16.72 Air Traffic Control Overview

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US Capacity Issue

• Prior to 9/11 the US Air Transportation system is approaching a critical saturation threshold where nominal interruptions (e.g. weather) resulted in a nonlinear amplification of delay

• US and Regional Economies highly dependant on Air Transportation
  □ Business travel (stimulated by info technology)
  □ Air Freight
  □ Personal travel

• System is highly complex and interdependent

• Need better understanding of system dynamics and real constraints to guide and justify efforts to upgrade NAS

• Current efforts will not provide capacity to meet demand which will re-emerge when the economy cycles up

• Impact of upcoming capacity crisis is not well understood
  □ Operational Impact
  □ Economic Impact

• Similar Issues in Europe

• Different Issues in Emerging Regions (eg China, India)
A DAY IN THE LIFE OF AIR TRAFFIC OVER THE CONTINENTAL U.S.

ANIMATION CREATED USING FUTURE ATM CONCEPTS EVALUATION TOOL (FACET)

FOR AVIATION SYSTEMS DIVISION (AF)
NASA Ames Research Center
Passenger Traffic by Region

Scheduled Revenue Passenger-Kilometers by Region

Source: ICAO, scheduled services of commercial air carriers
Trends in Aircraft Size

Source: DOT Form 41 data (including Regional Jets and Turboprops)
US Flight Delays
from 1995 to 2006

Data source: FAA Operational Network (OPSNET)
Flight Cancellations

Source: BTS, Airline On Time Performance data
US Flight Delays
from 2000 to 2006

National Delays (in minutes)

Source: FAA OPSNET data
Delays at Chicago O’Hare
Pressure for Demand Management

ORD: Total Delays

Source: FAA OPSNET data
Consumer complaints

Note: Year 2005 consumer complaints is an extrapolation using data from Jan-Mar 2005

Air Traffic Control Functions

• Aircraft Separation Assurance
• Traffic Congestion Management
• Flight Information
• Search and Rescue

• Example of a Command, Control and Information System
COMPONENTS OF AIR TRANSPORTATION INFRASTRUCTURE

• **Airports**
  - Runways
  - Terminals
  - Ground transport interface
  - Servicing
  - Maintenance

• **Air traffic management**
  - Communications
  - Navigation
  - Surveillance
  - Control

• **Weather**
  - Observation
  - Forecasting
  - Dissemination

• **Skilled personnel**

• **Cost recovery mechanism**
Current Control Structure

- **Surface Control**
  - “Ground”

- **Local Control**
  - “Tower”

- **Terminal Area Control (TRACON)**
  - “Approach and “Departure”

- **Enroute Control (ARTCC)**
  - “Center”

- **Oceanic Control (FIR)**
  - “Oceanic”

- **Flow Control (ATCSCC)**
  - “Central Flow”
High Level Sectors

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ATM System Current Functional Structure

Planning - Strategic Level

- Weather
- Schedule of Capacities
- Approved Flight Plans
- Planned Flow Rates
- Desired Sector Loads
- Planned Clearances

Execution - Tactical Level

- AOC
- Aircraft State
- Traffic Sensor
- Pilot
- Other Aircraft States

Efficiency

Throughput

Safety

Increasing Criticality Level

Source: A. Haraldsdottir Boeing
Emerging Approaches: ADS-B and Multi-Lateration
Radar Display Example

CO 123
350C
B757 310
ATM is a Human Centered Process

- **Contract process**
  - Negotiation
  - Execution
  - Monitoring
  - Re-negotiation/amendment

- **Agents**
  - Controllers
    - Strategic
    - Tactical
  - Pilots
  - Airlines
    - Dispatchers
    - ATC coordinators
  - Airports

- **Resources**
  - Airspace
  - Runway
  - Airport surfaces
Flight Progress Strip

Call Sign - Northwest 196

Departure Point - San Diego

Altitude - 37,000 feet

Destination - Minneapolis
Human Factors and Adaptation

• ATM is a human centered contract process for the allocation of airspace and airport surface resources.

• Current NAS has evolved over 60 years

• The system has significant local adaptations resulting in nonhomogeneity
  - Airspace design
  - Local procedures
  - Letters of agreement
  - Noise restrictions
  - Site specific training (FPL = 3-5 years)

• Major operational changes were event driven, enabled by technical capability
  - Positive radar control - Grand Canyon 1956
  - TCAS - Los Cerritos 1982
New York Arrival and Departure Tracks
ATC Workload as a System Constraint
Blocking

Air traffic controller

Blocking action

Block the flow to maintain number of aircraft within the acceptable level (ex. Set by AAR or OALT)

Finite capacity buffer

Number of aircraft threshold corresponding to, for example, AAR or OALT, (varies depending on current conditions)

For example, rate set by AAR or OALT

Saturated resource

AAR is Airport Acceptance Rate
OALT is sector Operationally Acceptable Level of Traffic
Downstream Flow Constraints

Flow Management

Gate Restrictions
Ramp Restrictions
Taxi Restrictions
Runway Restrictions

Capacity Constraint
ex. Miles In Trail through exit fix

Capacity Constraint
ex. Sector Operationally Acceptable Level of Traffic (OALT)

Departure flow

Destination airports

Gates
Ramp
Taxiways
Runways
Terminal area and exit fixes
En route sector airspace
Aircraft are condensed into distinct flows feeding 4 arrival fixes.

June
• Condensation and merges have reduced 116 trajectories at airport to 4

• June 14, 2001
Special use airspace provides additional constraints

- June 11, 2001
Projected % Developmental Controllers

From: ATCS Workforce Plan Briefing
Capacity Limit Factors

- **Demand**
  - Peak Demand
  - Hub & Spoke Networks

- **Airspace Capacity**
  - Airspace Design
  - Controller Workload
  - Balkanization

- **Airport Capacity**
  - Runways
  - Gates
  - Landside Limits (including Security)
  - Weather

- **Environmental Limits**
  - Noise (relates to Airport)
  - Emissions (local, Ozone, NOX, CO2)
Airport System Capacity Limit Factors

- **Runways**
- **Weather**
  - Capacity Variability
  - Convective Weather
- **Landside Limits**
  - Gates
  - Terminals & Security
  - Road Access
- **Downstream Constraints**
- **Controller Workload**
- **Environmental**
  - Community Noise
  - Emissions
- **Safety**
Airport Capacity Envelope
Boston (BOS)

Source: FAA Benchmark Data
Separation Requirements for Arrival (Same Runway)

- **Wake Turbulence Requirement**
  - Radar Separation requirements

<table>
<thead>
<tr>
<th>Leading Aircraft</th>
<th>Heavy</th>
<th>Large</th>
<th>Small</th>
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<td>4</td>
<td>5</td>
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<tr>
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<tr>
<td>Large</td>
<td>3(2.5)</td>
<td>3(2.5)</td>
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<tr>
<td>Small</td>
<td>3(2.5)</td>
<td>3(2.5)</td>
<td>3(2.5)</td>
</tr>
</tbody>
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- **Visual Separation requirements**
  - Pilots Discretion

- **Preceding arrival must be clear of runway at touchdown**
  - Runway Occupancy time
Variable Capacity Effects
1995 Delays vs Operations

Data from FAA Capacity Office, CY95

From John Andrews, MIT Lincoln Lab
VISUALIZATION OF FLIGHT DELAYS IN THE NAS ON A BAD WEATHER DAY

ANIMATION CREATED USING FUTURE ATM CONCEPTS EVALUATION TOOL (FACET) FOR AVIATION SYSTEMS DIVISION (AF)
Safety vs Capacity

- The current airborne system is extremely safe but conservative

- Increased capacity with current infrastructure implies Reduced Operational Separation
  - Airborne Separation Standards
  - Runway Occupancy Times
  - Wake Vortex
  - Controller Personal Buffers
  - ...

- How do you dependably predict the safety impact of changes in a complex interdependent system?
  - Statistics of small numbers
  - Differential analysis limited to small or isolated changes
  - Models??

- Safety Veto Effect

- Runway Incursions are an area of concern
EN ROUTE MINIMA HAVE NOT CHANGED DESPITE 5 x IMPROVEMENT IN RADAR PERFORMANCE

Azimuth resolution at maximum range as % of en route minima

1950

5 nm en route separation minima

2000

Long range primary radars

ARSR-1

1950

ARSR-4

2000

Medium range primary radars

ASR-6

1960

ASR-9

2000

Mode A

2000

Mode S

Medium range secondary radars
SEPARATION ASSURANCE CONSIDERATIONS

- PERSONAL SAFETY BUFFER
- MINIMUM SEPARATION STANDARD
- PROCEDURAL SAFETY BUFFER
- SURVEILLANCE UNCERTAINTY
- HAZARD ZONE
Improved surveillance has not led to reduced en route minima:

- Surveillance has improved, but separation minima have not changed: procedural safety buffer has implicitly increased.

When standards were developed (e.g. 1950s for en route radar) compared to an improved surveillance environment (e.g. today for en route radar).

Minimum Separation Standard

MIT ICAT

IMPROVED SURVEILLANCE HAS NOT LED TO REDUCED EN ROUTE MINIMA
Schedule Factors

- Peak Demand/Capacity issue driven (in part) by airline Hub and Spoke scheduling behavior
  - Peak demand often exceeds airport IFR capacity (VFR/IFR Limits)
  - Depend on bank spreading and lulls to recover
  - Hub and Spoke amplifies delay

- Hub and spoke is an efficient network
  - Supports weak demand markets

- Schedules driven by competitive/market factors
  - Operations respond to marketing
  - Trend to more frequent services, smaller aircraft
  - Ratchet behavior
  - Impact of regional jets

- Ultimately, airlines will schedule rationally
  - To delay tolerance of the market (delay homeostasis)

- Limited federal or local mechanisms to regulate schedule
Hub and Spoke Network

Completely Connected Network = 2(N-1) Flights
(eg., 50 Airports, 98 Flights)
Fully Connected Network

Completely Connected Network = N(N-1)
(eg., 50 Airports, 2450 Flights)
Capacity Example
(50 Flights/hr)
Capacity Example (40 Flights/hr)
Capacity Example
(30 Flights/hr)
Classic Delay vs Demand Curve

- **Delay** vs **Demand**
- **Linear Region**
- **Non-Linear Region**
- **Capacity Limit**
LGA Air 21 Impact

LaGuardia Airport

Maximum Hourly Operations Based on Current Airspace & ATC Design

Time of Day

Historic Movements • AIR-21 Induced Svc.

Source: William DeCota, Port Authority of New York
**LGA**

**Average Arrival and Departure Delay**

**Departure Delay:** (Actual scheduled pushback time) + (taxi-out time minus 10 minutes)

**Arrival Delay:** time spent waiting for proper separation from previous aircraft.

Source: William DeCota, Port Authority of New York
Flight Delays at LGA
from 2000 to 2006

Source: FAA OPSNET data
Suggested Political Solutions to Capacity Shortfall

- Full or Partial Privatization (eg AIR-21)
  - May improve modernization, costs and strategic management
  - Limited impact on capacity

- Re-regulation
  - Increased Costs to Consumer

- Demand Management (eg Peak Demand Pricing)
  - Reduced service to weak markets
  - Need to insure that revenues go to improved capacity

- Run System Tighter
  - Requires improved CNS
  - Safety vs Capacity Trade

- Build more capacity
  - Local community resistance

- Multi-modal transportation networks
Conclusion

- Technology in Pipeline will have limited impact on peak Capacity at Currently Stressed Airports
  - 20% to 40% Optimistically

- System will become (is) Capacity Restricted

- Airlines will Schedule in Response to Market Demand
  - Delay Homeostasis (at Hubs)
  - Increased Traffic at Secondary Airports
  - High Frequency Service
  - Changing Value for Reliability

- Overall system response is not clear

- Need
  - Protection of Airport and Spectrum Resources
  - More runways in critical locations
  - New ATM paradigms

- Need for leadership
Multi-Stakeholder Considerations & Role of System Transition Plans

- Demand
- Performance
- System Capability
- Implementation
- Change Process
  - Corrective Actions
  - Transformative Actions
- Selected Actions
- Research and Development
- Research Needs
- Research Capabilities
- FAA > OEP
- JPDO > NGATS
- EU > CESARE

NAS

Monitoring & Forecasting
- Aggregate Inefficiency Metrics
- Stakeholder Awareness or Perception $A_i$
- Stakeholder Values $V_i$
- Stakeholder Objectives $O_i$
- System Concepts
- Road Map
- System Transition Plans
Focus is the OEP 35 airports
NGATS Operational Improvements and Benefits

1. Broad Area and Precision Navigation ➤ Access and capacity
2. Airspace Access and Management ➤ Capacity
3. 4D Trajectory Based ATM ➤ Capacity and efficiency
4. Reduced Separation between Aircraft ➤ Capacity
5. Flight Deck Situational Awareness and Delegation ➤ Capacity and safety
6. ATM Decision Support ➤ Capacity
7. Improved Weather Data and Dissemination ➤ Capacity and safety
8. Reduced Cost to Deliver ATM services ➤ Cost
9. Greatly Expanded Airport Network and Improved Terminals ➤ Capacity