Terminal Chaos
George L. Donohue, Ph.D. and Russell Shaver III, Ph.D.
Volgenau School of Information Technology and Engineering

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

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
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.

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
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

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
What has Changed since 1947?

• 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

Passenger Total Delay – Airports

• 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)
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.
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.

20 U.S. airports generate most of the GDPs
Key Nodes in National Network are Predicted to be Saturated – Even with New Runways and Technology!

- Predicted Congested Metropolitan Regions with all NEXTGEN Technology and Runway Improvements

NYNJ comparison to Comparable European Airports - ATC Terminal Delay

<table>
<thead>
<tr>
<th>Airport</th>
<th>Total Movements</th>
<th>Total Passengers</th>
<th>Average Delays</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frankfurt, Gr (FRA)</td>
<td>490,147</td>
<td>458,731</td>
<td>52,219,412</td>
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<tr>
<td>London, UK (LHR)</td>
<td>477,884</td>
<td>466,815</td>
<td>67,915,403</td>
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<tr>
<td>Newark (EWR)</td>
<td>437,402</td>
<td>450,187</td>
<td>33,999,990</td>
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<td>Amsterdam, NL (AMS)</td>
<td>420,736</td>
<td>432,480</td>
<td>44,163,098</td>
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<tr>
<td>New York Laguardia (LGA)</td>
<td>404,853</td>
<td>384,554</td>
<td>&lt;29,000,000</td>
</tr>
<tr>
<td>Munich (MUC)</td>
<td>398,838</td>
<td>-</td>
<td>&lt;29,000,000</td>
</tr>
<tr>
<td>New York Kennedy (JFK)</td>
<td>&lt;353,000</td>
<td>&lt;384,000</td>
<td>41,885,104</td>
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<tr>
<td>Madrid, Sp (MAD)</td>
<td>415,677</td>
<td>&lt;384,000</td>
<td>41,940,059</td>
</tr>
</tbody>
</table>

Data taken from ACI-NA, EC PR2006 and FAA ASPM
Airline Load Factors are Increasing

Aircraft at Critical Hub Airports are Getting Smaller

Taken from Dorothy Robyn Brooking Paper July 2008
The Grand Experiment: 1990 - 2008

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?
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

Airline Business Planning (Economic) Airline Scheduling (Market)

Fuel Prices Markets Served
Slot Controls Aircraft Size
Economy Flights per Day

Airline Operational Costs Markets
Airline Revenue Flight Schedules Variance

Pax Demand Est Pax Demand

Air Fares

Est Pax Demand

NAS Restrictions

Airline Operations (Flight Performance)

# Delayed Flights
Avg Flight Delay
Cancelled Flights

Act Pax Demand

Cancelled Flights

Pax Delay

Load Factors
Outline

• How Bad and widespread is the Problem
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  • 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 Congress Do?

JFK Scheduled Gate-In/Gate-Out Demand Distribution (Count - Summer 07 ASPM)
Jet Blue and Delta AL are Competing for the JFK Market: Passengers Pay the Price in Flight Delays and Cancellations

JFK Summer 2007 Departures

- FAA Announced Departure Rate (weekday AVG +/- 2)
- Airline’s Scheduled Departures

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

Schedule Padding for Expected Taxi Delays
JFK Actual Wheels-On/Wheels-Off Demand Distribution (Count - Summer 07 ASPM)

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

95 Minutes!
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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Part 121 (Scheduled Commercial)
Accident Rates are Increasing

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
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

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)
  - \( \text{Cap}_{\text{max}} = 90 \text{ sec IAT at } 10^{-3} P_{\text{SRO}} = 40 \text{ Arr/RW/Hr} \)
  - Queuing Delay Onset at ~ 80% = 32 Arr/RW/Hr limit for Predictable Performance
Simultaneous Runway Occupancy

1. Simultaneous Runway Occupancy (SRO)
   - Can be avoided by go-around procedure
   \[
   P\{\text{SRO}\} = P\{LTI_{k,k+1} < ROT_k \& k \text{ lands}\}
   \]

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

Mix of Large and Small Aircraft Exacerbate Separation Problem
**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]

**It does Not Have to Be this Way**

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

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

Preliminary Model Results
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

Aircraft Gauge
(Model Results versus Fuel Price)

Increased Fuel Prices have greater effect on larger aircraft

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### LGA 2007 Demand & Airfare

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>QTR</td>
<td>3QTR 2007</td>
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<tr>
<td>Fuel Price</td>
<td>$2.06</td>
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<tr>
<td>Historical Data</td>
<td>73 Markets, 1003 Flights, 62 Average Seat Size, 62442 Seats</td>
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<tr>
<td>Profitable Markets</td>
<td>61</td>
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<tr>
<td>Capacity</td>
<td>8</td>
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<tr>
<td>Flights</td>
<td>792</td>
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<tr>
<td>Avg. Aircraft Size</td>
<td>75</td>
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<tr>
<td>Seats</td>
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<tr>
<td>Markets</td>
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<tr>
<td>Profitable Markets Out</td>
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EWR 2007 & 2008 Demand & Airfare

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</table>

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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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
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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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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

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<td>Historical Data</td>
<td>75 Markets, 989 Flights, 63 Average Seat Size, 62545 Seats</td>
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</table>

### Profitable Markets

| 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   | 54 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](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.
Assumptions of the Model (1 of 2)

General
- Schedule generated for non-stop domestic markets
- Aircraft sizes are grouped into increments 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.

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
**Schedule Optimization Model**

**Master Problem - IP**

Maximize Airline Profit

\[
\max \sum_{j \in J} z_j y_j
\]

**Sub Problem - LP**

Maximize Airline Market Profit

\[
\max \sum_{j \in J} \sum_{t \in T} R_{pt} x_{ptj} - \sum_{j \in J} \sum_{t \in T} C_{ptj} y_{ptj}
\]

**ST:**

- Flow Constraint
- Supply-Demand = 0
- Period Demand
- Period Revenue
- Relaxed 15min
- Relaxed Period

- Uncongested Capacity

\[
\sum_{j \in J} y_j \leq C_i \quad \forall i \in I
\]

- One Schedule per Market

- Supply (seats flown) – International Connector Demand ≥ 0

- One Arrival/Departure per 15 min /market

- Column Generation

- Dual Prices

- Set Packing

- Multi-commodity Flow

**Design of Experiments**

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<td>8 10 12</td>
<td>8 10 12</td>
</tr>
</tbody>
</table>

- 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