Airport Capacity

Limits, Technology, Strategy

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MIT International Center for Air Transportation
Department of Aeronautics & Astronautics
Airport System Capacity Limit Factors

- Runways
- Weather
  - Capacity Variability
- Gates
- Downstream Constraints
- Controller Workload
- Landside Limits
  - Terminals
  - Road Access
- Environmental
  - Community Noise
  - Emissions
- Safety
Airport System Capacity Limit Factors

- **Runways**
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- **Environmental**
  - Community Noise
  - Emissions
- **Safety**
ACARS Constraint Identification (Departure)

Normalized Total Departure Delay

One Airline, Ten Months (Jan-Oct. 97)
Separation Requirements for Arrival (Same Runway)

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

<table>
<thead>
<tr>
<th>Leading Aircraft</th>
<th>Trailing Aircraft</th>
<th>Heavy</th>
<th>Large</th>
<th>Small</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>B757</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Large</td>
<td>3(2.5)</td>
<td>3(2.5)</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Small</td>
<td>3(2.5)</td>
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- Visual Separation requirements
  - Pilots Discretion

- **Preceding arrival must be clear of runway at touchdown**
  - Runway Occupancy time
Separation Requirements for Departure (Same Runway)

- **Wake Turbulence is NOT a Factor**
  - Takeoff roll after leading takeoff is airborne AND:
    - satisfied distance separations, OR
    - cleared runway end or turned out of conflict

<table>
<thead>
<tr>
<th>Leading departure</th>
<th>Cat I (small, single prop)</th>
<th>Cat II (small, twin prop)</th>
<th>Cat III (all other)</th>
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<td>Trailing departure</td>
<td>Cat I</td>
<td>Cat II</td>
<td>Cat III</td>
</tr>
<tr>
<td>Cat I (small, single prop)</td>
<td>3000</td>
<td>4500</td>
<td>6000</td>
</tr>
<tr>
<td>Cat II (small, twin prop)</td>
<td>3000</td>
<td>4500</td>
<td>6000</td>
</tr>
<tr>
<td>Cat III (all other)</td>
<td>6000</td>
<td>6000</td>
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- **Wake Turbulence Application**
  - Trailing takeoff clearance min after leading Heavy or B757 takeoff roll, OR
  - Insure radar separations (miles), when trailing aircraft is airborne

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- **Takeoff clearance is granted when preceding landing is clear of the runway**
BOS Queuing Model
27/22L-22R Configuration
Runway Configuration Capacity Envelops

(Source: ETMS / Tower Records, 7-9 AM, 4-8 PM, July 1-15 1998 except Saturdays, Logan Airport)

- 4L/4R-9 (reported average 68 AAR - 50 DEP)
- 27/22L-22R (reported average 60 AAR - 50 DEP)
- 33L/33R-27 (reported average 44 AAR - 44 DEP)
- Single Runway (January 1999, reported average 34 AAR 34 DEP)
Demand vs. Capacity at Logan Airport (1987)

- Capacity under “good” conditions (79%)
- Capacity under “reduced” conditions (12%)
- Capacity under “unfavorable” conditions (9%)

Operations per hour vs. Time of day.
The Impact of Delays on Gate Congestion

Comparison of Scheduled vs. Actual Gate Usage on April 20, 1998 (American Airlines)

- Gate congestion was above scheduled at the end of the day due to an apparent missed arrival wave around 1730
- Not only was the peak higher, but it was sustained for a longer period of time
Airport System Capacity Limit Factors

- Runways
- **Weather**
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- Gates
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- Controller Workload
- Landside Limits
  - Terminals
  - Road Access
- **Environmental**
  - Community Noise
  - Emissions
- Safety
Air Traffic Delays in Thousands
Distribution of Delay Greater than 15 Minutes by Cause

Source: FAA 1997 ACE Plan

- Weather
- Terminal Volume
  - Closed
  - Runways/Taxiways
- Other
- NAS Equipment

MIT Lincoln Laboratory
Variable Capacity Effects
1995 Delays vs Operations

Data from FAA Capacity Office, CY95
From John Andrews, MIT Lincoln Lab
Weather Factors

- **IMC/VMC Capacity Variability**
  - Ceiling and Visibility
    - Start Time
    - Finish Time

- **Convective Weather**
  - Airport
  - Arrival/Departure Gates

- **Windshear**

- **Wind**
  - Runway Configuration

- **Precipitation**
  - Breaking Action
  - Plowing
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ACARS Constraint Analysis (Arrival)

Normalized Total Arrival Delay

One Airline, Ten Months (Jan-Oct. 97)
Low Predictability of Departure Demand based on Schedule

"Scheduled Departure Time" to "Ready for Push or Taxi"

Mean = 14 min (absolute)
Std. Dev = 17 min 22 sec
On Gate Departure Preparation

Petri Net Analysis
Airport System
Capacity Limit Factors

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Downstream Restrictions

Ground Stops

**Downstream Restrictions Effect on Departure Rate**
(source: CODAS/ETMS, Logan Airport, July 17-1998)

**Downstream Restrictions Effect on Delays**
(Source: ASQP, Logan Airport, All Airlines, July 17-1998)

**Average Departure Rate**
**July 17, All day restrictions**

GS to EWR, LGA, IAD, PHL, ORD and BWI 15:15 - 21:00, ACK GS 11:00 - 13:00

**Tax Out**
**Push Delay**
Downstream Restrictions
Local Departure Fix (MHT)

Downstream Restrictions Effect on Departure Rate
(source: CODAS/ETMS, Logan Airport, July 23-1998)

Downstream Restrictions Effect on Delays
(Source: ASQP, Logan Airport, All Airlines, July 23-1998)
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ATC Workload as a System Constraint

- Gate
  - Gate controller
  - Commands
- Ramp
  - Ramp Controller
  - Requests
- Taxi
  - Ground Controller
  - Taxi
- Runway
  - Local Controller
  - Runway
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Landside Limits

- **Passenger System Throughput**
- **Road Access Limits**
  - □ 1000 Originating Seats/15 min/Terminal
  - □ Parking
- **Security Throughput**
  - □ Passengers
  - □ Baggage (x 20)
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Community Noise Impact

- Example: Louisville Runway
  - 30 > 70 ops/hr
  - Runway
    - $447 M
  - Property within 65 DNL
    - $350 M
The estimated runway queueing time translates into:

- $6.1$ million in Direct Operating Costs,
- significant pollutant emissions:
  - $28$ tons of HC,
  - $136.4$ tons of CO,
  - $22.0$ tons of NO$_x$.

Pollutant emissions from runway queueing are equivalent to between $9,440$ and $22,330$ cars visiting the airport every day.

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Runway queue emissions per year</th>
<th>Equivalent car miles per year</th>
<th>Equivalent car round trips per day</th>
</tr>
</thead>
<tbody>
<tr>
<td>HC</td>
<td>28.0 tons</td>
<td>9.7 million</td>
<td>14,710</td>
</tr>
<tr>
<td>CO</td>
<td>136.4 tons</td>
<td>6.2 million</td>
<td>9,440</td>
</tr>
<tr>
<td>NO$_x$</td>
<td>22.0 tons</td>
<td>14.7 million</td>
<td>22,330</td>
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*Table 6: Environmental impact of current runway queueing.*
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Safety vs Capacity

- The current airborne system is extremely safe but conservative
- Runway Incursions are an area of concern
- 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 INCURSION STATISTICS

Vehicle/pedestrian deviations  Pilot deviations  Operational errors

Source: FAA
SEPARATION ASSURANCE
BUDGET COMPONENTS

NOTE: budget components not to scale (relative sizes have changed over time)
Potential Technology Impact

Examples

- **Runway Efficiency, Reduced Volatility**
  - Single Stream Compression
  - Close Parallel Approach
  - Wake Vortex Sensing (Dynamic)
  - Pairwize Self Separation
  - VFR Performance in IFR

- **Terminal Area Efficiency**
  - Flow to Final
  - Load Balancing
  - Multi-Runway Coordination

- **More Efficient Use of Resources (Systemwide and Local)**
  - Collaborative Decision Making
  - Information Sharing
  - Wx Prediction

- **Environmental Benefits**
  - Minimal Noise Procedures
  - Minimal Surface Runtime/Emissions
ATM Technology Components

- Physical Infrastructure
  - Runways
  - Gates
  - Terminals
  - Landside
- Communication
- Navigation
- Surveillance
- Information Architecture
  - Information Sharing Tools
  - Decision Support
  - Weather
  - Databases
- Control Systems/Procedures
Infrastructure

• Runways (Concrete)
  □ Marginal Increase in Peak Capacity Available at Existing High Demand Airports (less than 40%)
  □ New Runways Politically Difficult
    ◆ Noise
    ◆ Emissions

• Gates

• Terminals

• Landside

• Direct Impact on Capacity
Communications

- Satellite Communications
- Datalink
- CPDLC
  - Latency Problems (Terminal Area)
  - Approach Routing
  - Taxi Routing
- ACARS
  - PDC Clearance
  - Airline Coordination

- Limited direct impact on Airport Capacity
- Relives VHF Channel Saturation
Navigation

- **GPS**
  - Initial Approach (CA)
  - Cat I (WAAS)
  - Cat II, III (LAAS)
  - Surface (WAAS)

- **WAAS**
  - In trouble, integrity Issues

- **LAAS**
  - Carrier Phase
  - Code Based

- **Approach Guidance Potential Benefits**
  - Noise, Close Parallel Approaches

- **Surface Guidance**

- **Issues**
  - Jamming
  - Surveying, TERPS
  - Lighting
3° Decelerating Approach  
(JFK 13L)
Surveillance

- Enhanced Digital Radar Performance
  - Precision, Weather
- ADS-B (Compression Benefits)
- AMSS (Safety, Runway Incursions)
  - Radar
  - Multilateration
- AVOSS (Dynamic Vortex Separation)
- Synthetic/ Enhanced Vision
  - Aircraft (VMC Separation in IMC) (Compression)
  - Tower (Safety)
- Compression Benefits
  - Tighter Control Loops
  - Close Parallel Approaches
  - Pairwize Self Separation
  - Dynamic Vortex Separation
ATM Basic Control Loops

- Flight Strips
- Flight Plan Amendments
- Voice
- ACARS (Datalink)
- Initial Clearances
- Trajectory Commands
- Flight Management Computer
- Autodesk
- Autothrust
- Navigation

Pilot

- ATC
- Surveillance: Enroute: 12.0 s
- Terminal: 4.2 s
- ADS: 1 s

Manual Control

Aircraft

Decision Aids

State

MCP

 Controls

Displays

AOC: Airline Operations Center

CDU

State Commands
Radar Display Example

CO 123
350C
B757 310
Information Architecture

- Information Sharing
  - Collaborative/Informed Decision Making
    - Strategic
    - Tactical
- Decision Support Tools
- Weather
- Databases
- Improved/Use of Existing Resources
  - Capacity
  - Predictability, volatility
- **Note: Must consider degraded mode operation**
  - If high Traffic Density or Reduced Separation are Dependant on Surveillance, Navigation, Information Sharing, or Decision Support Tools need recovery strategy for failures.
Proposed CNS/ATM Information Technologies

Planning

- Flight Schedule
  - Filed Flight Plans
  - National Flow Planning
    - AOCNET CDM ASDI
    - Delay Est.
    - NASWIS
  - Weather NAS Status
  - Information Sharing
    - Surveillance
    - Decision Support
- Schedule of Capacities
  - Approved Flight Plans
  - Facility Flow Planning
  - Planned Flow Rates
  - Desired Sector Loads
  - Clearances
    - CPDLC
    - Voice
- Clearances
  - CPDLC
  - Vectors
  - Traffic Sensor
  - Other Aircraft States
  - AOC

Execution

- Approval
  - Handoffs
  - Traffic Control
  - Sector Traffic Planning
    - Negotiate Handoffs
    - 5 min
  - Traffic Schedule
    - Filed Flight Plans
    - Planned Flow Rates
    - Sector Traffic Planning
    - Approved Handoffs
- National Flow Planning
  - AOCNET CDM ASDI
  - CTAS
  - SMA
- Facility Flow Planning
  - UPR
  - URET
- ATN Radar Net
  - AC State Sensor
  - Tracker
    - ADS-A
    - ADS-B

Adapted from; A. Haraldsdottir Boeing
Collaborative Decision Making

• **Strategic Level**
  - Schedule
  - Cancellations
  - Response to Severe Weather
  - Response to Capacity Restrictions
    - Airport
    - Enroute

• **Tactical Level**
  - Diversions
  - Prioritization
  - Routing
  - Sequencing
    - Arrival
    - Departure

Diagram:
- **Airlines**
- **ATC/Airport Facilities**
- **Flow Control**
- **Aircraft**
- **AOC Dispatch**
- **ATC**
- **Information Sharing Paths**
ATM Tactical Information Architecture

Host Computer and ATC Information Network

Future Controller

Active Controller

Decision Aids (CTAS)
Procedures

Flight Strips, Flight Information Object

OAG
Flight Plan

Airline Dispatch AOC

ACARS Flight Plan

Flight Crew

Information Sharing and Decision Support Tools
CTAS
Decision Aid/Information Sharing Example

TMA Traffic Management Advisor
DA Descent Advisor
FAST Final Approach Spacing Tool
  p FAST
  a FAST
UPR User Preferred Routing
D2 Direct-To Tool
EDP Expedite Departure Path
CAP Collaborative Arrival

Future (?)
SMS Surface Movement System
DP Departure Planner
DAG Distributed Air Ground

TMA Scheduling Reference Points
(diagram is not to scale)
ATC Coordination Example  CTAS
Traffic Management Advisor (TMA)

TMA Provides
- Decision Support
- Scheduling
- Resource Allocation (Runways)
- Information Sharing
  - TRACON
  - Center (ARTCC)
  - TMU/TMC
CTAS Load Graph

Arrival Rate (per 10 min)
FAST

- Sequencing Runway Advisory
- Speed Advisory
- Turn Advisory

ARTS Flight Data Block with FAST Enhancements
Passive FAST vs. Current (DFW Trials)

IFR, 2 Runways
IFR, 3 Runways
VFR, 3 Runways

Arrival Rate (aircraft/hour)

Baseline
FAST

From Tom Davis (NASA Ames)

11:30 am rush,
VFR corrected for inboard landings
Passive FAST vs. Current (Excess in-trail Separations)

DFW
11:30 am rush, measured at Outer Marker

From Tom Davis (NASA Ames)
Departure Planning Tools

• Decision Aiding Tools to Improve the Efficiency of the Departure Process

• Meter and Sequence Departure Queues to:
  ✉️ Utilize system resources efficiently (primarily at peak traffic)
    ◆ Maximize runway throughput
    ◆ Minimize taxi time delays (pushback and other clearances)
    ◆ Balance runway loads
  ✉️ Minimize environmental impact
    ◆ Engine emissions during taxiing
    ◆ Noise regulations
  ✉️ Reduce economic inefficiencies
    ◆ Minimize “engine-run” (taxi) times
  ✉️ Guarantee fair treatment among all airport users

• “Virtual Queue”
Departure Planning Tool 1 (N Control)

\[ \bar{T}_S(t+6 \text{ min.}) \text{ as a function of } N_{dep}(t) \text{ in configuration 9} \]

(ASQP data, Boston Logan, 1996)

Runway 9-4R Configuration
34 departures/hr
Weather Decision Aid Example
New York City ITWS

Sensor Fusion

One-Minute Coverage Region

Common User Displays

NYC Situational Display

Source: MIT Lincoln Laboratory
Future Synoptic Civil Weather

Source: MIT Lincoln Laboratory
Database Example
Flight Information Object (FIO)
Capacity Increase Potential
Free Flight Phase 1

- Collaborative Decision Making
  - Improved Coordination of Limited Resources

- URET Conflict Probe
  - No Direct Impact

- Traffic Management Advisor
  - Improved Runway Balancing
  - Flow Coordination

- p FAST
  - Runway Load Balancing
  - Runway Schedule Compression (10-15%)
Potential Future Improvements to Capacity Management

- **Time Based ATM Operations**
  - Required Time of Arrival (RTA)
- **Formation Approach Procedures**
- **Integrated Terminal Multi-Airport Operations**
- **Airport Capacity Markets**
  - Arrival Departure Balancing
- **Automated Passenger Screening**
- **Integrated Multi-Modal Transportation Systems**
Suggested Political Solutions to Capacity Shortfall

- Privatization, the silver bullet?
  - May improve modernization, costs and strategic management
  - Limited impact on capacity

- Re-regulation
  - Increased Costs

- Peak Demand Pricing
  - Reduced service to weak markets

- 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%
- System will become (is) Capacity Restricted
- Airlines will Schedule in Response to Market Demand
  - Delay Homeostasis
  - Increased Traffic at Secondary Airports
  - High Frequency Service
- Technology will not be a panacea
- Overall system response is not clear
- Need for leadership
Capacity Limit Factors

- **Airport Capacity**
  - Runways
  - Gates
  - Landside Limits
  - Weather

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

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

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

- **Peak Demand/Capacity issue driven 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**
Capacity Limits as Market Drivers for Large Aircraft?

- **Do large aircraft increase passenger throughput?**
  - Wake Vortex Separation Requirements
  - Runway Occupancy Time
  - Taxi Speeds
  - Aircraft Turn Time
    - Southwest (25-30 min)
    - International (3-5 hours)

- **Can you incentivize/require larger aircraft?**
  - Landing Fees
    - Currently charge by weight/size (disincentive)
    - Peak period pricing
      - Impact on secondary markets (cost, schedule)
      - Political Issues
  - Slots
    - Used in Europe (still have large delays)
    - Not used in US except (LGA,DCA,ORD,JFK)
Airport Issues

- Gate Design
  - 80m box, jetways,
- Taxiway Design (80m box)
- Runway Loading/Wear
- Taxiway Loading
  - Tenerife
- Emergency Response Capacity
- Community Noise
- Landside limits
- Maintenance Facilities
PAIRED PARALLEL APPROACHES

A→B wake protection

A→C wake protection

B→D wake protection

INDEPENDENT PARALLEL APPROACHES

PAIRED PARALLEL APPROACHES

A→B blunder protection

DEPENDENT PARALLEL APPROACHES