Sustainability of the Air Transportation System: Successes, Challenges & Opportunities

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Overview

• U.S. Domestic Air Transportation System (ATS):
  – amazing success story over last 50 years
  – significant contributor to the U.S. economy
• ATS is faced with (9) major challenges
• Understand structure and dynamics of ATS
  1. System Architecting
  2. Dynamic System Modeling/Control Theory
  3. Simulation & Modeling
Organization

1. Success & Challenges
2. Air Transportation System Model
3. Results of Analysis
4. Opportunities
1. Successes, Challenges
Air Transportation Faces Challenges

EU: Airlines Must Compensate Passengers

By ACIFE WHITE
The Associated Press
Tuesday, January 10, 2006, 8:34 AM

BRUSSELS, Belgium -- European airlines lost a legal bid Tuesday that aimed to strike down new EU rules guaranteeing passengers compensation for flight delays or cancellations.

The European Court of First Instance said Tuesday there were a fair degree of preciseness, and did not disregard the impact of the air traffic disruption on passengers.

Los Angeles World Airports to Undertake Historic Noise Studies That May Lead to Future Noise Restrictions at Los Angeles and Van Nuys Airports

By Gregor Evers
Los Angeles World Airports, March 21, 2006 (PRIMEZONE) - The Los Angeles Board of Airport Commissioners today awarded a $5.62 million contract to Paris Miller Miller and Harza, Inc., of Burlington, Mass., for noise studies at Los Angeles International (LAX) and Van Nuys (VNY) airports.

The studies will support efforts to seek restrictions from the Federal Aviation Administration on aircraft noise generation and aircraft operations. Los Angeles World Airports (LAXA) has the first major airport in the United States to embark on two simultaneous FAA studies at both airports. In addition, the VNY study is the first in the U.S. to attempt to implement multiple proposed noise and access restrictions.

FAA: Atlanta Airport Is Busiest in U.S.

By Kimberly Johnston
The Associated Press
Tuesday, January 10, 2006, 4:25 PM

The Federal Aviation Administration, one of the few agencies to link pay to a 3.1 percent salary increase and an additional 1 percent, on average, in order to pay raise.

The performance raise, known as an "organizational success increase," is based on whether the FAA meets its set of business and air traffic goals.

Among those eligible for the raise are 13,000 employees covered by the FAA's Core Compensation Plan and about 13,000 employees involved in air traffic control.

In Announcing Increases, FAA Chief Says Tops

By Gregor Evers
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Success – Capacity

Air Transportation Capacity and Demand

Source: ATA (2005), BTS
Success - Airfares

Source: ATA (2005)

Yield = Before Tax Revenue per Seat-Mile
Success – Aircraft Performance

<table>
<thead>
<tr>
<th>Form 41 Code</th>
<th>Aircraft Type</th>
<th>Year of Introduction</th>
<th>No. of Powerplants</th>
<th>Body Type</th>
<th>Average Seats</th>
<th>Average Stage Length</th>
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<tr>
<td>6941</td>
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<td>2</td>
<td>Narrow</td>
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<td>1054</td>
<td>Short-range</td>
</tr>
</tbody>
</table>

Stage-length and Seats for Short-range Aircraft
Success – Aircraft Performance

Direct Operating Cost – Fuel Costs for Short-range Aircraft
Success – Aircraft Performance

Direct Operating Cost – Fuel Costs for Long-range Aircraft
Success – Aircraft Performance

Prices for Long-range Aircraft
Challenges?

1. Airline Profit/Loss Cycles
   – Finding economic equilibrium?
2. Equal Access
   – Airlines consolidating service to high socio-economic metro areas
   – Eroding access from small communities (Essential Air Service subsidies)
3. Passenger Experience
   – delays and cancellations, lack of predictability
4. Congestion
   • wasted resources and low predictability
5. Environmental issues (emissions, noise)
6. Airport & Airspace Trust Fund eroding
7. Airport & Airspace innovation cycle is dormant
   • Innovation IFR to VFR, but Runway throughput stagnant
     • Runway Occupancy Time (ROT), Inter-Arrival Time (IAT), Inter-Departure Time (IDT)
8. ATC innovation cycle is dormant
   – Modernization managed top-down, “big-bang R&D”
9. ATC labor issues (salary, staffing)
Challenges – Airline Finances

Airline Finances

Cum Net Profit/Loss & Operating Profit ($)

Source: ATA (2005)

Symptom or cause?

11 year oscillation profit/loss (Jiang & Hansman, 2004)
Challenges – Airline Bankruptcy

Airline Bankruptcy Filing

Annual Filings

Cumulative Filings


0 2 4 6 8 10 12 14 16 18

0 20 40 60 80 100 120 140 160 180
Challenges ? – Equal Access

• Economic geography is shifting (Florida, 2004;
  – Economic productivity and transactions significantly higher in large metropolitan areas
  – Businesses and population are shifting to these areas (Flight of the Creative Class Florida, 2004)

• Airlines free to migrate scheduled routes to profitable Origin/Destination pairs
  – Network structure (rich nodes-get-richer)
Challenges – Equal Access

Essential Air Service (EAS) Subsidies
[no Alaska]
Challenges – Passenger Experience?

Velocity = 54.874 * Distance^{0.2859}

R^2 = 0.9068

Avg Velocity 308 knots

Symptom or cause?

Data Prepared By: Danyi Wang
Challenges – Passenger Experience?

Average = 1.5%
FLL-ORD, PHL-CLT

Symptom or cause?

Data Prepared By: Danyi Wang
Challenges – Passenger Experience

Average Passenger Delay = 18 minutes

Data Prepared By: Jonathan Drexler & Danyi Wang

Symptom or cause?
Challenges – Congestion & Cascading Delays?

- **Unimpeded Gate-to-Gate = 110 minutes**
- **Schedule Gate-to-Gate =** Actual Gate-to-Gate Block Time
  - Accounts for weather, ATC, airline practices
  - Cost to airline 2-3% of revenue from flight
- **Schedule Gate-to-Actual Gate >> Schedule Gate-to-Gate**
  - Cascading delays
  - Airlines lose 12% utilization to adjust
- **Variability makes planning difficult**
  - Schedule Gate-to-Gate $\mu/\sigma = 17.6$
  - Actual Gate-to-Gate $\mu/\sigma = 7.3$
  - Schedule Gate-to-Actual Gate $\mu/\sigma = 3.3$

*Atlanta – O’Hare Block Time Study - Schaar, Drexler, Sherry (2005)*
Challenges – A&ATF

Airport & Airway Trust Fund

expenses $M
income $M
ticket tax income $M

Source: ATA (2005)

Shift to RJs, results in more ATC operations, A&TF less revenue
Challenges – ATC Labor

ATSC Hiring

- Shortfall in Certified ATCS
- # Candidate + Developmental + Certified ATCS on Payroll
- ATSC in Excess of Target Level of Staffing on Payroll

Cumulative Rate of Attrition of ATCS

Year vs. # of ATSC

2001 2002 2003 2004 2005 2006 2007 2008 2009 2010

# Certified ATCS

FAA-NATCA Target Staffing Level

# ATSC Attrition = #ATCS Hired

# Developmental ATCS

# Certified ATCS
Addressing the Challenges?

• Are Challenges symptoms or causes?
  – What are cause-effect relationships?

• What is the systemic structure of the industry?
  – Can this knowledge explain behavior?
  – Can this knowledge focus R&D?
  – How do policies, regulations, and procedures affect the system
  – How does NextGen affect these success and challenges
2. Air Transportation System
Air Transportation System

- Air Transportation System is ...
  - Layers of networks
  - Networks composed of agents
  - Agents:
    - Distributed
    - Autonomous
- Networks and agents operating with own objective functions
  - Reinforce/Undermine each other
- Networks exhibit:
  - stochastic behavior
  - operate in non-equilibrium state
    - Economically
    - System Performance
# ATS Stakeholders

<table>
<thead>
<tr>
<th>STAKEHOLDERS</th>
<th>OBJECTIVE FUNCTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Passengers and Cargo</strong></td>
<td>- Purchase air transportation services</td>
</tr>
<tr>
<td></td>
<td><strong>Airlines</strong></td>
</tr>
<tr>
<td></td>
<td>- Provide capacity for air transportation of passengers and cargo</td>
</tr>
<tr>
<td></td>
<td>- Scheduled Flights (routes, frequency and aircraft)</td>
</tr>
<tr>
<td></td>
<td><strong>Airports &amp; Airways</strong></td>
</tr>
<tr>
<td></td>
<td>- Provide capacity for Airline’s Scheduled Flights</td>
</tr>
<tr>
<td></td>
<td>- Airways and their navigational aids, Flightlevels, Runways, Gates, …etc.</td>
</tr>
<tr>
<td></td>
<td><strong>Air Traffic Control</strong></td>
</tr>
<tr>
<td></td>
<td>- Provide sequencing and separation of air traffic (flow)</td>
</tr>
<tr>
<td></td>
<td><strong>Public Natural Resources</strong></td>
</tr>
<tr>
<td></td>
<td>- Provides “natural resources” consumed by air transportation</td>
</tr>
</tbody>
</table>

|                                     | Optimize costs, time and reliability                                                 |
|                                     | Profit                                                                               |
|                                     | Marketshare in competitive marketplace                                               |
|                                     | Maximize economies of scope and scale                                                |
|                                     | Regional Economy                                                                    |
|                                     | Effective Capacity                                                                   |
|                                     | Congestion                                                                           |
|                                     | Throughput (Delays)                                                                  |
|                                     | Airports & Airspace Utilization                                                     |
|                                     | Accidents/Incidents                                                                  |
|                                     | Workload                                                                             |
|                                     | Capacity                                                                             |
|                                     | Rate of Utilization                                                                  |
|                                     | Rate of Replenishment                                                                |
Relationship between Stakeholders

PUBLIC NATURAL RESOURCES

AIR TRAFFIC CONTROL

- SEQ. & SEP. OF FLOW OF TRAFFIC
- CAPACITY FOR ABSORBING NOISE EMISSIONS FROM TRAFFIC
- FLOW OF TRAFFIC

AIRSPACE & AIRPORTS

- GATES, RUNWAYS, AIRWAYS,…
- SCHEDULED OPERATIONS

AIRLINES & OTHER USERS OF THE NAS

- AVAILABLE SEATS
- UNCON-STRAINED TRIP DEMAND

PASSENGERS & CARGO

AIR TRANSPORTATION SYSTEM

NOISE, EMISSIONS FROM TRAFFIC

SCHEDULED OPERATIONS

SEQ. & SEP. OF FLOW OF TRAFFIC

CAPACITY FOR ABSORBING NOISE EMISSIONS FROM TRAFFIC

FLOW OF TRAFFIC

GATES, RUNWAYS, AIRWAYS,…
(1) Pax & Cargo

- Consumers of air transportation
  - Speed and cost advantageous over other modes (grows with trip length)

- Demand exhibits Variability
  - Seasonality, Day of week, Hour of day
  - Income Elasticity (Engels Law)
    - As income rises, people spend proportionately more on luxuries (and not on necessities)
  - Price Elasticity
    - Sensitivity of demand to price
    - Tourist elasticity > Business elasticity
(2) Airlines

- **Suppliers** of air transportation service: Seats
  - Network of routes, Schedules on each route (i.e. frequency of service), Gauge of service (i.e. aircraft size, fleet)

- **Consumers** of Airport & Airspace Services

- Subject to variability from:
  - Pax & Cargo demand Prices of competing modes
  - Prices determined by competition
  - Supply Chain price (e.g. Fuel)
  - Technology (speed, costs of operation)
  - Supply of resources (e.g. gates, aircraft)
(3) Airports & Airspace

- **Service Provider of Infrastructure:**
  - Intersection with other modes of transportation at Origin/Destination
    - Gates, runways, navigational services
  - Routes and Crz FLs
    - SIDs, STARs, airways, …

- **Consumer of:**
  - air traffic flow services
  - Natural resources

- **Subject to variability from:**
  - Environment
  - Demographics
  - Weather
  - Criteria for safety
(4) Air Traffic Management & Control

- **Service Provider** of air traffic flow
  - Sequencing and separation in Airspace & Airports
    - Coordinated by procedures
    - Performed manually today
- **Involves:**
  - Airline Operations Centers (AOCs)
  - Traffic Flow Management (TFM)
  - Centers, TRACONs, Towers
- **Subject to variability:**
  - Congestion
  - Accident prevention
  - Subject to variation due to weather

AIR TRANSPORTATION SYSTEM
(5) Natural Resources

- **Service Provider** of natural resources
  - Noise
  - Emissions (NO\textsubscript{x})
- Managed by federal, state, local governments
- Subject to variability:
  - Global weather patterns
  - Scientific advancements in health monitoring and sensing of natural resources
  - Social and political trends
Another View: Signaling & Feedback Loops

AIR TRANSPORTATION SYSTEM
3. ATS Dynamics
Sustainability & Dynamics

- Dynamics of ATS determined by:
  - **Time Constants** for supply/demand
  - **Signaling** between supply/demand

- Sustainability occurs when supply changes occur in *anticipation* of changes in demand
  1. ability to *anticipate* changes
  2. makes changes in time
  3. anticipation needs *strong signaling*
Different Time Constants

- **Changes in Pax & Cargo demand**
  - $\tau = \text{Weeks to Months}$

- **Changes in Airlines supply**
  - Routes, Frequency, Gauge
    - $\tau = \text{Weeks to 3 -6 Months}$
  - Increased Fleet
    - $\tau = 3 \text{ years}$

- **Changes in A&A supply**
  - Sector changes
    - $\tau = \text{3-6 months, 2 years}$
  - Runways, gates, routes, Crz FLs
    - $\tau = 10 – 30 \text{ years}$

- **Changes in ATC**
  - Staffing, Sectors
    - $\tau = 7 – 10 \text{ years}$

Traffic Flow Service Providers: Air Traffic Control (TFM, AOCs, ARTCCs, TRACONs, Towers)

Infrastructure Service Providers: Airports and Airspace

Air Transportation Service Providers: Airlines

Air Transportation Consumers: Passengers & Cargo

AIR TRANSPORTATION SYSTEM
Strong/Weak Signaling

- **Strong Signaling**
  - Equilibrium

- **Weak Signaling**
  - No Equilibrium

Phase-plane

**Consumers**
- Unconstrained Demand
- Increase Capacity

**Service Providers**
- Constrained Demand
- Signal

Demand, Capacity

- **Strong Signaling**
  - Equilibrium
- **Weak Signaling**
  - No Equilibrium
Pax v. Airline Seats - Signaling (1)

- **Strong signaling & feedback-loop**
  - Airfares set by airlines based on demand for available seats
  - Scarce resources (seats) result in higher prices
    - Revenue Management
  - Loop has no external costs

- **Feedback distorted by:**
  - Hyper-competition for marketshare
  - Monopolies on given routes
  - Bankruptcy protection
  - Network integrity
  - Use-it-or-Lose it rules

- **Innovation Rate**
  - Very high
Pax v. Airline Seats - Signaling (1)

Source: ATA (2005), BTS (2005)
Pax v. Airline Seats - Equilibrium (1)
Scheduled Flights v. Airspace & Airports - Signaling (2)

- **Weak signaling & feedback-loop**
  - Fees and Taxes:
    - based on Revenue-neutrality
  - Aircraft Utilization
    - based on Block Times
    - Airline set Schedule to Gate-to-Gate Block Times
    - Airlines **not** set Schedule to Schedule Gate-to-Actual Gate
      - 12% loss of utilization
  - Administrative measures (slots, uni-laterals)
    - chokepoints only (not network)
    - not responsive to market
  - Passengers absorb costs
    - Third party
    - Delays and cancellations
Airports & Airspace v. ATC Flow - Signaling (3)

• **Weak signaling & feedback-loop**
  – Contract, budget & staffing plans:
    • staffing levels based on forecasts and work rules

• **Innovation Rate Slow**
  – Negligible productivity in aircraft per sector improvements
Airports & Airspace v. PNR - Signaling (4)

- **Weak signaling & feedback-loop**
  - Regulations (noise abatement, engine upgrades)
  - Capacity and Rate-of-Replenishment is under debate
  - Costs to environment borne by *third party* public
4. Opportunities
## Opportunities

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<tr>
<th>Success/Challenge</th>
<th>Agents</th>
<th>Signal</th>
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<tbody>
<tr>
<td>Airline Capacity</td>
<td>Pax v. Airline – Seats</td>
<td>Strong</td>
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<tr>
<td>Airline Yield</td>
<td>Pax v. Airline – Seats</td>
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<td>Airline – Flights v. Airports &amp; Airspace</td>
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<tr>
<td>Equal Access</td>
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<tr>
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<td>Airline – Flights v. Airports &amp; Airspace</td>
<td>Weak</td>
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<tr>
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<td>Airline – Flights v. Airports &amp; Airspace</td>
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<tr>
<td>Environmental</td>
<td>Airport &amp; Airspace v. PNR</td>
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<td>Air Traffic Flow v. Airports &amp; Airspace</td>
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<tr>
<td>ATC Labor</td>
<td>Air Traffic Flow v. Airports &amp; Airspace</td>
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Opportunities

• Interaction between incentives of autonomous agents results in ATS that is partially in equilibrium
  – Loops with weak signals
    • inefficient use of resources (Golaszewski, 2005)
      – not able to adapt to changes efficiently
    • not self-sustaining (Miller and Clarke, 2005)
      – do not incentivise innovation
        » “Modernization” is top-down applying existing technologies
  – Loops with strong signals
    • Enable efficient use of resources
    • Establish value for service/product
      – Value establishes return-on-investment (ROI)
      – ROI encourages industry investment & venture capital (VC)
      – VC enables best-minds from investing time & energy
Opportunities

• **NextGen** is one-time opportunity to:
  – “design” in mechanisms to signal demand & capacity
  – Leverage growth in passenger and cargo demand to fund investment in innovation
  – “Design Issues”
    • Air Transportation System (ATS) Strategic Plan (Pax, Airlines, Airports & Airways, ATS, PNR)
      – See Gore Commision
    • Property Rights (for all agents in model)
    • Fees for Use Signals and Loops
      – Set based on costs as well as scarcity of resources
Opportunities (Non-Proprietary)

**Passengers**

1. Congestion will get worse, and passengers will continue to absorb delays
   - Until high cancellation rates strand passengers
   • **Opportunity** to provide Passengers means to differentiate flights based on Cancellations, and Delays
     • e.g. flightstats.com, Greenflights.info

2. Passengers start to migrate to Air-taxi, Fractional-Jets
   - Long, slow process
   - Infrastructure needs to be developed
   • **Opportunity** to provide “Portal” to allow passengers to trade-off Scheduled Airline Service with Air-Taxi
Opportunities (Non-Proprietary)

Airlines

1. Airlines will continue to try to provide differentiated service by cost (not by quality)
   - Due to the equity-principle of the ATS
   - **Opportunity** Establish “pass” for preferred service
     • Does not require legislation, only FAA rule change
     • Used as lever for equipage upgrade (ADS-B)
     • Is there a passenger market for on-time service (between major hubs)
       - What is demand elasticity

2. Airlines need to begin competing with Biz Jets and Fractional Jets as passengers migrate
Opportunities (Non-Proprietary)

**Airlines**

3. Airlines will continue to leverage IT for process improvements
   - AOC IT Infrastructure has aged and is due for upgrade
   - further optimize Turn-times and Maintenance
     • Upload software and Nav Data-base changes during turns (not maintenance checks)
   - **Opportunity** to develop Enterprise Architecture for Airline with new biz model
Opportunities (Non-Proprietary)

**Airlines**

4) Airlines will start to pressure aircraft manufacturers to address runway operations
   - Reduced Runway Occupancy Time (ROT), Inter-Arrival Times (IAT), Inter-Departure Times

5) ROA/UAV for Cargo operations in under-serviced areas
   - subsidized by government (e.g. mail service)
     - Essential Air Service (must differentiate on cost)
   - Need test-bed for “platooning” aircraft
     - GA experimental aircraft has no need for this
Opportunities (Non-Proprietary)

Airports & Airways

1. Airport Terminals are design and built for the “golden age of aviation” not for the low carrier business model
   - Low Cost Carrier airports in China (De Neuville, 2006)
   - Opportunity to rethink passenger & baggage flow for low-cost-carrier

2. Airport Terminal “chokepoints” are baggage hand-over & security
   - Opportunities to pre-process baggage (e.g. porter services) and passengers
   - Treat as supply-chain
Opportunities (Non-Proprietary)

**Airports**

3) Modify and design runways and arrival/departure procedures to minimize, ROT, IAT, IDT
   - Runway surface friction
   - Flexibility in runway high speed exits (wider)

4) Airport Productivity Metrics
Opportunities (Non-Proprietary)

**Air Traffic Control**

1. Congress will eventually adopt User Fees (Poole, 2005)
   - Design of the User Fee assessment and payment system
2. VLJ’s are coming
3. ATC vendors will compete for NGATS funding
   - Position to win competition, what technologies to build low-cost solution
Summary (A)

A) Challenges faced by ATS are the result of the structure and dynamics of the Air Transportation System:
   - No single cause of failure, no single agent responsible
   - Slow response to match capacity with shifts in demand results:
     • Inefficient use of resources
     • Inability to withstand perturbations in robust manner
   - Incentives not aligned for sustainable growth that results in (relatively) low innovation rate (in some areas)
     • Low Productivity increases in Air Traffic Flow Management
     • Marginal Enhancements in Airspace & Airport Capacity at “chokepoints”
     • Inefficient use of scarce resources (over-scheduled runways, natural resources)
Summary (B)

B) Challenge faced by stakeholders:

- not how to incentivize industry to invest in ATS
- how to incentivize industry to innovate

  - Return on Investment in innovative technology/services?
    - **Current**
      - Competitive Contracts to provide Government defined solution
        » incentivized by FAA Material Acquisition System
    - **Alternative**
      - Fee for service operation to provide most profitable and safe solution
        » incentivized by the ROI for growing demand for air transportation
Summary (C)

C) Sustainability in a future ATS (e.g. NextGen) can only be attained by “designing” mechanisms throughout the ATS to:

a) signal capacity and demand in system
b) use signals to balance capacity and demand
c) use signals to initiate capacity and productivity improvement
d) use signals to establish value of ROI to incentivize innovation (not investment)