bipartite gate to airport

December 14, 2020

[1]:
```
import skmob
import networkx as nx
import osmnx
import pandas as pd
import numpy as np
import cartopy
import cartopy.crs as ccrs
import cartopy.feature as cfeature
import cartopy.io.shapereader as shpreader
import matplotlib.pyplot as plt
import operator
import geopandas as gpd
import os

from pprint import pprint
from matplotlib.lines import Line2D
from collections import Counter
from networkx.algorithms import bipartite
```

1 Data Processing

1.1 Load in gate traffic, import origin airports with lat/long coordinates

[2]:
```
q12_2018 = pd.read_excel('AOD 2018 Q1-Q2 Analyzed.xlsx',sheet_name = [0,2])
airport_locs = pd.read_csv('airport-codes_csv.csv')
```

[3]:
```
# separate flights by timestamp
start_time = pd.Timestamp(year=2018, month=1, day=1, hour=0)
end_time = pd.Timestamp(year=2018, month=2, day=12, hour=0)
```

[4]:
```
airport_locs.head()
```

[4]:
```
  ident           type                               name  elevation_ft  \
0   00A       heliport                  Total Rf Heliport          11.0
1  00AA  small_airport                Aero B Ranch Airport        3435.0
2  00AK  small_airport                       Lowell Field         450.0
3  00AL  small_airport                       Epps Airpark         820.0
```

```
4  00AR         closed  Newport Hospital & Clinic Heliport         237.0

  continent iso_country iso_region  municipality gps_code iata_code  \
0       NaN          US      US-PA      Bensalem      00A       NaN
1       NaN          US      US-KS         Leoti     00AA       NaN
2       NaN          US      US-AK  Anchor Point     00AK       NaN
3       NaN          US      US-AL       Harvest     00AL       NaN
4       NaN          US      US-AR       Newport      NaN       NaN

  local_code                            coordinates
0        00A     -74.93360137939453, 40.07080078125
1       00AA                 -101.473911, 38.704022
2       00AK            -151.695999146, 59.94919968
3       00AL  -86.77030181884766, 34.86479949951172
4        NaN                    -91.254898, 35.6087
```

[5]:

```
airport_icao = airport_locs.set_index('ident')
```

[6]:

```
airport_icao.head()
```

[6]:

```
                type                                name  elevation_ft  \
ident
00A         heliport                   Total Rf Heliport          11.0
00AA   small_airport                Aero B Ranch Airport        3435.0
00AK   small_airport                        Lowell Field         450.0
00AL   small_airport                        Epps Airpark         820.0
00AR          closed  Newport Hospital & Clinic Heliport         237.0

      continent iso_country iso_region  municipality gps_code iata_code  \
ident
00A         NaN          US      US-PA      Bensalem      00A       NaN
00AA        NaN          US      US-KS         Leoti     00AA       NaN
00AK        NaN          US      US-AK  Anchor Point     00AK       NaN
00AL        NaN          US      US-AL       Harvest     00AL       NaN
00AR        NaN          US      US-AR       Newport      NaN       NaN

      local_code                            coordinates
ident
00A          00A     -74.93360137939453, 40.07080078125
00AA        00AA                 -101.473911, 38.704022
00AK        00AK            -151.695999146, 59.94919968
00AL        00AL  -86.77030181884766, 34.86479949951172
00AR         NaN                    -91.254898, 35.6087
```

[7]:

```
# map states to their abbreviations
abbrev_df = pd.read_csv('./List-of-US-States/states.csv')
```

```
state_to_abbrev = dict(zip(list(abbrev_df['State'].
 ↪values),list(abbrev_df['Abbreviation'].values)))
abbrev_to_state = {v: k for k, v in state_to_abbrev.items()}
```

[8]:
```
abbrev_df.head()
```

[8]:
```
        State Abbreviation
0     Alabama           AL
1      Alaska           AK
2     Arizona           AZ
3    Arkansas           AR
4  California           CA
```

[9]:
```
clean_flight = q12_2018[0].copy()
archive = q12_2018[2].copy()
clean_flight.loc[3,:]
```

[9]:
```
Combined Tail ID        43101_N34455_82
Terminal                              3
Gate                                 82
Time Arr            2018-01-01 05:03:26
Time Dep            2018-01-01 08:46:32
Tot Time                            223
Airline                 UNITED AIRLINES
Dom or Int                    Passenger
Classification                        N
Type                               B739
Sub Type                    737-924ER(W)
Full Plane Type        B739-737-924ER(W)
Name: 3, dtype: object
```

[10]:
```
test_flight = clean_flight.copy()
clean_flight = test_flight.loc[(test_flight['Time Arr']>start_time) &␣
 ↪(test_flight['Time Arr']<end_time),:].copy()
print(test_flight.shape)
print(clean_flight.shape)
```

```
(4616, 12)
(4616, 12)
```

[11]:
```
print(clean_flight.shape)
```

```
(4616, 12)
```

[12]:
```
# separate timestamp into month, day, hour
archive['Time Arr Hour'] = archive['ACTUAL_AOD_TIME'].apply(lambda x: x.hour)
archive['Time Arr Hour'] = archive['Time Arr Hour'].fillna(-1)
```

```
archive['Time Arr Hour'] = archive['Time Arr Hour'].astype(int)
archive['Time Arr Day'] = archive['ACTUAL_AOD_TIME'].apply(lambda x: x.day)
archive['Time Arr Day'] = archive['Time Arr Day'].fillna(-1)
archive['Time Arr Day'] = archive['Time Arr Day'].astype(int)
archive['Time Arr Month'] = archive['ACTUAL_AOD_TIME'].apply(lambda x: x.month)
archive['Time Arr Month'] = archive['Time Arr Month'].fillna(-1)
archive['Time Arr Month'] = archive['Time Arr Month'].astype(int)
archive['Matched'] = archive['Matched'].fillna('FALSE').copy()
# grab all origin airports in dataset
airports = set()
origins = []
dest = []
num_flights = {}
num_dest = {}
for idx in clean_flight.index:
    flight = clean_flight.loc[idx,:]
    tail_id = flight['Combined Tail ID']
    time_arr = flight['Time Arr']
    route = archive.loc[(archive['Time Arr Day'] == time_arr.day) &
                        (archive['Time Arr Hour'] == time_arr.hour) &
                        (archive['Combined Tail ID']==tail_id) &
                        (archive['ARRIVAL_OR_DEPARTURE']=='ARR') , 'ROUTE']
    origin_airport = route.values[0].split(' /')[0]

    # repeat for departure flights
    time_dep = flight['Time Dep']
    route = archive.loc[(archive['Time Arr Day'] == time_dep.day) &
                        (archive['Time Arr Hour'] == time_dep.hour) &
                        (archive['Combined Tail ID']==tail_id) &
                        (archive['ARRIVAL_OR_DEPARTURE']=='DEP') , 'ROUTE']
    dest_airport = route.values[0].split(' /')[1]
    dest_airport = dest_airport.split(' ')[0]
    # count number of flights to and from this airport
    try:
        num_flights[origin_airport] = num_flights[origin_airport]+1
        num_dest[dest_airport] = num_dest[dest_airport]+1
    except: # Key is missing
        num_flights[origin_airport] = 1
        num_dest[dest_airport] = 1

    origins.append(origin_airport)
    dest.append(dest_airport)
    airports.add(origin_airport)
    airports.add(dest_airport)
# create new column detailing the origin airport
clean_flight['origin'] = origins
clean_flight['destination'] = dest
```

[13]:

```
clean_flight.head()
```

[13]:

```
        Combined Tail ID Terminal      Gate             Time Arr  \
0        43101_N76523_69        3        69 2018-01-01 04:09:51
1        43101_N77865_85        3        85 2018-01-01 04:47:32
2        43101_N33103_88        3        88 2018-01-01 04:57:37
3        43101_N34455_82        3        82 2018-01-01 05:03:26
4  43101_N29907_G96             3  G96      2018-01-01 05:30:08

             Time Dep  Tot Time          Airline Dom or Int Classification  \
0 2018-01-01 07:49:00       220  UNITED AIRLINES  Passenger              N
1 2018-01-01 09:23:23       276  UNITED AIRLINES  Passenger              N
2 2018-01-01 09:10:26       253  UNITED AIRLINES  Passenger              N
3 2018-01-01 08:46:32       223  UNITED AIRLINES  Passenger              N
4 2018-01-01 11:29:31       359  UNITED AIRLINES  Passenger              W

   Type           Sub Type         Full Plane Type origin destination
0  B738  737-824(W)(ETOPS)  B738-737-824(W)(ETOPS)   PHOG        KPHX
1  B753         757-33N(W)         B753-757-33N(W)   PHOG        PHOG
2  B752  757-224(W)(ETOPS)  B752-757-224(W)(ETOPS)   PHLI        PHLI
3  B739       737-924ER(W)       B739-737-924ER(W)   PHKO        KMSY
4  B788              787-8              B788-787-8   LLBG        RJBB
```

[14]:

```
import copy

# Calculate lat and long for all airports
airports = list(airports)
lat = []
lon = []
origin_state = []
destination_state = []
i = 0
for airport in clean_flight['origin']:
    # get airport coordinates
    try:
        airport_coords = airport_locs.
 ↪loc[airport_locs['ident']==airport,'coordinates']
        airport_coords = airport_coords.values[0].split(', ')
        lat.append(float(airport_coords[0]))
        lon.append(float(airport_coords[1]))
    except:
        # cannot find airport
        lat.append(np.nan)
        lon.append(np.nan)
    i+=1
a = len(clean_flight.index.values)
airport_map = {}
```

```
new_num_flights = copy.copy(num_flights)
for airport in num_flights.keys():
    try:
        airport_coords = airport_locs.
 ↪loc[airport_locs['ident']==airport,'coordinates']
        airport_coords = airport_coords.values[0].split(', ')
        airport_coords = [float(x) for x in airport_coords]
        airport_map[airport] = airport_coords
    except:
        del new_num_flights[airport]

num_flights = new_num_flights

# drop missing airports
print(len(clean_flight.index.values))
clean_flight['origin_lat'] = lat
clean_flight['origin_lon'] = lon
clean_flight = clean_flight.dropna().copy()
b = len(clean_flight.index.values)
print(f'Number of elements removed: {a-b}')

for airport in clean_flight['origin']:
    try:
        airport_state = airport_icao.loc[airport,'iso_region'] # This returns a␣
 ↪string like US-PA --> Pensylvannia
        airport_state = abbrev_to_state[airport_state.split('-')[1]]
        origin_state.append(airport_state)
    except:
        origin_state.append(np.nan)

# Repeat for destination column
dest_lat = []
dest_lon = []
new_num_flights = copy.copy(num_flights)
for airport in clean_flight['destination']:
    # get airport coordinates
    try:
        airport_coords = airport_locs.
 ↪loc[airport_locs['ident']==airport,'coordinates']
        airport_coords = airport_coords.values[0].split(', ')
        dest_lat.append(float(airport_coords[0]))
        dest_lon.append(float(airport_coords[1]))
    except:
        # cannot find airport
        dest_lat.append(np.nan)
        dest_lon.append(np.nan)
```

```
for airport in num_dest.keys():
    try:
        airport_coords = airport_locs.
 ↪loc[airport_locs['ident']==airport,'coordinates']
        airport_coords = airport_coords.values[0].split(', ')
        airport_coords = [float(x) for x in airport_coords]
        airport_map[airport] = airport_coords
    except:
        del new_num_flights[airport]

for airport in clean_flight['destination']:
    try:
        airport_state = airport_icao.loc[airport,'iso_region'] # This returns a␣
 ↪string like US-PA --> Pensylvannia
        airport_state = abbrev_to_state[airport_state.split('-')[1]]
        destination_state.append(airport_state)
    except:
        destination_state.append(np.nan)

# Append results to dataframe
clean_flight['destination_lat'] = dest_lat
clean_flight['destination_lon'] = dest_lon

clean_flight['origin_state'] = origin_state
clean_flight['destination_state'] = destination_state
a = len(clean_flight.index.values)
clean_flight = clean_flight.dropna().copy()
b = len(clean_flight.index.values)
print(f'Number of elements removed: {a-b}')
clean_flight.reset_index(drop = True,inplace=True)
```

```
4616
Number of elements removed: 11
Number of elements removed: 520
```

[15]:
```
clean_flight.head()
```

[15]:
```
  Combined Tail ID Terminal Gate            Time Arr            Time Dep  \
0  43101_N76523_69        3   69 2018-01-01 04:09:51 2018-01-01 07:49:00
1  43101_N77865_85        3   85 2018-01-01 04:47:32 2018-01-01 09:23:23
2  43101_N33103_88        3   88 2018-01-01 04:57:37 2018-01-01 09:10:26
3  43101_N34455_82        3   82 2018-01-01 05:03:26 2018-01-01 08:46:32
4  43101_N879DN_42        1   42 2018-01-01 06:08:43 2018-01-01 08:43:56

   Tot Time          Airline Dom or Int Classification  Type  \
0       220  UNITED AIRLINES  Passenger              N  B738
1       276  UNITED AIRLINES  Passenger              N  B753
```

```
2       253  UNITED AIRLINES  Passenger             N  B752
3       223  UNITED AIRLINES  Passenger             N  B739
4       155  DELTA AIR LINES  Passenger             N  B739

              Sub Type          Full Plane Type origin destination  origin_lat  \
0  737-824(W)(ETOPS)  B738-737-824(W)(ETOPS)   PHOG        KPHX -156.429993
1         757-33N(W)         B753-757-33N(W)   PHOG        PHOG -156.429993
2  757-224(W)(ETOPS)  B752-757-224(W)(ETOPS)   PHLI        PHLI -159.339005
3       737-924ER(W)       B739-737-924ER(W)   PHKO        KMSY -156.045603
4       737-900ER(W)       B739-737-900ER(W)   PHNL        KMSP -157.924228

   origin_lon  destination_lat  destination_lon origin_state destination_state
0   20.898600      -112.012001        33.434299       Hawaii           Arizona
1   20.898600      -156.429993        20.898600       Hawaii            Hawaii
2   21.976000      -159.339005        21.976000       Hawaii            Hawaii
3   19.738783       -90.258003        29.993401       Hawaii         Louisiana
4   21.320620       -93.221802        44.882000       Hawaii         Minnesota
```

[16]:

```
# Sort incoming traffic by terminal

# Create terminal sets
terminal1 = [str(terminal) for terminal in range(20,49)]
terminal1+=[str(terminal)+'A' for terminal in range(20,49)]
terminal1+=[str(terminal)+'B' for terminal in range(20,49)]
terminal2 = [str(terminal) for terminal in range(50,60)]
terminal2+=[str(terminal)+'A' for terminal in range(50,60)]
terminal2+=[str(terminal)+'B' for terminal in range(50,60)]
terminal3 = [str(terminal) for terminal in range(60,91)]
terminal3+=[str(terminal)+'A' for terminal in range(60,91)]
terminal3+=[str(terminal)+'B' for terminal in range(60,91)]
terminal3+=[str(terminal)+'C' for terminal in range(60,91)]
terminal3+=[str(terminal)+'D' for terminal in range(60,91)]
intG = ['G'+str(terminal) for terminal in range(91,103)]
intA = ['A'+str(terminal) for terminal in range(1,13)]+['A'+str(terminal)+'B'␣
 ↪for terminal in range(1,13)]+['A11A']
```

[17]:

```
# Sort gates by terminal
gate_list = set(list(clean_flight['Gate'].apply(lambda x: str(x).split(' ')[0]).
 ↪values
                    ))
gate_list = sorted(list(gate_list))

gates_in_1 = []
gates_in_2 = []
gates_in_3 = []
gates_in_G = []
gates_in_A = []
```

```

gates = [gates_in_1, gates_in_2, gates_in_3, gates_in_A, gates_in_G]
terminals = [terminal1, terminal2, terminal3, intA, intG]
for gate in gate_list:
    idx = 0
    for terminal in terminals:
        if set([gate]).issubset(set(terminals[idx])):
            gates[idx].append(gate)
        idx += 1
        if idx == len(terminals)+1:
            raise Exception()
clean_flight['Gate'] = list(clean_flight['Gate'].apply(lambda x: str(x).split('␣
 ↪')[0]).values)
```

[18]:

```
terminal_names = ['1','2','3','A','G']
terminal_dict = dict(zip(terminal_names,gates))
gate_map = {}

i = 0
for pair in terminal_dict.values():
    for gate in pair:
        gate_map[gate] = terminal_names[i]
    i+=1

mapped_terminal = []
for idx in clean_flight.index:
    mapped_terminal.append(gate_map[str(clean_flight['Gate'].iloc[idx])])

clean_flight['terminal'] = mapped_terminal
```

[19]:

```
clean_flight.head()
```

[19]:

```
  Combined Tail ID Terminal Gate            Time Arr            Time Dep  \
0  43101_N76523_69        3   69 2018-01-01 04:09:51 2018-01-01 07:49:00
1  43101_N77865_85        3   85 2018-01-01 04:47:32 2018-01-01 09:23:23
2  43101_N33103_88        3   88 2018-01-01 04:57:37 2018-01-01 09:10:26
3  43101_N34455_82        3   82 2018-01-01 05:03:26 2018-01-01 08:46:32
4  43101_N879DN_42        1   42 2018-01-01 06:08:43 2018-01-01 08:43:56

   Tot Time          Airline Dom or Int Classification  Type  …  \
0       220  UNITED AIRLINES  Passenger              N  B738  …
1       276  UNITED AIRLINES  Passenger              N  B753  …
2       253  UNITED AIRLINES  Passenger              N  B752  …
3       223  UNITED AIRLINES  Passenger              N  B739  …
4       155  DELTA AIR LINES  Passenger              N  B739  …

          Full Plane Type origin destination  origin_lat  origin_lon  \
0  B738-737-824(W)(ETOPS)   PHOG        KPHX -156.429993   20.898600
1         B753-757-33N(W)   PHOG        PHOG -156.429993   20.898600
2  B752-757-224(W)(ETOPS)   PHLI        PHLI -159.339005   21.976000
3       B739-737-924ER(W)   PHKO        KMSY -156.045603   19.738783
4       B739-737-900ER(W)   PHNL        KMSP -157.924228   21.320620

   destination_lat  destination_lon  origin_state destination_state terminal
0      -112.012001        33.434299        Hawaii           Arizona        3
1      -156.429993        20.898600        Hawaii            Hawaii        3
2      -159.339005        21.976000        Hawaii            Hawaii        3
3       -90.258003        29.993401        Hawaii         Louisiana        3
4       -93.221802        44.882000        Hawaii         Minnesota        1

[5 rows x 21 columns]
```

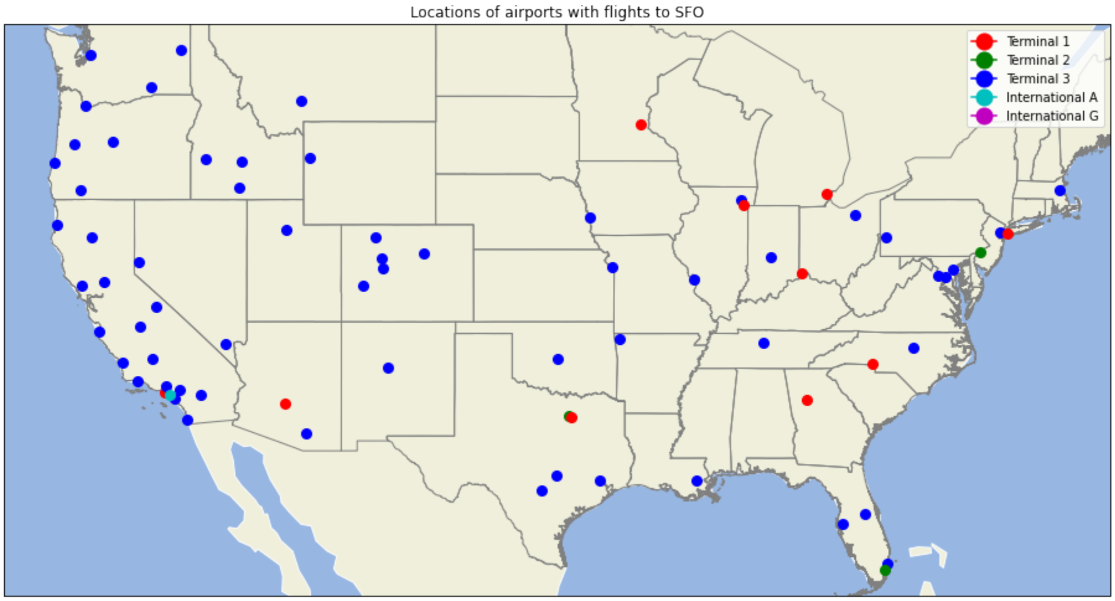
[20]:

```
clean_flight.to_csv('AOD_2018_q1-263.csv')
```

[21]:

```
# Plot majority terminal for each gate in continental United States
vals = list(airport_map.values())
airport_lat = [x[1] for x in vals]
airport_lon = [x[0] for x in vals]
color_palette = ['r','g','b','c','m']
terminal_color = dict(zip(terminal_names,color_palette))
plt.figure(figsize=(16, 12))
ax = plt.axes(projection=ccrs.Mercator())

custom_lines = [Line2D([0], [0], marker='o', color='r', markersize=13),
                Line2D([0], [0], marker='o', color='g', markersize=13),
                Line2D([0], [0], marker='o', color='b', markersize=13),
                Line2D([0], [0], marker='o', color='c', markersize=13),
                Line2D([0], [0], marker='o', color='m', markersize=13)
                ]


for airport in airport_map.keys():
    if (airport[0] != 'K'):
        continue

    # Find terminal where the majority of flights go to
    airport_terminal = Counter(list(clean_flight['terminal'].
 ↪loc[clean_flight['origin']==airport].values))
    airport_terminal = max(airport_terminal,key = airport_terminal.get)

    num_flights_to_airport = num_flights[airport]
    color = terminal_color[airport_terminal]
    plt.
↪plot(airport_map[airport][0],airport_map[airport][1],color=color,marker='.',␣
↪markersize=16, label=airport_terminal,
     transform=ccrs.Geodetic()
     )
#     plt.text(airport_map[airport][0],airport_map[airport][1]+0.
↪01,airport,transform=ccrs.Geodetic())
# ax.stock_img()
ax.add_feature(cartopy.feature.OCEAN, zorder=0)
ax.add_feature(cartopy.feature.LAND, zorder=0, edgecolor='white')
us_shapes = list(shpreader.Reader('gadm36_USA_1.shp').geometries())
ax.add_geometries(us_shapes, ccrs.PlateCarree(), edgecolor='gray',
              facecolor='none')
plt.title('Locations of airports with flights to SFO')
plt.legend(custom_lines, ['Terminal 1', 'Terminal 2', 'Terminal␣
↪3','International A', 'International G'])
plt.savefig('cont_airports.png')
plt.show()
```

```
C:\Users\orcal\.conda\envs\skmob\lib\site-packages\cartopy\mpl\geoaxes.py:388:
MatplotlibDeprecationWarning:
The 'inframe' parameter of draw() was deprecated in Matplotlib 3.3 and will be
removed two minor releases later. Use Axes.redraw_in_frame() instead. If any
parameter follows 'inframe', they should be passed as keyword, not positionally.
  inframe=inframe)
```



2 Create network

[22]:

```
# Import COVID data
filepath = r'C:
↪\Users\orcal\Documents\UCB\CE263N\Project\COVID-19\csse_covid_19_data\csse_covid_19_daily_r
covid_19_filenames = os.listdir(filepath)
new_names = []
date_names = [filename.split('.')[0] for filename in covid_19_filenames]
for path in covid_19_filenames:
    new_path = os.path.join(filepath,path)
    new_names.append(new_path)

covid_19_filenames = new_names

# Drop regions that are not covered in the entire dataset
state_incidence_rate = []
for csv_file in covid_19_filenames:
    df = pd.read_csv(csv_file)
    df.set_index('Province_State',inplace=True)
    try:
        df.drop(['American Samoa'],axis=0,inplace=True)
    except:
        pass

    try:
        df.drop(['Recovered'],axis=0,inplace=True)
    except:
        pass

    try:
        df.drop(['Virgin Islands'],axis=0,inplace=True)
    except:
        pass
    state_incidence_rate.append(list(df['Incident_Rate'].values))

# Rename index to state names
last_df = df
state_index = list(last_df.index)
incidence_df = pd.DataFrame(state_incidence_rate).T
incidence_df.columns = date_names
incidence_df.drop(list(incidence_df.index[-2:]))
incidence_df.index = state_index
```

[23]:

```
# map states to their abbreviations
abbrev_df = pd.read_csv('./List-of-US-States/states.csv')
state_to_abbrev = dict(zip(list(abbrev_df['State'].
↪values),list(abbrev_df['Abbreviation'].values)))
```

```
abbrev_to_state = {v: k for k, v in state_to_abbrev.items()}
abbrev_df.head()
```

[23]:
```
        State Abbreviation
0     Alabama           AL
1      Alaska           AK
2     Arizona           AZ
3    Arkansas           AR
4  California           CA
```

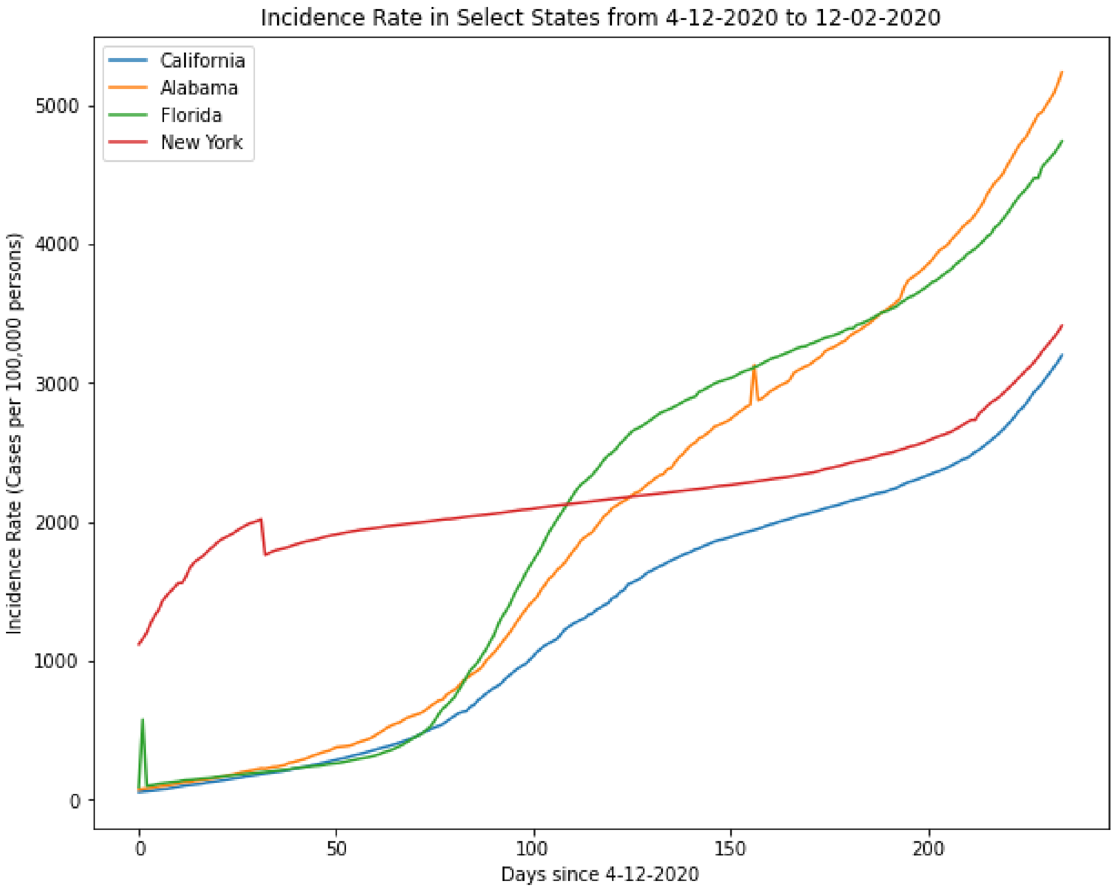
[24]:
```
incidence_df.tail()
```

[24]:
```
               04-12-2020  04-13-2020  04-14-2020  04-15-2020  04-16-2020  \
Virginia       140.527668   72.680319   78.181614   82.203249   87.122798
Washington      44.822441  140.872066  143.044424  144.938613  146.461912
West Virginia   64.565739   46.182987   48.374979   53.061305   55.026538
Wisconsin       54.299735   66.247038   68.701347   71.909343   74.885435
Wyoming         19.947773   55.305285   56.713056   57.718607   59.528598

               04-17-2020  04-18-2020  04-19-2020  04-20-2020  04-21-2020  \
Virginia        94.736083  101.843503  108.027716  113.693417  121.787276
Washington     152.555109  155.985844  162.330717  160.463019  166.410510
West Virginia   58.579076   59.334935   67.271455   68.178486   68.632001
Wisconsin       78.325334   81.146824   83.987639   86.944406   89.379390
Wyoming         61.338589   62.143030   62.947470   63.751911   89.091787

               …   11-23-2020   11-24-2020   11-25-2020   11-26-2020  \
Virginia       …  2589.625774  2619.430640  2651.274047  2681.734995
Washington     …  1937.479621  1983.205805  2021.118353  2021.118353
West Virginia  …  2294.119846  2348.189072  2402.146699  2465.199562
Wisconsin      …  6521.207454  6637.104002  6740.102163  6837.415418
Wyoming        …  5085.190900  5176.420583  5314.992942  5314.992942

                11-27-2020   11-28-2020   11-29-2020   11-30-2020  \
Virginia       2699.824111  2736.998184  2764.237301  2786.415214
Washington     2077.074491  2109.471532  2136.602576  2167.056057
West Virginia  2513.521491  2558.104888  2622.385329  2669.535479
Wisconsin      6861.838193  6955.836683  7025.481096  7071.441256
Wyoming        5489.849834  5516.631275  5613.562813  5754.554141

                12-01-2020   12-02-2020
Virginia       2812.517903  2840.834869
Washington     2195.907415  2236.958550
West Virginia  2723.995297  2784.648804
Wisconsin      7151.047139  7229.450776
Wyoming        5840.945886  5959.475360
```

```
[5 rows x 235 columns]
```

[25]:
```
california_incidence = incidence_df.loc['California',:].to_numpy()
alabama_incidence = incidence_df.loc['Alabama',:].to_numpy()
florida_incidence = incidence_df.loc['Florida',:].to_numpy()
ny_incidence = incidence_df.loc['New York',:].to_numpy()
```

[26]:
```
plt.figure(figsize=(10,8))
plt.plot(california_incidence,label='California')
plt.plot(alabama_incidence,label='Alabama')
plt.plot(florida_incidence,label='Florida')
plt.plot(ny_incidence,label='New York')
plt.title('Incidence Rate in Select States from 4-12-2020 to 12-02-2020')
plt.xlabel('Days since 4-12-2020')
plt.ylabel('Incidence Rate (Cases per 100,000 persons)')
plt.legend()
plt.savefig('incidence_compare.png')
plt.show()
```



[27]:

```
graph = nx.DiGraph()

# Remove all airports not in the continental United States
all_airports = set(list(clean_flight['origin'].
 ↪values)+list(clean_flight['destination'].values))
cont_airports = set()
for airport in all_airports:
    if airport[0] == 'K':
        cont_airports.add(airport)
# bipartite = 0 for gate nodes
# bipartite = 1 for airport nodes

# add nodes with risk factor attribute
gate_nodes = []
for gate in gate_list:
    node = (gate,{'weight':1,'bipartite':0})
    gate_nodes.append(node)
graph.add_nodes_from(gate_nodes)
graph.add_nodes_from(all_airports,bipartite=1)
```

[28]:

```
origin_pairs = list(zip(clean_flight.Gate,clean_flight.origin))
destination_pairs = list(zip(clean_flight.Gate,clean_flight.destination))

origin_set = set(origin_pairs)
destination_set = set(destination_pairs)

origin_count = {}
destination_count = {}

for origin in origin_pairs:
    try:
        origin_count[origin]+=1
    except:
        origin_count[origin]=1

for destination in destination_pairs:
    try:
        destination_count[destination]+=1
    except:
        destination_count[destination]=1

# add edges between gates and airports in the continental United States
for origin in origin_set:
    #weight = origin_count[origin]
#     if origin[1][0] != 'K':
#         continue
    weight=1
    graph.add_edge(origin[1],origin[0],weight=weight)

for destination in destination_set:
#     if destination[1][0] != 'K':
#         continue
    #weight = destination_count[destination]
    weight=1
    graph.add_edge(destination[0],destination[1],weight=weight)
```

[29]:

```
nx.is_bipartite(graph)
```

[29]:

```
True
```

[30]:

```
# remove disconnected nodes
def trim_nodes(G):
    deg = G.degree()
    to_keep = []
    for node in G.nodes():
        if deg[node] != 0:
            to_keep.append(node)
        else:
            pass
            #print("Node: ",node," degree: ",deg[node])
    #Create the network only with connected nodes
    G=G.subgraph(to_keep)
    return G

graph = trim_nodes(graph)
```

2.1 Bipartite set projections

2.1.1 Get projections for gate set and airport set

[31]:

```
# Projection onto gates
def proj_function(graph, node_u, node_v, weight="weight"):
    pass
    return # int or float
top = nx.bipartite.sets(graph)[0]
bot = nx.bipartite.sets(graph)[1]
gate_proj = bipartite.projected_graph(graph, top)
airport_proj = bipartite.projected_graph(graph, bot)
# Projection onto airports
```

[32]:

```
# Map time series of incidence rates to airports
day = '09-25-2020'
origin_incidence = []
destination_incidence = []
```

```
# test for valid date
try:
    incidence_df.loc['California',day]
except:
    print('Invalid Date!')
for state in clean_flight['origin_state']:
    origin_incidence.append(incidence_df.loc[state,day])

for state in clean_flight['destination_state']:
    destination_incidence.append(incidence_df.loc[state,day])

clean_flight['origin_incidence'] = origin_incidence
clean_flight['destination_incidence'] = destination_incidence
clean_flight['mixing_rate_1'] = clean_flight['origin_incidence']/
 ↪clean_flight['destination_incidence']
clean_flight['mixing_rate_2'] = clean_flight['destination_incidence']/
 ↪clean_flight['origin_incidence']
clean_flight['mixing_rate'] = clean_flight[['mixing_rate_1','mixing_rate_2']].
 ↪max(axis=1)
clean_flight['mixing_rate'] = clean_flight['mixing_rate'].abs()
```

[33]:
```
all_pairs = list(set(airport_proj.edges))
all_pairs.sort()
pair_mix_rate = {}
icao_mix_rate = {}
for pair in all_pairs:
    origin = pair[0]
    destination = pair[1]
    valid_flights = (clean_flight['origin']==origin) &␣
 ↪(clean_flight['destination']==destination)
    if valid_flights.any():
        first_valid = valid_flights.argmax()
        pair_mix_rate[pair] = clean_flight.loc[first_valid,'mixing_rate']
        icao_mix_rate[pair] = clean_flight.loc[first_valid,'mixing_rate']
    else:
        pair_mix_rate[pair] = 0
        icao_mix_rate[pair] = 0
```

[34]:
```
# calculate mixing rate for each gate
gate_mix_risk = {}
for gate in gate_list:
    # get all flights going through a specific gate
    flights_through_gate = clean_flight.loc[clean_flight['Gate']==gate,:]

    # now get all unique origin-destination pairs
    unique_flight_pairs = set(list(zip(flights_through_gate['origin'].values,
                                           flights_through_gate['destination'].
↪values)))
    gate_risks = np.array([])
    for pair in unique_flight_pairs:
        # determine the mixing rate for each pair
        if pair[0] == pair[1]:
            pair_risk = 0
        else:
            pair_risk = pair_mix_rate[pair]
        gate_risks = np.append(gate_risks,pair_risk)

    if np.sum(gate_risks) == 0:
        gate_mix_risk[gate] = 1.0
    else:
        gate_mix_risk[gate] = np.sum(gate_risks)
```

[36]:
```
clean_flight['Gate'] = clean_flight['Gate'].astype('str')
```

[37]:
```
clean_flight['Gate'].values[0]
```

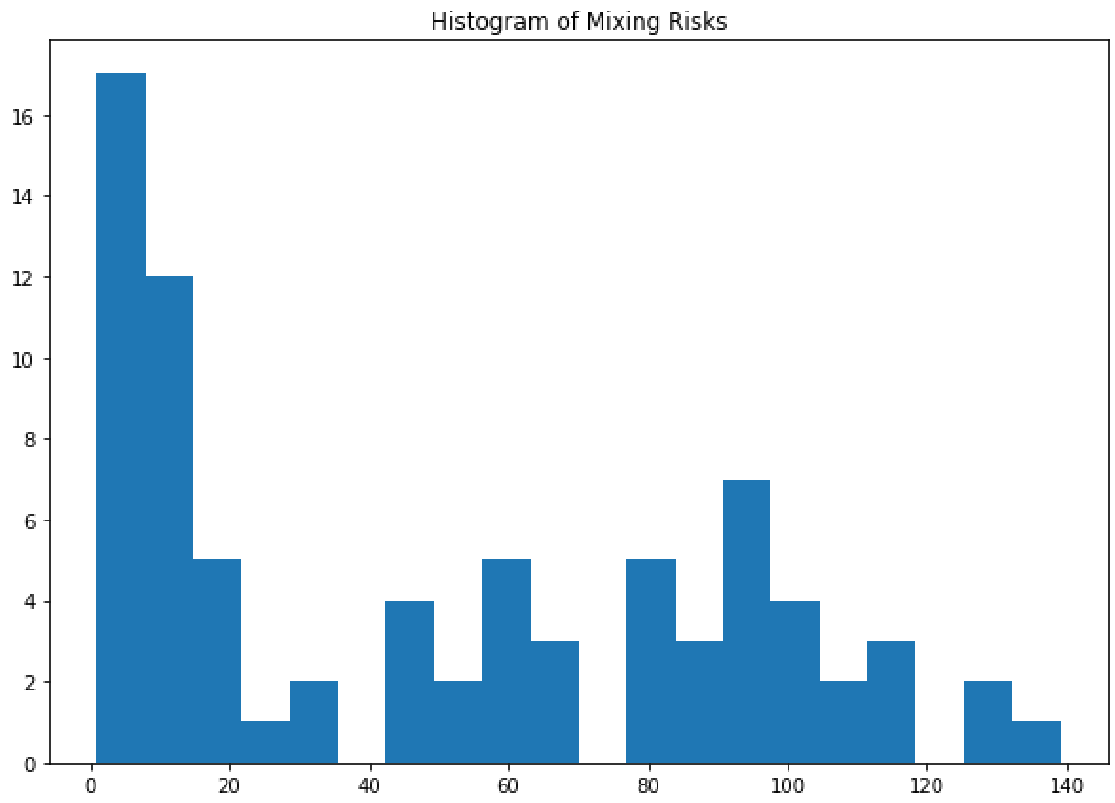
[37]:
```
'69'
```

[38]:
```
gate_mix_df = pd.DataFrame.from_dict(gate_mix_risk, orient='index')
gate_mix_df.columns=['Mixing_Risk']
gate_mix_df.sort_values(by='Mixing_Risk',inplace=True,ascending=False)
```

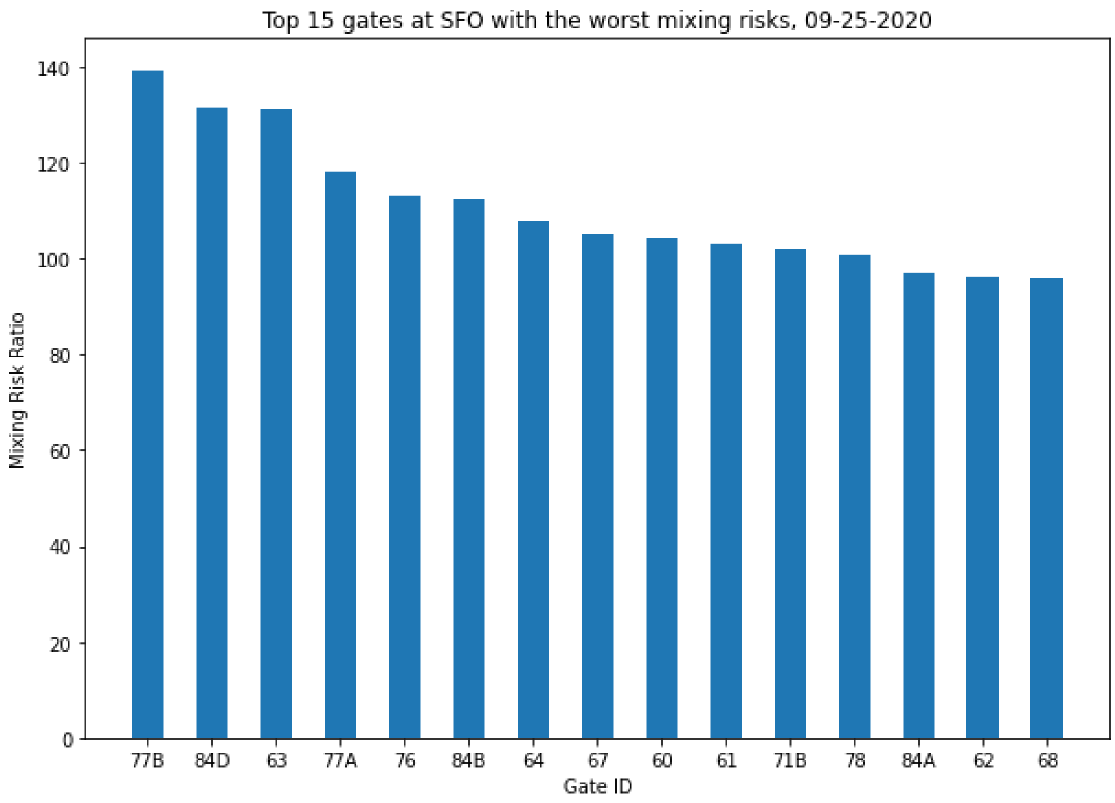
[39]:
```
gate_mix_df.head()
```

[39]:
```
     Mixing_Risk
77B   139.077434
84D   131.672557
63    131.182955
77A   118.115084
76    113.032459
```

[40]:
```
gate_mix_df.hist(column='Mixing_Risk',bins=20,grid=False,figsize=(10,7))
plt.title('Histogram of Mixing Risks')
plt.savefig('hist_mix.png')
```



[41]:
```
top_n = 15 # get top 10 worst risk gates
labels = list(gate_mix_df.index.values)[0:top_n]
risks = list(gate_mix_df.Mixing_Risk.values)[0:top_n]
x = np.arange(len(labels))
width = 0.5

fig, ax = plt.subplots(figsize=(10,7))
rects1 = ax.bar(x, risks, width,color = 'tab:blue')
ax.set_ylabel('Mixing Risk Ratio')
ax.set_xlabel('Gate ID')
ax.set_title(f'Top {top_n} gates at SFO with the worst mixing risks, {day}')
ax.set_xticks(x)
ax.set_xticklabels(labels)
plt.savefig('top_mix_risk.png')
plt.show()
```



[42]:
```
flights_through_gate['mixing_rate'].sum()
```

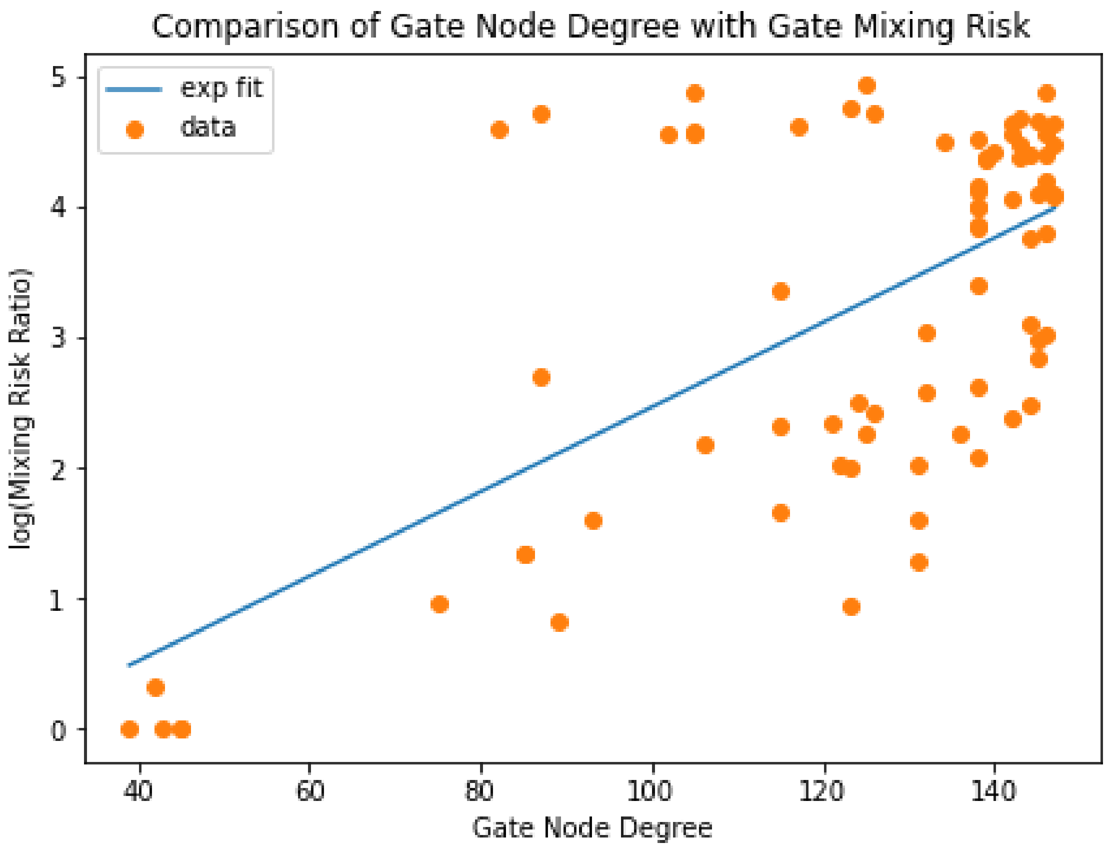
[42]:
```
1.004963123542546
```

[43]:
```
gate_nodes = list(gate_proj.nodes)
gate_nodes.sort()
```

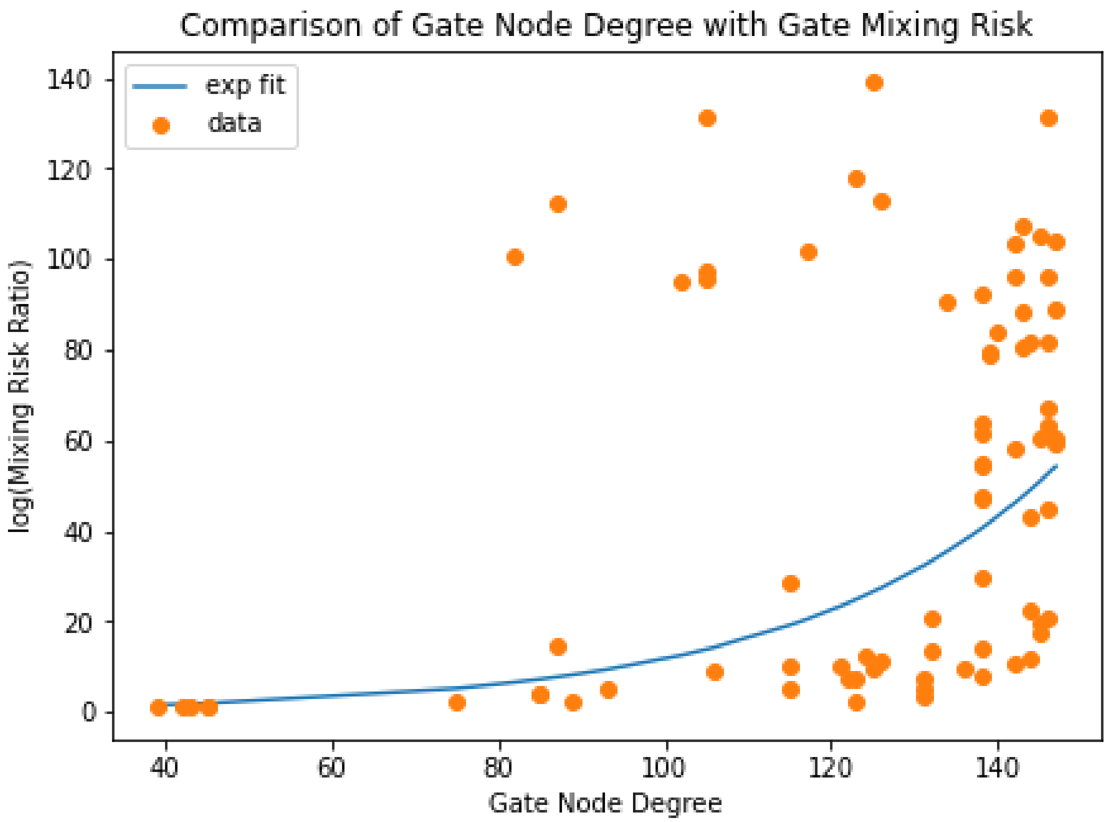
[44]:
```
print(gate_nodes)
```

```
['22', '23', '24', '25', '26', '27', '28', '40', '41', '42', '43', '44', '45A',
'45B', '46', '47', '48', '50A', '50B', '51A', '51B', '52', '53', '54A', '54B',
'55', '56A', '56B', '57', '58A', '58B', '59A', '60', '61', '62', '63', '64',
'65', '66', '67', '68', '69', '70', '71A', '71B', '72', '73', '73A', '74', '75',
'76', '77A', '77B', '77C', '78', '79', '80', '81', '82', '83', '84A', '84B',
'84C', '84D', '85', '86', '87', '88', '89', '90', 'A10', 'A12', 'A2', 'A4',
'A6', 'A8', 'A9', 'G93']
```

[45]:
```
import scipy as sp
import scipy.optimize

node_degree = []
for gate in gate_mix_df.index.values:
    node_degree.append(gate_proj.degree[gate])

gate_mix_df['Gate_Node_Degree'] = node_degree

def model_func(x,a,b):
    return a*x+b

def fit_exp_nonlinear(t, y):
    opt_parms, parm_cov = sp.optimize.curve_fit(model_func, t, y, maxfev=10000,␣
 ↪p0 = [1,1])
    a,b = opt_parms
    return a,b

def exp_model_func(x,a,b):
    return np.exp(a*x)*np.exp(b)

plt.figure(figsize=(7,5))
ax1 = plt.axes()
data = gate_mix_df[['Gate_Node_Degree','Mixing_Risk']].
 ↪sort_values(by='Gate_Node_Degree')
# data['Mixing_Risk'] = np.log(data['Mixing_Risk'])
x = data['Gate_Node_Degree'].to_numpy()
y = data['Mixing_Risk'].to_numpy()
a,b = fit_exp_nonlinear(x,np.log(y))
fit_y = model_func(x,a,b)
plt.plot(x, fit_y,label='exp fit')
plt.plot(gate_mix_df['Gate_Node_Degree'],np.
 ↪log(gate_mix_df['Mixing_Risk']),'o',label='data')
ax1.set_title('Non-linear Fit')

# fit exp curve
# fit_params = np.polyfit(gate_mix_df['Gate_Node_Degree'].to_numpy(),np.
 ↪log(gate_mix_df['Mixing_Risk'].to_numpy()), 1)
# y = np.exp(fit_params[0] * (gate_mix_df['Gate_Node_Degree'].to_numpy()))*np.
 ↪exp(fit_params[1])
# plt.plot(gate_mix_df['Gate_Node_Degree'],np.
 ↪log(gate_mix_df['Mixing_Risk']),'o')
# plt.plot(gate_mix_df['Gate_Node_Degree'].sort_values(),np.sort(y))
plt.xlabel('Gate Node Degree')
plt.ylabel('log(Mixing Risk Ratio)')
plt.title('Comparison of Gate Node Degree with Gate Mixing Risk')
plt.legend()
plt.savefig('degree_log_risk.png',bbox_inches = "tight")
plt.show()
```



[46]:
```
plt.figure(figsize=(7,5))
ax1 = plt.axes()
fit_y = exp_model_func(x,a,b)
plt.plot(x, fit_y,label='exp fit')
plt.
 ↪plot(gate_mix_df['Gate_Node_Degree'],gate_mix_df['Mixing_Risk'],'o',label='data')
plt.legend()
plt.xlabel('Gate Node Degree')
plt.ylabel('log(Mixing Risk Ratio)')
ax1.set_title('Comparison of Gate Node Degree with Gate Mixing Risk')
plt.savefig('degree_risk.png',bbox_inches = "tight")
plt.show()
```

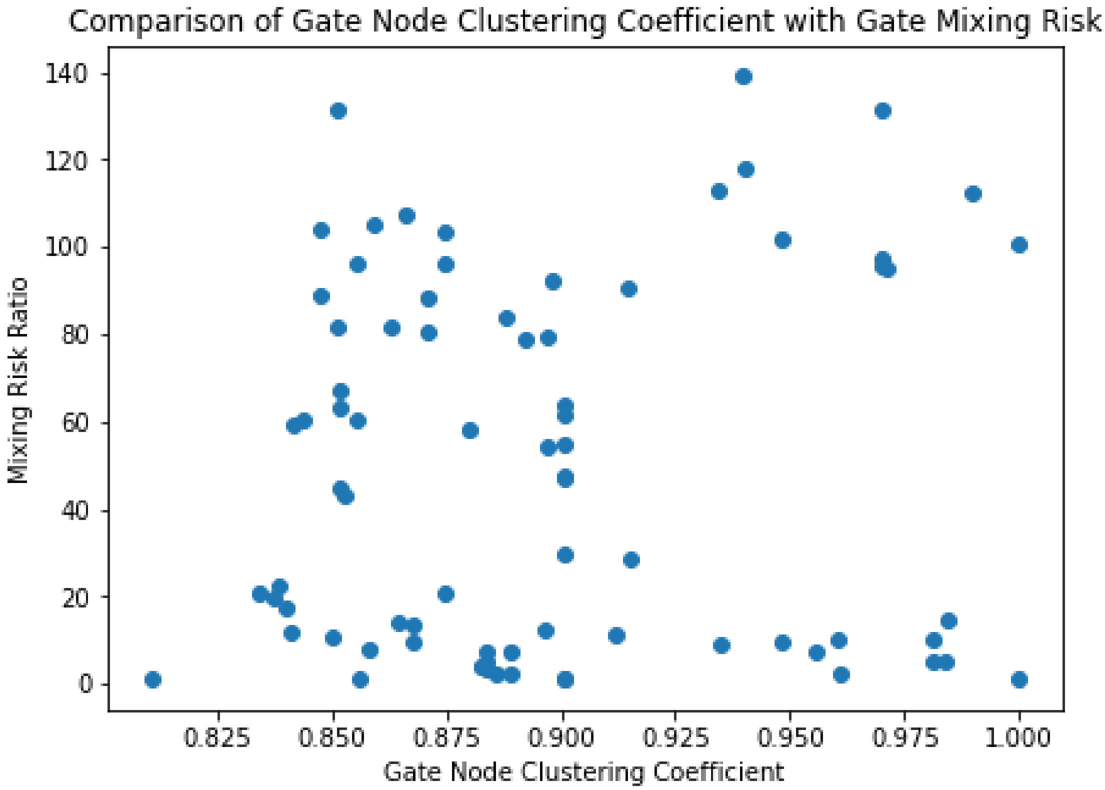


```
[48]: data.iloc[0:10,:]
```

```
[48]:      Gate_Node_Degree  Mixing_Risk
      A4                 39     1.000000
      A6                 42     1.389082
      G93                43     1.004963
      A9                 45     1.000000
      A8                 45     1.000000
      A2                 75     2.630715
      78                 82   100.675463
      A10                85     3.872348
      A12                85     3.872348
      86                 87    14.809642
```

```
[49]: node_degree = []
      clustering = nx.clustering(gate_proj)
      for gate in gate_mix_df.index.values:
          node_degree.append(clustering[gate])

      gate_mix_df['Gate_Node_CC'] = node_degree
```

```
plt.figure(figsize=(7,5))
plt.scatter(gate_mix_df['Gate_Node_CC'],gate_mix_df['Mixing_Risk'])
plt.xlabel('Gate Node Clustering Coefficient')
plt.ylabel('Mixing Risk Ratio')
plt.title('Comparison of Gate Node Clustering Coefficient with Gate Mixing Risk')
plt.savefig('cc_risk.png')
plt.show()
```



[50]:
```
data = gate_mix_df[['Gate_Node_Degree','Mixing_Risk']].sort_values(by='Gate_Node_Degree')
```

[52]:
```
clean_flight.head()
```

[52]:
```
  Combined Tail ID Terminal Gate            Time Arr            Time Dep  \
0  43101_N76523_69        3   69 2018-01-01 04:09:51 2018-01-01 07:49:00
1  43101_N77865_85        3   85 2018-01-01 04:47:32 2018-01-01 09:23:23
2  43101_N33103_88        3   88 2018-01-01 04:57:37 2018-01-01 09:10:26
3  43101_N34455_82        3   82 2018-01-01 05:03:26 2018-01-01 08:46:32
4  43101_N879DN_42        1   42 2018-01-01 06:08:43 2018-01-01 08:43:56
```

```
   Tot Time          Airline Dom or Int Classification  Type  …  \
0       220  UNITED AIRLINES  Passenger              N  B738  …
1       276  UNITED AIRLINES  Passenger              N  B753  …
2       253  UNITED AIRLINES  Passenger              N  B752  …
3       223  UNITED AIRLINES  Passenger              N  B739  …
4       155  DELTA AIR LINES  Passenger              N  B739  …

  destination_lat destination_lon origin_state destination_state  terminal  \
0     -112.012001       33.434299       Hawaii           Arizona         3
1     -156.429993       20.898600       Hawaii            Hawaii         3
2     -159.339005       21.976000       Hawaii            Hawaii         3
3      -90.258003       29.993401       Hawaii         Louisiana         3
4      -93.221802       44.882000       Hawaii         Minnesota         1

   origin_incidence  destination_incidence  mixing_rate_1 mixing_rate_2  \
0        839.835804            2972.598055       0.282526      3.539499
1        839.835804             839.835804       1.000000      1.000000
2        839.835804             839.835804       1.000000      1.000000
3        839.835804            3526.247883       0.238167      4.198735
4        839.835804            1670.126703       0.502858      1.988635

  mixing_rate
0    3.539499
1    1.000000
2    1.000000
3    4.198735
4    1.988635

[5 rows x 26 columns]
```

```
[53]: gate_mix_df.head()
```

```
[53]:      Mixing_Risk  Gate_Node_Degree  Gate_Node_CC
      77B   139.077434               125      0.939597
      84D   131.672557               105      0.969969
      63    131.182955               146      0.851042
      77A   118.115084               123      0.940035
      76    113.032459               126      0.934101
```

To use skmob's FlowDataFrame, we need to map the gate and airport names to integer IDs

```
[54]: gate_edges = list(gate_proj.edges(data=True))
```

```
[55]: gate_df = pd.read_excel('gate_coords.xlsx')
      gate_df = gate_df.dropna().copy()
      gate_df.reset_index(inplace=True,drop=True)
```

[56]:
```
gate_df['loc'] = gate_df['loc'].apply(lambda x: list(x.split(', ')))
```

[57]:
```
gate_df['long'] = gate_df['loc'].apply(lambda x: float(x[1]))
gate_df['lat'] = gate_df['loc'].apply(lambda x: float(x[0]))
```

[58]:
```
gate_df.head()
```

[58]:
```
  gate                                        loc        long        lat
0   20   [37.61391155436734, -122.38543787963708] -122.385438  37.613912
1   21   [37.61391334101065, -122.38491912385682] -122.384919  37.613913
2   22    [37.61352805858318, -122.3853107748032] -122.385311  37.613528
3   23   [37.61346431755819, -122.38473007655958] -122.384730  37.613464
4   24  [37.613539324514264, -122.38531143607227] -122.385311  37.613539
```

[59]:
```
comb_df_1 = gate_df.copy()
comb_df_1.drop(['loc'],axis=1,inplace=True)
```

[60]:
```
comb_df_1.rename({"gate":"location"},inplace=True,axis='columns')
comb_df_1.head()
```

[60]:
```
  location        long        lat
0       20 -122.385438  37.613912
1       21 -122.384919  37.613913
2       22 -122.385311  37.613528
3       23 -122.384730  37.613464
4       24 -122.385311  37.613539
```

[61]:
```
cont_map = copy.copy(airport_map)
```

[62]:
```
# Check that all airport nodes are in the airport mapping to coordinates
airport_nodes = list(airport_proj.nodes)
airport_nodes.sort()

# if true, all nodes are in the airport mapping
print(Counter(airport_nodes) == Counter(list(cont_map.keys())))
```

```
False
```

[63]:
```
airport_df = pd.DataFrame.from_dict(cont_map).T
airport_df.reset_index(inplace=True)
airport_df.columns = ['location','long','lat']
```

[64]:
```
airport_df.head()
```

[64]:
```
  location        long        lat
0     PHOG -156.429993  20.898600
1     PHLI -159.339005  21.976000
```

```
2     PHKO -156.045603  19.738783
3     LLBG   34.886700  32.011398
4     YSSY  151.177002 -33.946098
```

[65]:

```
comb_df = pd.concat([comb_df_1,airport_df],ignore_index=True)
```

[66]:

```
comb_df.head()
```

[66]:

```
  location        long        lat
0       20 -122.385438  37.613912
1       21 -122.384919  37.613913
2       22 -122.385311  37.613528
3       23 -122.384730  37.613464
4       24 -122.385311  37.613539
```

[67]:

```
comb_df['location'] = comb_df['location'].astype('str')
location_id = set(list(comb_df['location'].values))
location_id = list(location_id)
location_id.sort()
```

[68]:

```
# Map names to integer IDs
location_map = {}
for i in range(len(location_id)):
    location_map[location_id[i]] = i+1

def map_col(df,col_name,map):
    new_locs = []
    for location in df[col_name].values:
        new_locs.append(location_map[location])

    df[col_name] = new_locs
    return df

comb_df = map_col(comb_df,'location',location_map)
```

[69]:

```
# convert edge view to list of lists with [source, dest, **edge_attr]
# specify edge_attr to extract with list of strings corresponding to edge␣
 ↪attributes
def edge_view_to_list(graph,edge_attr=None):
    edge_view = list(graph.edges(data=True))
    edge_list = []
    for edge in edge_view:
        source = edge[0]
        dest = edge[1]
        attrs = []
        if edge_attr is None:
            pass
        else:
            for attr in edge_attr:
                attrs.append(edge[2][attr])
        edge_list.append([source,dest]+attrs)
    return edge_list

edge_list = edge_view_to_list(graph,edge_attr=['weight'])

flow_df = pd.DataFrame(edge_list,columns = ['origin','destination','flow'])

# dataframe for building a FlowDataFrame for the whole bipartite network
flow_df = map_col(flow_df,'origin',location_map)
flow_df = map_col(flow_df,'destination',location_map)
```

[70]:

```
gate_proj_edge_list = edge_view_to_list(gate_proj)
airport_proj_edge_list = edge_view_to_list(airport_proj)

# dataframe for building a FlowDataFrame for the bipartite projected gate nodes␣
 ↪network
gate_proj_df = pd.
 ↪DataFrame(gate_proj_edge_list,columns=['origin','destination'])
gate_proj_df['flow'] = 1
gate_proj_df = map_col(gate_proj_df,'origin',location_map)
gate_proj_df = map_col(gate_proj_df,'destination',location_map)

# dataframe for building a FlowDataFrame for the bipartite projected airport␣
 ↪nodes network
airport_proj_df = pd.
 ↪DataFrame(airport_proj_edge_list,columns=['origin','destination'])
airport_weighted_df = airport_proj_df.copy()
airport_proj_df['flow'] = 1
airport_proj_df = map_col(airport_proj_df,'origin',location_map)
airport_proj_df = map_col(airport_proj_df,'destination',location_map)

weighted_flow = []

for idx in airport_weighted_df.index:
    origin = airport_weighted_df.loc[idx,'origin']
    destination = airport_weighted_df.loc[idx,'destination']
    weighted_flow.append(icao_mix_rate[(origin,destination)])
```

[71]:

```
airport_weighted_df['flow'] = weighted_flow
airport_weighted_df = map_col(airport_weighted_df,'origin',location_map)
airport_weighted_df = map_col(airport_weighted_df,'destination',location_map)
```

[72]:

```
airport_weighted_df.head()
```

```
[72]:    origin  destination      flow
      0     147          179  0.000000
      1     147          186  0.000000
      2     147          180  0.000000
      3     147          176  0.000000
      4     147          170  1.250539
```

```
[73]: flow_df.head()
```

```
[73]:    origin  destination  flow
      0       3          160     1
      1       3          145     1
      2       3          131     1
      3       3          164     1
      4       4          195     1
```

```
[74]: # geoDataFrame contains all the coordinate point locations for eacb gate/airport
      gdf = gpd.GeoDataFrame(comb_df, geometry = gpd.points_from_xy(comb_df.long,␣
       ↪comb_df.lat))
```

```
[75]: # create flowDataFrame with edge data using whole bipartite graph or its␣
       ↪projections
      fdf = skmob.FlowDataFrame(flow_df,tessellation = gdf,tile_id = 'location')
      gate_proj_fdf = skmob.FlowDataFrame(gate_proj_df,tessellation = gdf,tile_id =␣
       ↪'location')
      airport_proj_fdf = skmob.FlowDataFrame(airport_proj_df,tessellation =␣
       ↪gdf,tile_id = 'location')
      airport_weighted_fdf = skmob.FlowDataFrame(airport_weighted_df,tessellation =␣
       ↪gdf,tile_id = 'location')
```

```
C:\Users\orcal\.conda\envs\skmob\lib\site-
packages\scikit_mobility-1.0-py3.7.egg\skmob\core\flowdataframe.py:145:
UserWarning: The tessellation crs is None. It will be set to the default crs
WGS84 (EPSG:4326).
```

```
[76]: fdf.plot_flows(flow_color='red',flow_weight=0.8)
```

```
[76]: <folium.folium.Map at 0x21d1ea60608>
```

```
[77]: gate_proj_fdf.plot_flows(flow_color='cadetblue',opacity=0.5,flow_weight=0.2)
```

```
[77]: <folium.folium.Map at 0x21d18496388>
```

```
[78]: airport_proj_fdf.plot_flows(flow_color='green',opacity=0.5,flow_weight=0.2)
```

```
[78]: <folium.folium.Map at 0x21d1bc24e88>
```

```
[79]: airport_weighted_fdf.plot_flows(flow_color='red',flow_weight=0.35)
```

```
[79]: <folium.folium.Map at 0x21d1bc0e048>
```

```
[80]: airport_weighted_fdf.head()
```

```
[80]:   origin destination      flow
      0    147         179  0.000000
      1    147         186  0.000000
      2    147         180  0.000000
      3    147         176  0.000000
      4    147         170  1.250539
```

```
[81]: flow_df.head() # flows are edge weights
```

```
[81]:    origin  destination  flow
      0       3          160     1
      1       3          145     1
      2       3          131     1
      3       3          164     1
      4       4          195     1
```

```
[82]: nx.write_gexf(graph,'airport_graph.gexf')
```