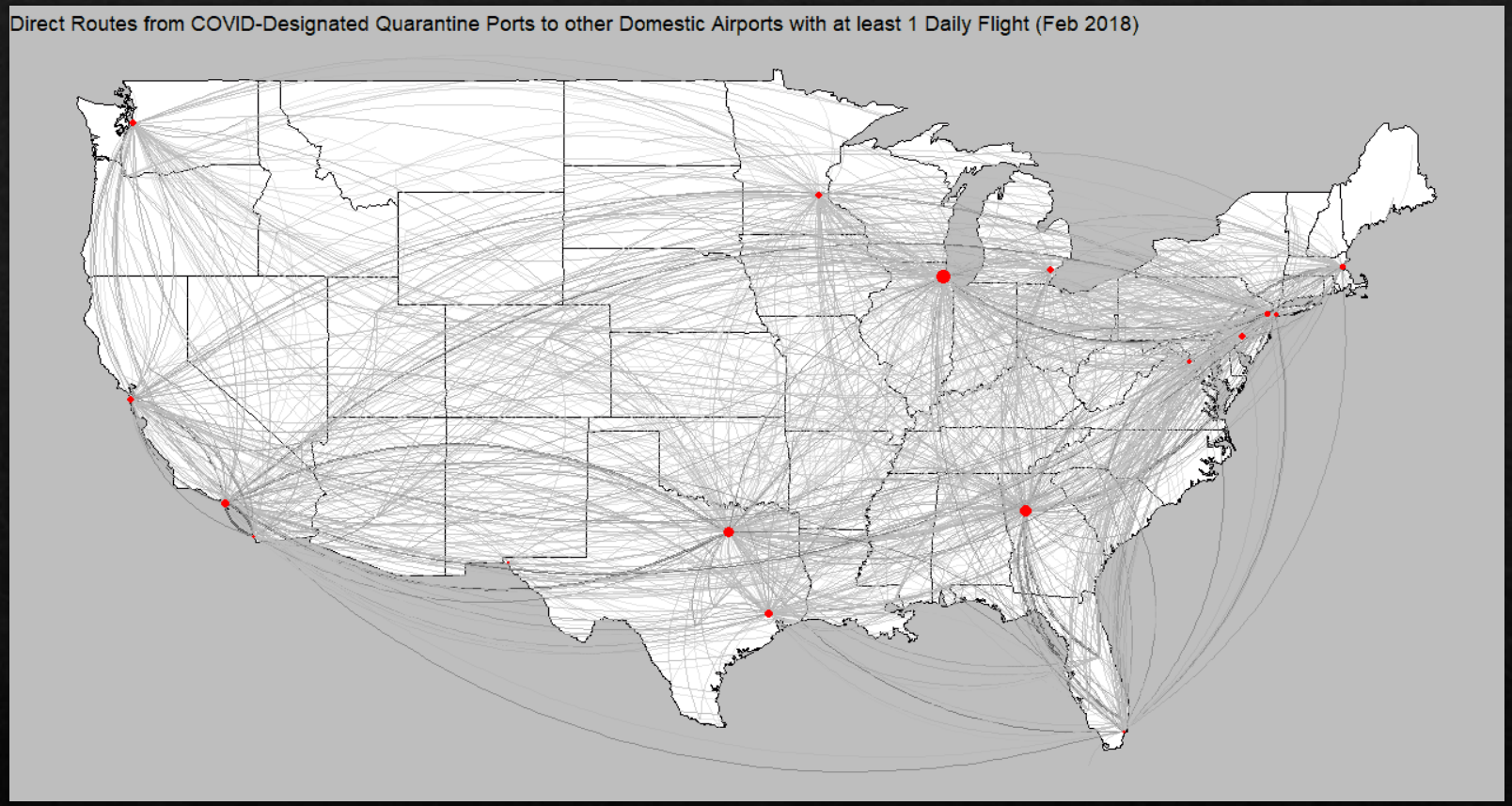
# *Coronavirus Screening Network Metrics*

| | All 2018 Flights | All 2018 Flights WITHOUT Screening Airports | To/From Covid-Screening Airports |
|---|---|---|---|
| **Degree Centrality** | 76.6 | 49.9 | 53.2 |
| **Diameter** | 9 | 13 | 4 |
| **Mean Distance** | 3.3 | 4.2 | 2.6 |
| **Betwteen-ness** | 2700.0 | 3593.3 | 849.6 |
| **# Nodes** | 1264 | 1213 | 657 |
| **# Edges** | 47716 | 30251 | 17465 |
| **Total # Flights** | 8,514, 517 | 3,127,595 | 5,386,922 |

*Numbers are for unweighted network with US Territories included

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Delta in 1998

American in 1998

Delta in 2018

American in 2018

United in 1998

Southwest in 1998

United in 2018

Southwest in 2018

# *Limitations & Next Steps*

- What happens to the network after taking certain airports out of the equation?
  - Which airports have the greatest affect the network efficiency and dynamics?
  - In the case of coronavirus spread, which airports specifically could/should be shut down? Does removing epicenters disconnect the whole network?
- Exploring and building weighted null models in R
- Examining to what extent each network is "scale-free"
- Visualizing this number of nodes and edges with non-geospatial layouts
- Explore dynamics of merging airline networks (e.g. US Airways/AMR/American Airlines, or United Airlines / Continental Airlines)
- Compare to biological or social network (measure assortativity)

# *References*


- Csardi G, Nepusz T (2006). "The igraph software package for complex network research." InterJournal, Complex Systems, 1695. http://igraph.org.
- Network Science by Albert-László Barabási. (n.d.). Retrieved April 13, 2020, from http://networksciencebook.com/
- OST_R | BTS | Transtats. (n.d.). Retrieved April 13, 2020, from https://www.transtats.bts.gov/DL_SelectFields.asp?Table_ID=311
- The weighted random graph model Related content. (n.d.). https://doi.org/10.1088/1367-2630/11/7/073005
- Verma, T., Araújo, N. A. M., & Herrmann, H. J. (2014). Revealing the structure of the world airline network. Scientific Reports, 4(1), 1–6. https://doi.org/10.1038/srep05638
- Introduction to Network Theory: Modern Concepts, Algorithms, and Applications, Ernest Estrada, University of Strathclyde, Glasgow, Retrieved April 13, 2020, from https://slideplayer.com/slide/3893394/
- E. N. Gilbert. Random graphs. The Annals of Mathematical Statistics, 30:1141-1144, 1959.


- Link to github:
  - https://github.com/redhairedcelt/network_science_flights