Terminal Chaos

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CENTER FOR AIR TRANSPORTATION SYSTEMS RESEARCH

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Three Most Important Ideas to take Away from Today's Discussion

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1. **Major US Airports are Overscheduled**
   1. **Slot Control & Allocation Policy Must be Designed**
2. **FAA cannot Fix this Problem as it is Currently Organized**
   1. **Separate Safety Oversight from Operations**
   2. **Outsource ATC Command Center & Upper Airspace Operational Responsibility**
   3. **Move to a Fee for Service System**
3. **The Rules of the Game MUST be Changed**
   1. **Congress is the Major Player**

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Setting the Stage

Major US Airports are over-scheduled

Congestion in one area causes congestion throughout the NAS

Single airline or airport is incapable of altering the situation

Only ATM policy changes can fix the situation

- **Multiple players with differing goals:**

  Congress, Airlines, Airports, AirTraffic Control, Passengers

In order to choose appropriate ATM policy alternatives we need to understand consequences of alternative actions!

Thus, we need to study major Metroplex and Airline *Interdependencies* and be able to predict the most important 'levers' to use to manage congestion and safety.

3

The Predicted Growth in Aviation Demand is based on *Passenger Demand* NOT Aircraft Operations

- **Larger Aircraft will be required to meet X2 or X3 demand**
- **Business Jet and VLJ Air Taxi Service will emerge to compete with Commercial aviation due to current System Failure**
  - **May not be able to put the Geni back in the Bottle**
  - **Environmental Implications?**
- **New Aircraft (e.g. B 787) should be Environmentally Friendly & Fuel Efficient (Emissions/passenger/mi.?)**
  - **US airlines are not currently ordering them due to poor financial position**
- **New Public Policy will be needed to Deal with these Complex Adaptive System Problems**
  - **NextGen System not addressing these issues**
  - **Airports cannot make these changes by themselves**

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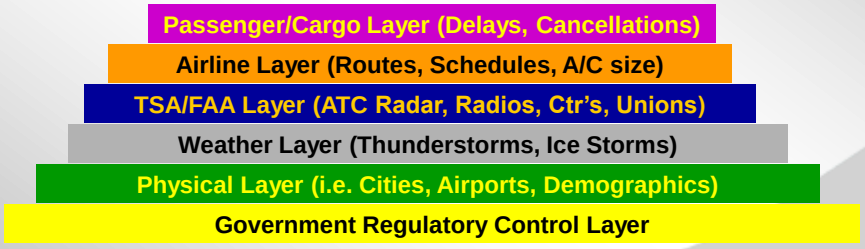
Air Transportation System (ATS) is a CAS with 6 Interacting Network Layers

•The ATS is a Public - Private Partnership with conflicting objective functions:

- •Public – Commerce and safety; interest groups
- •Private – Profit maximization



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Outline

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  - What Has Changed Since 1947
  - Passenger QOS
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  - Airport Arrival Time Slot Auctions
  - Economic Impact
- What Should the Congress Do

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What has Changed since 1947?

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- Modern Jet Aircraft "Gate-to-Gate" Travel Time is the Same or Longer than Propeller aircraft (DC-6 circa 1947) for many routes in NE Triangle
  - Typical Jet Aircraft is 70% Faster and fly's 80% Higher
- Jet Aircraft can fly Over most bad weather
- Modern Commercial Jet Aircraft can land in very low visibility
- Airport Congestion Causes Most ATC Delays and Airline Schedule Padding Masks Real "Gate-to-Gate" Delay

- WHAT HAS NOT CHANGED
  - Air Traffic Controllers talking to Pilots using WW II AM Radio Technology

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Passenger Total Delay – Airports

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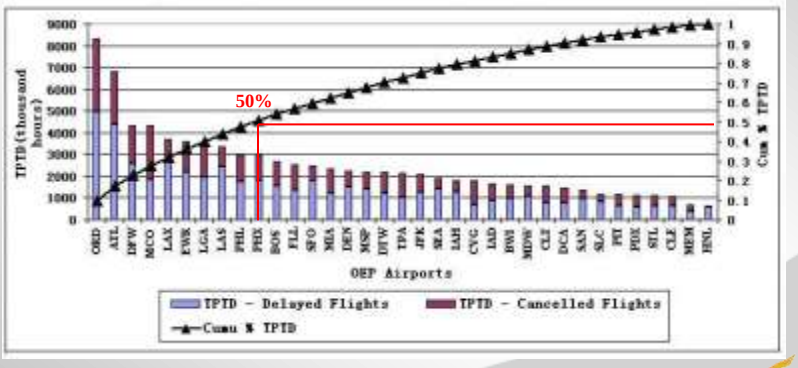
- 10 of the OEP-35 airports → 50% Total EPTD
- some airports significantly impact Passenger Delay more than others (e.g. ORD, ATL, DFW and MCO)



Close Network of OEP35 Airport in 2004

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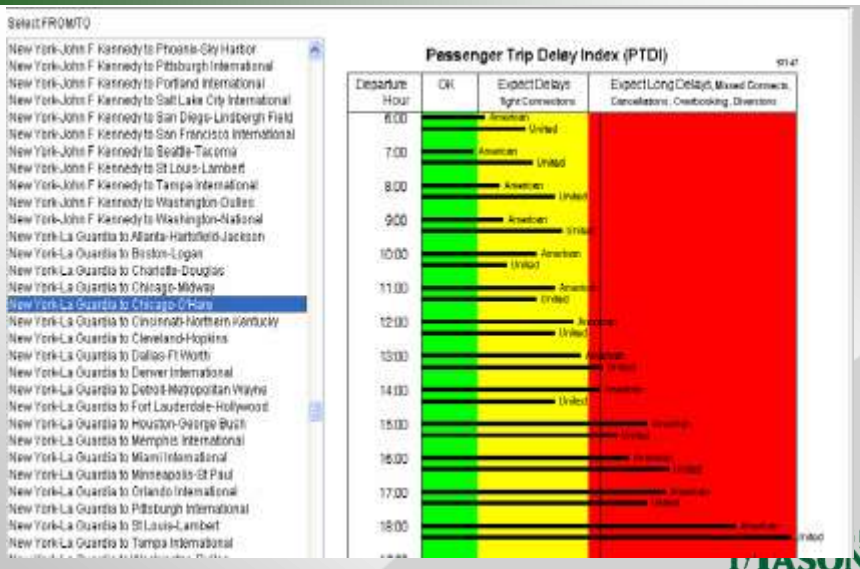
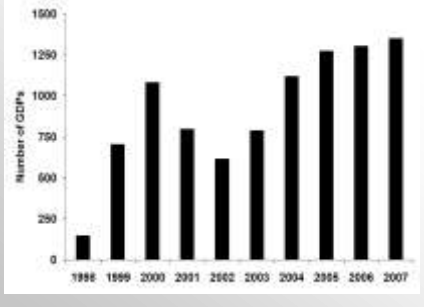
Today's Lack of Predictability is Predictable!

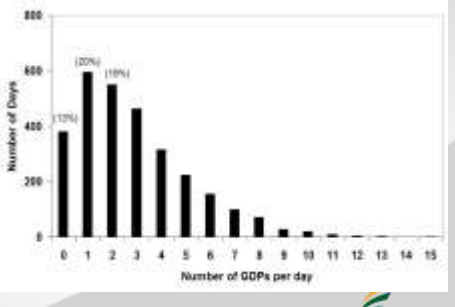


FAA's Role in Poor Quality of Service: GDPs occurs almost everyday…

- **The number of *FAA initiated Ground Delay Programs (GDPs)* in the NAS has been increasing.**
  - The number of GDPs is steadily increasing over the years.
  - There is a 87% chance that at least one GDP will be implemented in the NAS every day.



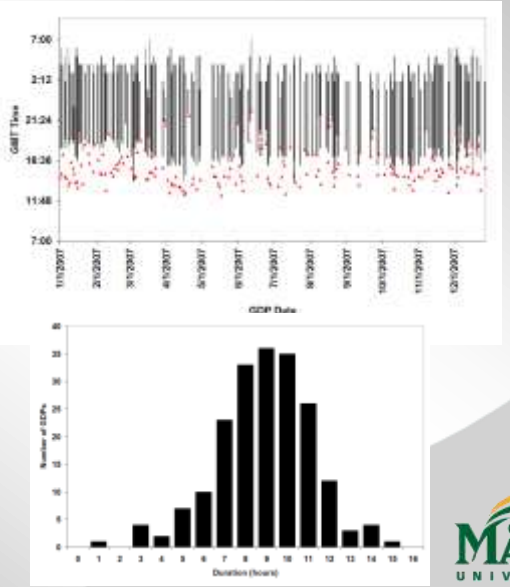
[1998 – 2007]



[2000 – 2007]

EWR GDPs (2007): Most Not Weather Related

- 197 GDPs in 2007.
- **GDP Duration:** Average 10 hours.
- **GDP Lead Time:** Average 96 minutes
- **GDP Scope**:
  - 51% Tier scope (NoWest+Canada) (All +Canada)
  - 49% Distance scope (1800nm+Canada)
- **GDP Capacity (PAAR):**
  - Average 10 flights/15 minutes.



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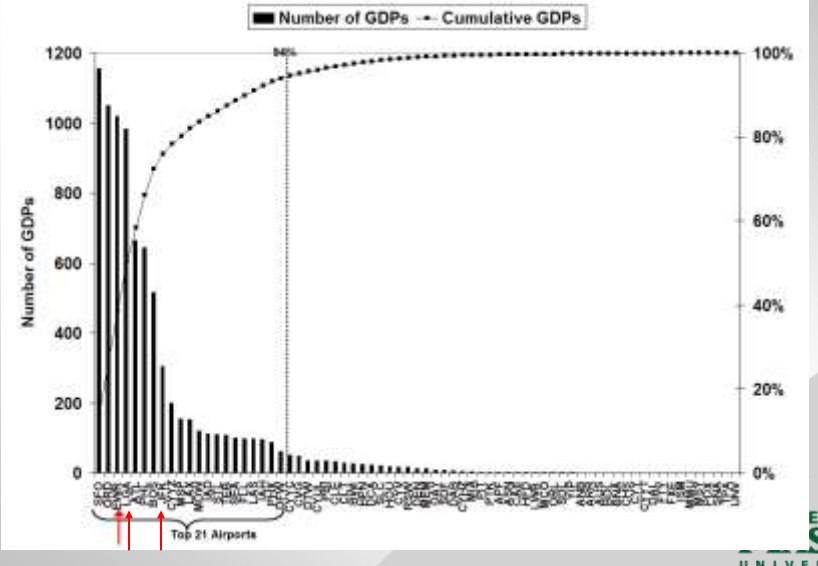
20 U.S. airports generate most of the GDPs



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Key Nodes in National Network are Predicted to be Saturated – Even with New Runways and Technology!

2007	2015	2025
New York	New York	New York
	Los Angeles	Los Angeles
	Philadelphia	Philadelphia
	San Francisco	San Francisco
		Atlanta
		Las Vegas
		Phoenix
		San Diego

Airports of Interest

Predicted Congested Metropolitan Regions with all NEXTGEN Technology and Runway Improvements

FAA FACT 2 Report May 2007

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NYNJ comparison to Comparable European Airports - ATC Terminal Delay

Airport	Total Movements		Total Passengers		Average Delays Minutes
	2005	2000	2005	2000	2006
Frankfurt, Gr (FRA)	490,147	458,731	52,219,412	49,360,630	2.7
London, UK (LHR)	477,884	466,815	67,915,403	64,606,826	3
Newark (EWR)	437,402	450,187	33,999,990	34,188,468	28.8
Amsterdam, NL (AMS)	420,736	432,480	44,163,098	39,606,925	0.7
New York Laguardia (LGA)	404,853	384,554	<29,000,000	<28,000,000	23.4
Munich (MUC)	398,838	-	<29,000,000		1.8
New York Kennedy (JFK)	<353,000	<384,000	41,885,104	32,856,220	24.3
Madrid, Sp (MAD)	415,677	<384,000	41,940,059	32,893,190	1.8

Data taken from ACI-NA, EC PR2006 and FAA ASPM

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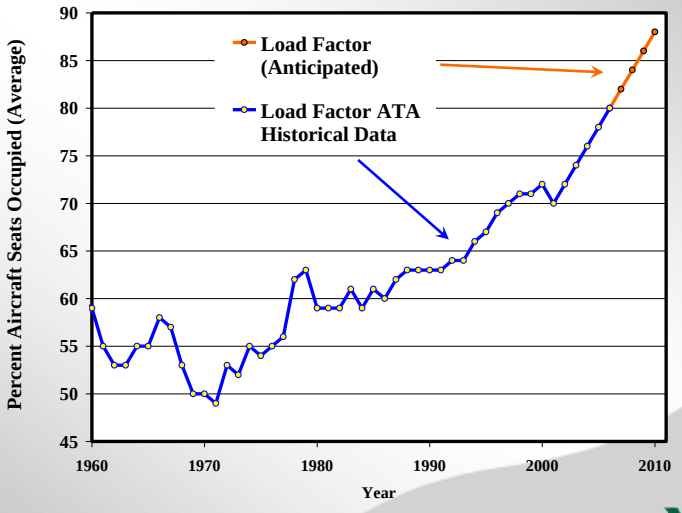
Airline Load Factors are Increasing



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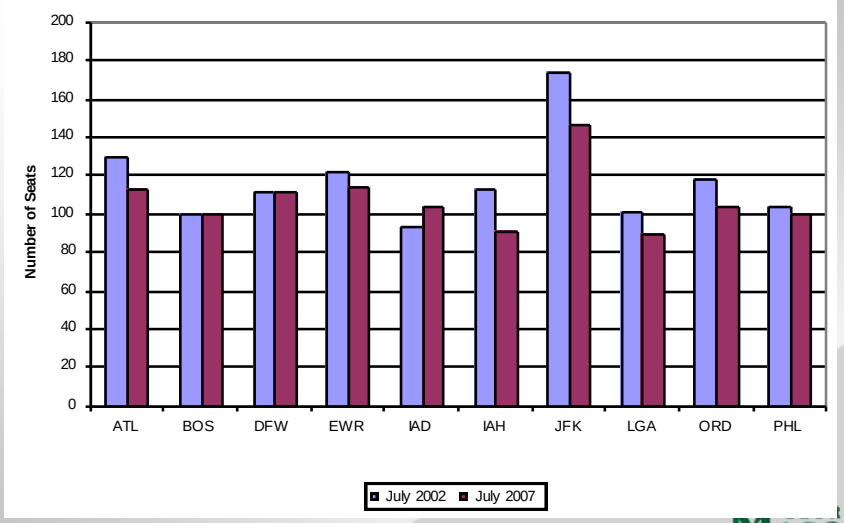
Aircraft at Critical Hub Airports are Getting Smaller



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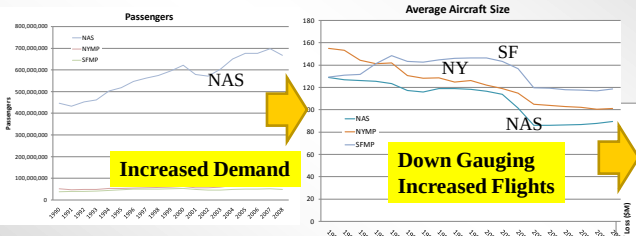
Taken from Dorothy Robyn Brooking Paper July 2008

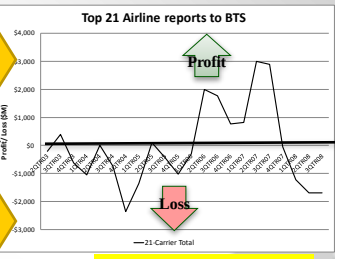
The Grand Experiment: 1990 - 2008

Economic Behavior | **Airline Behavior** | **Results**

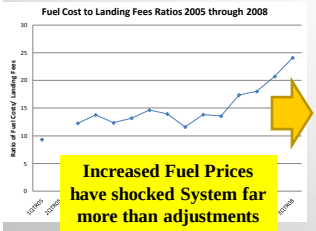


Increased Demand

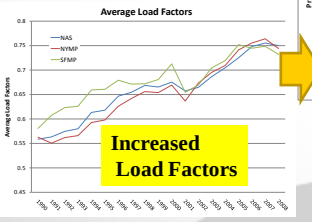
Down Gauging
Increased Flights



Airline Profit Reports



Increased Fuel Prices have shocked System far more than adjustments to Landing Fees could have



Increased Load Factors

NAS = National Airspace
NY = New York Metroplex
SF = San Francisco Metroplex

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A Major Research Focus: Passenger Capacity

How will Airline Scheduling Behavior be influenced by future Changes in Technology (i.e. NEXTGEN, B787, A380, etc.) , ATM Policy (i.e. Slot Controls, CDM rules, etc.) and the Economic Environment?

- **Will limiting airport scheduled operations affect the number of markets served and the aircraft gauge servicing them?**
- **Will Increasing fuel prices affect airline scheduling and/or the aircraft gauge?**
- **Will new aircraft fuel efficiency offset potential Down-gauging trends?**

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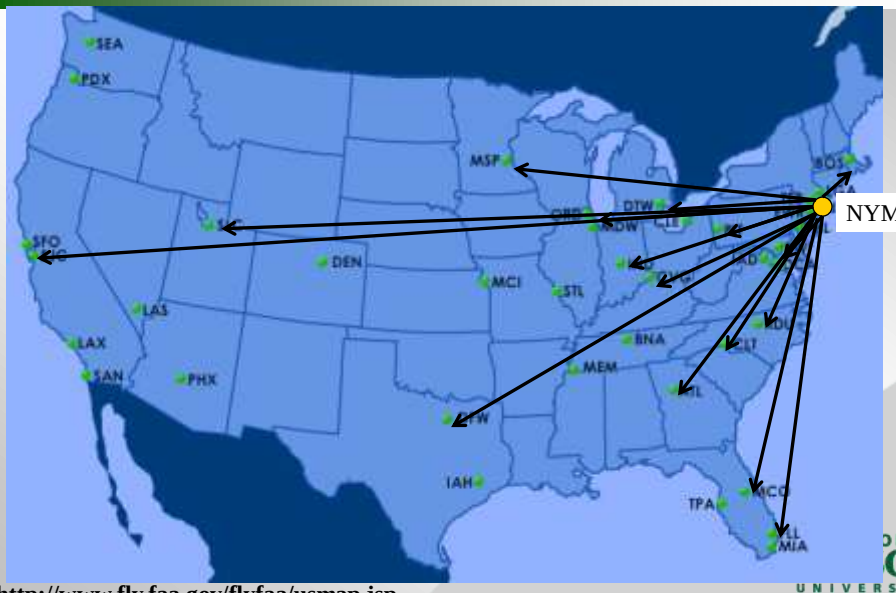
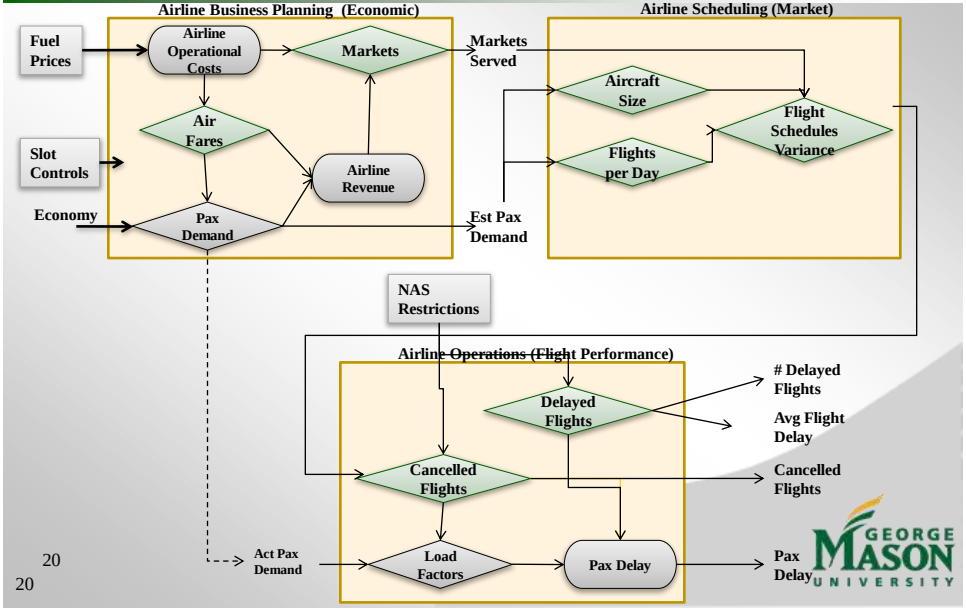
Optimization Model: Represents non-stop segment markets (not all markets are shown here) to and from NY Area



http://www.fly.faa.gov/flyfaa/usmap.jsp

Functional Representation of Airline Behavior



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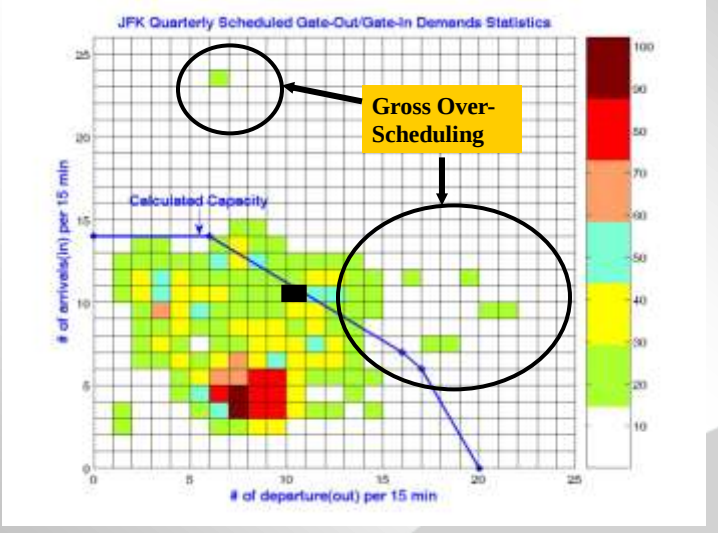
JFK Scheduled Gate-In/Gate-Out Demand Distribution (Count - Summer 07 ASPM)



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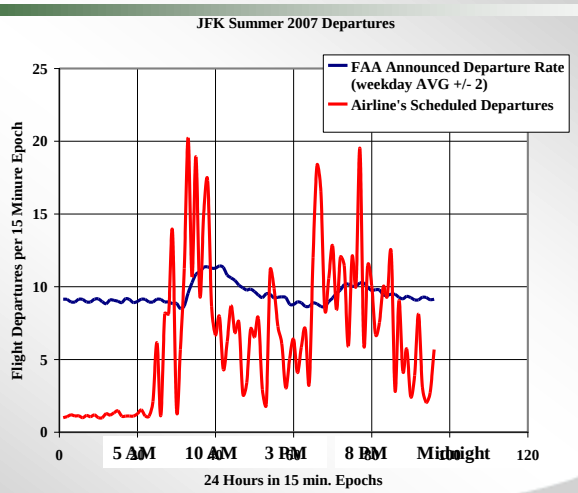
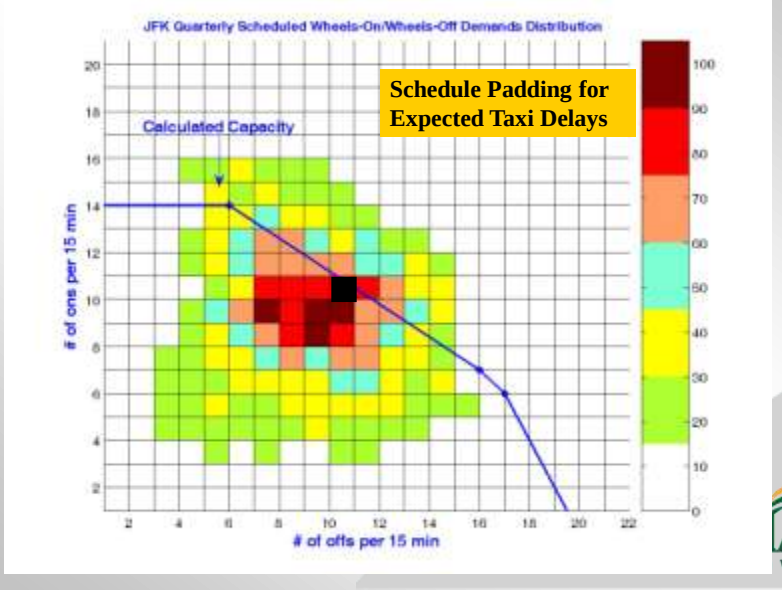
Jet Blue and Delta AL are Competing for the JFK Market: Passengers Pay the Price in Flight Delays and Cancellations



23

JFK Scheduled Wheels-On/Wheels-Off Demand Distribution (Count - Summer 07 ASPM)



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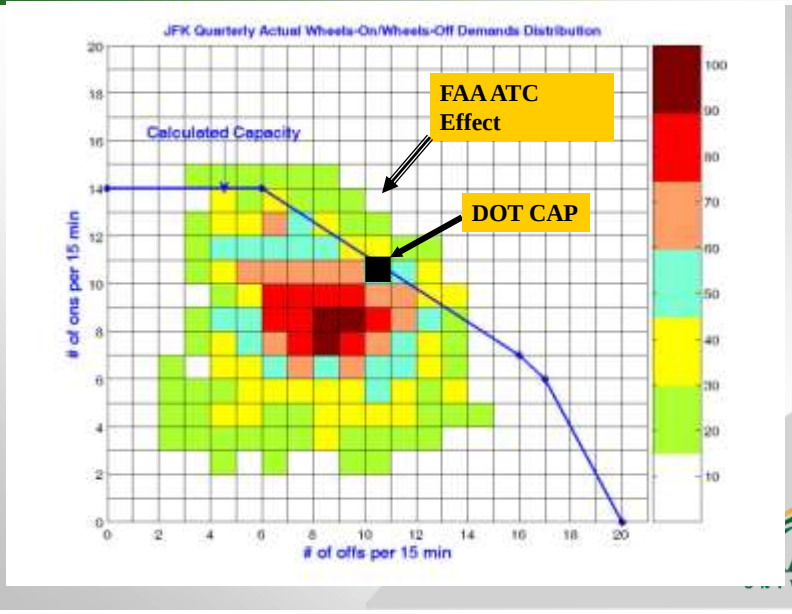
JFK Actual Wheels-On/Wheels-Off Demand Distribution (Count - Summer 07 ASPM)



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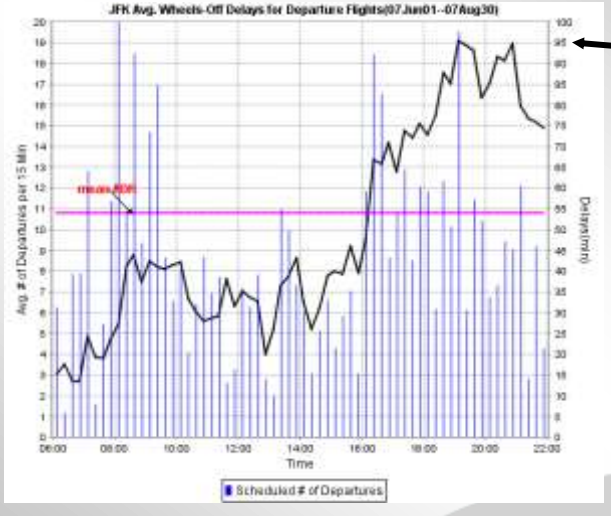
Result of this Schedule on Network Delay: AVG Wheels-Off Delays At JFK (ASPM)



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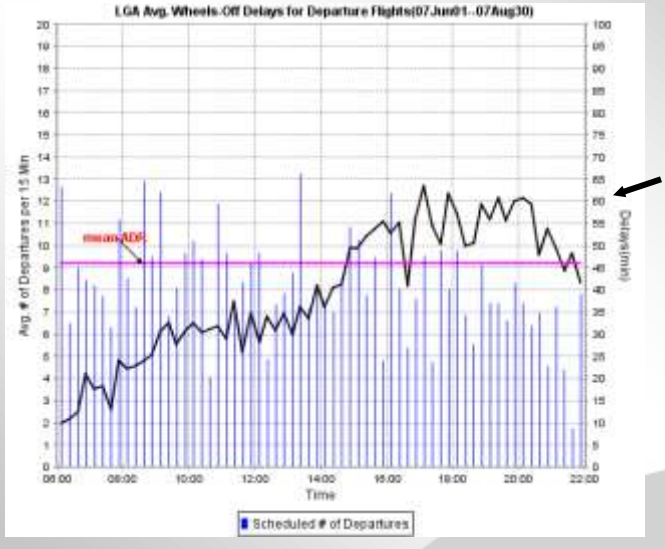
Effect of LGA Slot Control Program: Still Unacceptably High Network Delays!



60 Minutes!

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Why do the Airlines Schedule beyond the Maximum Safe RW Capacity with Flights that Loose Revenue?

- **There is no government regulation to limit schedules for safety or compensate passengers for delays and cancellations**
  - **These were errors in the 1978 Deregulation Act**
- **Passenger surveys indicate that frequency and price are the most desirable characteristics of a flight**
- **Passengers are not told of consequences of schedule to travel predictability**
- **If any one airline decided to offer rational schedules, their competition will offer more frequency to capture market share**
  - **Thus, still producing delays and cancellations for all**
- **In Game Theory, this is called the Prisoner's Dilemma**

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  - **Economic Impact**
- **What should the Congress Do?**

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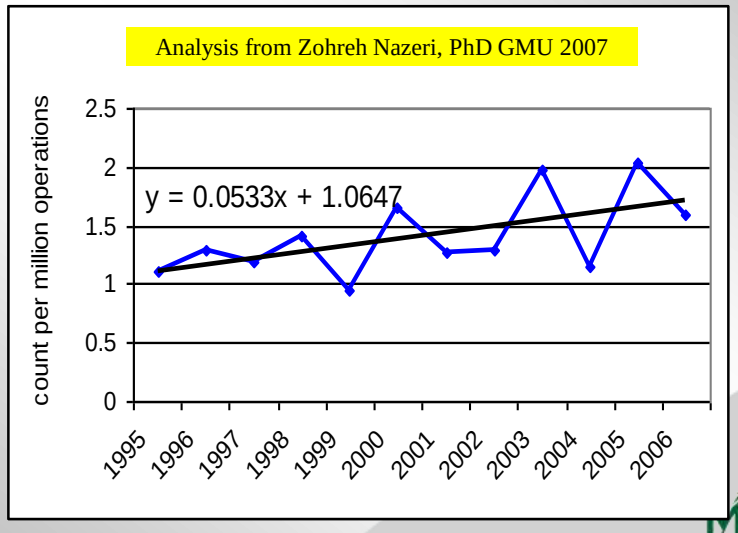
Part 121 (Scheduled Commercial) Accident Rates are Increasing



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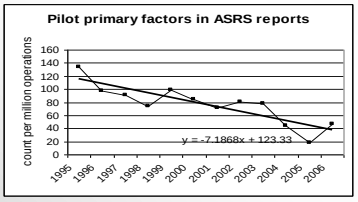
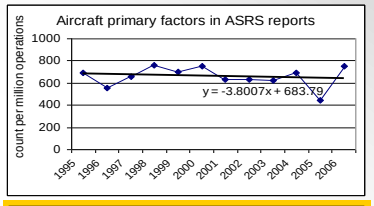
Trends for Incidents Associated with Accidents

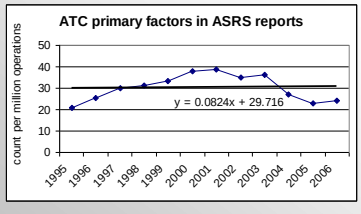
Trends of the factors in incident databases

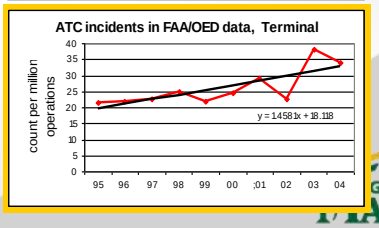
- Pilot factors decreasing
- Aircraft factors slowly decreasing
- ATC factors increasing

Analysis from Zohreh Nazeri, PhD GMU 2007









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ATC factors – Communication Errors

Top complexity factors associated with ATC factors:

- **number of aircraft in airspace -- airspace design**
- **runway configuration -- controller experience**

These factors will get worse over time:

- **Air Traffic Operations are projected to grow for the next 10 years - SMALLER Aircraft**
- **Majority of controllers will retire within next few years**

Analysis from Zohreh Nazeri, PhD GMU 2007

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Safety at Principle Network Nodes (i.e. Airports) is the Capacity Constraint

- **Aircraft Safety Separation Time over the Runway Threshold sets the ATS capacity limits**
- **Critical Technical Parameters that Define Network Capacity:**
  - **Runway Occupancy Time (ROT)**
  - **Aircraft Landing Time Interval (LTI)**
  - **Cap_{max} = 90 sec IAT at 10^{-3} P_{SRO} = 40 Arr/RW/Hr**
  - **Queuing Delay Onset at ~ 80% = 32 Arr/RW/Hr limit for Predictable Performance**

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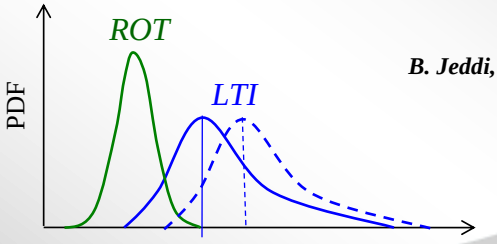
Simultaneous Runway Occupancy

1. Simultaneous Runway Occupancy (SRO)
   - Can be avoided by go-around procedure

$P\{SRO\} = P\{LTI_{k,k+1} < ROT_k \ \& \ k \text{ lands}\}$

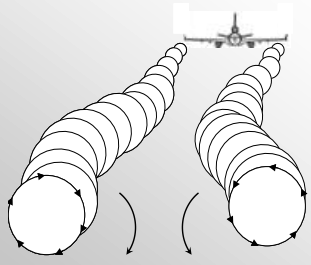


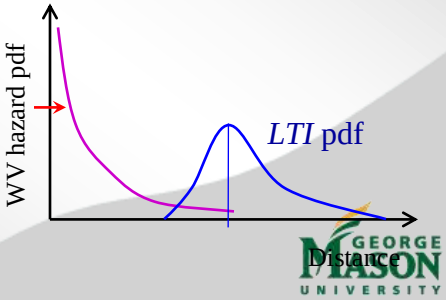
B. Jeddi, et. Al. 2006,2008

(Throughput, $Risk_{WV}$, $Risk_{SRO}$) = f(***LTI***, *ROT*, WV strength/position)

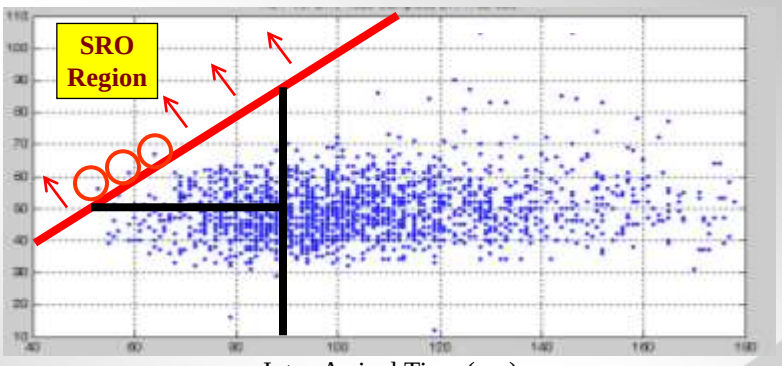
Mix of Large and Small Aircraft Exacerbate Separation Problem

2. Wake Vortex (WV) hazard
   - Depends on follow-lead aircraft pair type
   - Meteorological condition
   - Strength and position of the WV and position of the following aircraft





ROT vs. LTI to find Simultaneous Runway Occupancy (SRO) Probability: est to be ~ 2 / 1000



- Detroit Metropolitan Airport (DTW)
- Freq (*IAT* < *ROT*) ~= 0.0016 in peak periods and 0.0007 overall (including non-peak periods - 1870 total samples)
- IMC: 1 / 669= 0.0015 in peak periods
- Correlation coefficient = 0.15 [*B. Jeddi, et. Al. 2006,2008*]

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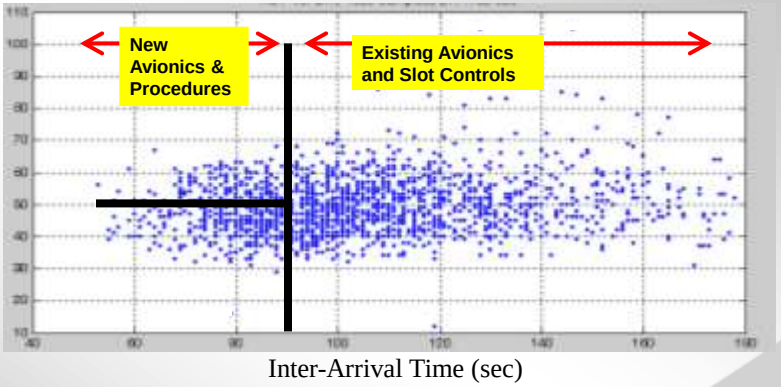
It does Not Have to Be this Way



Changes in FAA Procedures, Airport Slot Controls and New Avionics Will Improve BOTH Safety and Capacity

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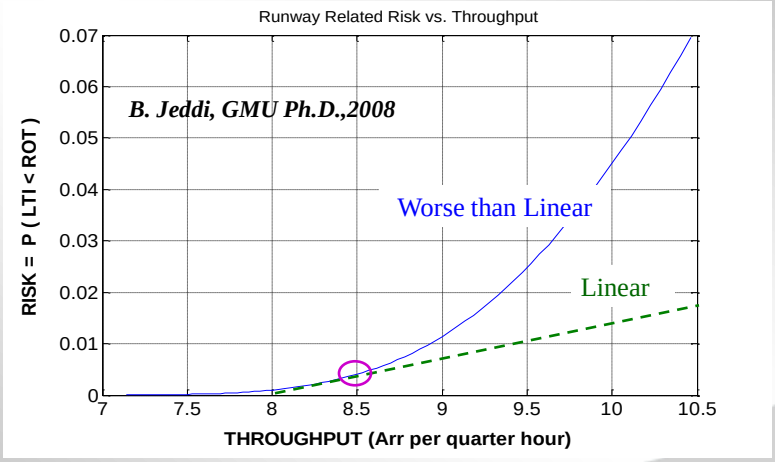
Risk vs. Throughput



39 ***Risk*** is the other side of the ***throughput coin***!

A Natural DoT – Congressional Question?

Is There an Optimal Allocation of Scarce Runway Resources?

- **What would happen if schedules at major airports were Capped at Safe, Predictable Runway Capacity and allocated by a Market mechanism?**
  - **What markets would be served?**
  - **How would airline schedules change?**
    - **Frequency**
    - **Equipment (#seats per aircraft)**
  - **How would passenger demand change?**
    - **At airport**
    - **On routes**
  - **How would airfares change?**
    - **What would happen to airline profit margins?**
  - **How would airport and network delays be altered?**

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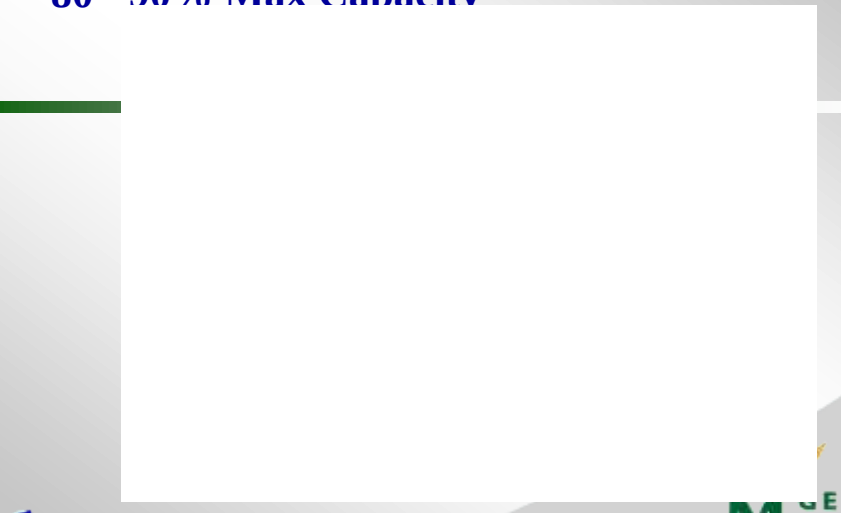
Economic Optimum Slot Allocation is at 80 - 90% Max Capacity



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Preliminary Model Results

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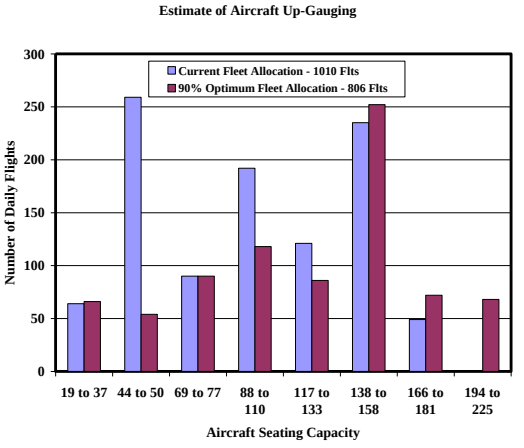
Calculated Optimum Airline Schedule to an All Weather Predictable Schedule Restriction at LGA



RESULTS:

- **20 % Fewer Scheduled Flights using a Mix of LARGER Aircraft**
- **Increased Passenger Throughput**
- **Same Airfares**
- **Loss of 3 Unprofitable Markets**
- **70% Less Delay**

L. Lee Ph.D. GMU 2006

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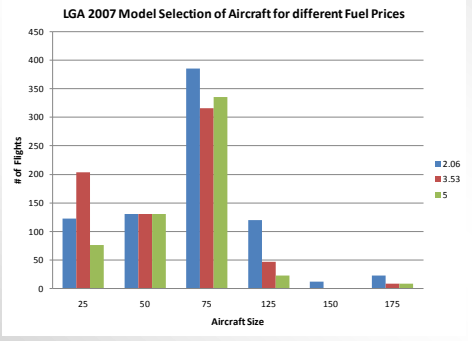
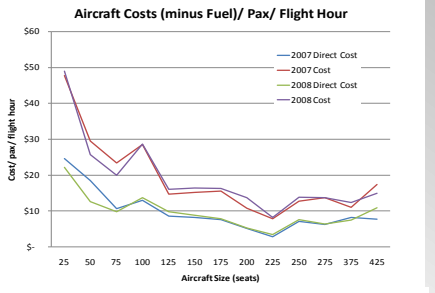
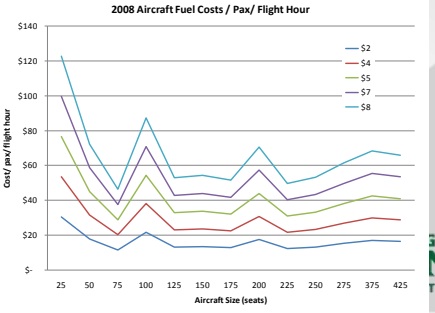
Aircraft Gauge (Model Results versus Fuel Price)







Increased Fuel Prices have greater effect on larger aircraft

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LGA 2007 Demand & Airfare

Airport	LGA								
QTR	3QTR 2007								
Fuel Price	$2.06			$3.53			$5		
Historical Data	73 Markets, 1003 Flights, 62 Average Seat Size, 62442 Seats								
Profitable Markets	61			61			51		
Capacity	8	10	12	8	10	12	8	10	12
Flights	792	844	856	704	730	738	572	582	586
Avg. Aircraft Size	75	72	72	60	60	59	66	66	65
Seats	59,150	61,100	61,800	42,450	43,500	43,650	37,750	38,150	38,300
Markets	58	59	61	60	61	61	50	50	51
Profitable Markets Out	3	2	0	1	0	0	1	1	0

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LGA 2007 Demand & Airfare

Airport	LGA								
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Avg. Aircraft Size	75	72	72	60	60	59	66	66	65
Seats	59,150	61,100	61,800	42,450	43,500	43,650	37,750	38,150	38,300
Markets	58	59	61	60	61	61	50	50	51
Profitable Markets Out	3	2	0	1	0	0	1	1	0

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EWR 2007 & 2008 Demand & Airfare

Airport	EWR	
QTR	3QTR 2007	3QTR 2008
Fuel Price	$2.06	$3.53
Historical Data	99 Markets, 920 Flights, 78 Average Seat Size, 72290 Seats	93 Markets, 917 Flights, 74 Average Seat Size, 68302 Seats
Profitable Markets	80	69
Capacity	10	10
Flights	728	592
Avg. Aircraft Size	97	83
Seats	70850	49200
Markets	79	65
Profitable Markets Out	1	4

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Observations to Date

- Airlines are NOT increasing Passenger Capacity by up-gauging at Congested airports
- Airlines tend to retain non-profitable flights for strategic reasons (model does not)
- Fuel Price increases tend to REDUCE average gauge size and number of markets served
- Slot Control Caps tend to allow Airlines to capture Scarcity Rents

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Outline

- **How Bad and widespread is the Problem**
  - **What Has Changed Since 1947**
  - **Passenger QOS**
  - **NYC Example**
- **What are the Underlying Causes**
  - **Too Many Scheduled Flights into Too Few Runways**
- **Why the Airlines cannot fix the Problem Themselves**
  - **Prisoners Dilemma and Curse of the Commons**
- **Safety is the Underlying Capacity Constraint**
  - **Current Safety Trends**
  - **Airport Arrival Time Slot Auctions**
  - **Economic Impact**
- **What Should the Congress Do?**

Congress Should Do the Following

1. Support DoT efforts to Reduce Network-wide Congestion and Return Air Travel Predictability
2. Provide DoT with unambiguous Authority to Allocate Safety Limited Airport Capacity Efficiently (i.e. Maximum Efficient Gauge) using Market Mechanisms
3. Support Proposals to Separate FAA Safety Oversight Responsibility from Operational Responsibility

Congress Should Do the Following

1. Support DoT efforts to Reduce Network-wide Congestion and Return Air Travel Predictability
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Slot Control and Allocation: Outstanding Issues that need to be Addressed

- **What are the Airport/Airline/DOT Property Rights?**
- **What is the Best Equity Metric?**
- **How should Max. Capacity be Determined?**
- **What Fraction of Max. Capacity should be Allocated?**
- **How Should these Airport Operations be Coordinated?**
- **How should Small and Medium sized Communities be Served?**
- **How will Market Allocation affect Service?**
- **Desired Market Service Redundancy?**
- **Desired Market Service Frequency?**
- **Desired Aircraft Gauge Distribution?**

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Congress Should Do the Following

1. Support DoT efforts to Reduce Network-wide Congestion and Return Air Travel Predictability
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FAA Safety vs. Operations Responsibility

1. **A Corporatized "Fee-for-Service" based Upper Airspace ANSP would be able to Modernize the System Faster and Safer than the current approach**
2. **Command Center Too sophisticated a function for FAA personnel & not Safety Critical- should be outsourced to industry**
    1. **Growth in ATC System Command Center Ground Delay Programs => A Scheduling Overload Band-Aid**
    2. **A Ration by Passenger Rule Could be used to influence Airline behavior vs. Ration by Schedule currently in use**

Center for Air Transportation System Research Publications and Information

- http://catsr.ite.gmu.edu
  - Other Useful Web Sites
- http://mytravelrights.com
- http://gao.gov
- http://www.airconsumer.ost.dot.gov

BACKUP Material

LGA 2008 Demand & Airfare

Airport	LGA								
QTR	3QTR 2008								
Fuel Price	$2.06			$3.53			$5		
Historical Data	75 Markets, 989 Flights, 63 Average Seat Size, 62545 Seats								
Profitable Markets	65			59			34		
Capacity	8	10	12	8	10	12	8	10	12
Flights	784	850	856	692	724	730	518	518	518
Avg. Aircraft Size	67	65	64	65	64	64	73	73	73
Seats	52,250	54,850	55,050	44,800	46,150	46,550	37,950	37,950	37,950
Markets	64	65	65	58	59	59	34	34	34
Profitable Markets Out	1	0	0	1	0	0	0	0	0

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Summary of European Passenger Bill of Rights - http://news.bbc.co.uk/1/hi/business/4267095.stm

- **Overbooked Flights**
  - **Passengers can now get roughly double the existing compensation if they are bumped off a flight.**
    - **Compensation must be paid immediately.**
    - **These passengers must also be offered the choice of a refund, a flight back to their original point of departure, or an alternative flight to continue their journey.**
  - **May also have rights to meals, refreshments, hotel accommodation if necessary even free e-mails, faxes or telephone calls.**
- **Cancelled Flights**
  - **Offered a refund of your ticket, along with a free flight back to your initial point of departure, when relevant. Or, alternative transport to your final destination.**
  - **Rights to meals, refreshments, hotel accommodation if necessary, even free e-mails or telephone calls.**
    - **Airlines can only offer you a refund in the form of travel vouchers if you agree in writing**
  - **Refunds may also be paid in cash, by bank transfer or cheque**
  - **If the reason for your flight's cancellation is "within the airline's control", it must pay compensation.**
  - **Compensation for cancellations must be paid within seven days.**
- **Delayed Flights**
  - **Airline may be obliged to supply meals and refreshments, along with accommodation if an overnight stay is required.**
  - **If the delay is for five hours or more, passengers are also entitled to a refund of their ticket with a free flight back to your initial point of departure if this is relevant.**

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Assumptions of the Model (1 of 2)

General

- **Schedule generated for non-stop domestic markets**
- **Aircraft sizes are grouped into increment of 25 seats.**
- **Arrival time drives demand (instead of departure time).**
- **Only one arrival/departure per 15 minutes per market.**
- **Time based demand shares are proportional to time based seat shares.**
- **Data from reporting carriers is representative of behavior for all carriers.**

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Assumptions of the Model (2 of 2)

Economic

- **Monopolistic Airline (no competition, total market power), but…**
  - **Benevolent (i.e. want to handle all passengers at current ticket prices and serve as many markets as possible while remaining profitable).**
- **Current Demand versus Prices represents price elasticity for market.**
- **Market will be flown only if profitable schedule exists.**
- **Revenue for the 15 min time windows is nested into 3 periods (12am-12pm,12pm-5pm, & 5pm-12am) to ensure the sum of the 15min revenues does not exceed the revenue from the period.**
- **Segment fares are proportionally to the squared root of distances of segments in the itinerary.**

Airline Behavior

- **Will only fly current size aircraft for markets (but want to change this…)**
- **Load factor is at least 80% for each flight**
- **45 min turn around for all fleets**

MARKETS are NOT STATIC but COMPETE for SCHEDULE and GAUGE IS OPTIMIZED

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Schedule Optimization Model

CATSR

Master Problem - IP	Sub Problem - LP

Master Problem - IP

Maximize Airline Profit

$$\max \sum_{j \in S} Z_j y_j$$

ST:

$$\sum_{j \in S} a_{ij} y_j \leq C_i \quad \forall i \in T$$

Uncongested Capacity

$$\sum_{j \in S} d_{ij} y_j \leq C_i \quad \forall i \in T$$

$$\sum_{j \in S(m)} y_j \leq 1 \quad \forall m \in M$$

One Schedule per Market

$$y \in B^{|S|}$$

Capacity (per 15 min) minus International, Cargo, Other Flights

Column Generation

Dual Prices

Sub Problem - LP

Maximize Airline Market Profit

$$\max z = \sum_{i \in T} \sum_{q \in Q(i)} R_{iq} \lambda_{iq} - \sum_{(i,j) \in A^P} \sum_{k \in K} C^k_{ji} x^k_{ji}$$

ST:

$$\sum_{(j,i) \in A} x^k_{ji} - \sum_{(i,j) \in A} x^k_{ij} = 0 \quad \forall i \in T, k \in K$$ Flow Constraint planes

$$\sum_{k \in K} \sum_{(j,i) \in A^P} S^k x^k_{ji} - \sum_{q \in Q(i)} A_{iq} \lambda_{iq} = 0 \quad \forall i \in T$$ Supply-Demand =0

$$\sum_{i \in T(p)} \sum_{q \in Q(i)} A_{iq} \lambda_{iq} - \sum_{r \in Q(p)} A_{pr} \beta_{pr} = 0 \quad \forall p \in P$$ Period Demand

$$\sum_{i \in T(p)} \sum_{q \in Q(i)} R_{iq} \lambda_{iq} - \sum_{r \in Q(p)} R_{pr} \beta_{pr} \leq 0 \quad \forall p \in P$$ Period Revenue

$$\sum_{q \in Q(i)} \lambda_{iq} = 1 \quad \forall i \in T$$ Relaxed 15min

$$\sum_{r \in Q(p)} \beta_{pr} = 1 \quad \forall p \in P$$ Relaxed Period

$$x \in Z_+^{|A^P||K|}, \lambda_i \in R_+^{|Q(i)|}, \beta_p \in R_+^{|Q(p)|}$$

Supply (seats flown) – International Connector Demand ≥ 0

One Arrival/ Departure /market /15 min

Set Packing **Multi-commodity Flow**

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Design of Experiments

CATSR

Airport	LGA																		EWR					
QTR	3QTR 2007									3QTR 2008									3QTR 2007					
Fuel Price	\$2.06			\$3.53			\$5.00			\$2.06			\$3.53			\$5.00			\$2.06			\$3.53		
Capacity	8	10	12	8	10	12	8	10	12	8	10	12	8	10	12	8	10	12	8	10	12	8	10	12

Capacity 8 = 8 arrivals and 8 departures per 15 min
= 64 arrivals and departures per hour
Capacity 10 = 10 arrivals and 10 departures per 15 min
= 80 arrivals and departures per hour
Capacity 12 = 12 arrivals and 12 departures per 15 min
= 96 arrivals and departures per hour

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