Airline Passenger Trip Reliability: Why NextGen May Not Improve Passenger Trip Delays

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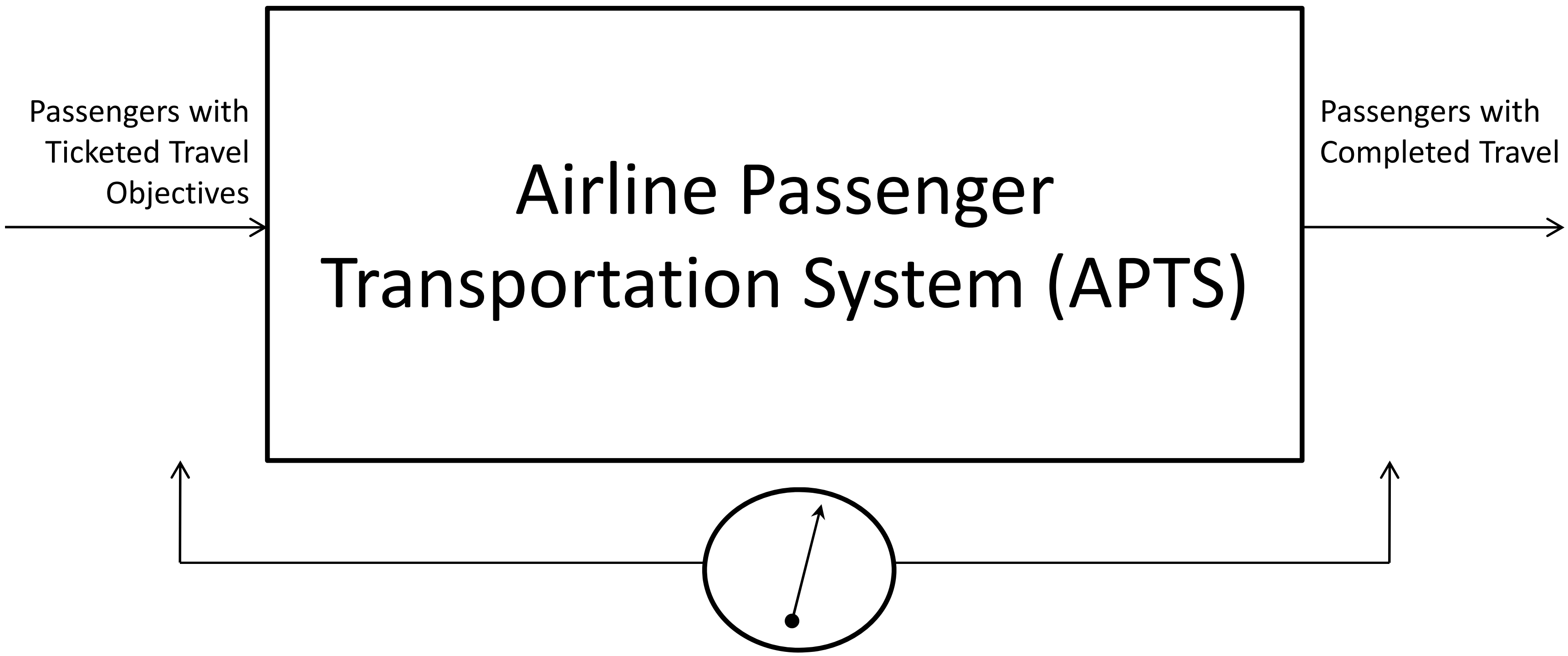
Organization

- Definitions & Terminology

1. Problem Statement
2. Model
3. Results
4. Conclusions

Airline Passenger Transportation System



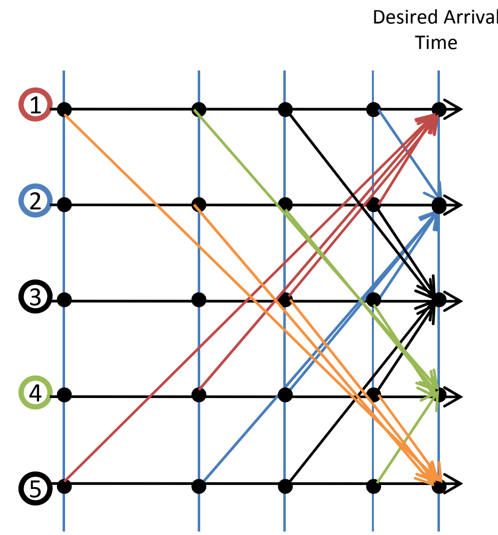
1. **Quality (i.e. passenger safety)**
2. **Cost (i.e. total cost per passenger mile = airfare + terminal + ATC + …+ external costs)**
3. **Time (i.e. trip reliability)**

Trip Time & Reliability of APTS

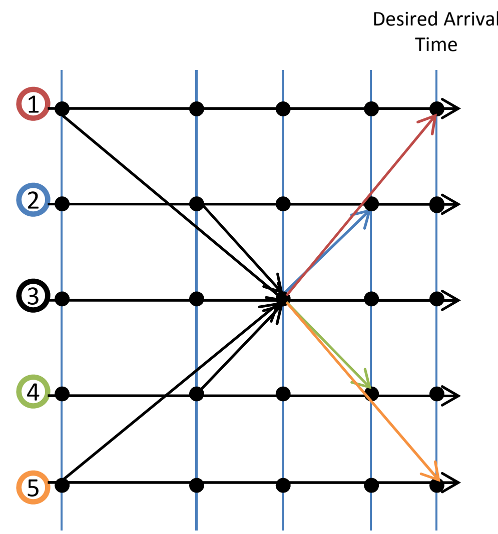
- Trip Reliability = Passenger Trip Delays
  - Actual arrival time – Scheduled arrival time
  - Trip delays are a function of the number of passengers on itineraries in the time-space network of flights

Space-time 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



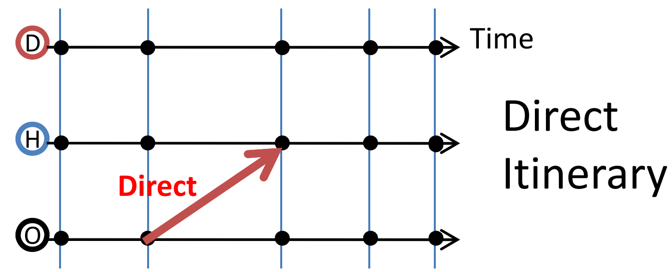
Point-to-Point

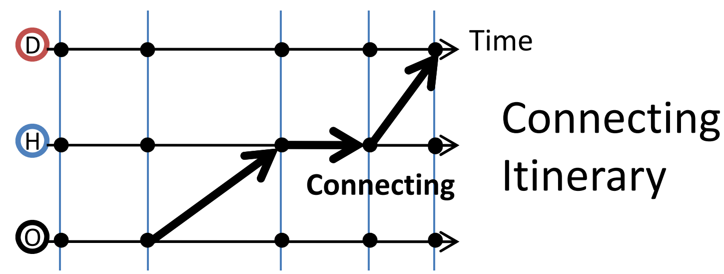


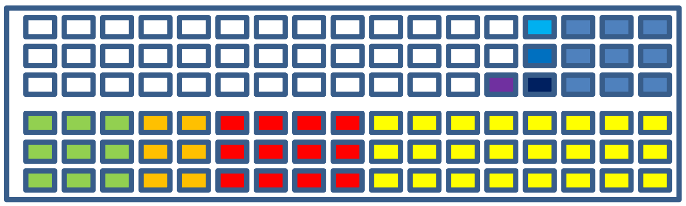
Hub-and-Spoke

Itineraries and Flights

- 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 with different itineraries







Multiple Itineraries on a Flight

Passenger Trip Reliability

- Reliability of APTS is measured by performance of itineraries (not flights)
- Itineraries disrupted by;
  - Delayed flights (includes Tarmac Delays, GDP/AFP/GS/MIT, …)
  - Cancelled flights (includes mechanicals, tactical, …)
  - Missed Connections
  - Over-booking
  - Diversions

Passenger Trip Performance Metrics

- Itinerary Performance Metrics
  1. Total Itinerary Delays
     - Cumulative delays
  2. % Itineraries Disrupted
     - Likelihood of a disruption
  3. Average Delay on Disrupted Itineraries
     - magnitude of delays
- Passenger Trip Performance = Itinerary Performance * # Passengers on each Itinerary

2007 Statistics

- Total Passenger Trip Delay = 30,000 years
- Percentage of Trips Disrupted = 22%
- Average Delay for a Disrupted Trip = 110 minutes

- Estimated Cost to Economy $16B (NEXTOR, 2010)

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NextGen & AIP

- Airport Improvement Plan (AIP)
  - Increase capacity at key nodes in network
  - Focused on airside capacity (runways, taxiways, …)
- NextGen
  - Increase effective-capacity through productivity improvement
    - Super Density Operation (SDO)
    - Trajectory-based Operations (TBO) …

Observation 2007 - 2009

	2007	2008	2009
Total Passenger Trip Delay (years)	29,873	26,605	16,957
Percentage of Passengers on Disrupted Trips	**22%**	**20%**	**17%**
Average Trip Delay for Disrupted Passengers (mins)	**110**	**110**	**92**

- Why did the % of Pax on Disrupted Trips and Average Delay not decrease proportionally?
- What phenomenon could be *nullifying* the effects of improved Flight Performance (i.e. reductions in Flight Delays and Cancellations)?

Observation 2007 - 2009

Airline adaptations to market demand and fuel prices have shaped the "network structure"

Changes in Market and Industry	Effects on Airlines Passenger Transportation System
Changes in passenger travel geographic demand, and changes in airlines networks (e.g. seasonal, consolidation/expansion of competing hubs, or consolidation, or consolidation/expansion of own network, availability of other modes of transportation)	• Changes is airports served in the hub-and-spoke network • Changes in % Passengers on Direct and Connecting Itineraries
Efforts to reduce airline costs and provide improve passenger quality of service	• Changes in time between banks (e.g. rolling banks, continuous banks)
Changes in travel demand in existing network	• Changes in Aircraft Size
Airlines adjust airfares and over-booking rates to meet revenue, profit, and market-share	• Changes in Load Factor
Reduced schedules or increased airport and airspace capacity and productivity (e.g. NextGen and SESAR)	• Improved flight delays (and cancellation rates)

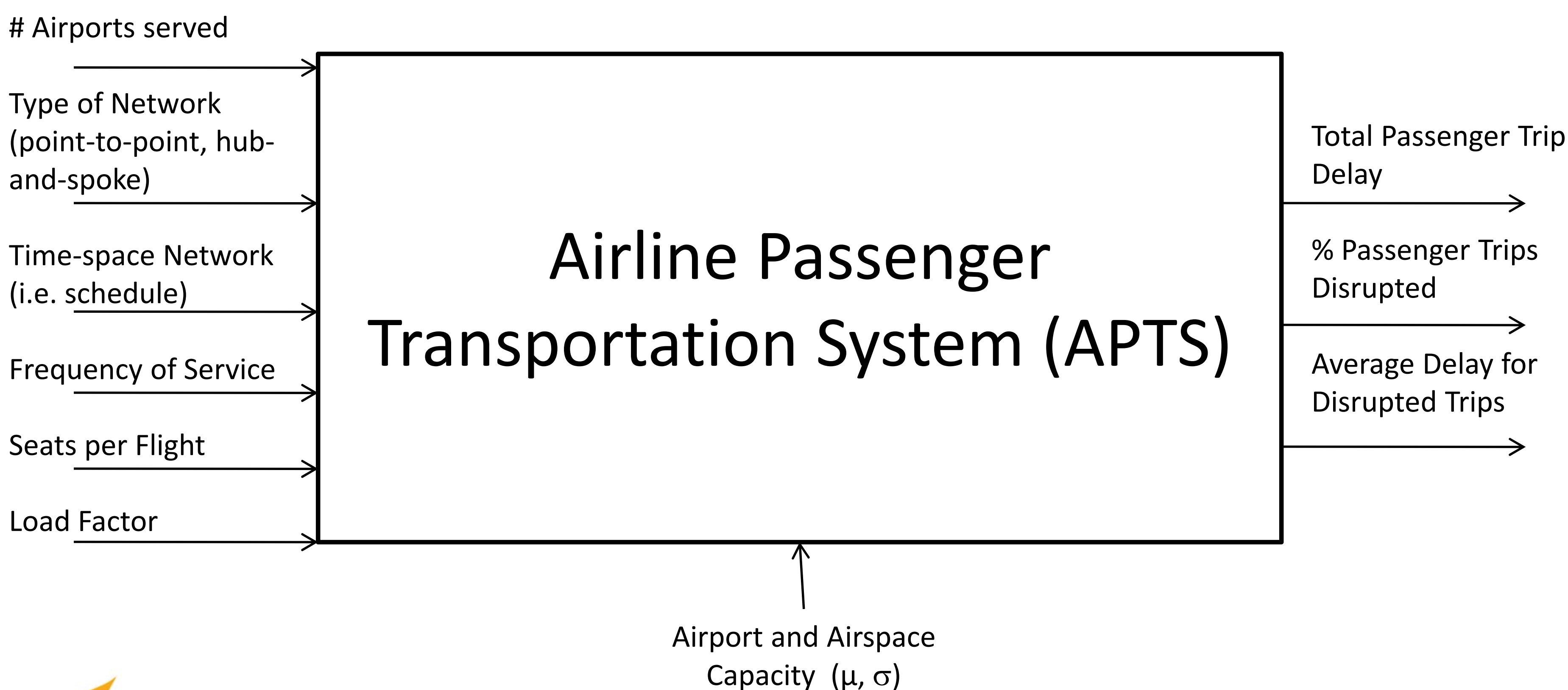
Problem Statement

- What role do "network structural" changes have on Passenger Trip Delay
  1. Frequency of Service
     - e.g. reduced service to spokes
  2. Rolling-banks
     - e.g. increased time between arrival and departure banks
  3. Load Factors
     - e.g. up/down-gauging
     - e.g. improved yield management
  4. Shifting itineraries from Direct to Connecting
  5. Schedules (peak, off-peak)
     - e.g. flight delays and flight cancellations

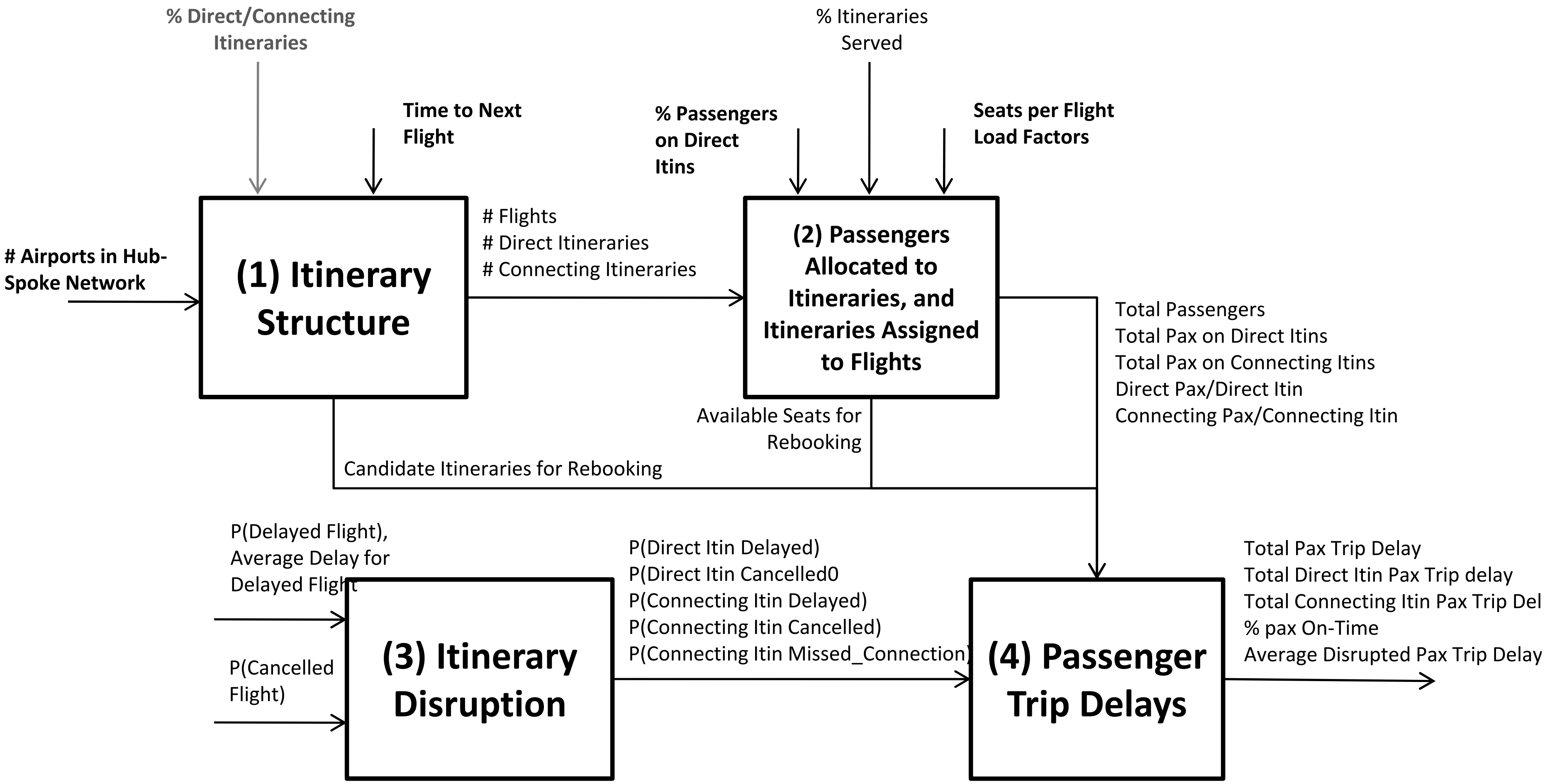
Research Approach

- Build a model of the "physics" of:
  - Time-space network of flights
  - Itineraries
  - Flight Performance
  - Passenger trips
- Model configured for a "canonical" representation
- Adjust the parameters to evaluate sensitivity

Model Airline Passenger Transportation System (APTS)



APTS System Structure



(1) Itinerary Structure
Single Bank, for a network with N spokes

- Hub-and-spoke network servicing N spoke airports
  - # Direct Itineraries = 2*N
  - # Connecting Itineraries = N(N-1)
  - % Direct Itineraries = 2N/(N(N-1)+2N) = 2/(N+1)
  - Flights = 2*N
  - Aircraft = N
- Example: 50 spoke, hub-and-spoke network
  - 100 Direct itineraries
  - 2450 Connecting itineraries
  - 3.9% Direct itineraries
  - Flights = 100
  - Aircraft = 50

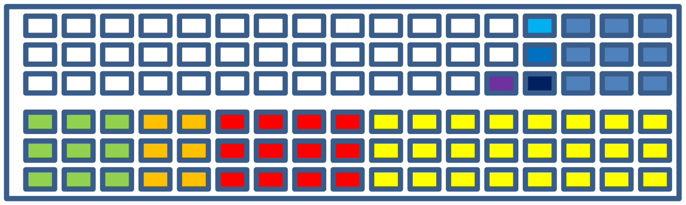
(2) Pax Allocation

- # Direct Passengers =

Seats per Flight * Load Factor * % Pax on Direct Itineraries * Itineraries per Flight (=1) * # Direct Itineraries

- # Connecting Passengers =

Seats per Flight * Load Factor * (1-% Pax on Direct Itineraries) * Itineraries per Flight (=N) * # Connecting Itineraries



Multiple Itineraries on a Flight

(3) Itinerary Disruption

Itinerary Type	Type of Itinerary Disruption	Probability of Itinerary Disruption	Magnitude of Disruption (Average)
Direct	Delayed	Based on Probability of Delayed Flight (typical 0.3)	$10*e^{(\text{Probability of Delay Flight} *6)}$. (Typical 60 mins)
	Cancelled	$0.004^{(\text{Probability of Delay Flight} *6.67)}$. (Typical 0.02)	$(0.0483*e^{(5.8902*\text{Load Factor})})$*Time to Next Flight. Based on Availability of Seats on subsequent flights and Time to next flight (average = 300 mins)
Connecting	Delayed	Based on Probability of Delayed Flight (typical 0.3)	$10*e^{(\text{Probability of Delay Flight} *6)}$. (Typical 60 mins)
	Cancelled	$2 * 0.004^{(\text{Probability of Delay Flight} *6.67)}$. Twice probability of Cancelled Flight (typical 2 * 0.02)	$(0.0483*e^{(5.8902*\text{Load Factor})})$*Time to Next Flight. Based on Availability of Seats on subsequent flights and Time to next flight (average = 645 mins)
	Missed Connection	0.1 * Probability of Delayed Flight. A function of connecting times and airline policies regarding holding flights (typical 0.03)	$(0.0483*e^{(5.8902*\text{Load Factor})})$*Time to Next Flight. Based on Availability of Seats on subsequent flights and Time to next flight (average = 645 mins)

Ball et al, 2004/6/7; Tien, Churchill, 2009; Subramanian, 2007; Bratu & Barnhart, 2005; Zhu, 2007; Wang & Sherry, 2006; Le, 2007

(4) APTS Performance

- Total Passenger Trip Delay =
  - ∑ PTD_DDF+PTD_DCF+PTD_CDF+PTD_CCF+PTD_CMC
- % Passengers on Disrupted Trips =
  - Total Pax on Disrupted Itineraries / Total Passengers
- Average Delay for Disrupted Trips =
  - Total Pax Trip Delay / # Disrupted Passengers

Results (50 spoke Hub-and-Spoke)

Factors	**Impact of Factors**		
	Total Passenger Trip Delay	**Percentage Passengers Disrupted**	**Average Trip Delay for Disrupted Passengers**
Proportion of Passengers on Connecting Itineraries increases	Linear increase (+34 days for every 10% shift from Direct to Connecting)	Linear decrease (-1% for every 10% shift from Direct to Connecting)	Linear decrease (+16 minutes for every 10% shift from Direct to Connecting)
Load Factor	Non-linear Increase (natural log exponent 0.2)	No Change	Non-linear Increase (natural log exponent 0.2)
Time to Next Flight	Linear Increase (+23 days for every 60 minute increase in Time to Next Flight)	No Change	Linear Increase (+25 minutes for every 60 minute increase in Time to Next Flight)
Flight On-Time Performance	Non-linear increase (natural log exponent 0.34 exponent)	Linear Increase (+5% for every 5% degradation in on-time performance)	Non-linear Increase (natural log exponent 0.15)

50 spoke Hub-and-Spoke

Scenario	% Passengers on Direct	% Load Factor (Seats Adjusted)	% Delayed & Cancelled Flights	Time between Banks	*Change in Total Pax Trip Delay*	*Change in % Pax Disrupted*	*Change in Average Disrupted Pax Delay*
Baseline	**50%**	80%	30% / 2%	120 mins	-	-	-
Consolidating flights to hubs resulting in shift to Connecting Itineraries	**45%**	80%	30% / 2%	120 mins	*Increase 6%*	*Decrease 1.7%*	*Increase 4.5%*
Downguaging and/or Improved Revenue Management resulting in Increased Load Factor	50%	**88%**	30% / 2%	120 mins	*Increase 32%*	*No Change*	*Increase 43%*
Reduced Frequency and/or Rolling Banks resulting in longer Time to Next Flight	50%	80%	30% / 2%	**180 mins**	*Increase 37%*	*No Change*	*Increase 36%*
ATC/Airport Capacity decrease or Peaking congested Schedules resulting in improved Flight On-time Performance	50%	80%	**25% / 1.8%**	120 mins	*Decrease 16%*	*Decrease 18%*	*Decrease 12%*
All of the above scenarios combined	**45%**	**88%**	**25% / 1.8%**	**180 mins**	*Increase 55%*	*Decrease-19%*	*Increase 92%*

Conclusions

- Model demonstrates role of “network structure’ on Passenger Trip Delays
  - network structure can nullify/amplify effects of improved flight performance

Conclusions - Airline Decisions

- Airlines obliged to continuously adjust their operations
- In many cases enterprise actions are **not** congruent with the goal of maximizing the reliability of passenger trips
  - Revenue Management (Cross, 1997) and Demand-Driven Dispatch (Berge et. al, 1993) → longer delays for rebooked pax
    - increased load factors
    - increased time between flights
- Increased time between banks improves on-time flight performance and reduces likelihood of missed connection, but increases time-to-next flight

Conclusions - NextGen

- Implications:
  - NextGen benefits case of *improved flight operations* subject to "network structure"
- Example (under certain circumstances)
  - 10% increase in load factor can nullify the benefits of a 5% improvement in flight on-time performance

Conclusions – NextGen Benefits Analysis

- Implications:
  - NAS-wide simulations tools simulate the operation of up to 60,000 flights per day .
  - Passenger itineraries not considered
  - Lost economic productivity under-reported
    - passenger trip delays due to delayed flights only account for approximately 45% of the total passenger trip delays.
  - Careful book-keeping must be done to capture underlying factors (load factors, bank structure, …)

Conclusions

- Implications:
  - Consumer Protection initiatives need to consider "network structure"
    - Cancelling passengers on Direct Itinerary different than cancelling passengers on Connecting Itinerary (e.g. Tarmac delay)
    - One-size-fits-all-rule not compatible with complex shades of grey system