Airline Passenger Transportation System: Structure and Dynamics

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04/2101

Pre-Test

A flight from DFW to ABQ has an on-time performance of 70%. For delayed flights the average delay is 30 minutes.

The flight is cancelled 1% of the time. For passengers on cancelled flights the average delay is 10 hours.

The typical flight has 100 passengers.

The Total Passenger Trip Delay expected is:

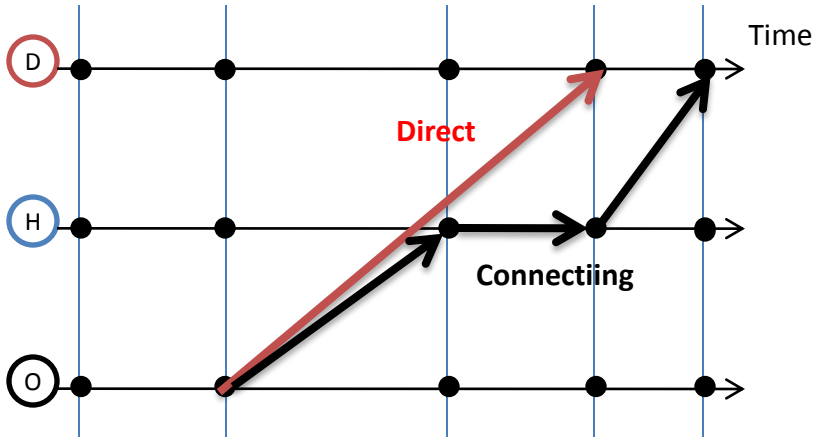
a) (0.7 * 100 * 30) = 2100 mins
b) (0.3 * 100 * 30) = 900 mins
c) (0.3 * 100 * 30) + (0.1 * 100 * 10) = 1000 mins
d) (0.3 * 100 * 30) + (0.1 * 100 * 600) = 6900 mins

Organization

1. Passenger Transportation System
2. Itinerary Performance
3. Network System Performance

Passenger Trip

- 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
  - 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

Itinerary Performance

Itinerary Performance

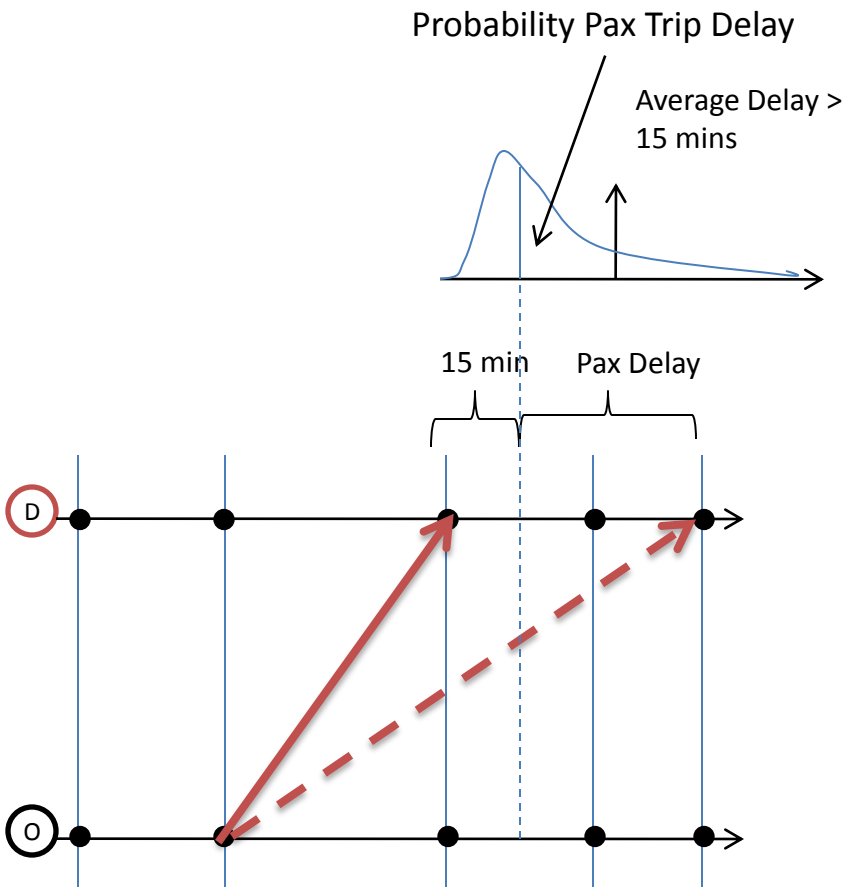
- Passenger Trip Delay = Actual Passenger Arrival Time – Scheduled (i.e. Ticketed) Arrival Time

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

Passenger Trip Delays – Direct Itin

<u>Delayed Flight</u>

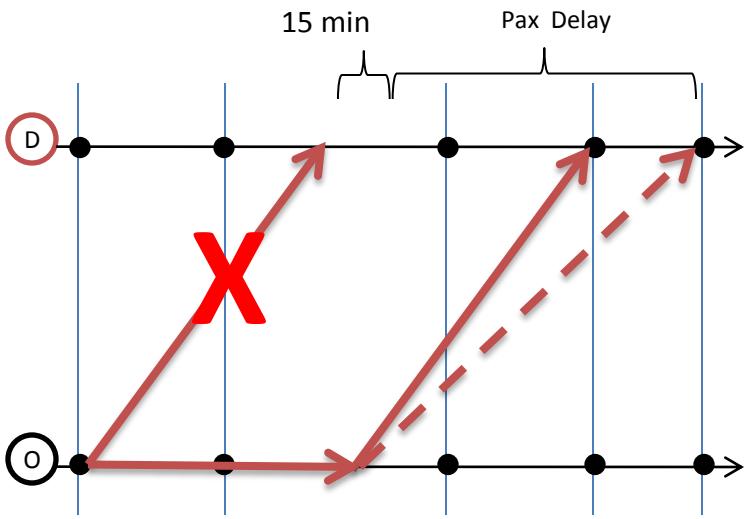
- Pax Trip Delay
  - Ticketed Arrival Time – Actual Arrival Time – 15 min
  - $D_{DelayedFlight}$
- Probability of Pax Trip Delay
  - Probability Flight Delay > 15 minutes
  - $P_{DelayedFlight}()$



Passenger Trip Delays – Direct Itin

<u>Cancelled Flight</u>

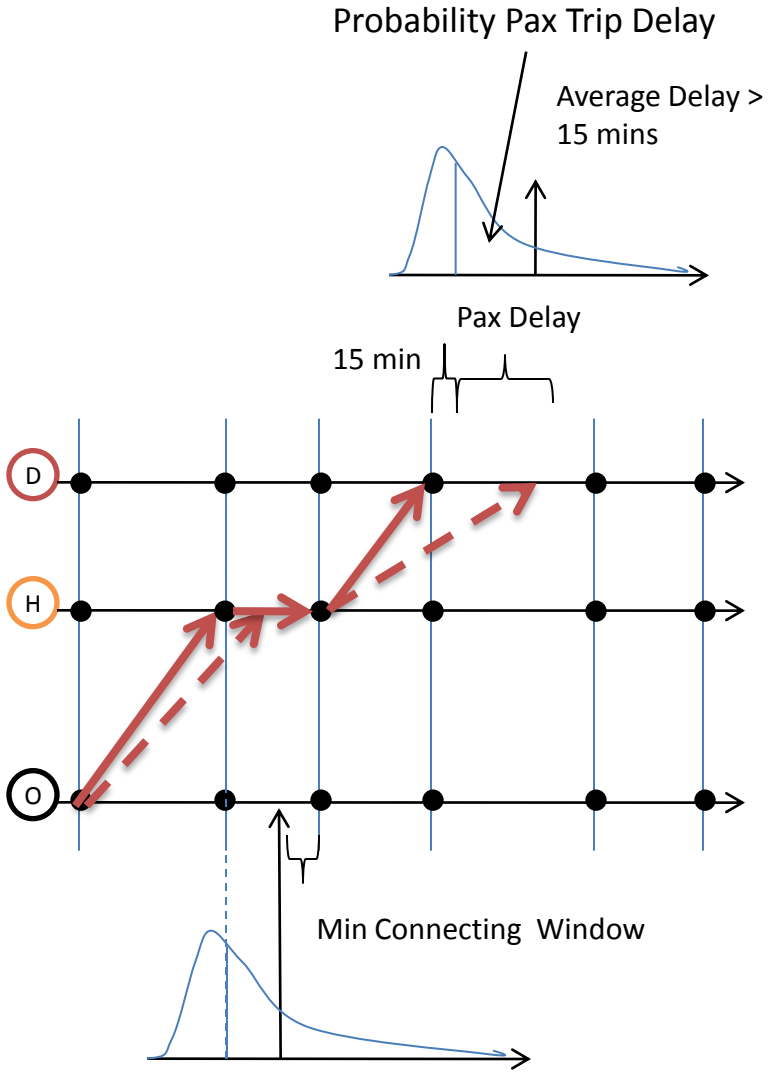
- Pax Trip Delay
  - Ticketed Arrival Time – Actual Arrival Time
  - $D_{CancelledFlight} = f$ (Frequency of Service O-D)
- Probability of Pax Trip Delay
  - Probability Flight Cancelled
  - $P_{CancelledFlight}()$



Passenger Trip Delays – Connected Itin

<u>Delayed Flight</u>

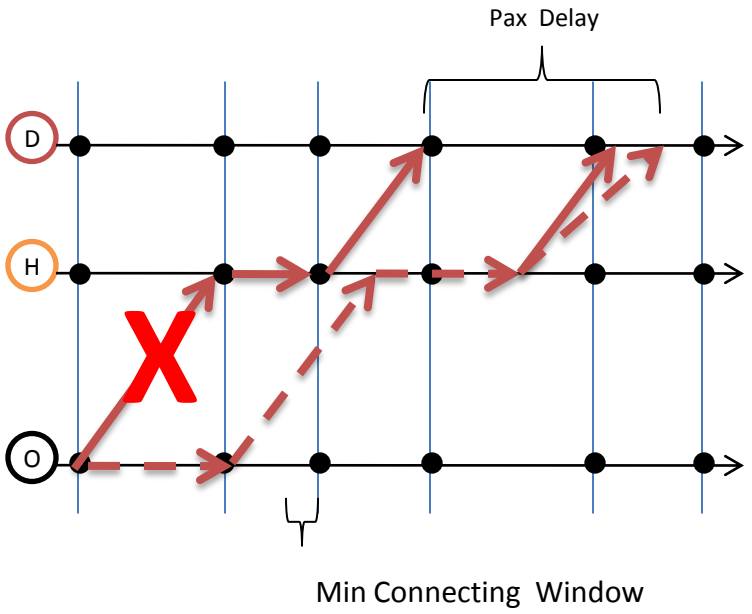
- Pax Trip Delay
  - Ticketed Arrival Time – Actual Arrival Time – 15 min
  - $D_{DelayedFlight\ H\text{-}D} = f$ (Frequency of Service O-D)
- Probability of Pax Trip Delay
  - Probability H-D Flight Delay > 15 minutes
  - $P_{DelayedFlight\ H\text{-}D}$



Passenger Trip Delays – Connected Itin

Cancelled Flight (O-H)

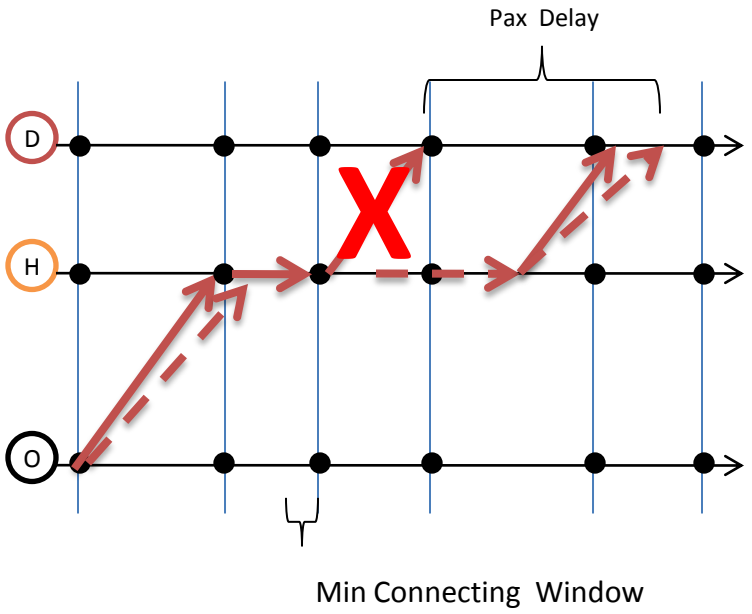
- Pax Trip Delay
  - Ticketed Arrival Time – Actual Arrival Time – 15 min
  - $D_{CancelledFlight\ withConnection} = f$ (Frequency of Service O-H, H-D)
- Probability of Pax Trip Delay
  - Probability O-H Cancelled
  - $P_{CancelledFlightO\text{-}H}$ ()



Passenger Trip Delays – Connected Itin

<u>Cancelled Flight (H-D)</u>

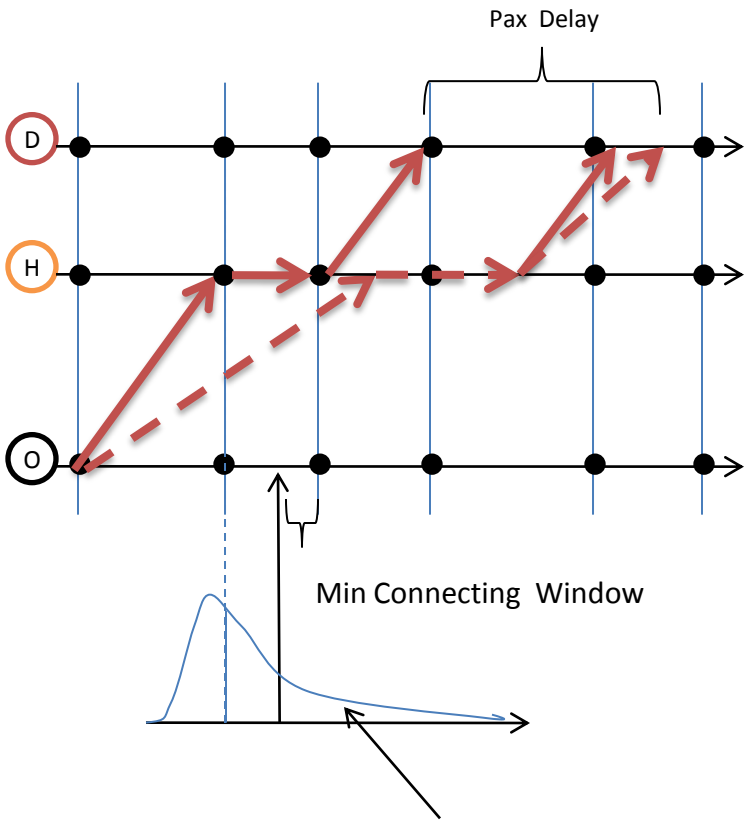
- Pax Trip Delay
  - Ticketed Arrival Time – Actual Arrival Time – 15 min
  - $D_{CancelledFlight}$ = f (Frequency of Service H-D)
- Probability of Pax Trip Delay
  - Probability H-D Cancelled
  - $P_{cancelledFlightO\text{-}H}$ ()

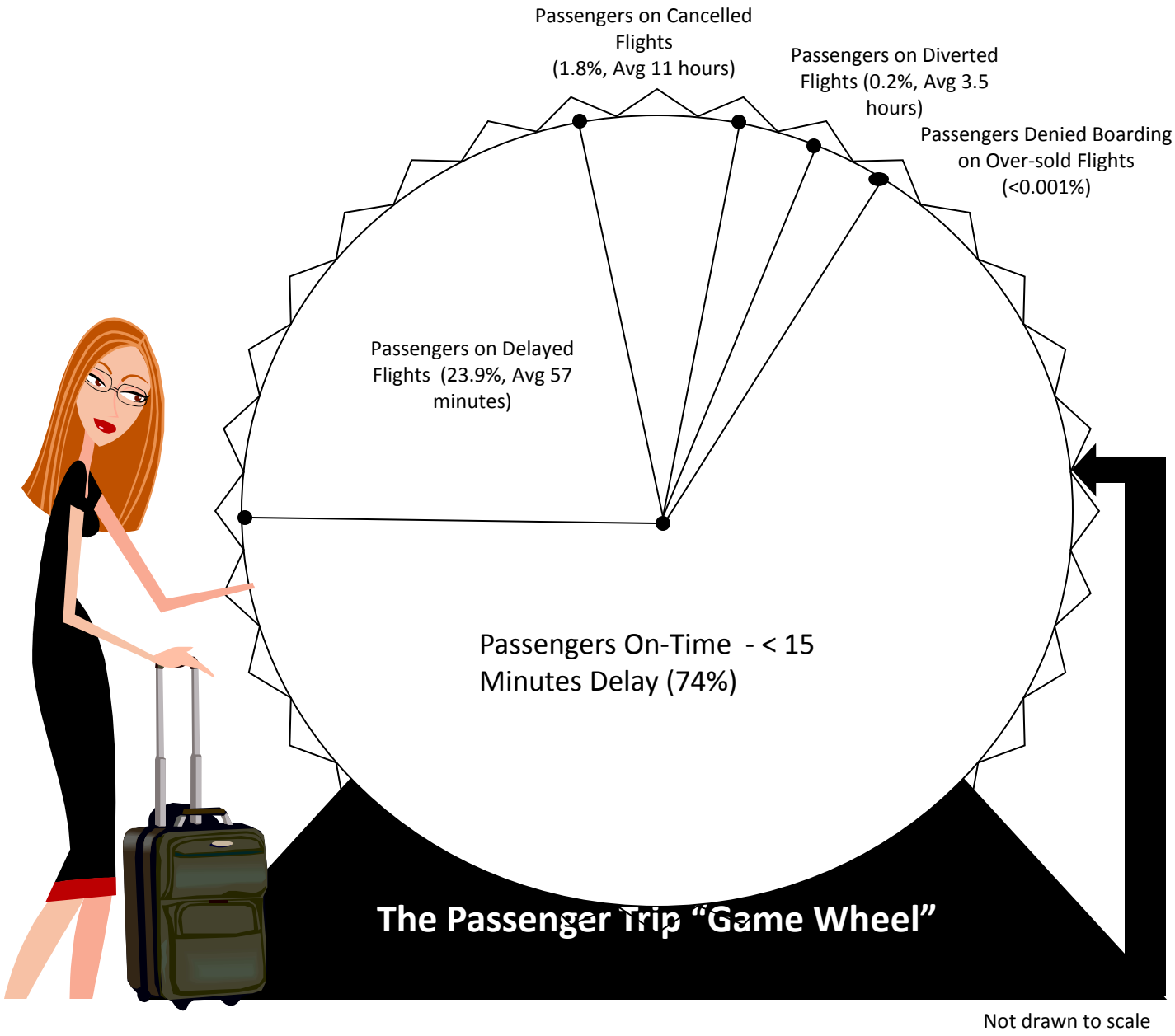


Passenger Trip Delays – Connected Itin

Missed Connection Flight

- Pax Trip Delay
  - Ticketed Arrival Time – Actual Arrival Time – 15 min
  - $D_{MissedConnectionFlight} = f$ (Frequency of Service O-D)
- Probability of Pax Trip Delay
  - Probability O-H Flight Delay > 15 minutes AND Probability Pax Misses Connection
  - $P_{DelayedFlightO\text{-}H} * P_{MissedConnection}()$





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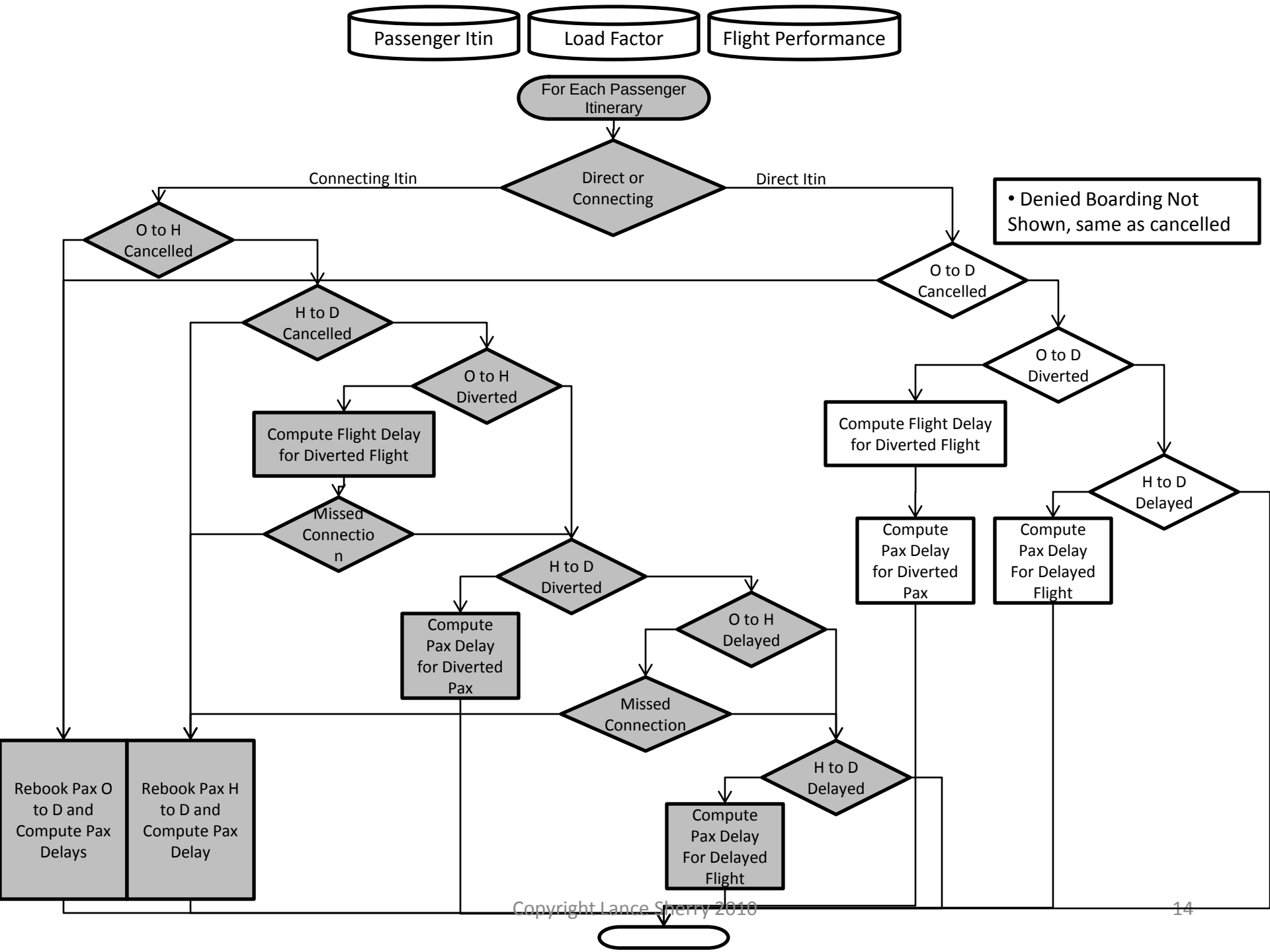


Calculating Passenger Trip Delay

	Scheduled Departure Time	Schduled Arrival Time	Seats	# Pax	Flight Status	Delay	Pax Trip Delay
O-D	06:00	08:00	100	100	Delayed	20 mins	100* 20
O-D	06:10	08:20	120	100	Cancelled		**(20 * 130)** +(50 * (210 +40)+ +(30 * 460)
O-H1-D	06:30	10:30	120	100	On-Time		0
O-D	09:30	11:50	150	100	Delayed	40 mins	100*40
O-H2-D	13:00	15:00	120	70	On-Time		0

Passenger Trip Delays

- Passengers on Direct Itinerary:

  Expected Pax Trip Delay =

  $(P_{DelayedFlight}() * D_{DelayedFlight}) +$

  $(P_{CancelledFlight}() * D_{CancelledFlight} * f$ (Frequency of Service O-D)

  Probability of Disrupted Trip =

  $(P_{DelayedFlight}() + (P_{CancelledFlight}())$

Passenger Trip Delay

- Passenger on Connecting Itinerary:

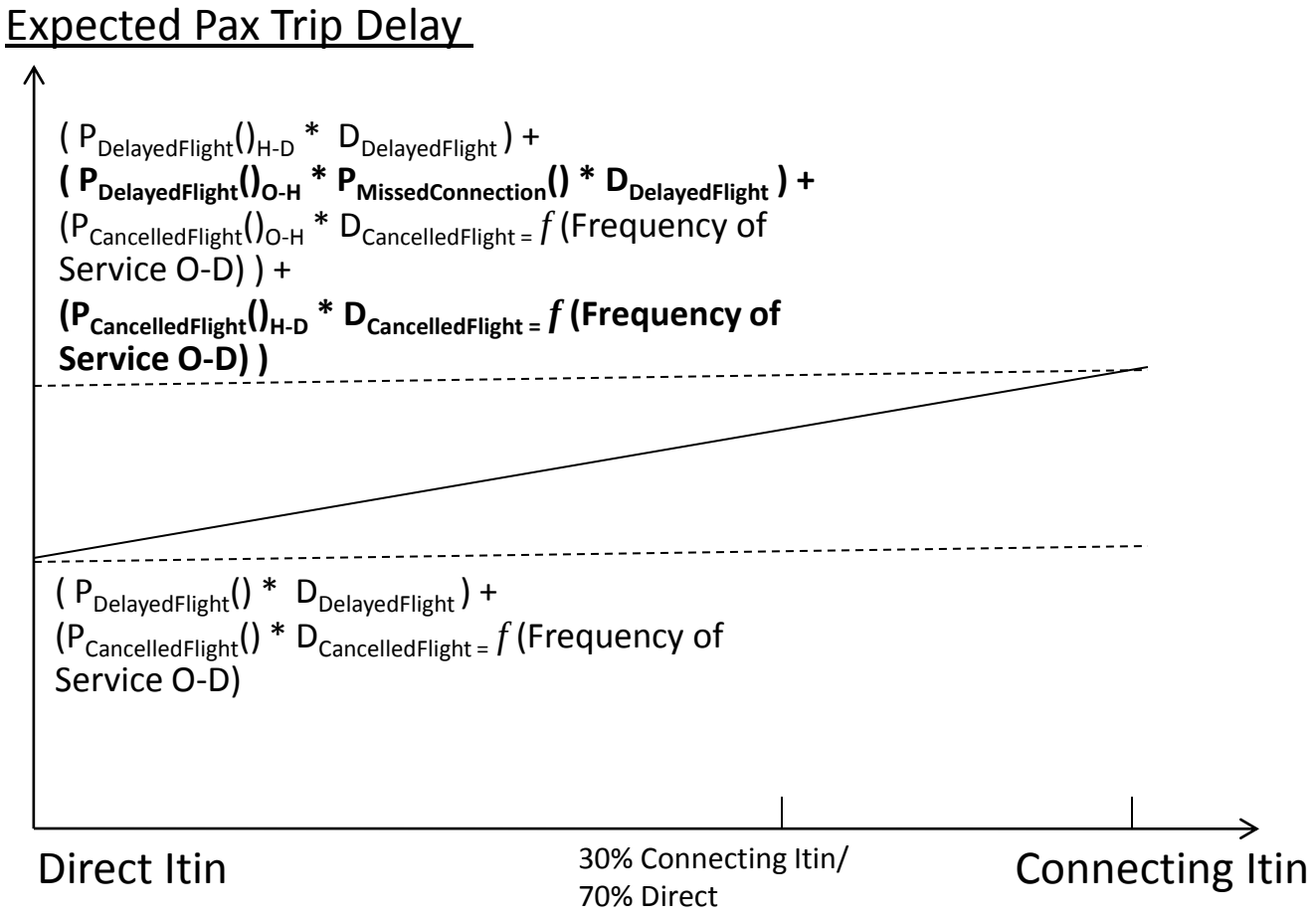
  Expected Pax Trip Delay =

  $(P_{DelayedFlight}()_{H\text{-}D} * D_{DelayedFlight}) +$
  $(P_{DelayedFlight}()_{O\text{-}H} * P_{MissedConnection}() * D_{DelayedFlight}) +$
  $(P_{CancelledFlight}()_{O\text{-}H} * D_{CancelledFlight} * f(\text{Frequency of Service O-D})) +$
  $(P_{CancelledFlight}()_{H\text{-}D} * D_{CancelledFlight} * f(\text{Frequency of Service O-D}))$

  Probability of Disrupted Trip =

  $(P_{DelayedFlight}()_{H\text{-}D}) +$
  $(P_{DelayedFlight}()_{O\text{-}H} * P_{MissedConnection}()) +$
  $(P_{CancelledFlight}()_{O\text{-}H}) +$
  $(P_{CancelledFlight}()_{H\text{-}D})$

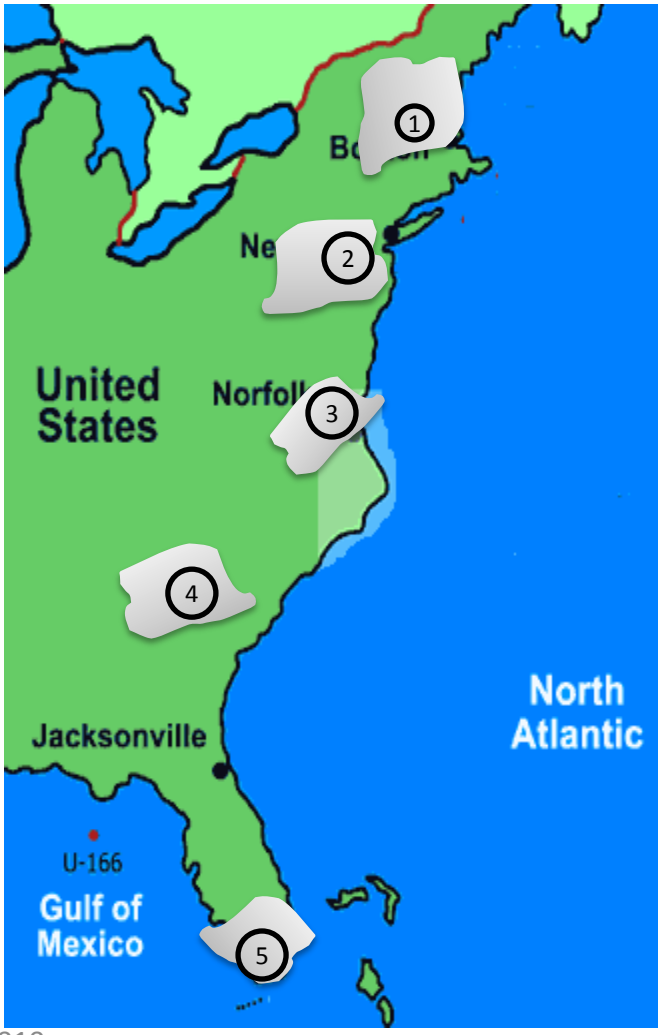
Itinerary Performance



Network Performance

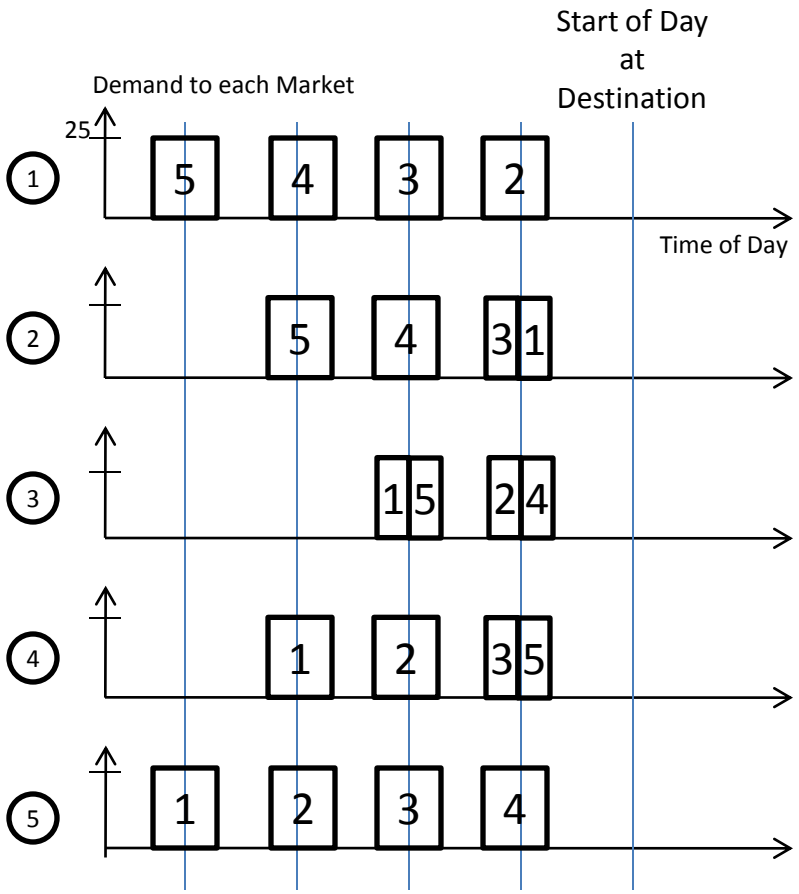
Passenger Trip Delays in a Transportation System

- 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)



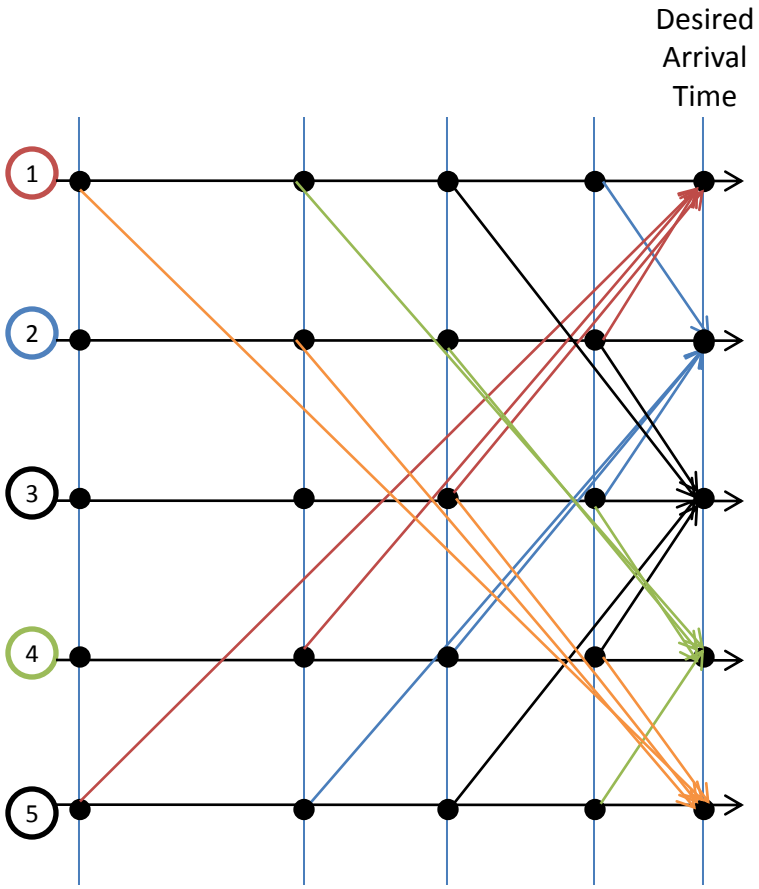
Transportation Demand

- Transportation demand
  - 100 trips to each Destination Market
  - 100 trips from each Origin Market
  - 25 trips from each Origin market to each Destination Market
  - 500 trips total
  - Passengers are required to be at Destination for start of day
  - 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 = 10 +10+7+7+6 = 40
- Total Trip Time = 40
- Total Arrival Displacement Time = 0 (all pax arrive at required time)
- Average Trip Time = 10/4 + 10/4 + 7/4 + 7/4 + 6/4
- Max Simultaneous Arrivals at each airport = 4 (at each airport)
- Max Simultaneous use of airspace = 5 (at each TRACON)

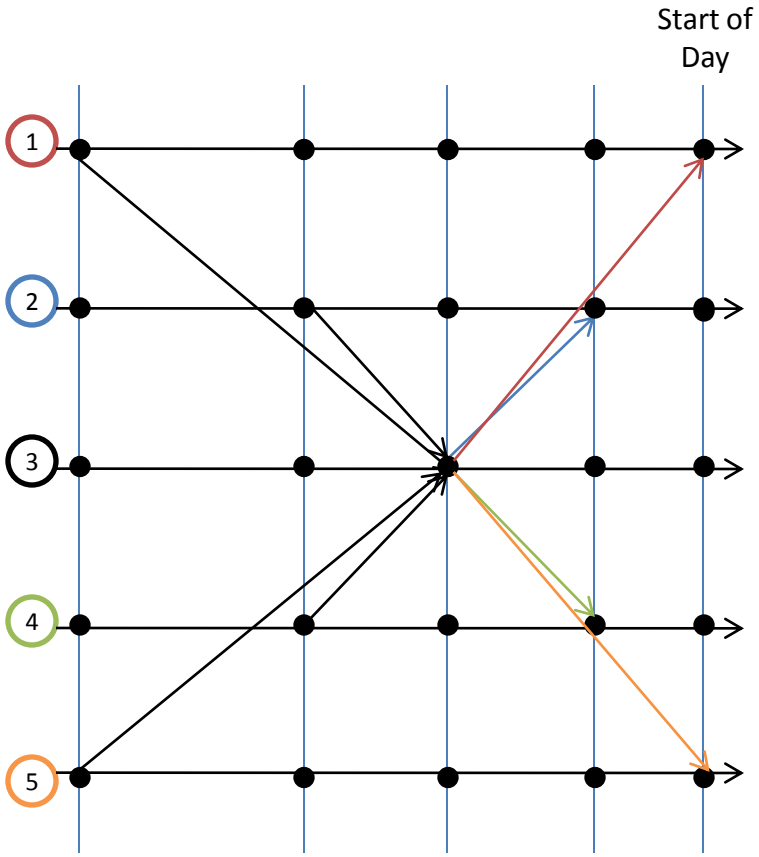


Direct Flight Network

Origin	Originating Pax	Destination	Itinerary = Flights	Pax per Itineray = Flight	Trip Time	Arrival Displacement
1	100	2 3 4 5	1-2 1-3 1-4 1-5	25 25 25 25	1 2 3 4	- - - -
2	100	1 3 4 5	2-1 2-3 2-4 2-5	25 25 25 25	1 1 2 3	- - - -
3	100	1 2 4 5	3-1 3-2 3-4 3-5	25 25 25 25	2 1 1 2	- - - -
4	100	1 2 3 5	4-1 4-2 4-3 4-5	25 25 25 25	3 2 1 1	- - - -
5	100	1 2 3 4	5-1 5-2 5-3 5-4	25 25 25 25	4 3 2 1	- - - -
TOTAL	500			500	60	0

Hub-n-Spoke Network

- Total Passengers = 500
- Total Itineraries = 20
- # Flights = 4 + 4 = 8
- Aircraft Size = 100 seats
- Distance Traveled = 12
- Total Trip Time =
  - (4+2+4+5) +
  - (4+1+3+4)+
  - (2+1+1+2)+
  - (4+3+1+4)+
  - (5+4+2+4)=60
- Total Arrival Displacement Time =
  - (some pax arrive earlier than needed)
- Average Trip Time = 60/16
- Max Simultaneous Arrivals at each airport = 4 (at hub only)
- Max Simultaneous use of airspace = 4 (at hub TRACON only)



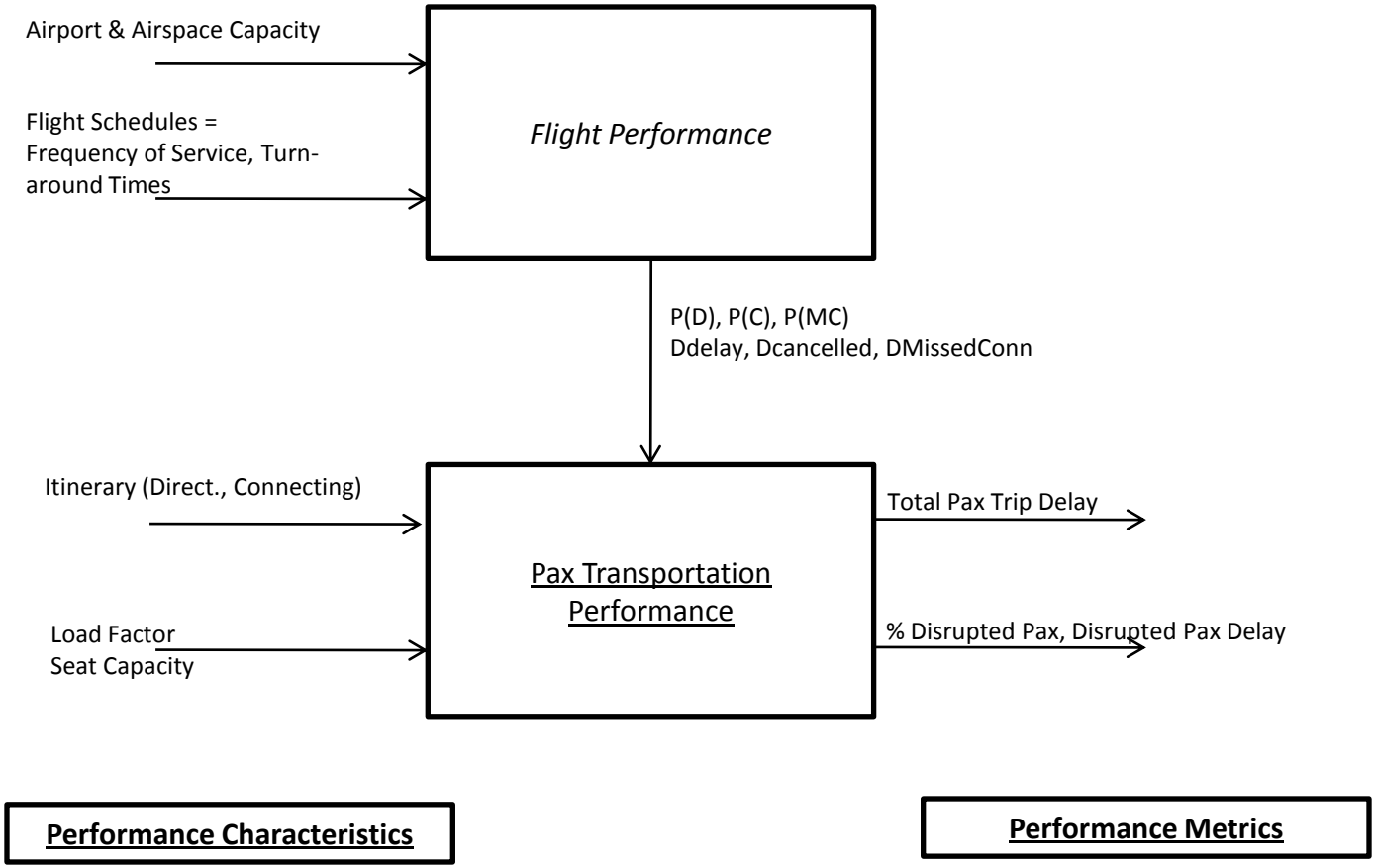
Hub-n-Spoke: Itinerary Table

Origin	Originating Pax	Destination	Itinerary	Pax per Itinerary	Total Trip Time	Arrival Displacement (Early)
1	100	2 3 4 5	1-3-2 1-3 1-3-4 1-3-5	25 25 25 25	4 2 4 5	1 2 1 -
2	100	1 3 4 5	2-3-1 2-3 2-3-4 2-3-5	25 25 25 25	5 1 3 4	- 2 1 -
3	100	1 2 4 5	3-1 3-2 3-4 3-5	25 25 25 25	2 1 1 2	- 1 1 -
4	100	1 2 3 5	4-3-1 4-3-2 4-3 4-3-5	25 25 25 25	4 3 1 4	- 1 2 -
5	100	1 2 3 4	5-3-1 5-3-2 5-3 5-3-4	25 25 25 25	5 4 2 4	- 1 2 1
TOTAL	500			500	57	16

Hub-n-Spoke: Flight Table

Origin	Destination	Pax per Flight	Total Trip Time
1	3	100	2
2	3	100	1
4	3	100	1
5	3	100	2
3	1	100	2
3	2	100	1
3	4	100	1
3	5	100	2

Passenger Transportation System: Network Performance



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 =
$\sum_{i=1,n,\ j=1,n} LF_{Oi\text{-}Dj} * SC_{Oi\text{-}Dj} * P(D)_{Oi\text{-}Dj} * D_{DelayedFlight\ Oi\text{-}Dj}$
- Total Passenger Trip Delay from Cancelled Flights

$= \sum_{i=1,n,\ j=1,n} LF_{Oi\text{-}Dj} * SC_{Oi\text{-}Dj} * P(C)_{Oi\text{-}Dj} * D_{CancelledFlight\ Oi\text{-}Dj}$

Network Performance

- Under assumption of homogeneous fleet, flight leg performance ….
  - $LF_{O1\text{-}D1} = LF_{O1\text{-}D2} = LF_{O1\text{-}D3} = \ldots = LF$
  - $SC_{O1\text{-}D1} = SC_{O1\text{-}D2} = SC_{O1\text{-}D3} = \ldots = SC$
  - $P(D)_{O1\text{-}D1} = P(D)_{O1\text{-}D2} = P(D)_{O1\text{-}D3} = \ldots = P(D)$
  - $D_{DelayedFlight\ O1\text{-}D1} = D_{DelayedFlight\ O1\text{-}D2} = \ldots = D_{DelayedFlight}$
- Total Passenger Trip Delay from Delayed Flights = $\sum_{i=1,n,\ j=1,n} LF_{Oi\text{-}Dj} * SC_{Oi\text{-}Dj} * P(D)_{Oi\text{-}Dj} * D_{DelayedFlight\ Oi\text{-}Dj}$

= #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)] *(#Flights*LF*SC)
- % Passengers Disrupted = P(D)+P(C)
- Total Passenger Trip Delay = #Flights*LF*SC [(P(D)* $D_{DelayedFlight}$)+ (P(C)* $D_{CancelledFlight}$)]
- 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 =

$(P(D)_{H\text{-}D} * \#Flights_{H\text{-}D} * LF*SC) +$
$(P(D)_{O\text{-}H} * P(MC) * \#Flights_{H\text{-}D} * LF*SC) +$
$(P(C)_{O\text{-}H} * \#Flights_{O\text{-}H} * LF*SC) +$
$(P(C)_{H\text{-}D} * \#Flights_{H\text{-}D} * LF*SC)$

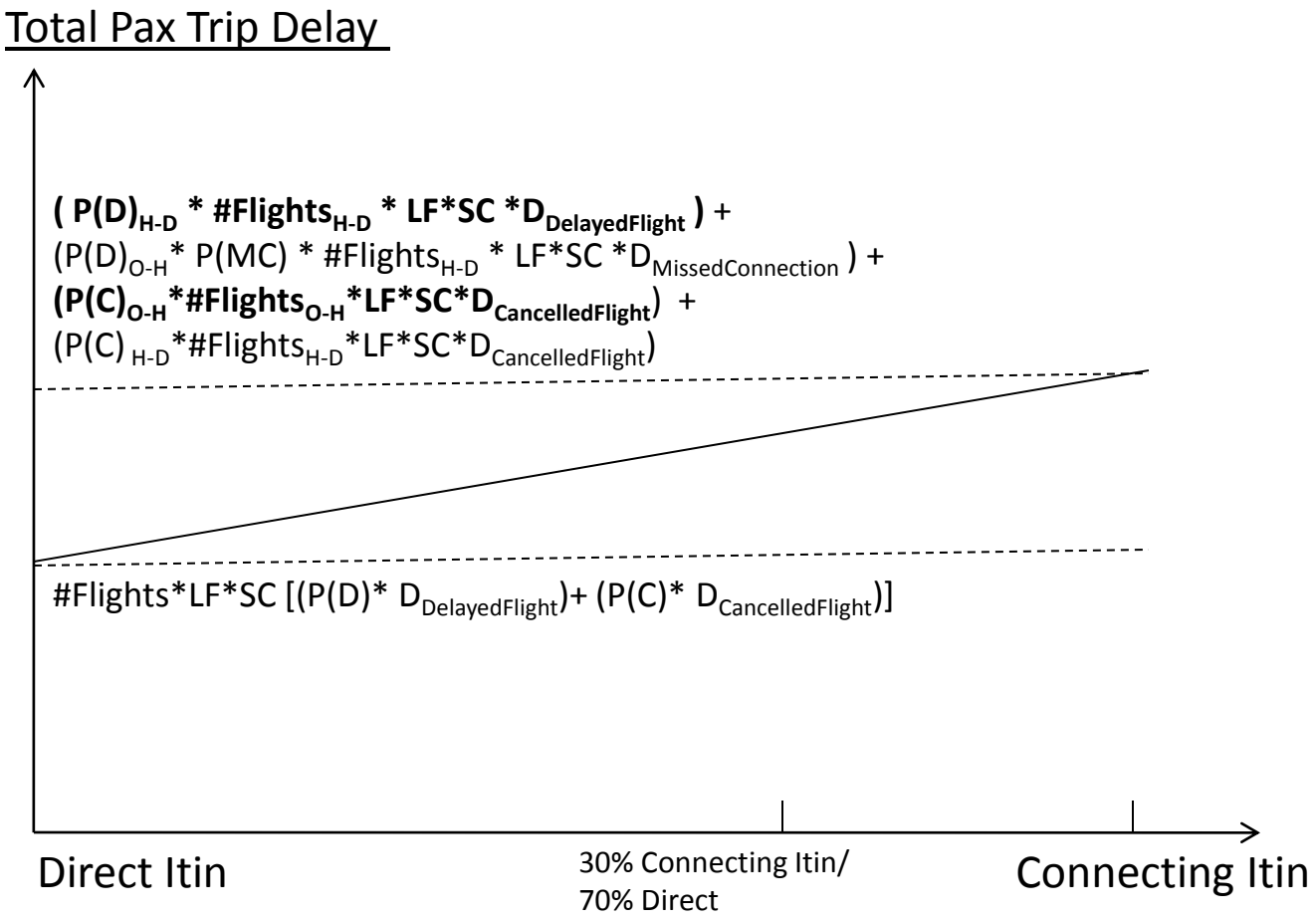
- % Passengers Disrupted = $P(D) + [P(D)*P(MC)] + 2P(C)$

- Total Passenger Trip Delay =

$(P(D)_{H\text{-}D} * \#Flights_{H\text{-}D} * LF * SC * D_{DelayedFlight}) +$
$(P(D)_{O\text{-}H} * P(MC) * \#Flights_{H\text{-}D} * LF*SC * D_{MissedConnection}) +$
$(P(C)_{O\text{-}H} * \#Flights_{O\text{-}H} * LF * SC * D_{CancelledFlight}) +$
$(P(C)_{H\text{-}D} * \#Flights_{H\text{-}D} * LF * SC * D_{CancelledFlight})$

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

Network Performance



PASSENGER TRIP DEMAND AND CAPACITY	2007	2008	2009	Change 07 to 08	Change 08 to 09
Passenger Itineraries (M)	453	432	308	-5%	-29%
Direct (M)	316	298	209	-5.5%	-30%
Connecting(M)	137	134	96	-3%	-26%
% Connect	30	31	32	+2%	+4%
Flights (millions)	7.4	7.0	6.4	-6%	-8%
Frequency of Service (average flights per day)	4	3.7	3.4	-7.5%	-8%

TOTAL

TOTAL PASSENGER TRIP DELAYS	2007	2008	2009	Change 07 to 08	Change 08 to 09
Total Passenger Trip Delays (million hours)	261.6	233	148.5	-11%	-36%
Average Passenger Trip Delay (minutes)	25	24	16	-6%	-32%

% OF TOTAL PASSENGER TRIP DELAY	2007	2008	2009	Change 07 to 08	Change 08 to 09
Passengers on Delayed Flights (mins)	41%	42%	44%	2%	5%
Passengers on Cancelled Flights (mins)	45%	45%	39%	0%	-14%
Passengers on Diverted Flights (mins)	0%	0%	1%	12%	69%
Passengers with Missed Connections (mins)	13%	12%	16%	-7%	32%

DISRUPTED PASSENGERS

DISRUPTED PASSENGERS	2007	2008	2009	Change 07 to 08	Change 08 to 09
% Passengers	22%	20%	17%	-10%	-16%
Total Passengers Disrupted (millions)	138.5	118.4	93.3	-15%	-21%
Average Disrupted Passenger Trip Delay (minutes)	110	110	92	-	-10%

% OF PASENGERS ON ...	2007	2008	2009	Change 07 to 08	Change 08 to 09
Delayed Flights	18%	16.5 %	14%	-14.5%	-9.8%
Cancelled Flights	1.7%	1.6%	1.1%	-9%	-31%
Diverted Flights	0.2%	0.3%	0.2%	+7.8%	-5.8%
Missed Connections	1.7%	1.5%	1.3%	-13%	-14%

AVERAGE TRIP DELAY	07	08	09	Change 07 to 08	Change 08 to 09
Passengers on Delayed Flights (mins)	57	57	52	-1.4%	-10%
Passengers on Cancelled Flights (mins)	653	644	588	-1.3%	-8.6%
Passengers on Diverted Flights (mins)	40	37	49	-6.2%	-31.2%
Passengers with Missed Connections (mins)	133	129	130	-2.8%	-7.2%

% OF TOTAL PASSENGER TRIP DELAY	2007	2008	2009
Passengers required to stay overnight	1.6	1.3	0.6
% of Total Itineraries	0.4%	0.3%	0.2%
% of Cancelled Itineraries	14.6%	13.8%	9.9%