Air Travel at the Edge of Chaos

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Outline

• How Bad and widespread is the Problem
  • What Has Changed Since 1947
  • Passenger QOS
  • Economic Impact

• 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

• High Payoff Research Topics
  • NEXTGEN ATM system
What has Changed since 1947?

• Transonic vs. Subsonic Aircraft
• 40,000 ft vs. 20,000 ft Altitude
• Avionics:
  • Flight Management Systems
  • Required Navigation Perf. 0.1nm
  • Required Time of Arrival
  • Traffic Collision Avoidance System – On the Aircraft!
  • AOC Data Links
  • Zero Visibility Landing Systems
• ATC radar Separation

• WHAT HAS NOT CHANGED
• Air Traffic Controllers talking to Pilots using WW II AM Radio Technology
Some Little Known Facts

- 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
Overscheduled Airports are the Problem: Average Delay per Flight

Ordered by Arrival Delay at Outbound Destination. (minute) [Ning Xu GMU 2007]

Summer 2005 at 34 OEP Airports
Delay Incurred at Major Airports Propagate *Network Wide* (Summer 2005)

*Total Delay* Ordered by Arrival Delay at Outbound Destination. (minute)

20,000 Flight Hours

[34 OEP Airport]

[Ning Xu GMU 2007]
NYNJ comparison to Comparable European Airports

<table>
<thead>
<tr>
<th>Airport</th>
<th>Total Movements</th>
<th>Total Passengers</th>
<th>Average Delays Minutes</th>
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<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>
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<td>Newark (EWR)</td>
<td>437,402</td>
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<td>Amsterdam, NL (AMS)</td>
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<td>Munich (MUC)</td>
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<td>New York Kennedy (JFK)</td>
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<td>Madrid, Sp (MAD)</td>
<td>415,677</td>
<td>&lt;384,000</td>
<td>41,940,059</td>
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</table>

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

- Government Regulatory Control Layer
- Physical Layer (i.e. Cities, Airports, Demographics)
- Weather Layer (Thunderstorms, Ice Storms)
- Airline Layer (Routes, Schedules, A/C size)
- TSA/FAA Layer (ATC Radar, Radios, Ctr’s, Unions)
- Passenger/Cargo Layer (Delays, Cancellations)
- Physical Layer (i.e. Cities, Airports, Demographics)
  Government Regulatory Control Layer
Air Transportation System is Designed to Move *Passengers* and Cargo

Passenger Tier Performance = f (Vehicle Tier Performance, Passenger Factors i.e. Aircraft Gauge, Load Factor, Cancellations)
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)

Close Network of OEP35 Airport in 2004
200 Routes generate 50% of Total Passenger Delay

- 17% of the 1044 routes between OEP-35 airports → 50% Total EPTD
- LGA, JFK, EWR, PHL connected Routes → 11 out of top 20 routes

Close Network of OEP35 Airport in 2004
### Top 20 Worst Airports in the US: Passenger Quality of Service Metric

<table>
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<td>10%</td>
<td>DCA</td>
<td>9%</td>
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D. Wang, GMU PhD. In Progress
Many Highly Congested Airports can Shift Passengers to other Large Airports

<table>
<thead>
<tr>
<th>Airport</th>
<th>Connecting Passengers %</th>
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<td>Newark NJ</td>
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<tr>
<td>NY LaGuardia</td>
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<tr>
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</tr>
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<td>Philadelphia</td>
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<td>Boston</td>
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<td>Washington Dulles</td>
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<tr>
<td>Dallas/Fort Worth</td>
<td>60</td>
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</table>

FAA 2006 NPIAS
Airline Load Factors are Increasing

Load Factor (Anticipated)

Load Factor ATA
Historical Data

Percent Aircraft Seats Occupied (Average)

Year

GMU Model Projects Passenger Delays to Greatly Exceed 2000 delays by 2010

![Graph showing Total Passenger Delays from 1998 to 2012](image)

- Delayed Flights
- Cancelled Flights
- Poly. (Delayed Flights)
- Poly. (Cancelled Flights)

D. Wang 2007
Annual Passenger Enplanements Predicted to be Lost: FAA Forecast to 2025

Annual Projected Enplanements Foregone Because of Airport Capacity Constraints

FAA 2005 TAF & 2004 Benchmark
Estimated Annual Cost to US (Lost Consumer Surplus, 2005$) due to Expected Airport Capacity Limitations

--FAA Assumptions on Growth in Airport Operations
--Boeing Passenger Growth Assumptions: 3.6% per year
--Aircraft Upgage: 5% in 2015, 10% in 2025

Assumes:
$200/segment ticket Price Elasticity = -1

Shaver 2007
Minimum Congestion Cost is a function of NEXTGEN Technology Effectiveness and Network Efficiency

- Consumer Surplus Costs Resulting From Limiting Airport Slots
- Costs Resulting from Passenger Delays and Flight Cancellations

Caution: Some Costs Not Included

Graph showing the relationship between Annual Congestion Cost ($B) and Congestion Factor.
Outline

• How Bad and widespread is the Problem
  • What Has Changed Since 1947
  • Passenger QOS
  • Economic Impact

• What are the Underlying Causes
  • Too Many Scheduled Flights into Too Few Runways

• Why the Airlines cannot fix the Problem Themselves
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• Safety is the Underlying Capacity Constraint
  • Current Safety Trends
  • Airport Arrival Time Slot Auctions

• High Payoff Research Topics
  • NEXTGEN ATM system
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

24 Hours in 15 min. Epochs

Flight Departures per 15 Minute Epoch

0 5 10 15 20 25
Reduction in Average Number of Aircraft Seats by Airport – All Departures

Dorothy Robyn
The Brattle Group
JFK Average Delay Profile (2006)

![Graph showing JFK average delay profile with time of day and delay per flight (minutes) on axes.](image)
New York LaGuardia Airport: Case Study of a Slot Controlled Airport

Data (2005):

- Throughput: 404,853 flights/yr
- Average flight delay: 38 min
- Revenue passengers: 26,671,787
- Average aircraft size: 96 passenger
- Average inter-city fare: $133
NYNJ Airport with Current Slot Controls: LGA 2004 – 2006 (DOT Data)

Calculated Capacity (Today) and Actual Throughput

Optimum Rate

Marginal Rate

IFR Rate

Each symbol represents actual traffic during a single hour.
Current Government Rules at LGA Lead to Poor Use of Runway Resources

Airports win
Airlines win
(High Load Factor/Large Aircraft)

Airports lose
Airlines lose
(Low load factor/Small Aircraft)
Outline

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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 \textit{Prisoner’s Dilemma}
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Part 121 (Scheduled Commercial)
Accident Rates are Increasing

Analysis from Zohreh Nazeri, PhD GMU 2007

y = 0.0533x + 1.0647
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 transportation is projected to grow for the next 10 years
- majority of controllers will retire within next few years

Analysis from Zohreh Nazeri, PhD GMU 2007
Aircraft factors

“Flight Control System” problems growing
Other aircraft factors decreasing

Analysis from Zohreh Nazeri, PhD GMU 2007
Safety at Principle Network Nodes (i.e. Airports) is the 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)
  - Landing Aircraft Inter-Arrival Time (IAT)
  - $\text{Cap}_{\text{max}} = 90 \text{ sec IAT at } 10^{-3} P_{\text{SRO}} = 40 \text{ Arr/RW/Hr}$
  - Queuing Delay Onset at $\sim 80\%$ = 32 Arr/RW/Hr limit for Predictable Performance
Queuing Delays set the Practical Capacity Limitation set by Safety Separation Standards

- Lack of Schedule Synchronization and 90 second IAT generate Queuing Delays above about 80% of Maximum Runway Capacity

![Theoretical Queueing Delay Graph]

- Delays are calculated using the formula $\approx K\rho/(1-\rho)$
- Cancellations begin above 0.8 demand
- 32 Arrivals per RW per Hour
Data Analysis Process to Estimate: IAT, IAD and ROT pdf's

<table>
<thead>
<tr>
<th>Aircraft Type</th>
<th>Threshold</th>
<th>Leave Runway</th>
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<tbody>
<tr>
<td>Heavy</td>
<td>10:23:14</td>
<td>10:24:04</td>
</tr>
<tr>
<td>Large</td>
<td>10:26:16</td>
<td>10:27:12</td>
</tr>
</tbody>
</table>

Col. Clint Haynie, USA PhD., 2002
Yue Xie, PhD. 2005
ROT vs. IAT to find Simultaneous Runway Occupancy (SRO) Probability: est to be $\sim \frac{2}{1000}$

- Detroit Metropolitan Airport (DTW)
- $\text{Freq (IAT < ROT)} \sim 0.0016$ in peak periods and $0.0007$ overall (including non-peak periods - 1870 total samples)
- IMC: $\frac{1}{669} = 0.0015$ in peak periods
- Correlation coefficient = 0.15 [Babak, Shortle and Sherry, 2006]
It does Not Have to Be this Way

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

- 40 Arrival per Runway per Hour is current Safety Maximum
- 32 Arrivals per Runway per Hour is ONSET of Queuing Delays
  - Using Current (OLD) Technology
  - Using Current (OUTDATED) ATC Procedures
- FAA has Refused to Mandate New Technology and Procedures to Reduce the Variability in IAT to Increase BOTH Safety and Capacity
**Calculated Capacity (Today) and Actual Throughput**

**Optimum Rate**

- Calculated Capacity - Today
- Facility Reported Rate - EWR (arrivals, departures per hr)

Each symbol represents actual traffic during a single hour

**Marginal Rate**

**IFR Rate**

**Capacity Increase:**
- Closer Spacing & better Schedule Synchronization

**All Weather**

**EWR :**
- DoT/FAA
- 2004 Capacity Benchmark Report
• 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?
Modeling Approach and Assumptions

- Port Authority of NY&NJ has the ability to Determine and Set an Optimum Schedule to:
  - Operate at Competitive Profit Margins
  - Maximize Passenger Throughput
  - Ensure an Airline Operating Profit (Max, 90%, 80%)
- All Current Origin and Destination Markets are Considered
  - 67 Scheduled Daily Serviced Markets
- Current Market Price Elasticity Remains Constant
NY LGA Has 67 Daily Markets
Airline Competitive Scheduling: Modeling Framework

Network Flow Optimization Problem

Demand-Price Elasticity

Auction IMC Rate:
32 Slots/Hr

Flight schedules
Fleet mix
Average fare
Flight delays

ASPM, BTS databases

(Le, 2006)
Model Estimate of Airline Response to an All Weather Predictable Schedule Restriction

- 20% Fewer Scheduled Flights
- Increased Passenger Throughput
- Same Airfares
- Loss of 3 Unprofitable Markets
- 70% Less Delay
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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 (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
IS NGATS addressing the Problem?

• ADS-B (out), 4-D trajectories, RNP-0.1
  • Good but NOT ENOUGH

• Aircraft Gauge, Schedule Synchronization and Network Load Balancing will Be Required
  • Annual Combinatorial Clock Slot Auctions ?

• Aircraft Separation in Terminal Airspace and on the Runways MUST be REDUCED by X3!
  • Closely Spaced, Fully-coupled Autopilot Formation Landings with 2 – Lane Runways?

• Closely Spaced Airports need to be Cross-linked with Runway Independent Air Transport
  • New Generation of Heavy Lift Helicopters?
Center for Air Transportation System Research
Publications and Information

- http://catsr.ite.gmu.edu

- Other Useful Web Sites

- http://mytravelrights.com