Airline Passenger Transportation System: Structure and Dynamics

Lance Sherry
Airline Passenger Transportation System (APTS)

- System that provides transportation of passengers:
  - Passengers that provide value at their destinations (e.g. consult, exchange technology, sales, ...)
  - Passengers that spend money at their destinations (e.g. vacation)

- This mode of transportation is characterized by:
  - Service across long geographic distances
  - Rapid
  - Affordable
  - High levels of safety
Airline Passenger Transportation System (APTS)

- Transportation accomplished through the *interaction of multiple agents*:
  - Airlines
    - Ticketing
    - Check-in
    - Flights
    - Baggage
  - Airports
    - Ground transportation
    - Security
    - Terminal services
    - Airside service (e.g. de-icing, snow removal, ...)
  - Air Navigation Service Providers
    - Navigation infrastructure
    - Surveillance function
    - Flow Management, Separation, ...
  - Other supply chain enterprises (rental cars, fuel providers, concessionaires, ... equipment manufacturers)
Airline Passenger Transportation System (APTS)

1. Quality (i.e. passenger safety)
2. Cost (i.e. airfares + other costs, externalities)
3. Time (i.e. scheduled trip time, reliability = actual trip time)
(1) Quality of APTS

- mortality risk of passenger air travel
- a passenger chooses a (nonstop) flight completely at random, what is the probability that the passenger will be killed during the flight?
(2) Cost of APTS

- Airfares + Other Costs of APTS determine demand for air travel
  1. Cost-based pricing
     • Direct and Indirect Operating Costs
  2. Demand-based pricing
     • Supply vs Demand
     • Competition
  3. Service-based pricing
     • Differentiation
(3) Time & Reliability of APTS

- $T = \text{Ground access/egress} + \text{Flight time} + \text{Schedule displacement}$
  - Ground Access/Egress
    - Airport processing
  - Flight Time is Scheduled “block time”
    - Includes “schedule padding”
  - Schedule Displacement
    - Time between when passenger wants to depart/arrive and flight is scheduled to depart/arrive

- Reliability = Passenger Trip Delays
  - Actual arrival time – Scheduled arrival time
  - Includes: delayed flights, diverted flights, rebooking for cancelled flights, missed connections, over-booking
Network
APTS Network

• Network is the manner in which airports are connected by flights
  – Network is a space-time network
  – Network determines the itineraries

• Two distinct types of networks
  – Point-to-point
  – Hub-and-Spoke
Direct Network

• Each Origin is connected to each Destination (e.g. 1-2, 1-3, 1-4, 1-5)
• Flights depart Origin in time to reach Destination at desired time (e.g. start of business day)
• # Flights required to provide service = \((n-1)n - 4 \times 5 = 20\)
• # Aircraft = # Simultaneous Flights = 20
Hub-and-Spoke Network

• Each Origin is connected to each Destination via a Hub (i.e. 3)
  – (e.g. 1-3-2, 1-3-4, 1-3-5)

• Flights depart Origin in time to reach Destination at desired time (e.g. start of business day)

• # Flights required to provide service = (n-1)2
  – 4* 2 = 8

• # Aircraft = # Simultaneous Flights = 4
Hub-and-Spoke

• Bank
  – Flights arrive from Origins at Hub, then depart from Hub to Destinations

• Typical hub network has 5 – 8 banks per day
  – Depends on geography/routes served
    • USAirways at CLT vs JetBlue at JFK

• Advantage of Hub – economies of scale
• Disadvantage of Hub – Flight time
Itineraries
Itineraries

• Itinerary is the sequence of flights taken by a given passenger from Origin to Destination
  – Direct Itinerary
  – Connecting Itinerary

• By definition a given flight (in a hub-and-spoke network) will have passengers on board different itineraries
Direct Itinerary

• Direct Itinerary:
  – Origin
  – Destination
  – Scheduled Departure Time Origin (as ticketed)
  – Scheduled Arrival Time Destination (as ticketed)
  – Flight Number
  – Flight Seat Capacity
  – Type: Direct
Connecting Itinerary

- Connecting Itinerary
  - Origin
  - Hub
  - Destination
  - Origin-Hub
    - Scheduled Departure Time – origin (as ticketed)
    - Scheduled Arrival Time - Hub (as ticketed)
    - Flight Number
    - Flight Seat Capacity
  - Hub-Destination
    - Scheduled Departure Time – origin (as ticketed)
    - Scheduled Arrival Time - Hub (as ticketed)
    - Flight Number
    - Flight Seat Capacity
  - Type: Direct
## Actual Itineraries (Hub ATL)

<table>
<thead>
<tr>
<th>ORIGIN</th>
<th>DEST</th>
<th>HUB</th>
<th>AIRLINE</th>
<th>DB1B PAX</th>
<th>FL_1_NUM</th>
<th>Seats</th>
<th>FL_2_NUM</th>
<th>Seats</th>
<th>T100 Load Factor</th>
<th>FL_2_NUM</th>
<th>Seats</th>
<th>T100 Load Factor</th>
<th>Pax Flight Itin Pax</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCA</td>
<td>ATL</td>
<td>NULL</td>
<td>DL</td>
<td>63</td>
<td>1137</td>
<td>143</td>
<td>NULL</td>
<td>NULL</td>
<td>0.85314685</td>
<td>NULL</td>
<td>NULL</td>
<td>0.85314685</td>
<td>19</td>
</tr>
<tr>
<td>LGA</td>
<td>ATL</td>
<td>DCA</td>
<td>DL</td>
<td>18</td>
<td>1961</td>
<td>134</td>
<td>1137</td>
<td>143</td>
<td>0.50746268</td>
<td>6</td>
<td>1137</td>
<td>0.85314685</td>
<td>10</td>
</tr>
<tr>
<td>LGA</td>
<td>ATL</td>
<td>DCA</td>
<td>DL</td>
<td>18</td>
<td>1963</td>
<td>134</td>
<td>1137</td>
<td>143</td>
<td>0.50746268</td>
<td>6</td>
<td>1137</td>
<td>0.85314685</td>
<td>10</td>
</tr>
<tr>
<td>DCA</td>
<td>BHM</td>
<td>ATL</td>
<td>DL</td>
<td>27</td>
<td>1137</td>
<td>143</td>
<td>574</td>
<td>146</td>
<td>0.85314685</td>
<td>3</td>
<td>836</td>
<td>0.86619718</td>
<td>8</td>
</tr>
<tr>
<td>DCA</td>
<td>CHS</td>
<td>ATL</td>
<td>DL</td>
<td>16</td>
<td>1137</td>
<td>143</td>
<td>1164</td>
<td>142</td>
<td>0.85314685</td>
<td>3</td>
<td>836</td>
<td>0.86619718</td>
<td>5</td>
</tr>
<tr>
<td>DCA</td>
<td>TPA</td>
<td>ATL</td>
<td>DL</td>
<td>19</td>
<td>1137</td>
<td>143</td>
<td>836</td>
<td>201</td>
<td>0.85314685</td>
<td>3</td>
<td>836</td>
<td>0.81592039</td>
<td>6</td>
</tr>
</tbody>
</table>
Example APTS Network
Example APTS (5 Airport)

• Markets
  – Five
  – Located in same Time Zone
  – Equal distance apart

• Transportation Service at each Market
  – Each market has own airport
  – Travel time = 1 Unit Time between airports
  – (e.g. Travel Time 1 to 4 = 4)
Transportation Demand

- Transportation demand
  - Total of 500 passengers
  - 100 passengers to each Destination Market
  - 100 passenger from each Origin Market
  - 25 passenger trips from each Origin market to each Destination Market
  - Passengers are required to be at Destination for start of day, so depart with enough time
  - Demand for travel at each Origin to arrive at Destination at start of day (shown on right)
    - 100 pax leave each market
    - 100 pax arrive at each market
Direct Flight Network

- Total Passengers = 500
- Total Itineraries = 20
- # Flights = 4 * 5 = 20
- Aircraft Size 25 seats
- Distance Traveled =
  - 4+3+2+1 = 10
  - 3+2+1+1 = 7
  - 2+1+1+2 = 6
  - 3+2+1+1 = 7
  - 4+3+2+1 = 10
  - 40
- Total Trip Time = 40
- Total Arrival Displacement Time = 0 (all pax arrive at required time)
- Average Trip Time = 40/20 = 2
- Max Simultaneous Arrivals at each airport = 4 (at each airport)
- Max Simultaneous use of airspace = 5 (at each TRACON)
# Direct Flight Network

<table>
<thead>
<tr>
<th>Origin</th>
<th>Originating Pax</th>
<th>Destination</th>
<th>Itinerary = Flights</th>
<th>Pax per Itinerary = Flight</th>
<th>Trip Time</th>
<th>Arrival Displacement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100</td>
<td>2</td>
<td>1-2</td>
<td>25</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>1-3</td>
<td>25</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>1-4</td>
<td>25</td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>1-5</td>
<td>25</td>
<td>4</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
<td>1</td>
<td>2-1</td>
<td>25</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>2-3</td>
<td>25</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>2-4</td>
<td>25</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>2-5</td>
<td>25</td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>100</td>
<td>1</td>
<td>3-1</td>
<td>25</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>3-2</td>
<td>25</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>3-4</td>
<td>25</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>3-5</td>
<td>25</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>100</td>
<td>1</td>
<td>4-1</td>
<td>25</td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>4-2</td>
<td>25</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>4-3</td>
<td>25</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>4-5</td>
<td>25</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>100</td>
<td>1</td>
<td>5-1</td>
<td>25</td>
<td>4</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>5-2</td>
<td>25</td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>5-3</td>
<td>25</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>5-4</td>
<td>25</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>TOTAL</td>
<td>500</td>
<td></td>
<td>500</td>
<td>60</td>
<td>0</td>
<td>-</td>
</tr>
</tbody>
</table>
Hub-n-Spoke Network

- Total Passengers = 500
- Total Itineraries = 20
- # Flights = 4 + 4 = 8
- Aircraft Size = 100 seats
- Distance Traveled = 12
- Total Trip Time = Flight + Turn + Flight
  - (5+3+5+6+)
  - (5+2+4+5)+
  - (3+2+2+3+)
  - (5+4+2+5+)
  - (6+5+3+5)=80
- Total Arrival Displacement Time = (some pax arrive earlier than needed)
- Average Trip Time = 80/20 = 4
- Max Simultaneous Arrivals at each airport = 4 (at hub only)
- Max Simultaneous use of airspace = 4 (at hub TRACON only)
## Hub-n-Spoke: Itinerary Table

<table>
<thead>
<tr>
<th>Origin</th>
<th>Originating Pax</th>
<th>Destination</th>
<th>Itinerary</th>
<th>Pax per Itinerary</th>
<th>Total Trip Time</th>
<th>Arrival Displacement (Early)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100</td>
<td>2</td>
<td>1-3-2</td>
<td>25</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>1-3</td>
<td>25</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>1-3-4</td>
<td>25</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>1-3-5</td>
<td>25</td>
<td>5</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
<td>1</td>
<td>2-3-1</td>
<td>25</td>
<td>5</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>2-3</td>
<td>25</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>2-3-4</td>
<td>25</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>2-3-5</td>
<td>25</td>
<td>4</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>100</td>
<td>1</td>
<td>3-1</td>
<td>25</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>3-2</td>
<td>25</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>3-4</td>
<td>25</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>3-5</td>
<td>25</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>100</td>
<td>1</td>
<td>4-3-1</td>
<td>25</td>
<td>4</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>4-3-2</td>
<td>25</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>4-3</td>
<td>25</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>4-3-5</td>
<td>25</td>
<td>4</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>100</td>
<td>1</td>
<td>5-3-1</td>
<td>25</td>
<td>5</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>5-3-2</td>
<td>25</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>5-3-4</td>
<td>25</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>5-3-4</td>
<td>25</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>TOTAL</td>
<td>500</td>
<td></td>
<td></td>
<td>500</td>
<td>57</td>
<td>16</td>
</tr>
</tbody>
</table>
# Hub-n-Spoke: Flight Table

<table>
<thead>
<tr>
<th>Origin</th>
<th>Destination</th>
<th>Pax per Flight</th>
<th>Total Trip Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>100</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>100</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>100</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>100</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>100</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>100</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>100</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>100</td>
<td>2</td>
</tr>
</tbody>
</table>
Load Factor
Load Factor

• Load Factor on a flight
  – Enplaned Passengers / Available Seats

• Average Load Factor for a set of flights
  – \[ \frac{\Sigma \text{(load factors for set of flights)}}{\text{number of flights}} \]

• Network Load Factor
  – Total enplaned passengers / Total available seats
  – Alternate: RPM/ASM
Load Factors

• Airlines control Load Factors by:
  1. Adjusting Aircraft Size
  2. Revenue Management (also known as Yield Management)
     • Computerized Reservation System (CRS)
     • Internet provides price transparency
Itinerary Performance
Reliability
Itinerary Performance

• Passenger Trip Delay = Actual Passenger Arrival Time – Scheduled (i.e. Ticketed) Arrival Time

• Disruptions resulting in Passenger Trip Delays
  1. Delayed flights
  2. Cancelled flights
  3. Diverted flights
  4. Denied Boarding
  5. Missed Connections
Direct Itin Disruption

Delayed Flight

• Pax Trip Delay
  – Ticketed Arrival Time – Actual Arrival Time – 15 min
  – $D_{\text{DelayedFlight}}$

• Probability of Pax Trip Delay
  – Probability Flight Delay > 15 minutes
  – $P_{\text{DelayedFlight}}()$
Direct Itin Disruption

Cancelled Flight

• Pax Trip Delay
  – Ticketed Arrival Time – Actual Arrival Time
  – $D_{\text{CancelledFlight}} = f(\text{Frequency of Service O-D})$

• Probability of Pax Trip Delay
  – Probability Flight Cancelled
  – $P_{\text{CancelledFlight}}$
Connected Itin Disruption

Delayed Flight

- Pax Trip Delay
  - Ticketed Arrival Time – Actual Arrival Time – 15 min
  - \( D_{\text{DelayedFlight H-D}} = f \) (Frequency of Service O-D)

- Probability of Pax Trip Delay
  - Probability H-D Flight Delay > 15 minutes
  - \( P_{\text{DelayedFlight H-D}} \)
Connected Itin Disruption

Cancelled Flight (O-H)

- Pax Trip Delay
  - Ticketed Arrival Time – Actual Arrival Time – 15 min
  - \( D_{\text{CancelledFlight withConnection}} = f \) (Frequency of Service O-H, H-D)

- Probability of Pax Trip Delay
  - Probability O-H Cancelled
  - \( P_{\text{CancelledFlightO-H}} () \)
Connected Itin Disruption

Cancelled Flight (H-D)

• Pax Trip Delay
  – Ticketed Arrival Time – Actual Arrival Time – 15 min
  – \( D_{\text{Cancelled Flight}} = f(\text{Frequency of Service H-D}) \)

• Probability of Pax Trip Delay
  – Probability H-D Cancelled
  – \( P_{\text{cancelled Flight O-H}}() \)
Connected Itin Disruption

Missed Connection Flight

• Pax Trip Delay
  – Ticketed Arrival Time – Actual Arrival Time – 15 min
  – \( D_{\text{MissedConnectionFlight}} = f \) (Frequency of Service O-D)

• Probability of Pax Trip Delay
  – Probability O-H Flight Delay > 15 minutes AND Probability Pax Misses Connection
  – \( P_{\text{DelayedFlightO-H}} \ast P_{\text{MissedConnection}}(\cdot) \)

Probability Missed Connection = Probability O-H is Delayed beyond Min Connecting Window to H-D
## Probability & Magnitude of Disruption

<table>
<thead>
<tr>
<th>Itinerary Type</th>
<th>Type of Itinerary Disruption</th>
<th>Probability of Itinerary Disruption</th>
<th>Magnitude of Disruption (Average)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct</td>
<td>Delayed</td>
<td>Based on Probability of Delayed Flight (typical 0.3)</td>
<td>10*e (Probability of Delay Flight *6). (Typical 60 mins)</td>
</tr>
<tr>
<td></td>
<td>Cancelled</td>
<td>0.004 (Probability of Delay Flight *6.67). (Typical 0.02)</td>
<td>Based on Availability of Seats on subsequent flights and Time to next flight (average = 300 mins)</td>
</tr>
<tr>
<td>Connecting</td>
<td>Delayed</td>
<td>Based on Probability of Delayed Flight (typical 0.3)</td>
<td>10*e (Probability of Delay Flight *6). (Typical 60 mins)</td>
</tr>
<tr>
<td></td>
<td>Cancelled</td>
<td>2 * 0.004 (Probability of Delay Flight *6.67). Twice probability of Cancelled Flight (typical 2 * 0.02)</td>
<td>(0.0483<em>e (5.8902</em>Load Factor))*Time to Next Flight. Based on Availability of Seats on subsequent flights and Time to next flight (average = 645 mins)</td>
</tr>
<tr>
<td></td>
<td>Missed Connection</td>
<td>0.1 * Probability of Delayed Flight. A function of connecting times and airline policies regarding holding flights (typical 0.03)</td>
<td>(0.0483<em>e (5.8902</em>Load Factor))*Time to Next Flight. Based on Availability of Seats on subsequent flights and Time to next flight (average = 645 mins)</td>
</tr>
</tbody>
</table>
Rebooking Passengers

Additional Flights Required each Day to Deal with a Cancelled Flights as Load Factor Increases

\[ \text{Additional Flights} = 0.0483e^{5.8902(\text{Load Factor})} \]

\[ R^2 = 0.9357 \]
## Calculating Passenger Trip Delay

<table>
<thead>
<tr>
<th>Flight</th>
<th>Scheduled Departure Time</th>
<th>Scheduled Arrival Time</th>
<th>Seats</th>
<th># Pax</th>
<th>Flight Status</th>
<th>Delay</th>
<th>Pax Trip Delay</th>
</tr>
</thead>
<tbody>
<tr>
<td>O-D</td>
<td>06:00</td>
<td>08:00</td>
<td>100</td>
<td>100</td>
<td>Delayed</td>
<td>20 mins</td>
<td>100* 20</td>
</tr>
<tr>
<td>O-D</td>
<td>06:10</td>
<td>08:20</td>
<td>120</td>
<td>100</td>
<td>Cancelled</td>
<td></td>
<td>(20 * 130)</td>
</tr>
<tr>
<td>O-H1-D</td>
<td>06:30</td>
<td>10:30</td>
<td>120</td>
<td>100</td>
<td>On-Time</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>O-D</td>
<td>09:30</td>
<td>11:50</td>
<td>150</td>
<td>100</td>
<td>Delayed</td>
<td>40 mins</td>
<td>100*40</td>
</tr>
<tr>
<td>O-H2-D</td>
<td>13:00</td>
<td>15:00</td>
<td>120</td>
<td>70</td>
<td>On-Time</td>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>
The Passenger Trip “Game Wheel”

- **Passengers On-Time** - < 15 Minutes Delay (74%)
- **Passengers on Delayed Flights** (23.9%, Avg 57 minutes)
- **Passengers on Cancelled Flights** (1.8%, Avg 11 hours)
- **Passengers on Diverted Flights** (0.2%, Avg 3.5 hours)
- **Passengers Denied Boarding on Over-sold Flights** (<0.001%)

Not drawn to scale
Algorithm

- For Each Passenger Itinerary
  - Direct or Connecting
    - O to H Cancelled
      - Compute Flight Delay for Diverted Flight
    - O to H Diverted
      - Compute Flight Delay for Diverted Flight
    - O to H Delayed
      - Missed Connection
      - Compute Flight Delay for Diverted Flight
    - H to D Cancelled
      - Rebook Pax O to D and Compute Pax Delays
      - Rebook Pax H to D and Compute Pax Delay
  - Direct Itin
    - O to D Cancelled
      - Compute Flight Delay for Diverted Flight
    - O to D Diverted
      - Compute Flight Delay for Diverted Flight
    - H to D Delayed
      - Compute Pax Delay For Delayed Flight

- Denied Boarding Not Shown, same as cancelled
Data Sources

- T-100 Domestic Segments Data (U.S. Carriers) – domestic segment data aggregated by month
- DB1B Coupons Data – a 10% sample of domestic itinerary data aggregated by quarter
- Flight On-Time Performance Data (ASQP) – daily on-time arrival data for domestic flights operated by major U.S. carriers
- FAA Aircraft Registry, which includes seating capacities by carrier and aircraft type
- Other secondary sources
Airline Passenger Transportation System

(1) Generate Itinerary Structure
- # Airports in Hub-Spoke Network
- % Direct/Connecting Itineraries
- # Flights
- # Direct Itineraries
- # Connecting Itineraries
- Time to Next Flight
- Candidate Itineraries for Rebooking
- P(Delayed Flight), Average Delay for Delayed Flight
- P(Cancelled Flight)

(2) Allocate Passengers to Itineraries and to Flights
- % Itineraries Served
- Seating per Flight Load Factors
- Total Passengers
- Total Pax on Direct Itins
- Total Pax on Connecting itins
- Direct Pax/Direct itin
- Connecting Pax/Connecting itin
- Available Seats for Rebooking

(3) Generate Itinerary Disruption Performance
- P(Direct Itin Delayed)
- P(Direct Itin Cancelled)
- P(Connecting Itin Delayed)
- P(Connecting Itin Cancelled)
- P(Connecting Itin Missed_Connection)

(4) Compute Passenger Trip Delays
- Total Pax Trip Delay
- Total Direct Itin Pax Trip delay
- Total Connecting Itin Pax Trip Delay
- % Pax On-Time
- Average Disrupted Pax Trip Delay
Network Performance Characteristics

- Transportation System has:
  - 16 itineraries
  - 500 trips

- Transportation Service is provided by:
  - Network Structure
  - Direct Flights vs. Hub-n-Spoke

- Each Flight has:
  - Seat Capacity = SC
  - Seat Utilization = Load Factor = LF
  - Likelihood of experiencing delay = P(D)
  - Likelihood of cancellation = P(C)

- Each Trip has Average Trip Delay
  - Trip Delay due to Delayed Flight = DDelayedFlight
  - Trip Delay due to Cancelled Flight = DCancelledFlight
  - Trip Delay due to Missed Connection = DMissedConnection
Network Performance

• Total Passenger Trip Delays =
  Total Passenger Trip Delay from Delayed Flights +
  Total Passenger Trip Delay from Cancelled Flights

• Total Passenger Trip Delay from Delayed Flights =
  \[ \sum_{i=1, n, j=1, n} LF_{Oi-Dj} \times SC_{Oi-Dj} \times P(D)_{Oi-Dj} \times D_{DelayedFlight Oi-Dj} \]

• Total Passenger Trip Delay from Cancelled Flights
  \[ = \sum_{i=1, n, j=1, n} LF_{Oi-Dj} \times SC_{Oi-Dj} \times P(C)_{Oi-Dj} \times D_{CancelledFlight Oi-Dj} \]
Network Performance

• Under assumption of homogeneous fleet, flight leg performance ....
  
  \[ \begin{array}{c}
  - LF_{O_1-D_1} = LF_{O_1-D_2} = LF_{O_1-D_3} = \ldots = LF \\
  - SC_{O_1-D_1} = SC_{O_1-D_2} = SC_{O_1-D_3} = \ldots = SC \\
  - P(D)_{O_1-D_1} = P(D)_{O_1-D_2} = P(D)_{O_1-D_3} = \ldots = P(D) \\
  - D_{DelayedFlight \ O_1-D_1} = D_{DelayedFlight \ O_1-D_2} = \ldots = D_{DelayedFlight}
  \end{array} \]

• Total Passenger Trip Delay from Delayed Flights =
  
  \[ \sum_{i=1,n, j=1,n} LF_{Oi-D_j} * SC_{Oi-D_j} * P(D)_{Oi-D_j} * D_{DelayedFlight \ Oi-D_j} \]
  
  = \#Flights * LF * SC * P(D) * D_{DelayedFlight}
Performance Metrics

1. % Disrupted Passengers
   - Total Disrupted Passengers
     • Passengers on Delayed Flights
     • Passengers on Cancelled Flights

2. Total Passenger Trip Delay

3. Average Passenger Trip Delay

4. Average Disrupted Passenger Trip Delays
   - Average Passenger Trip Delays due to Delayed Flights
   - Average Passenger Trip Delays due to Cancelled Flights
   - Average Passenger Trip Delays due to Missed Connections
Performance: Direct Network

- **Total Disrupted Passengers** = \([P(D) + P(C)] \times (#\text{Flights} \times \text{LF} \times \text{SC})\)

- **% Passengers Disrupted** = \(P(D) + P(C)\)

- **Total Passenger Trip Delay** = 
  \[#\text{Flights} \times \text{LF} \times \text{SC} \times ((P(D) \times D_{\text{DelayedFlight}}) + (P(C) \times D_{\text{CancelledFlight}}))\]

- **Average Trip Delay** = Total Passenger Trip Delay/#Pax

- **Average Disrupted Passenger Trip Delays** = Total Passenger Trip Delay/Total Disrupted Passengers
Performance: Hub-n-Spoke Network

- **Total Disrupted Passengers** = 
  \[ (P(D)_{H-D} \times \text{Flights}_{H-D} \times LF*SC) + (P(D)_{O-H} \times P(MC) \times \text{Flights}_{H-D} \times LF*SC) + (P(C)_{O-H} \times \text{Flights}_{O-H} \times LF*SC) + (P(C)_{H-D} \times \text{Flights}_{H-D} \times LF*SC) \]

- **% Passengers Disrupted** = \[ P(D) + [P(D)\times P(MC)] + 2P(C) \]

- **Total Passenger Trip Delay** = 
  \[ (P(D)_{H-D} \times \text{Flights}_{H-D} \times LF \times SC \times D_{DelayedFlight}) + (P(D)_{O-H} \times P(MC) \times \text{Flights}_{H-D} \times LF*SC \times D_{MissedConnection}) + (P(C)_{O-H} \times \text{Flights}_{O-H} \times LF*SC \times D_{CancelledFlight}) + (P(C)_{H-D} \times \text{Flights}_{H-D} \times LF \times SC \times D_{CancelledFlight}) \]

- **Average Trip Delay** = Total Passenger Trip Delay/#Pax
Network Performance

Total Pax Trip Delay

\[
\text{Total Pax Trip Delay} = (P(D)_{H-D} \times \#\text{Flights}_{H-D} \times LF*SC \times D_{\text{DelayedFlight}}) + \\
(P(D)_{O-H} \times P(MC) \times \#\text{Flights}_{H-D} \times LF*SC \times D_{\text{MissedConnection}}) + \\
(P(C)_{O-H} \times \#\text{Flights}_{O-H} \times LF*SC \times D_{\text{CancelledFlight}}) + \\
(P(C)_{H-D} \times \#\text{Flights}_{H-D} \times LF*SC \times D_{\text{CancelledFlight}})
\]

\[
\#\text{Flights} \times LF*SC \times ((P(D) \times D_{\text{DelayedFlight}}) + (P(C) \times D_{\text{CancelledFlight}}))
\]
Sensitivity Analysis - Total Passenger Trip Delay

- 5% Degradation in On-Time Performance
- One Hour Increase in Time to Next Flight
- 10% Increase in Load Factor
- 10% Shift from Direct to Connecting Itineraries

Sensitivity Analysis - % Passengers Disrupted

- 5% Degradation in On-Time Performance
- One Hour Increase in Time to Next Flight
- 10% Increase in Load Factor
- 10% Shift from Direct to Connecting Itineraries

Sensitivity Analysis - Average Trip Delay for Disrupted Passengers

- 5% Degradation in On-Time Performance
- One Hour Increase in Time to Next Flight
- 10% Increase in Load Factor
- 10% Shift from Direct to Connecting Itineraries

Average Trip Delay for Disrupted Passengers

- Pax on Direct Itins
- Pax on Connecting Itins