The Dynamics of the Emerging Capacity Crisis in the US Air Traffic Control System

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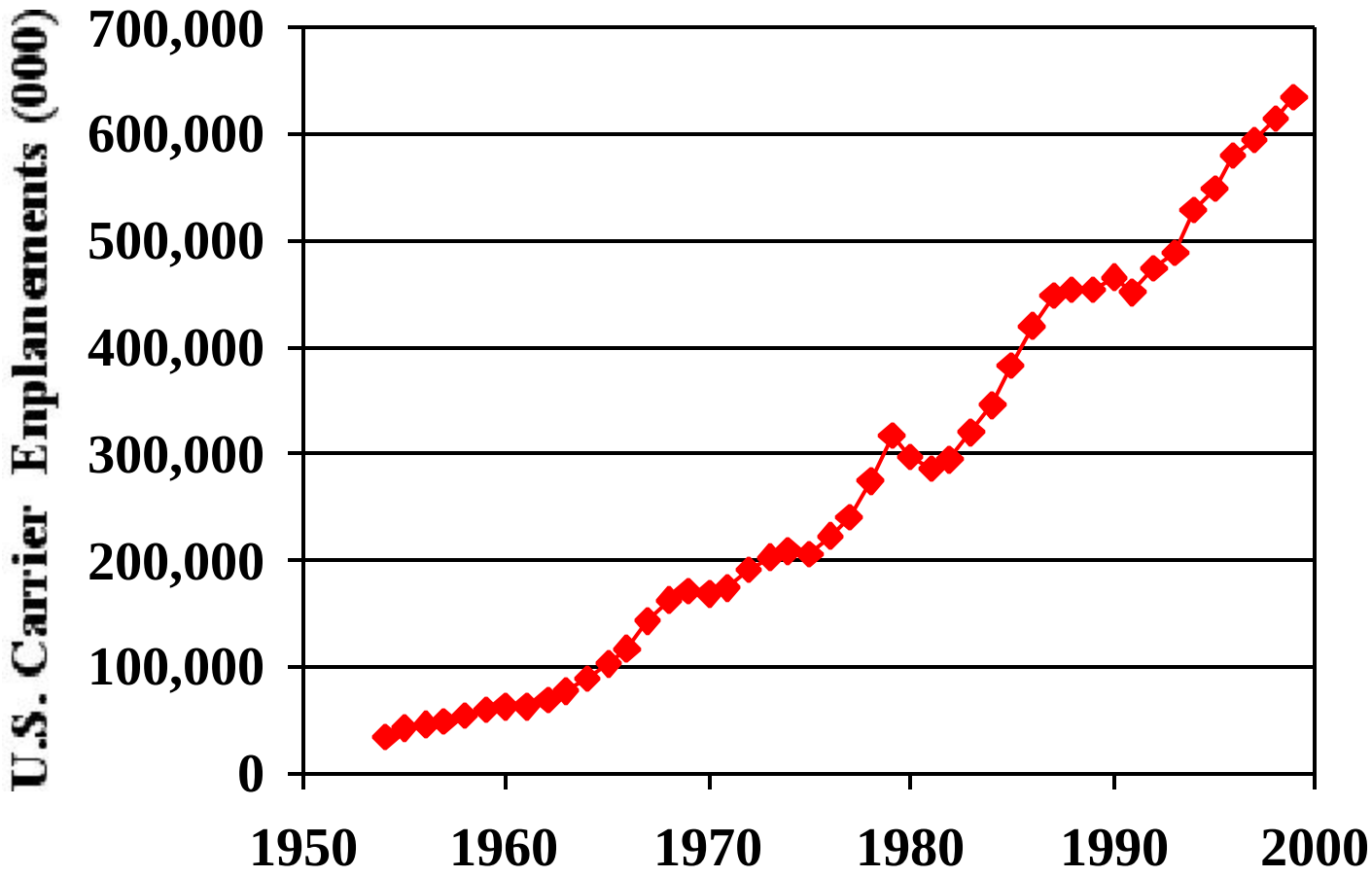
US Capacity Issue

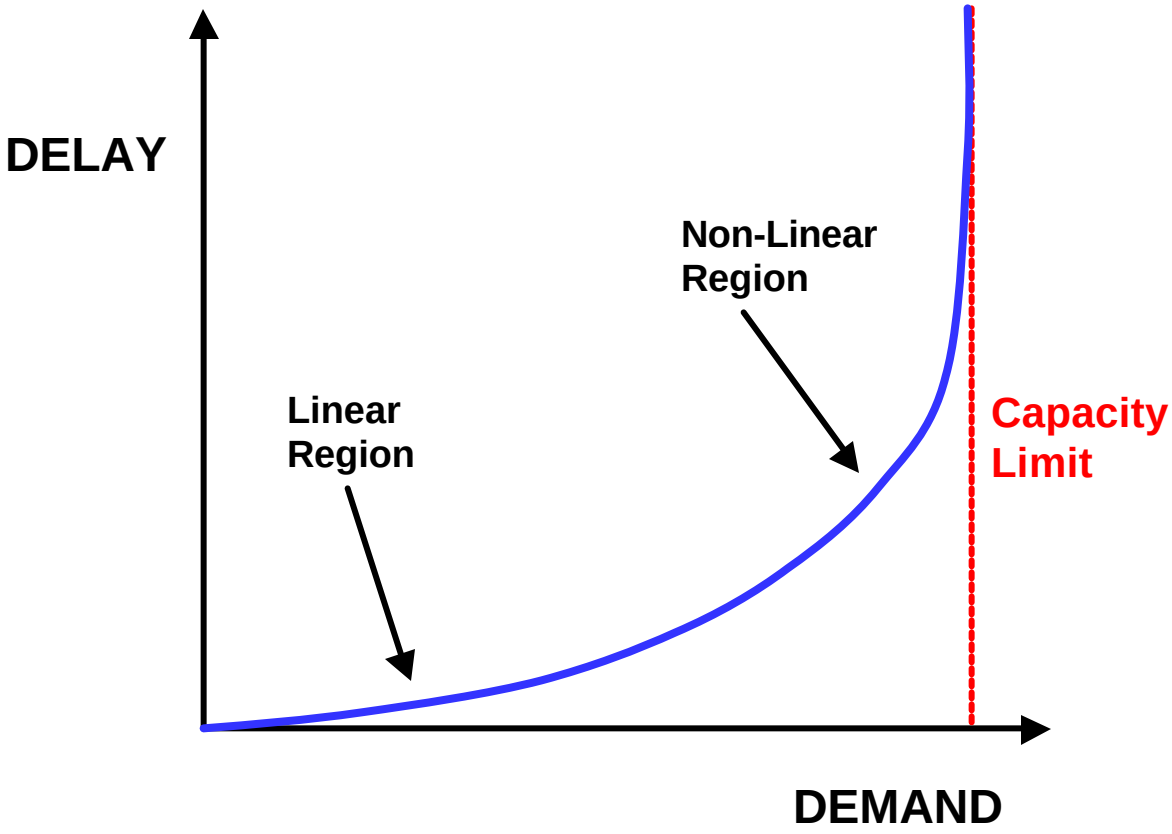
- **The US Air Transportation system is approaching a critical saturation threshold where nominal interruptions (e.g. weather) result in a nonlinear amplification of delay**
- **US and Regional Economies highly dependant on Air Transportation**
  - Business travel (stimulated by info technology)
  - 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**
- **Impact of upcoming capacity crisis is not well understood**
  - Operational Impact
  - Economic Impact

Increased Traffic Demand

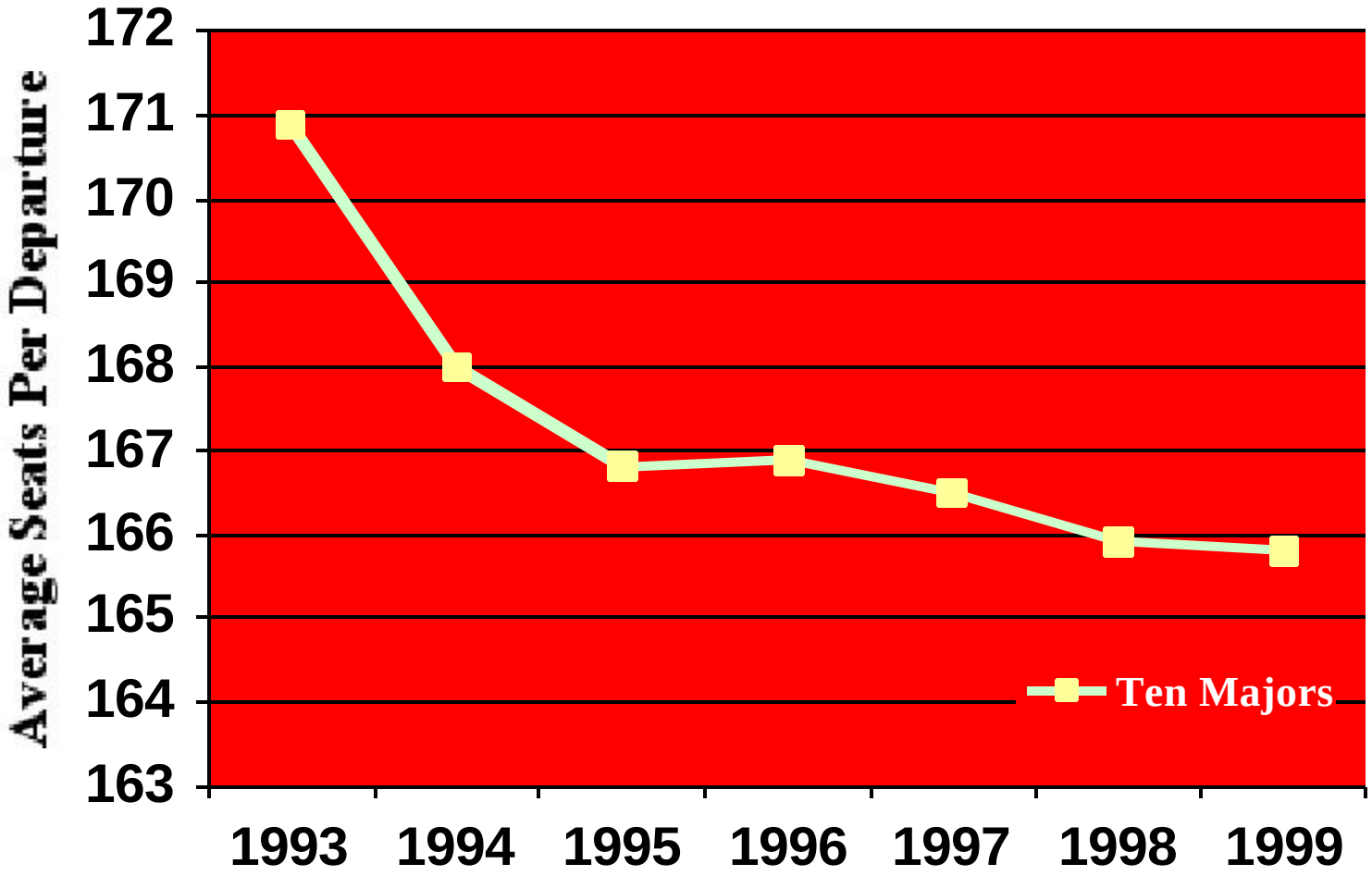


Source: BTS Historical Annual Air Traffic Data

Classic Delay vs Demand Curve

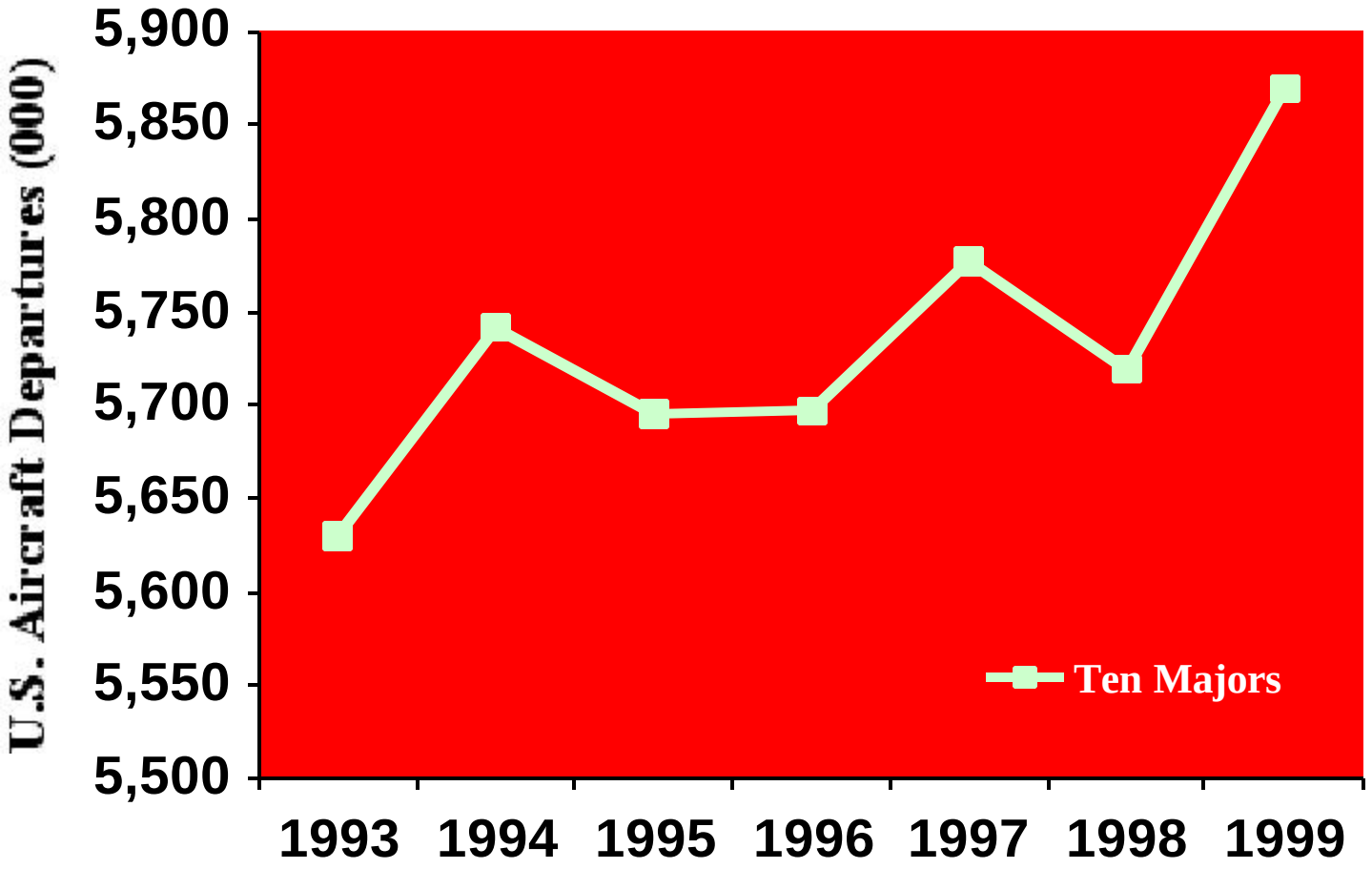


Decreasing Aircraft Size



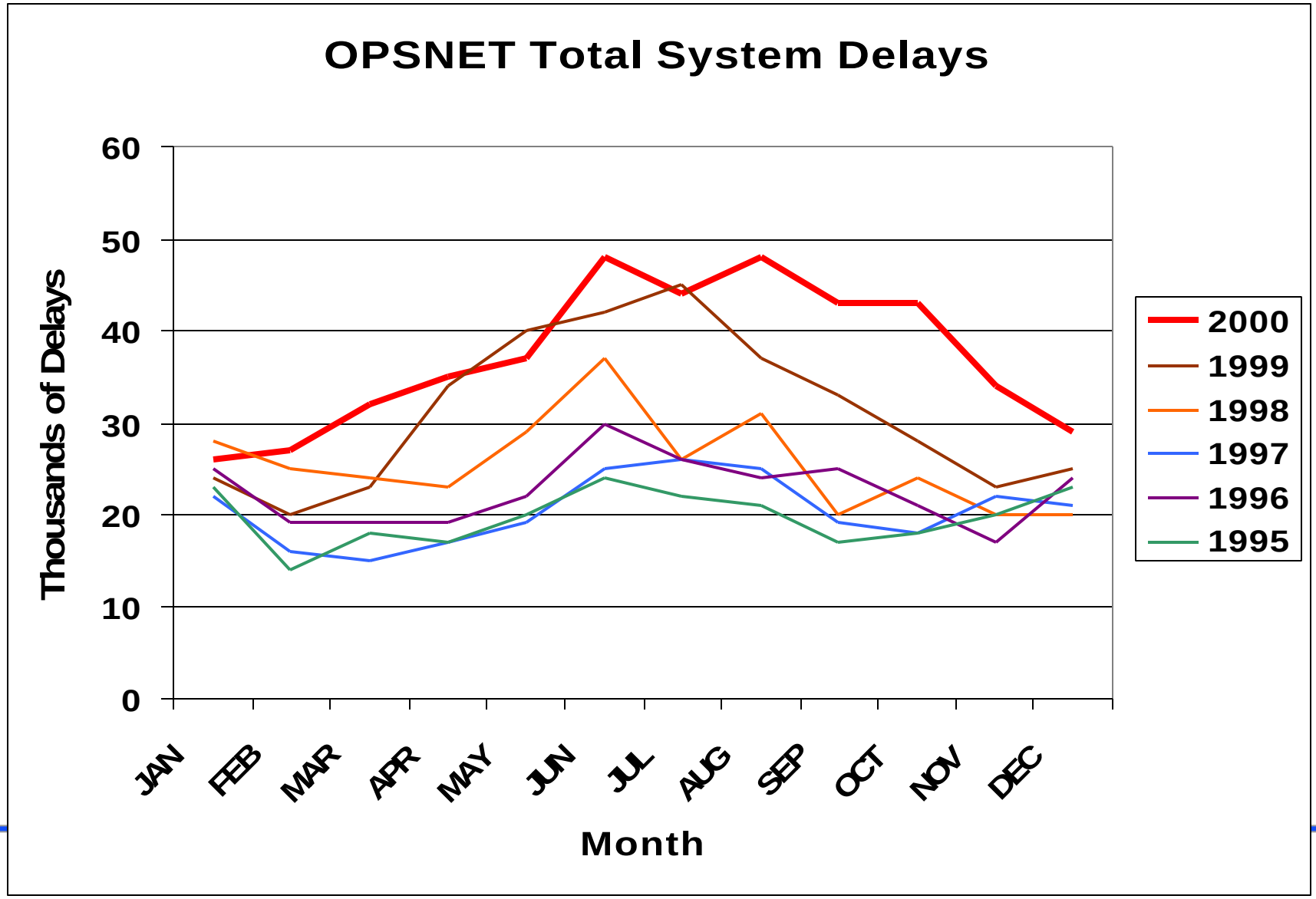
Source: DOT Form 41 Data

Increased Flights

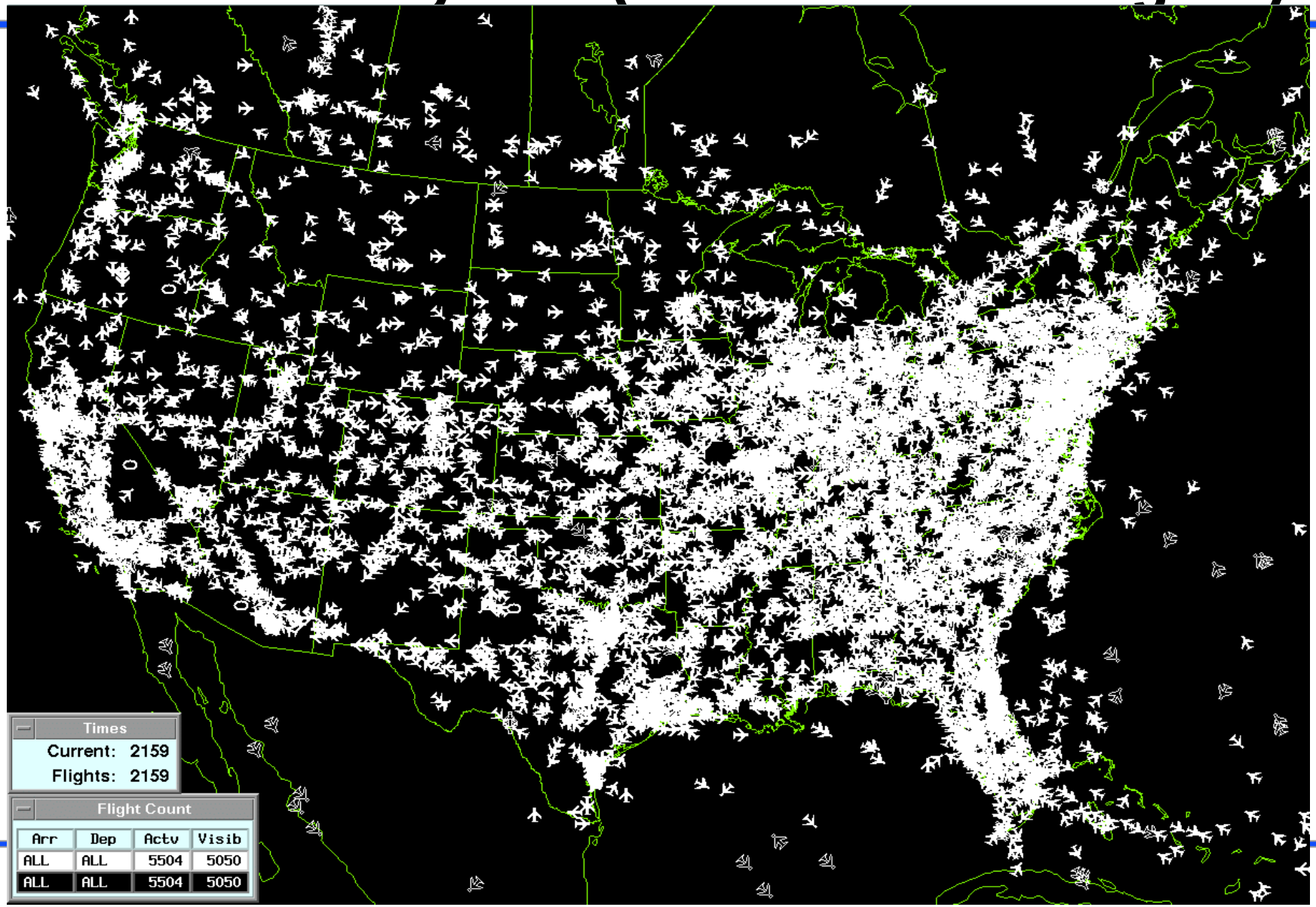


Source: DOT Form 41 Data

Delays in 2000 Are Worse Than In 1999



Typical US Traffic Situation Daytime (5500 Tracked Flights)

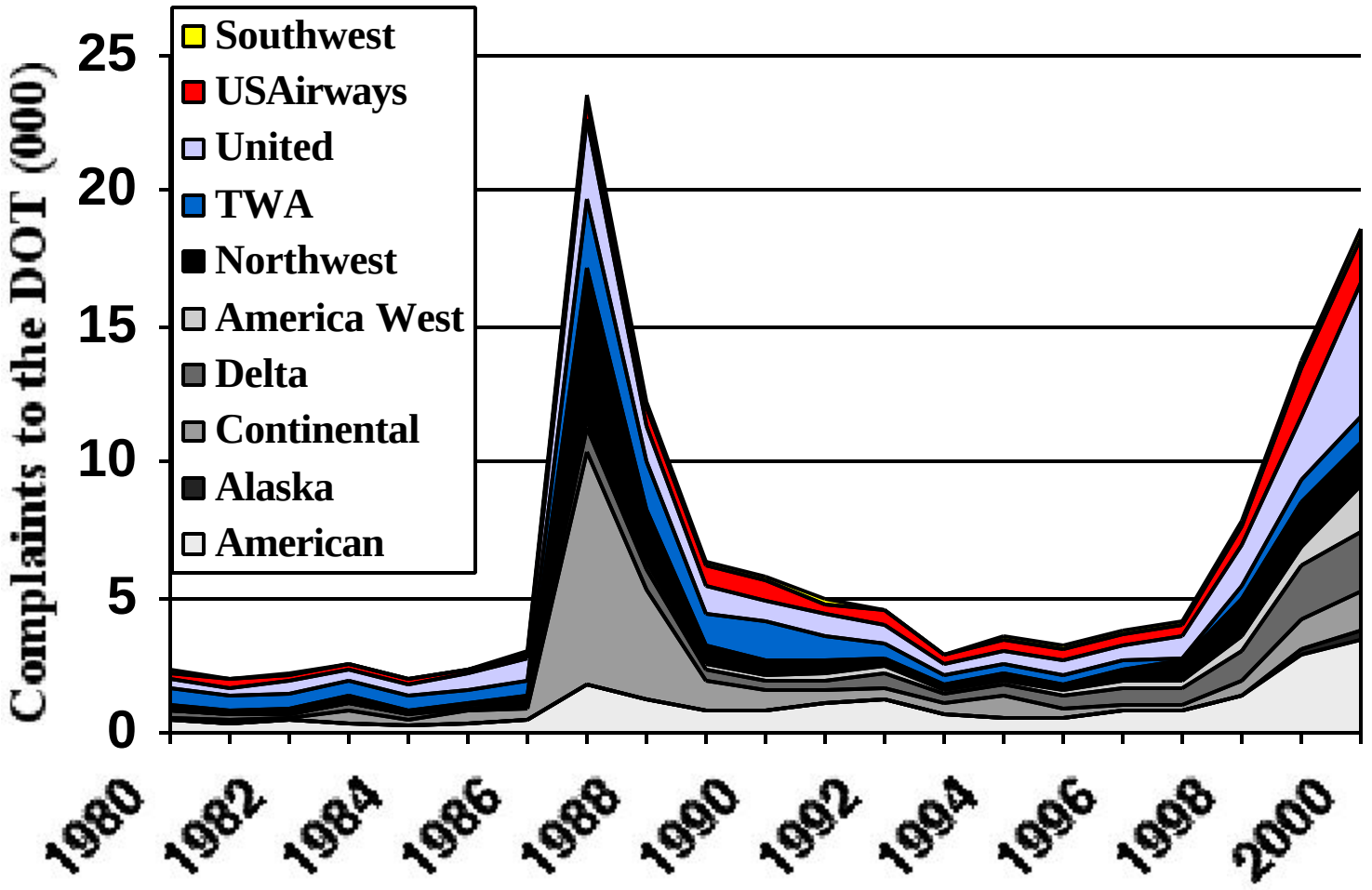


European Departure Delays (1999)

Dep Apt	% Flts Delayed	Average Delay (min)
Bologna	47	34.5
Milan/Malpensa	42	30.5
Palma Mallorca	35	34.9
Geneva	40	26.7
Milan/Linate	39	27.7
Zurich	41	23.8
Nice	33	28.1
Tenerife	30	28.4
Lyon	36	24.0
Basel	32	26.1
Madrid	31	26.9
Barcelona	27	30.0
Athens	24	30.2
Brussels	31	23.3
Munich	27	25.5

source: Eurocontrol (IHT4/1/00)

Consumer Complaints

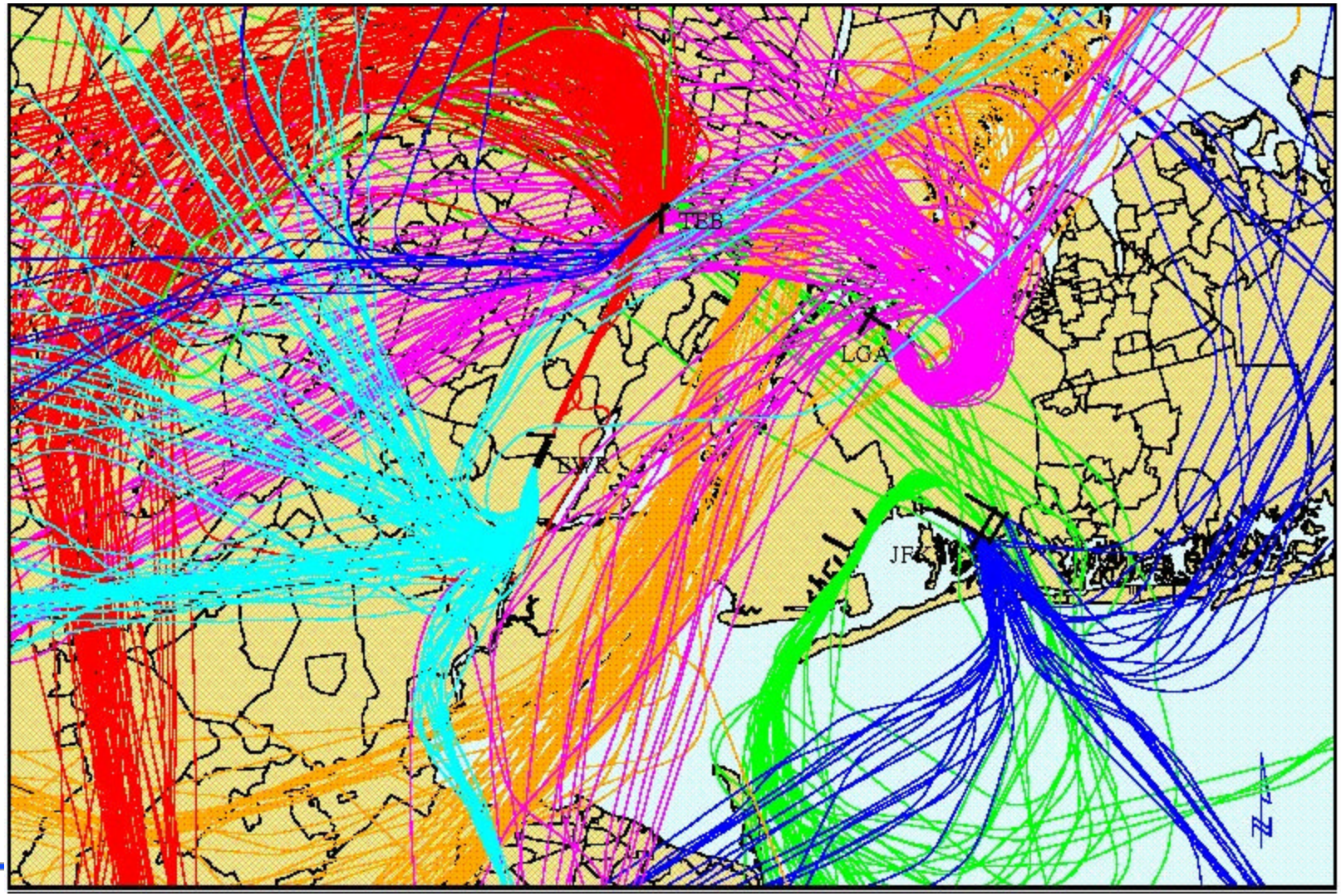


Source: FAA Air Travel Consumer Report

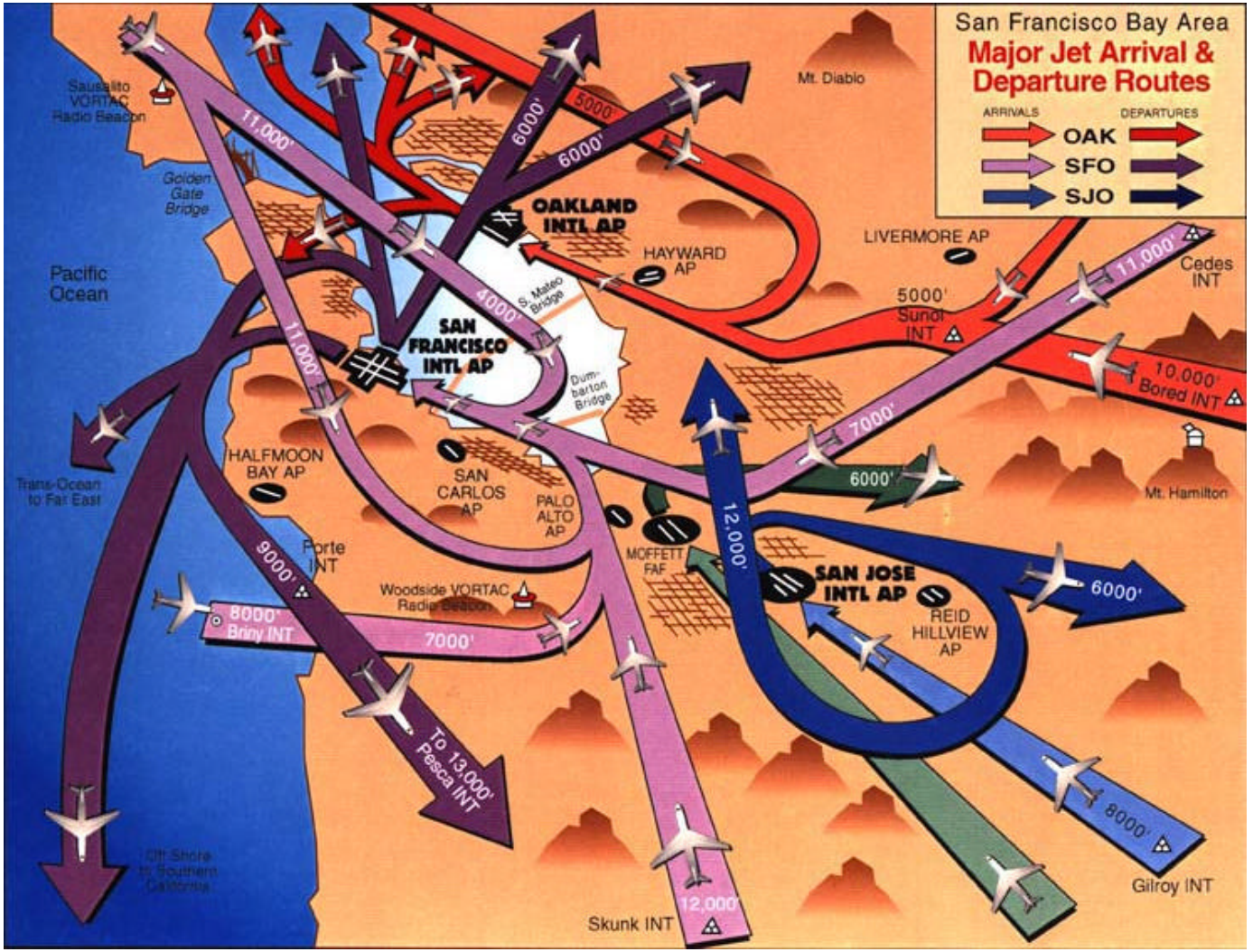
Human Factors and Adaptation

- **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



Bay Area Flow Pattern (West Flow)



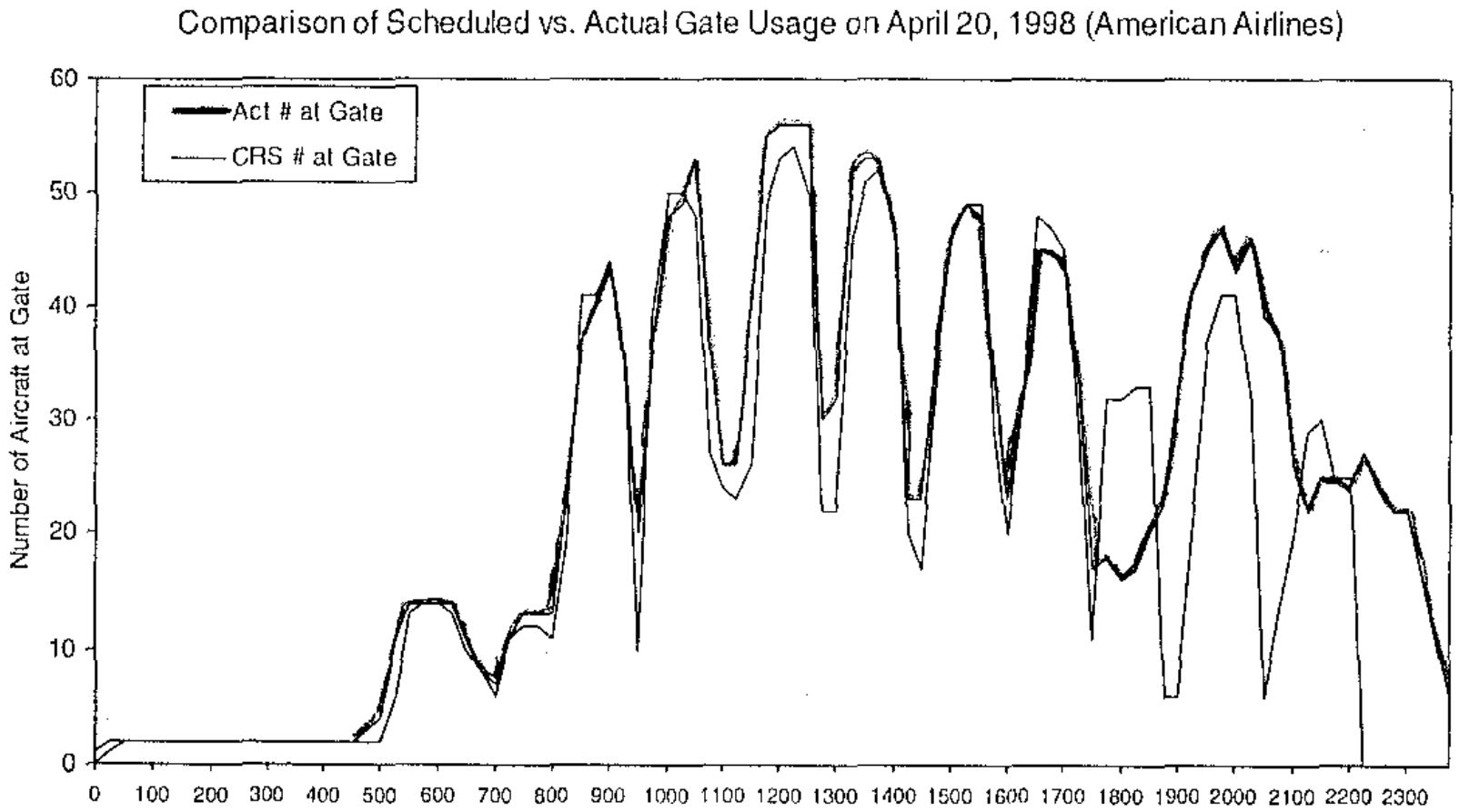
Capacity Limit Factors

- **Airport Capacity**
  - Runways
  - Gates
  - Landside Limits
  - Weather
- **Airspace Capacity**
  - Airspace Design
  - Controller Workload
  - Balkanization
- **Demand**
  - Peak Demand
  - Hub & Spoke Networks
- **Environmental Limits**
  - Noise (relates to Airport)
  - Emissions (local, Ozone, NOX, CO2)

Schedule Factors

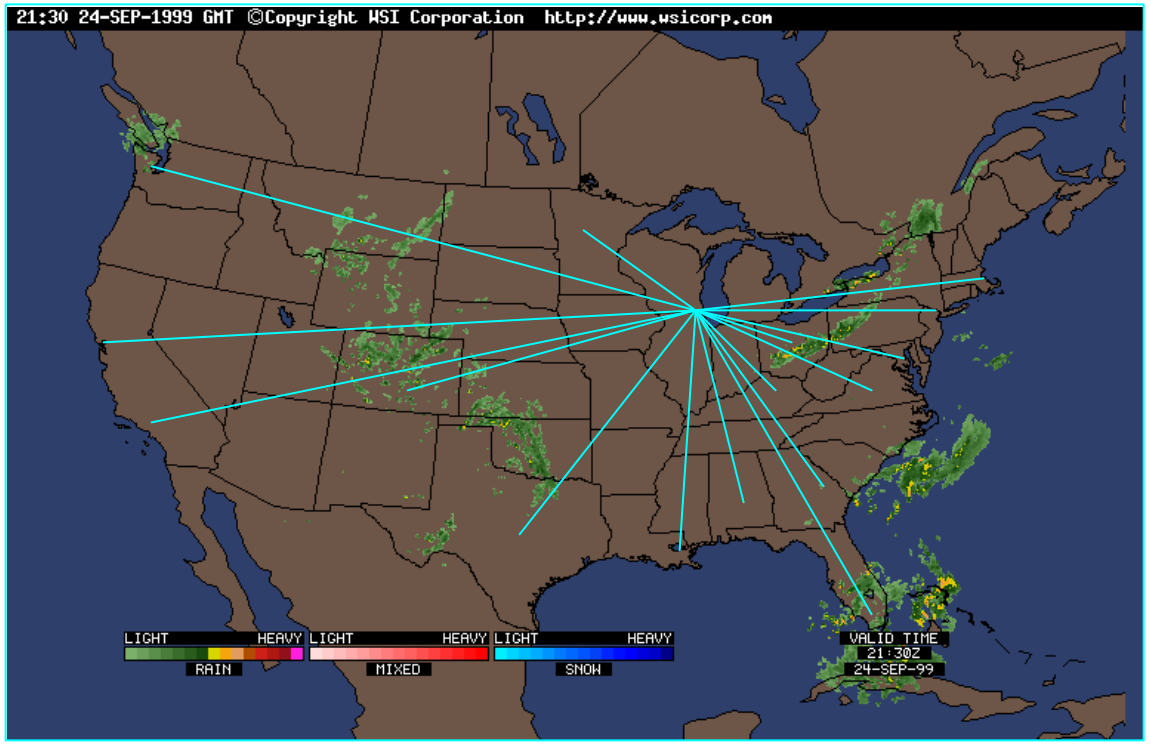
- **Peak Demand/Capacity issue driven (in part) by airline Hub and Spoke scheduling behavior**
  - Peak demand often exceeds airport IFR capacity (VFR/IFR Limits)
  - Depend on bank spreading and lulls to recover
  - Hub and Spoke amplifies delay
- **Hub and spoke is an efficient network**
  - Supports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

The Impact of Delays on Gate Congestion



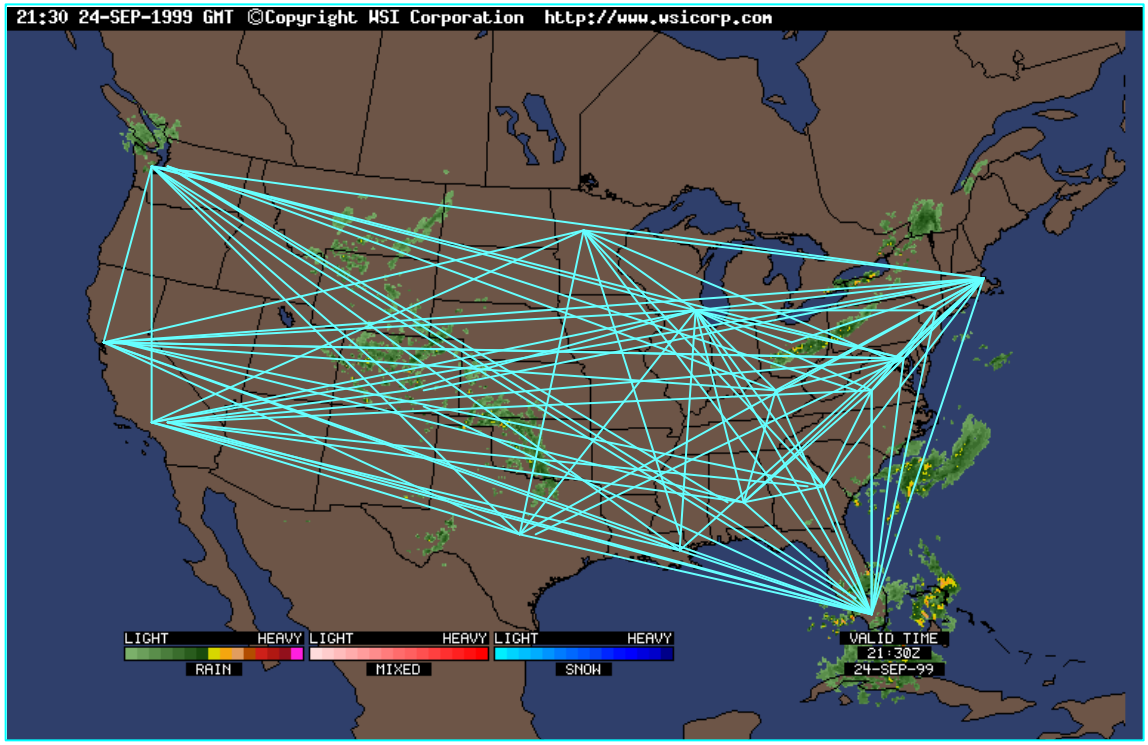
- Gate congestion was above scheduled at the end of the day due to an apparent missed arrival wave around 1730
- Not only was the peak higher, but it was sustained for a longer period of time

Hub and Spoke Network



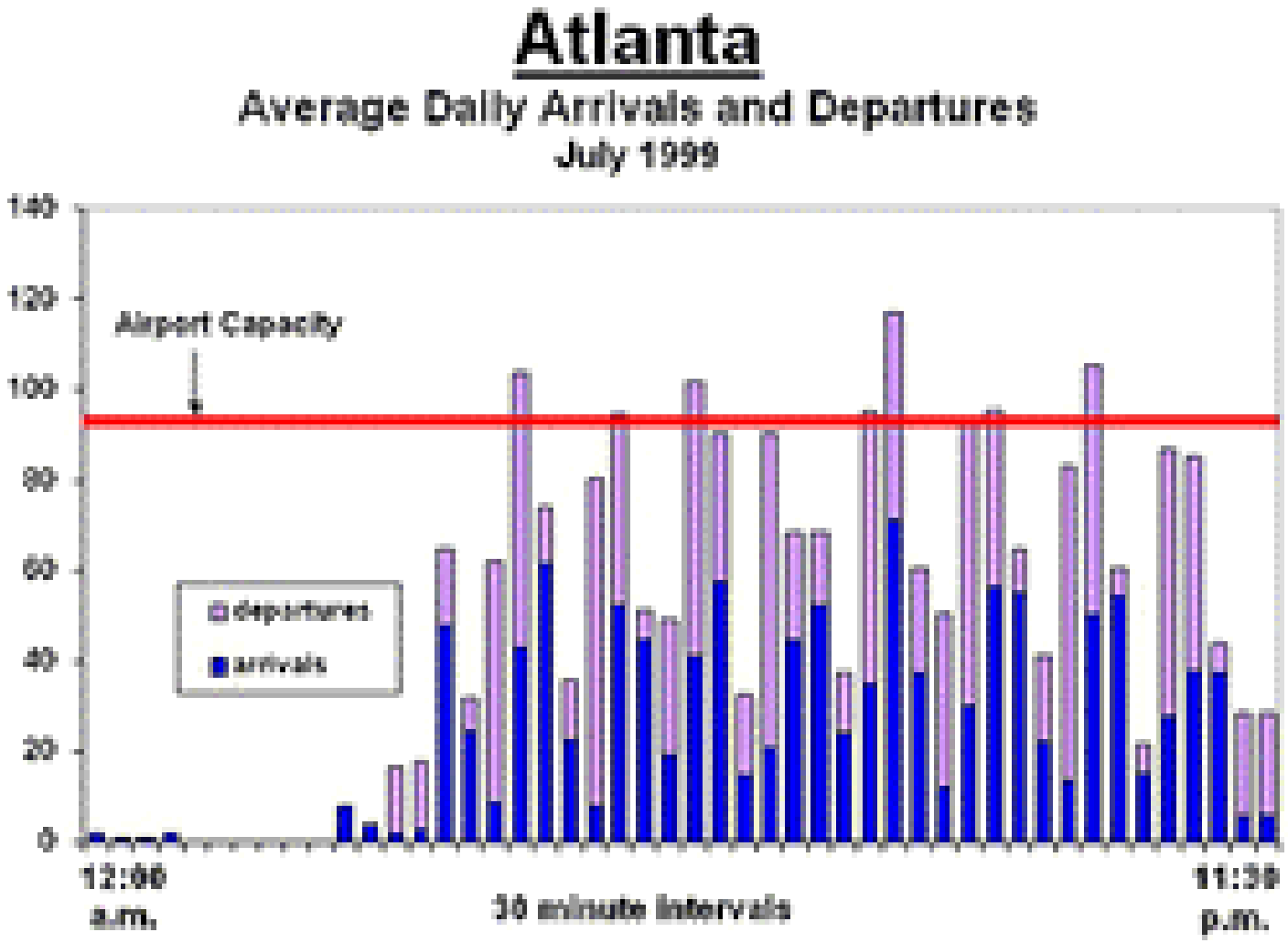
Completely Connected Network = 2(N-1) Flights
(eg., 50 Airports, 98 Flights)

Fully Connected Network



Completely Connected Network = N(N-1)
(eg., 50 Airports, 2450 Flights)

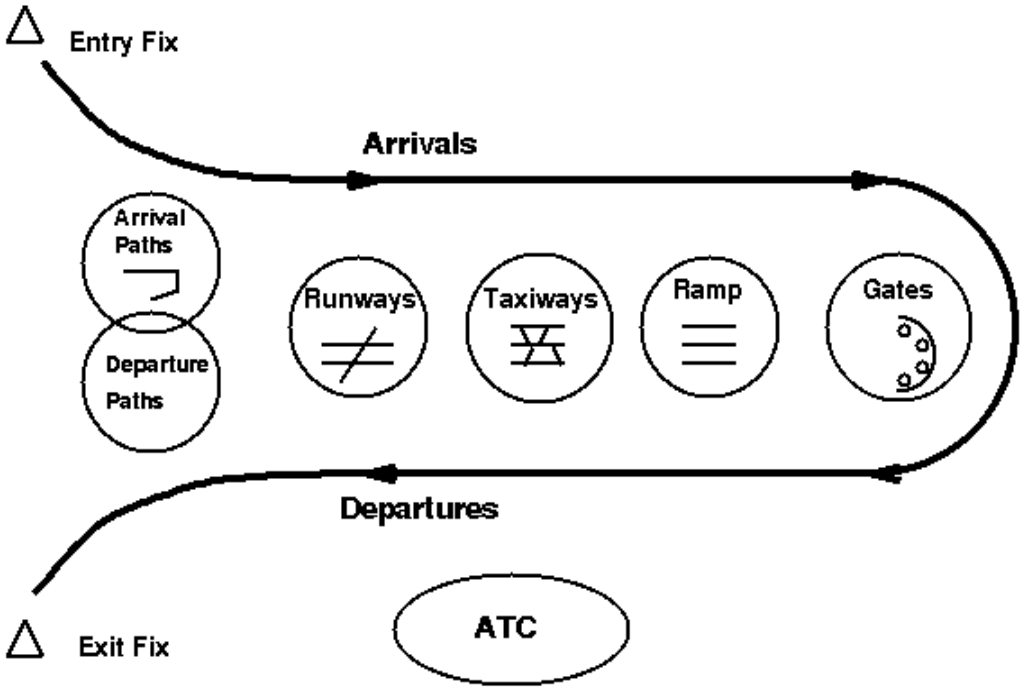
ATL Schedule (July 99)



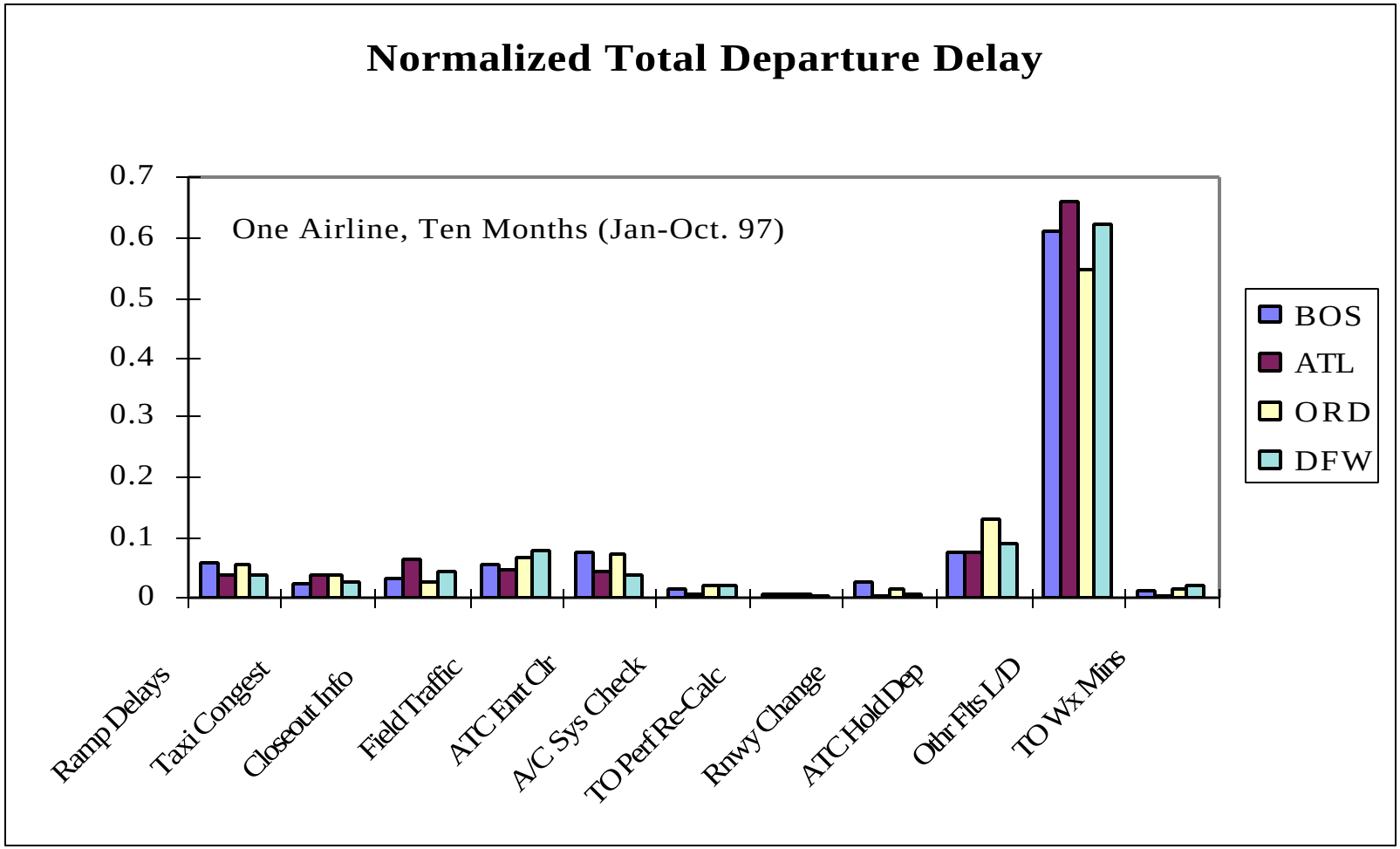
Source: ATA Website

Airport System Capacity Limit Factors

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



ACARS Constraint Identification (Departure)



Separation Requirements for Arrival (Same Runway)

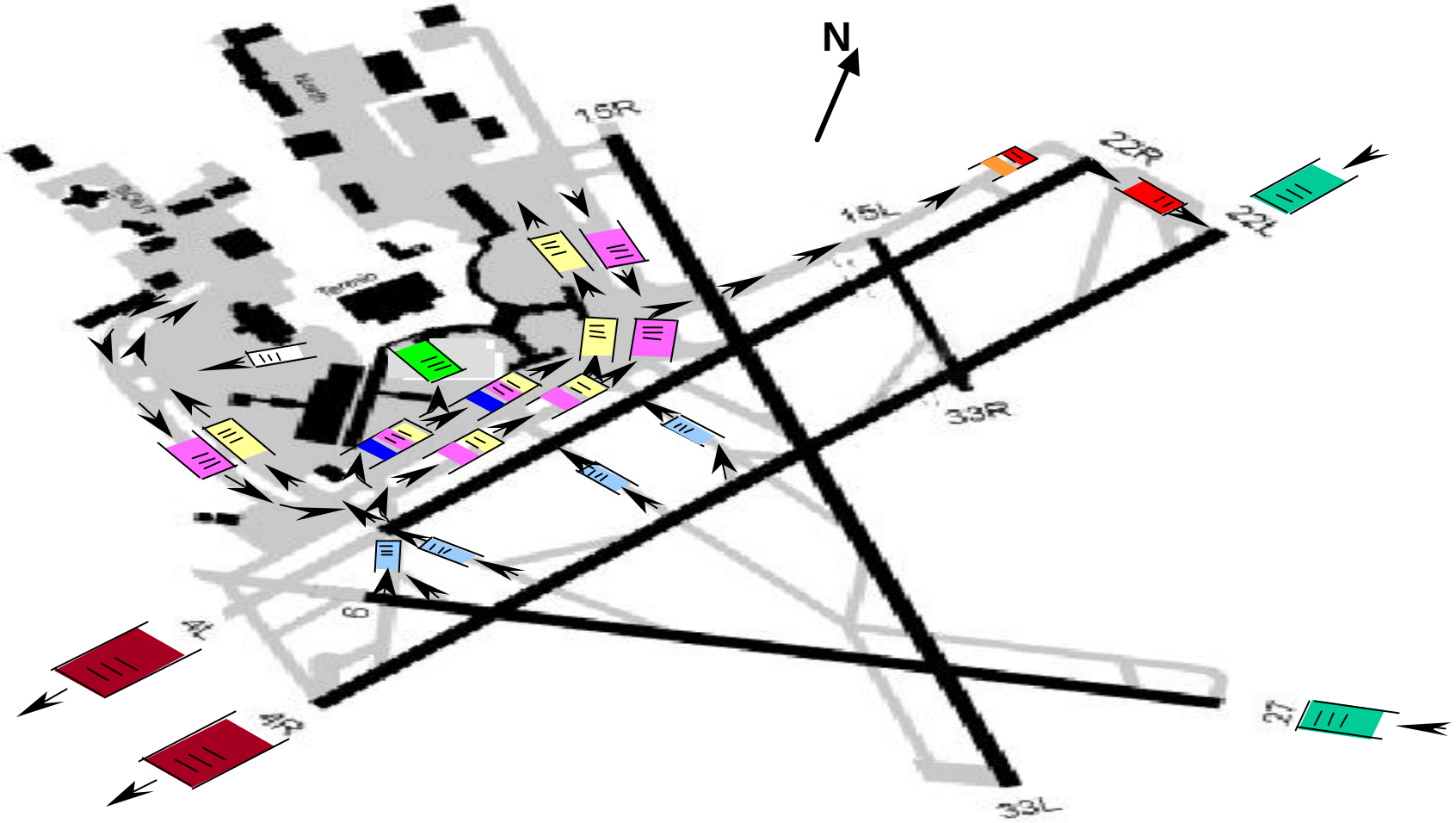
- **Wake Turbulence Requirement**
  - Radar Separation requirements

Trailing Aircraft

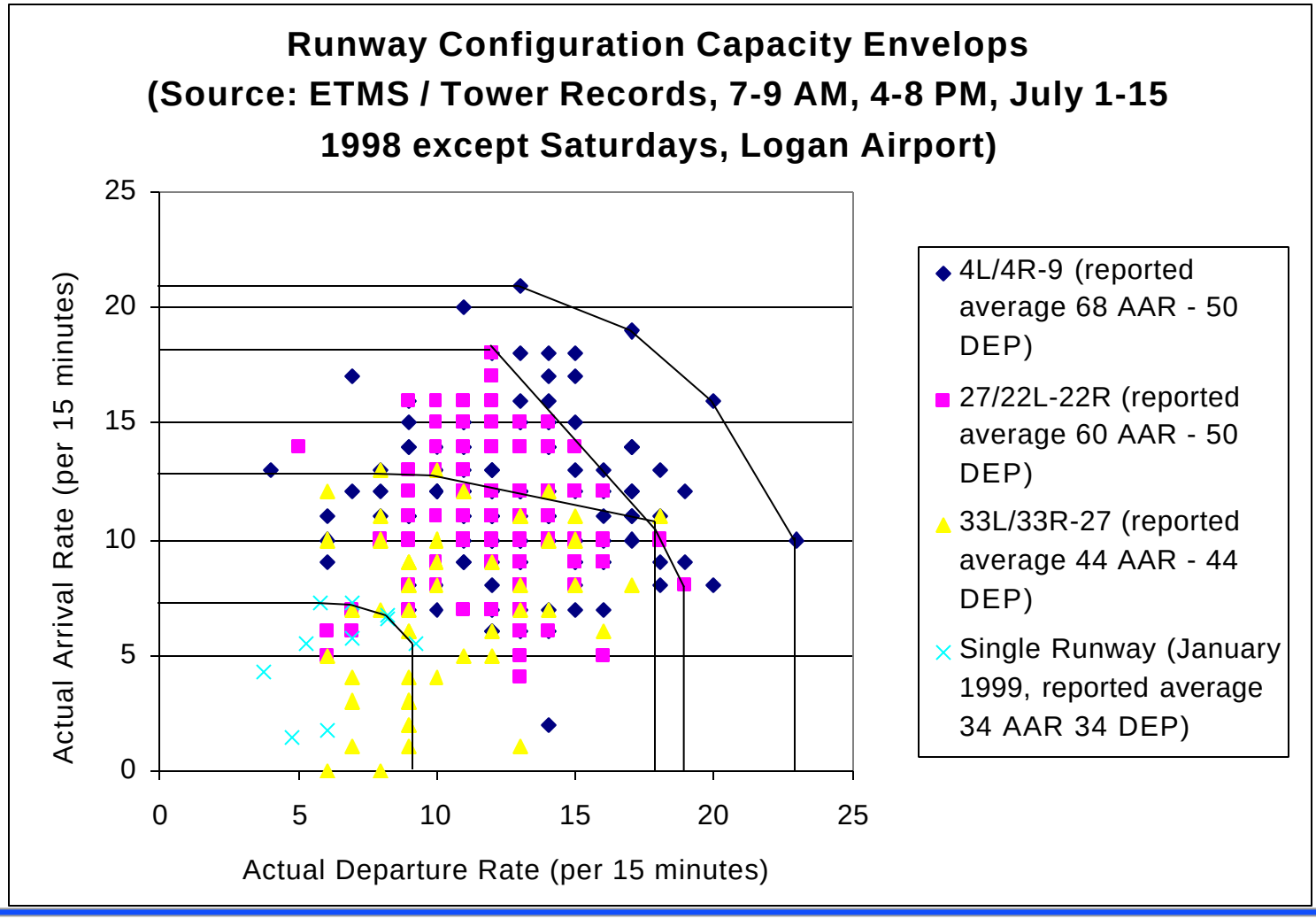
Leading Aircraft	Heavy	Large	Small
Heavy	4	5	5
B757	4	4	5
Large	3(2.5)	3(2.5)	4
Small	3(2.5)	3(2.5)	3(2.5)

  - Visual Separation requirements
    - Pilots Discretion
- **Preceding arrival must be clear of runway at touchdown**
  - Runway Occupancy time

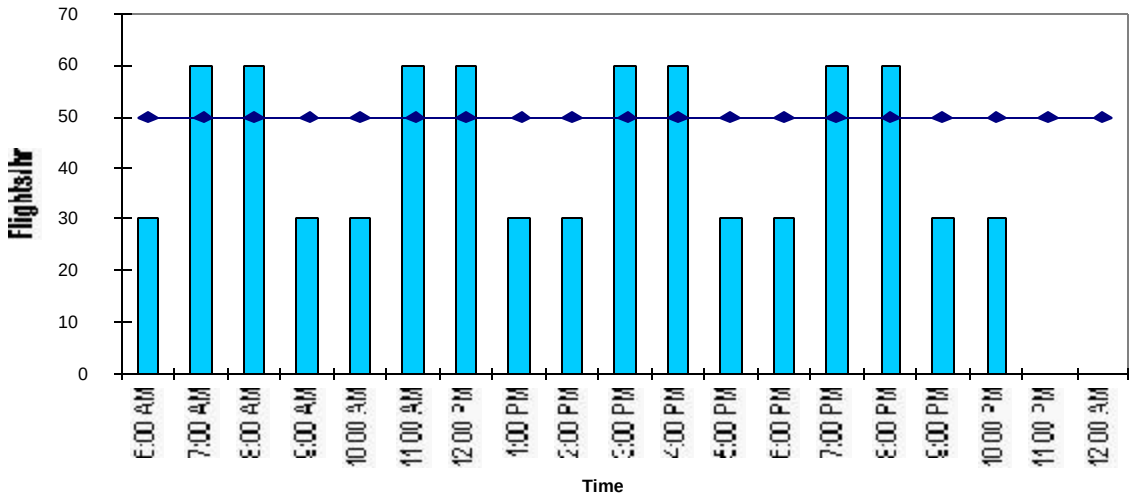
BOS Queuing Model
27/22L-22R Configuration

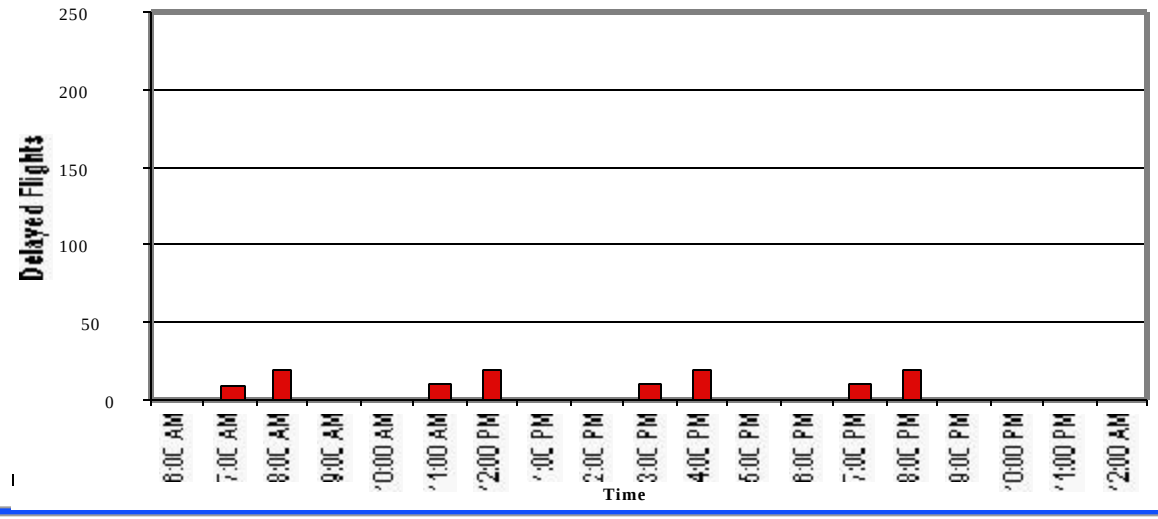


Runway Configuration Capacity Envelops

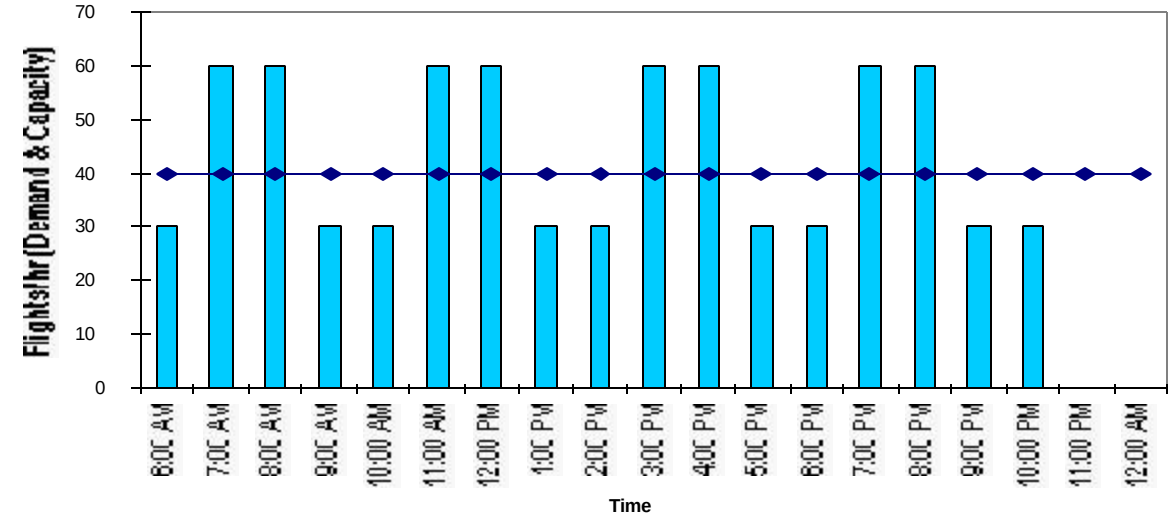


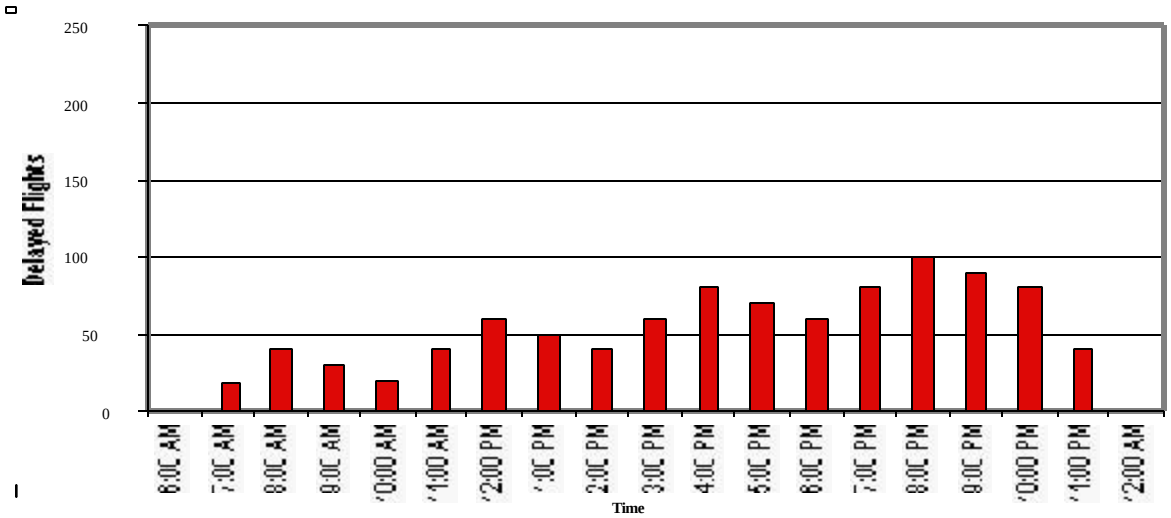
Capacity Example (50 Flights/hr)



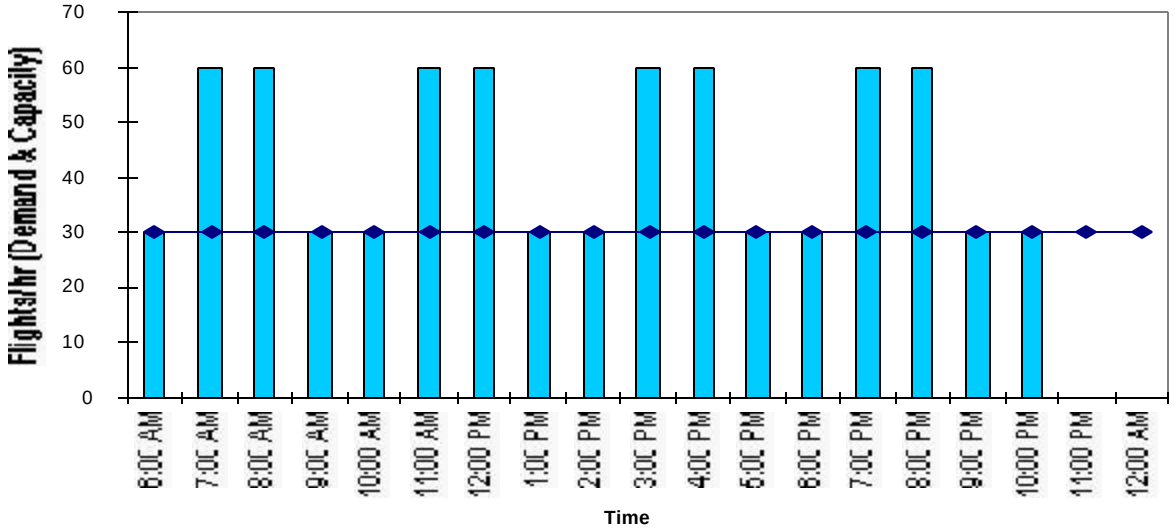


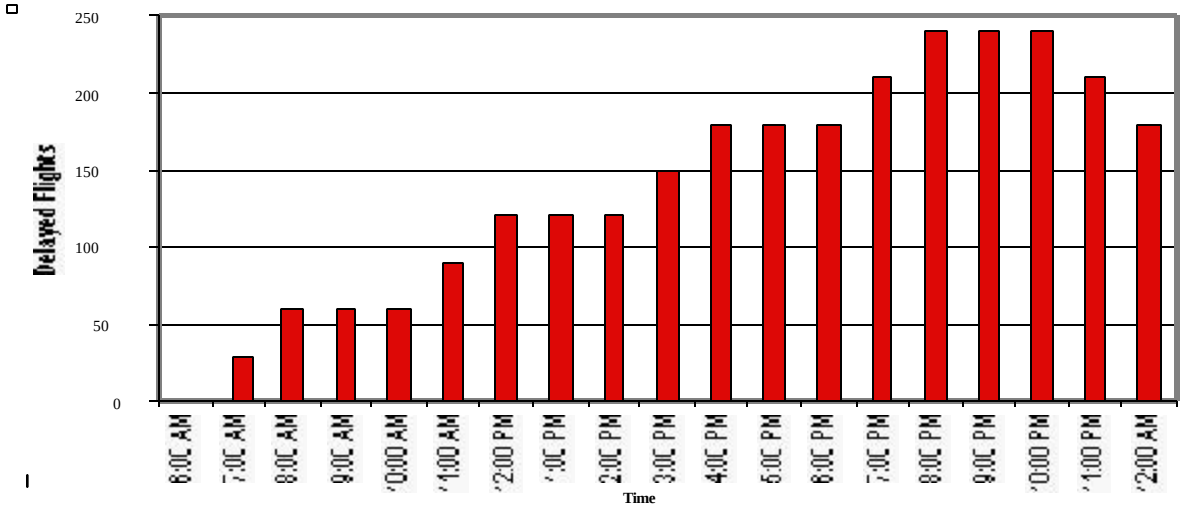
Capacity Example (40 Flights/hr)





Capacity Example (30 Flights/hr)





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  - Emissions
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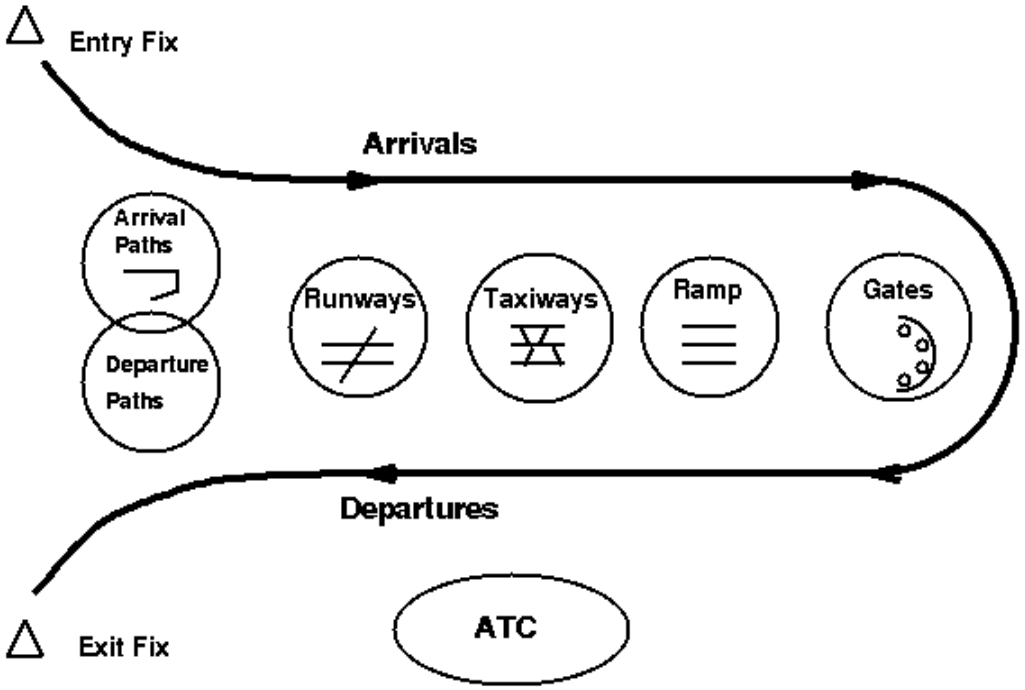
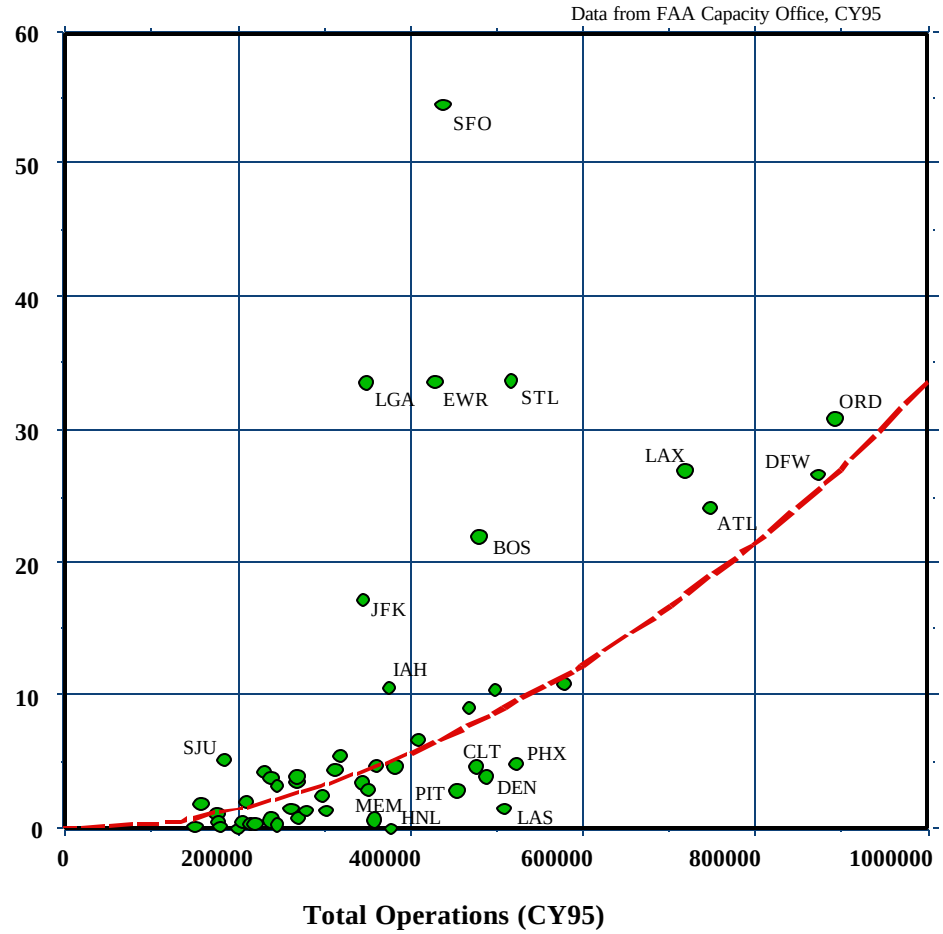


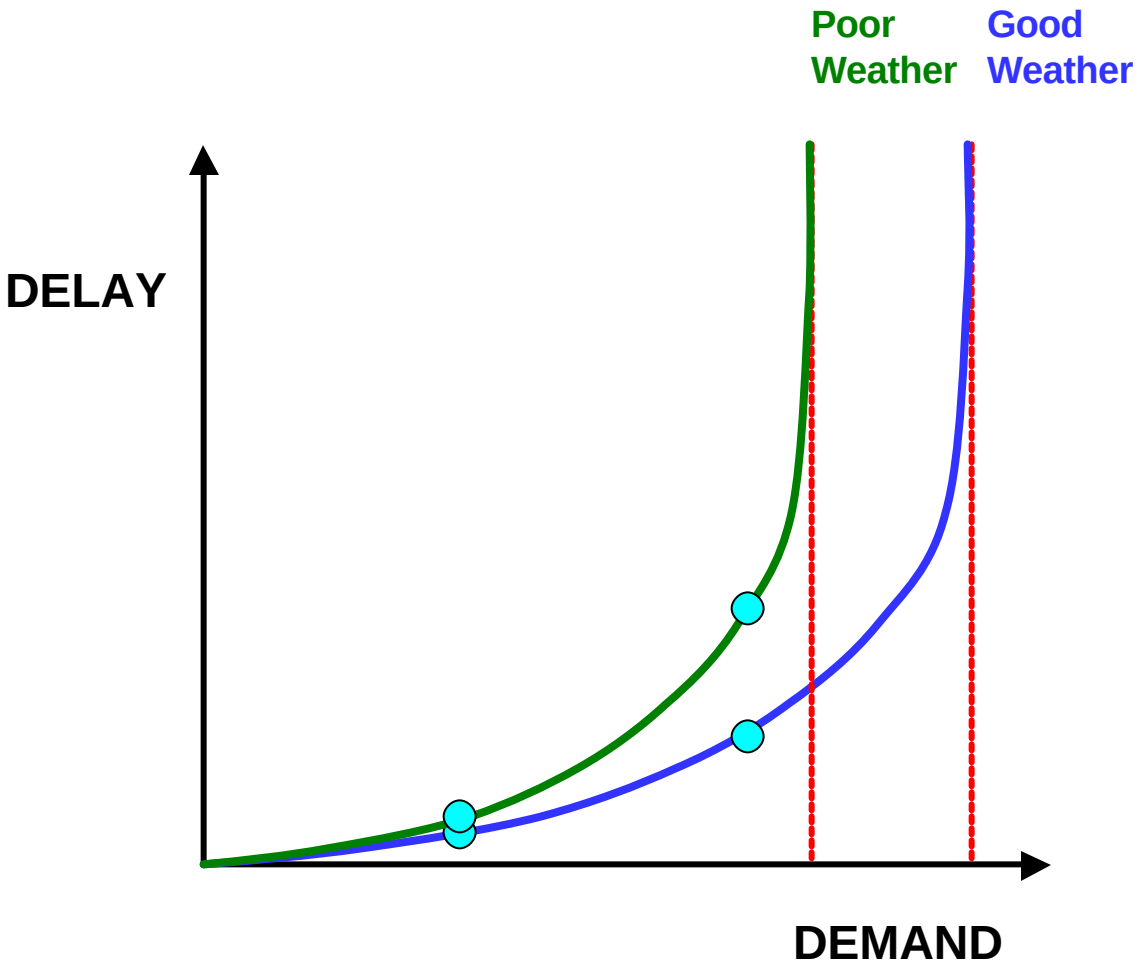
Variable Capacity Effects

1995 Delays vs Operations

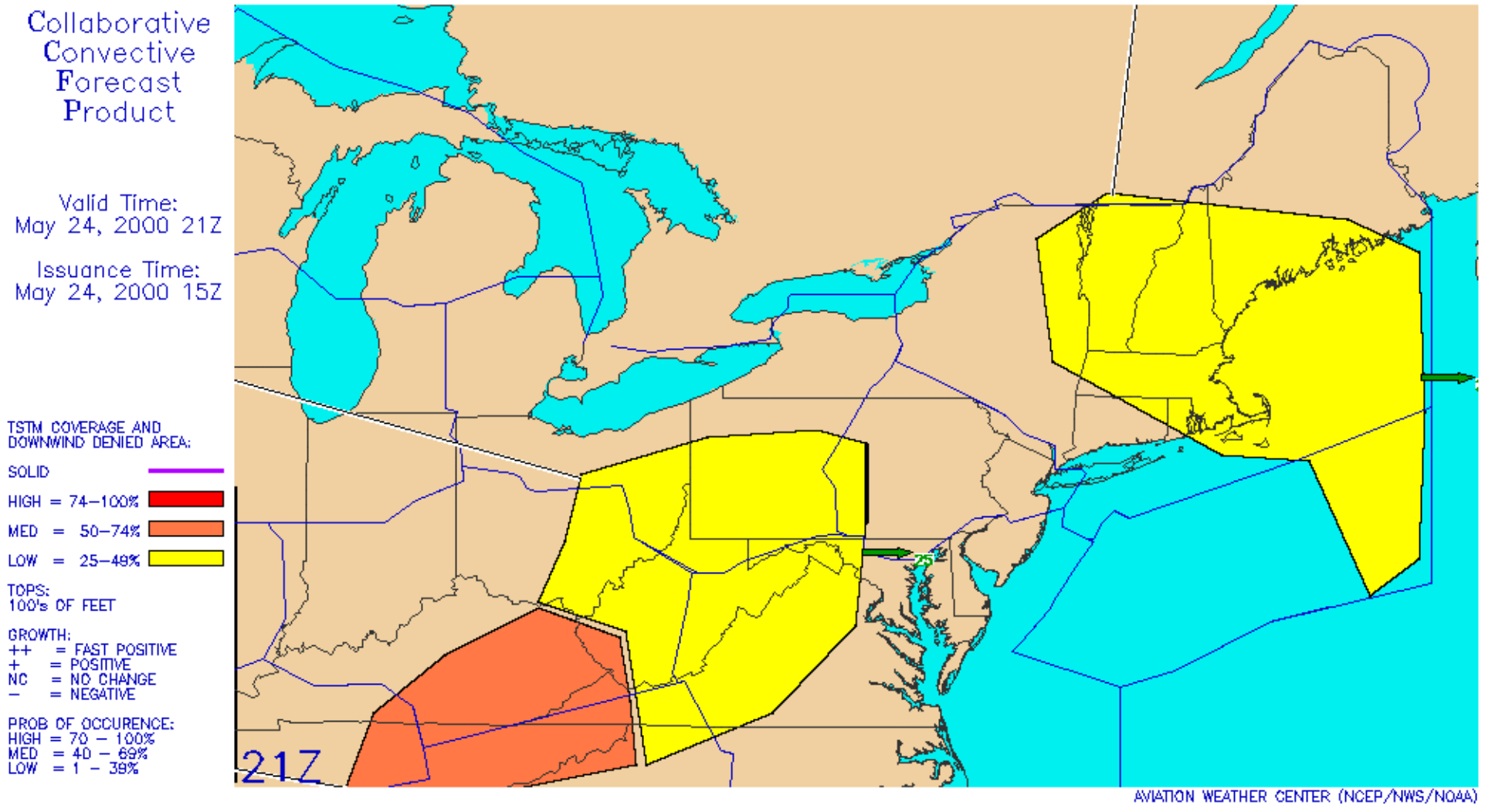


From John Andrews, MIT Lincoln Lab

Effect of Capacity Variability



Collaborative Convective Weather Forecast



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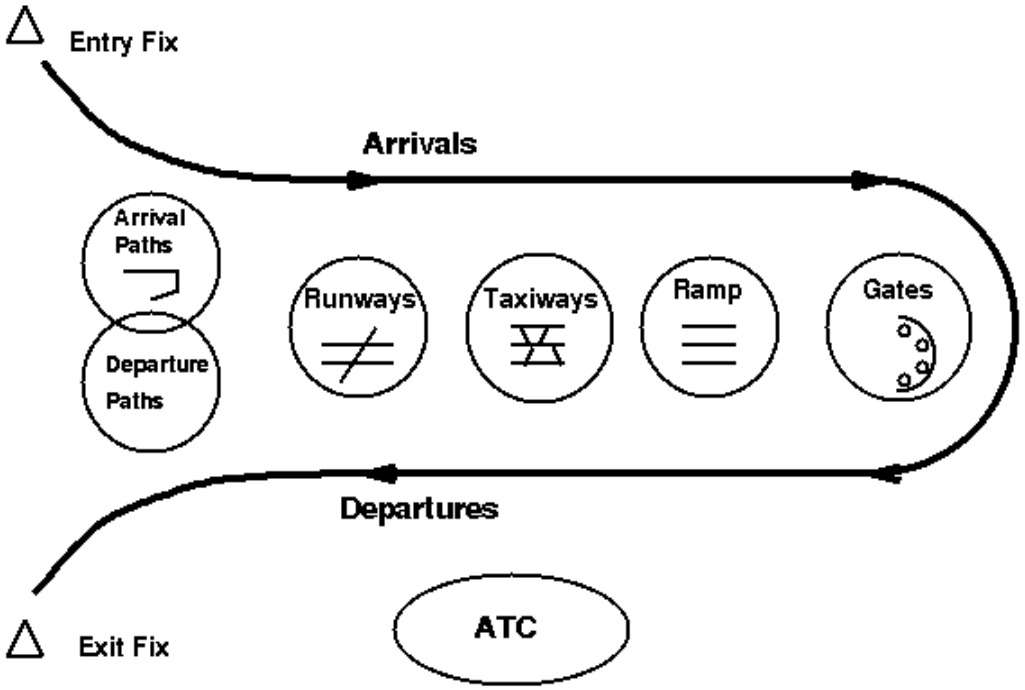

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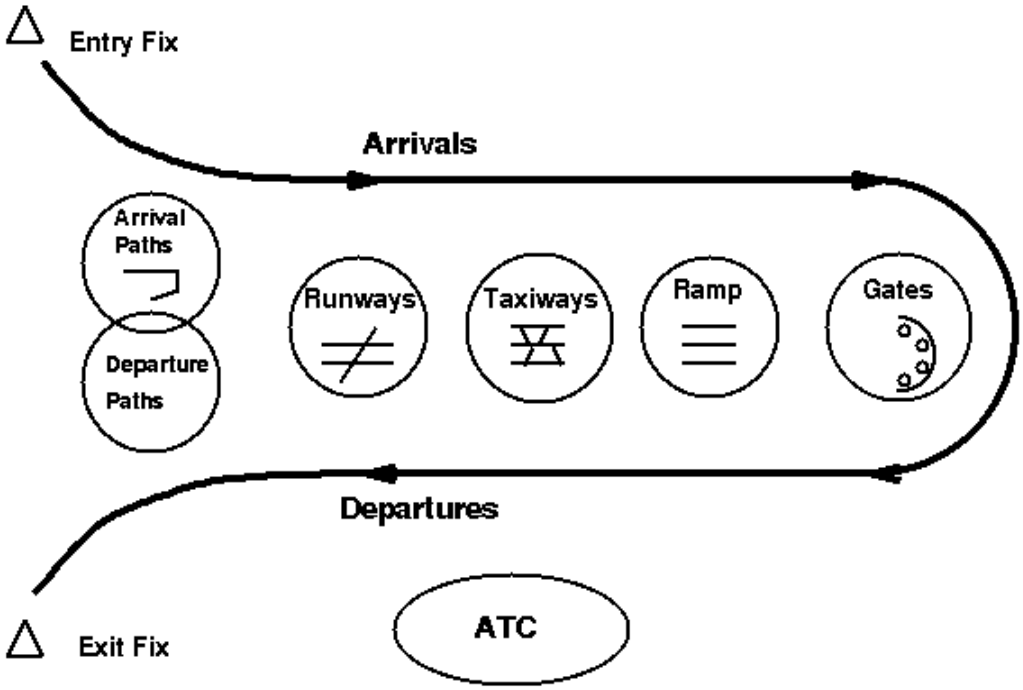

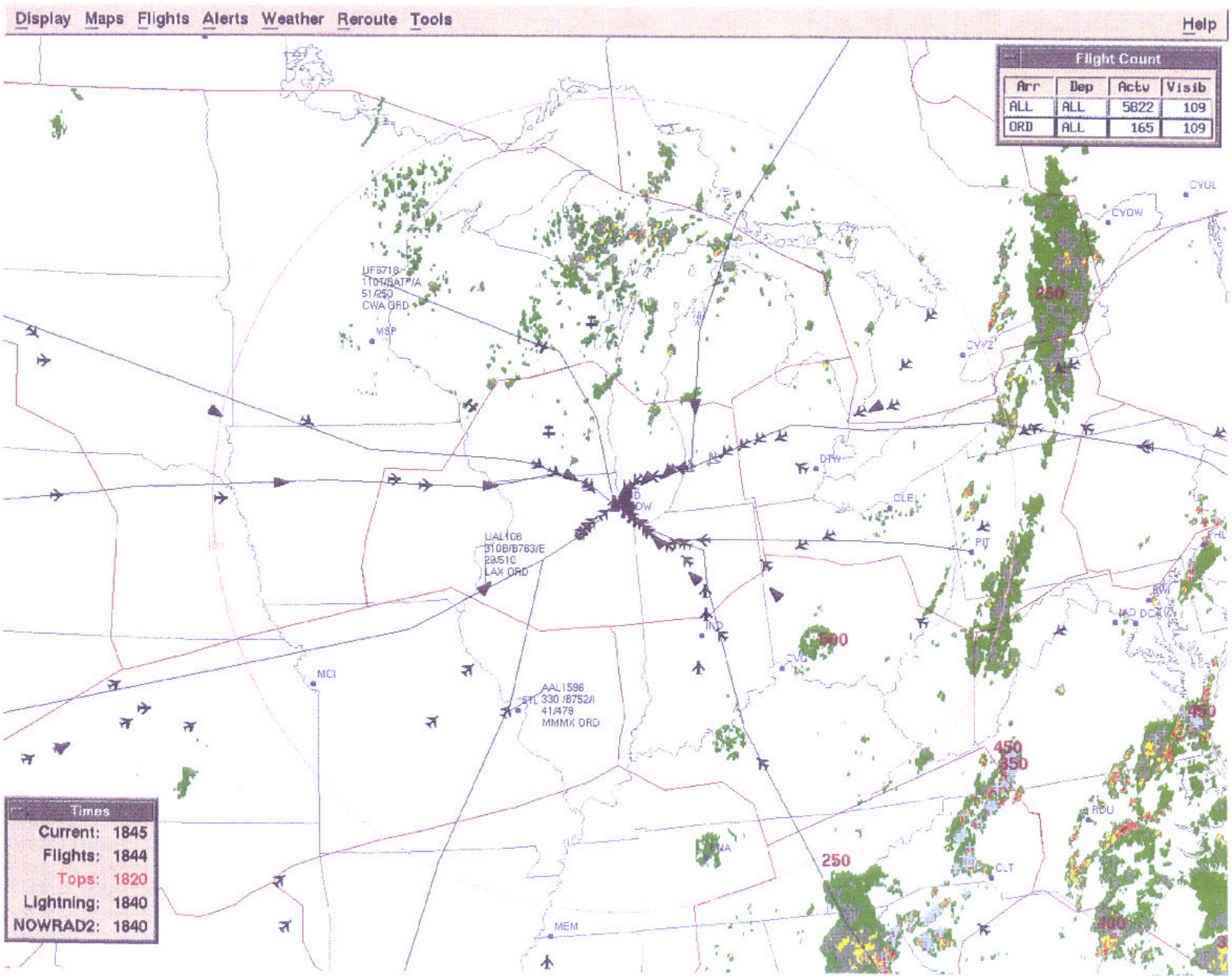
Display Maps Flights Alerts Weather Reroute Tools
Help
Flight Count
Arr Dep Actv Visib
ALL ALL 5822 109
ORD ALL 165 109
UAL108
310B/B763/E
23/510
LAX ORD
AAL1596
STL 330 /B752/I
41/479
MMMX ORD
UF6718
MSP
MCI
IND
DTW
CLE
PIT
CVG
CLT
MEM
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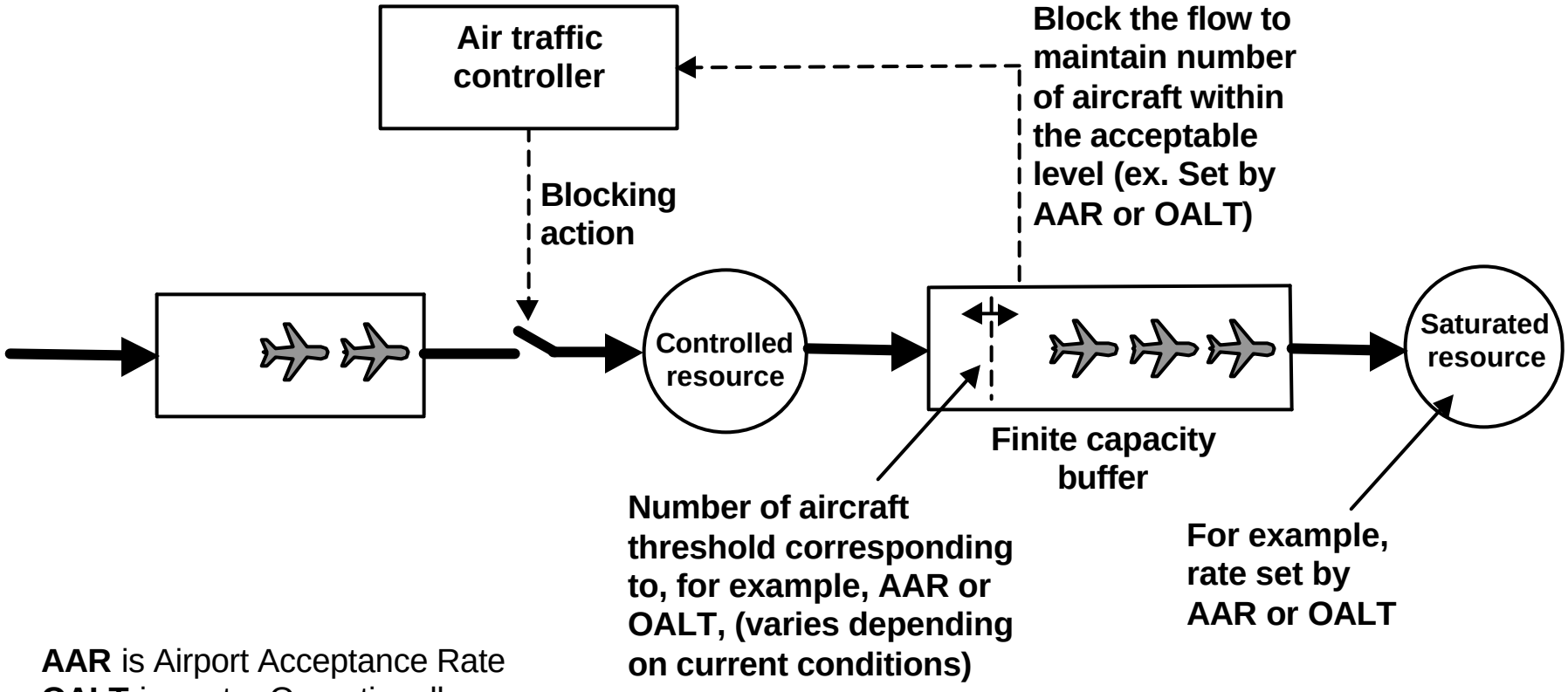
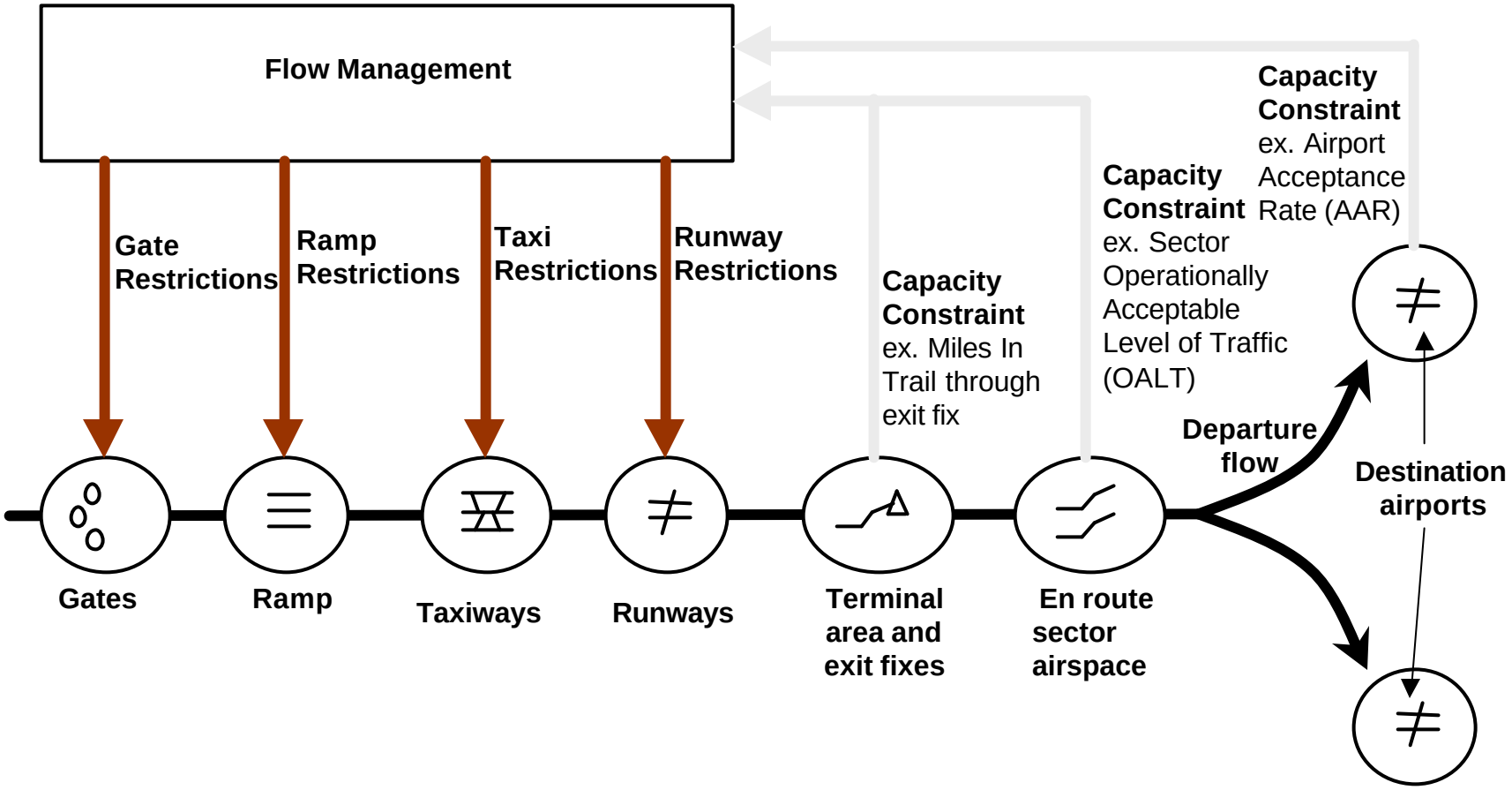
Times
Current: 1845
Flights: 1844
Tops: 1820
Lightning: 1840
NOWRAD2: 1840

Blocking



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

Downstream Flow Constraints



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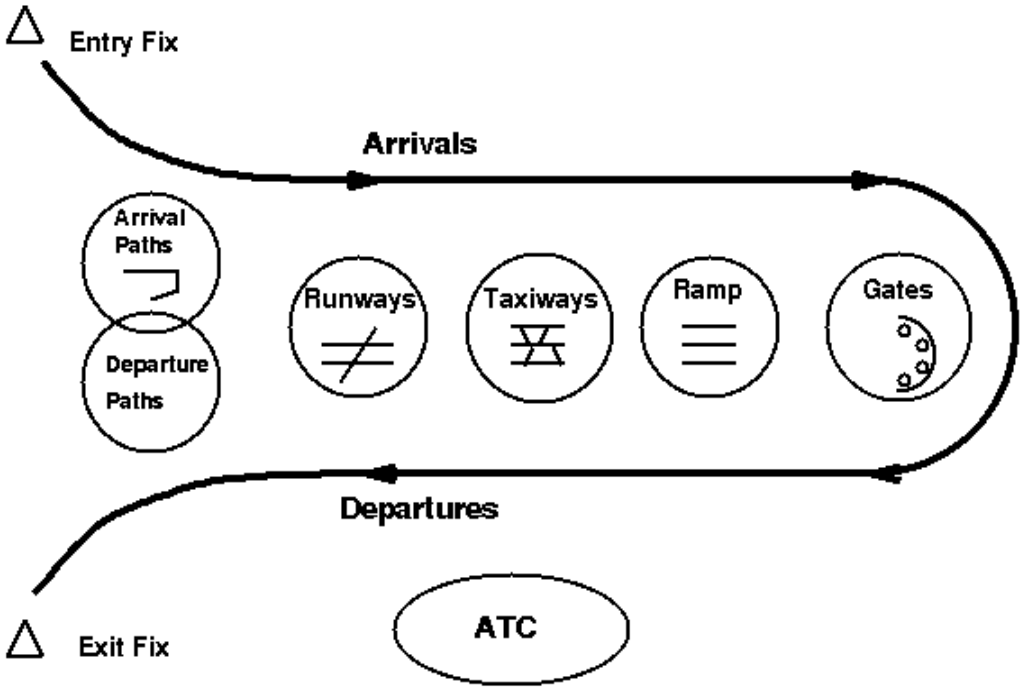
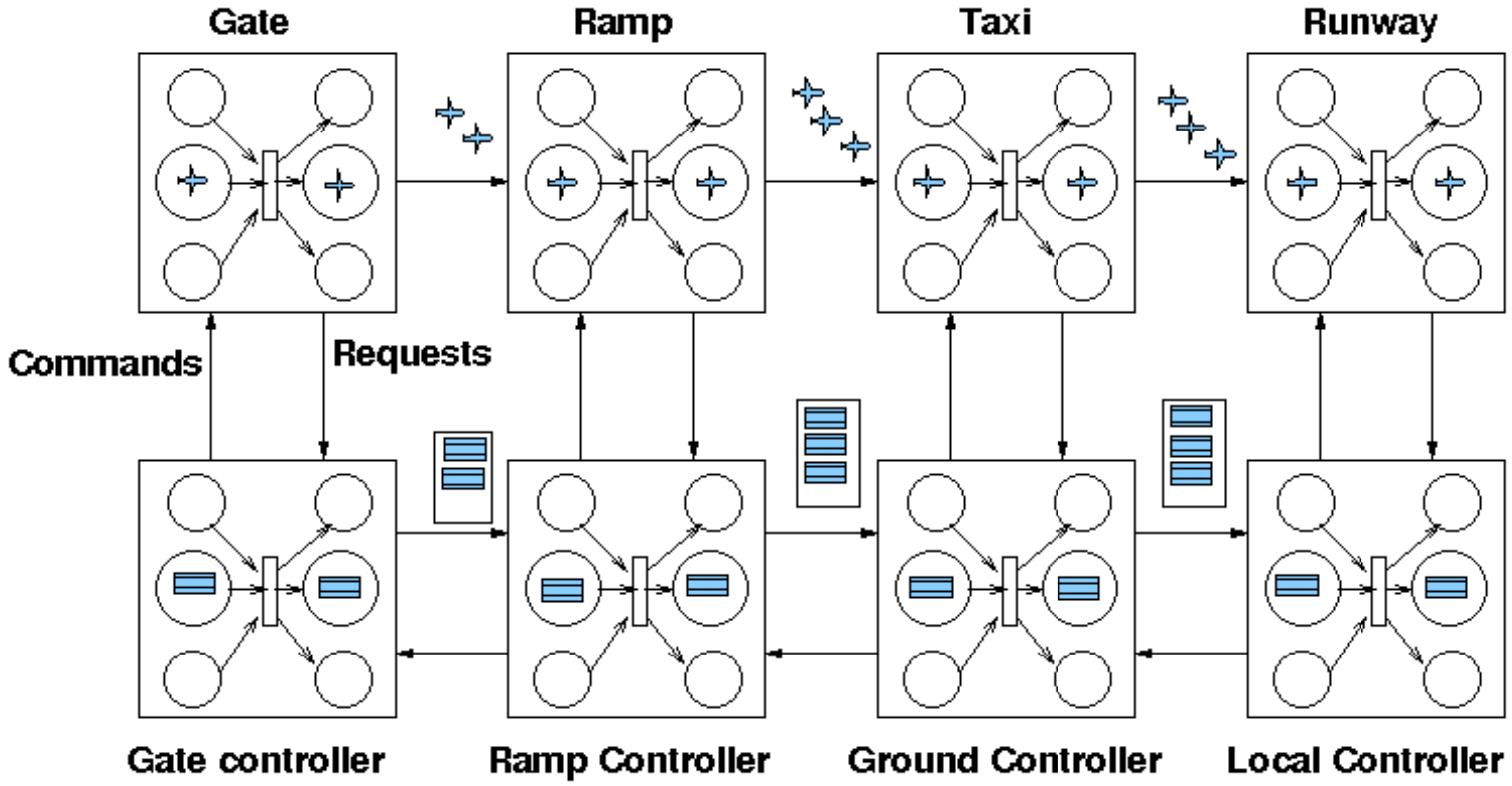
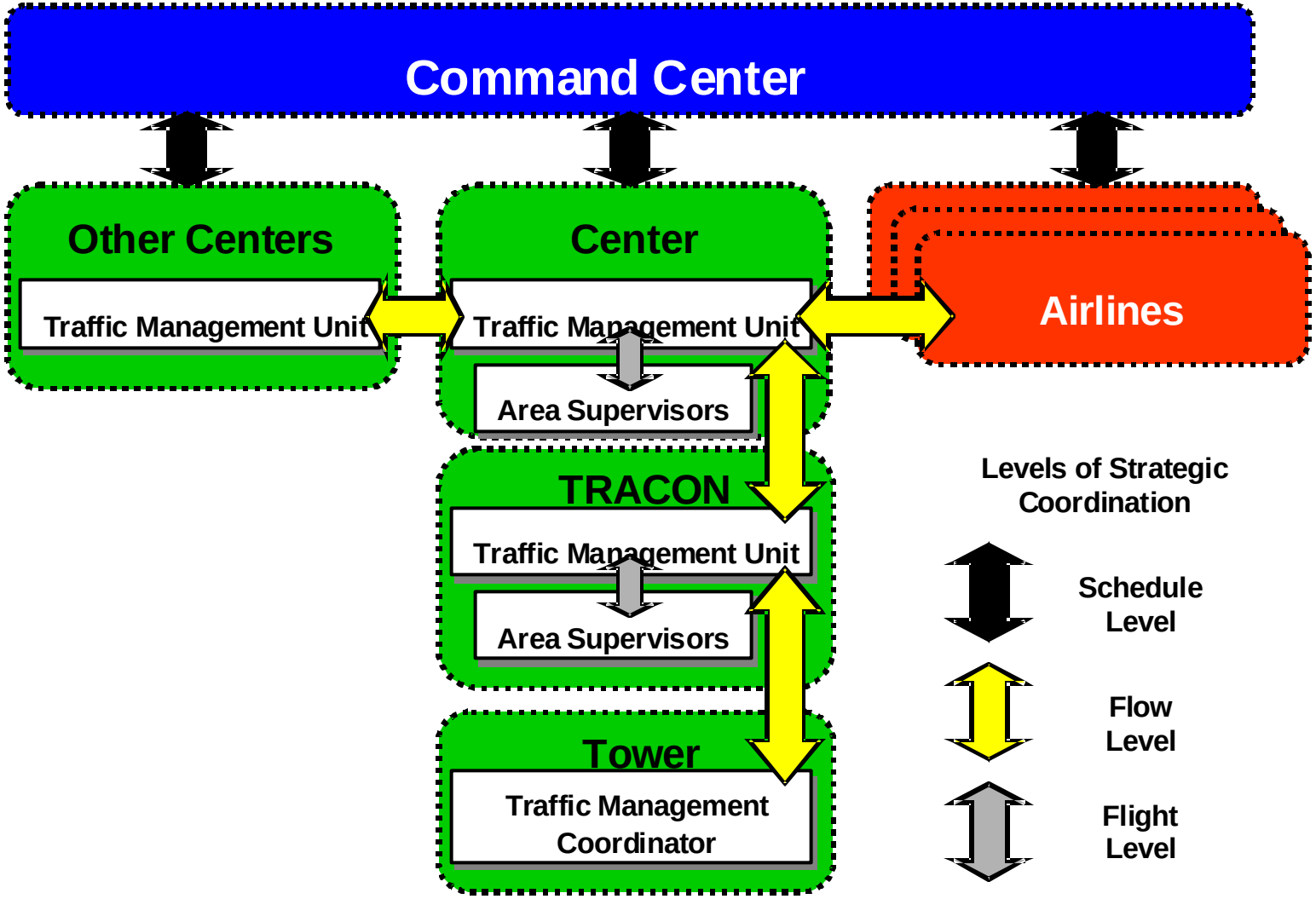


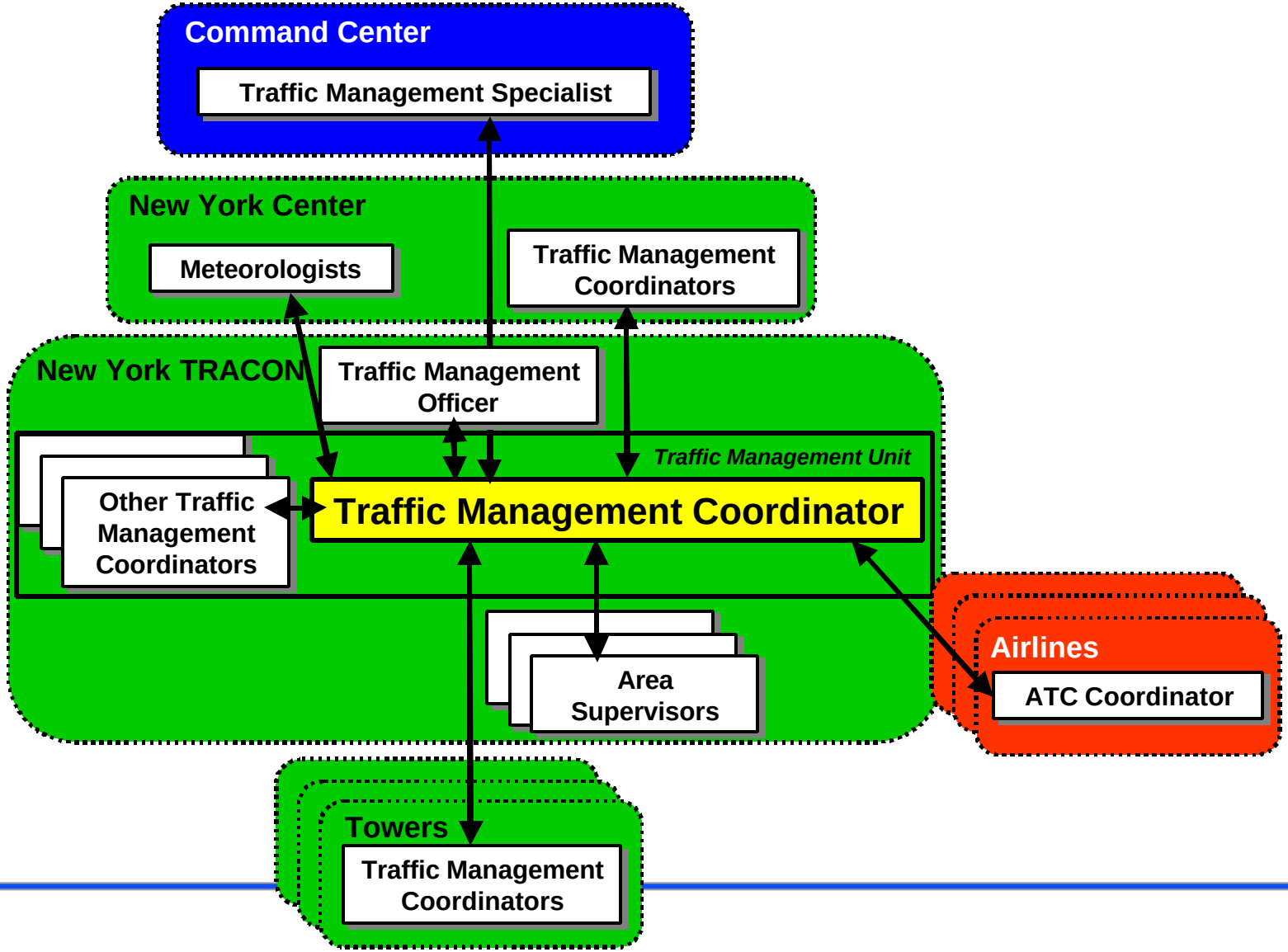
ATC Workload as a System Constraint



Inter-Facility Coordination



Communication Structure of the New York TRACON TMC



Current System Structure Lacks Flexibility

- **Current Responsibility Structure Balkanized**
  - Safety is key objective
  - Position is to protect safety and integrity of “own” unit
  - High priority in avoiding overloading own facility
  - Ambiguity between Command Center and TMC Authority
- **Lack of “System” concern**
- **Negotiation process is adversarial**
  - Protect own position.
  - Importance of personal contact
- **Extremely difficult to conduct negotiations with more than 2 agents in real-time.**
- **Results in imposition of rigid constraints in the interest of safety.**
- **Opportunity for information sharing and tools for Inter-Facility CDM at the tactical level**

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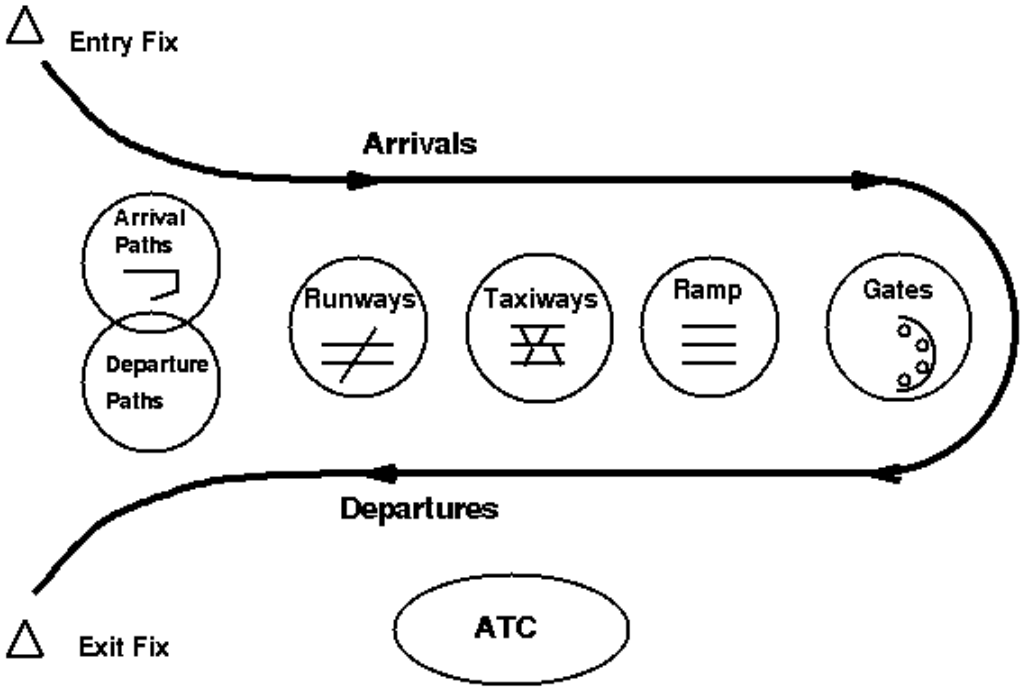

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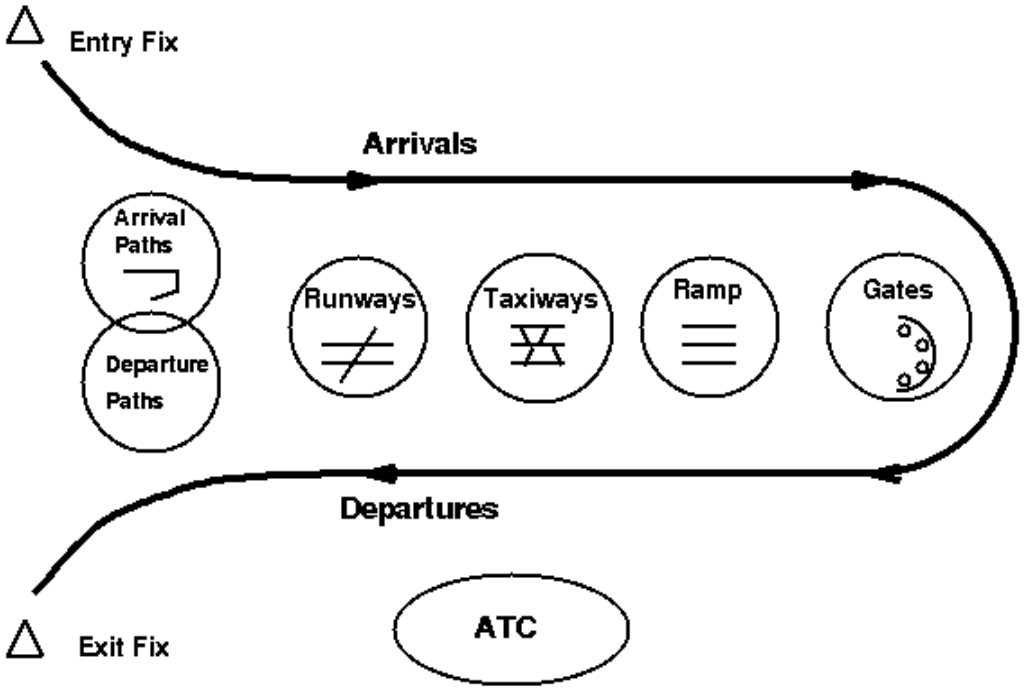
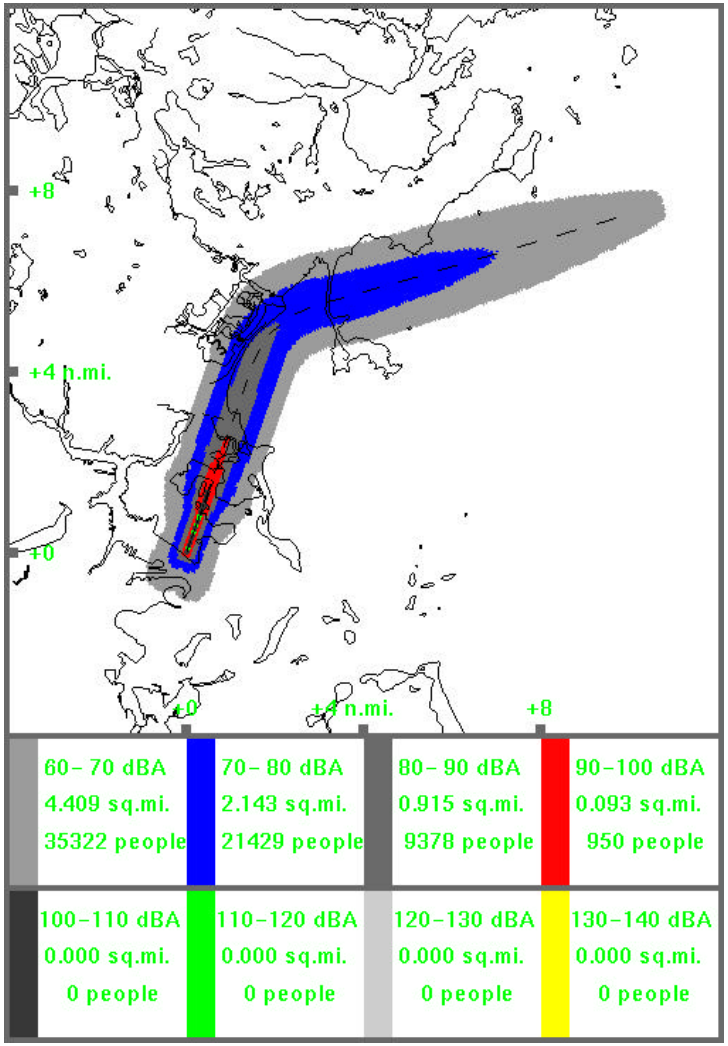


Community Noise Impact

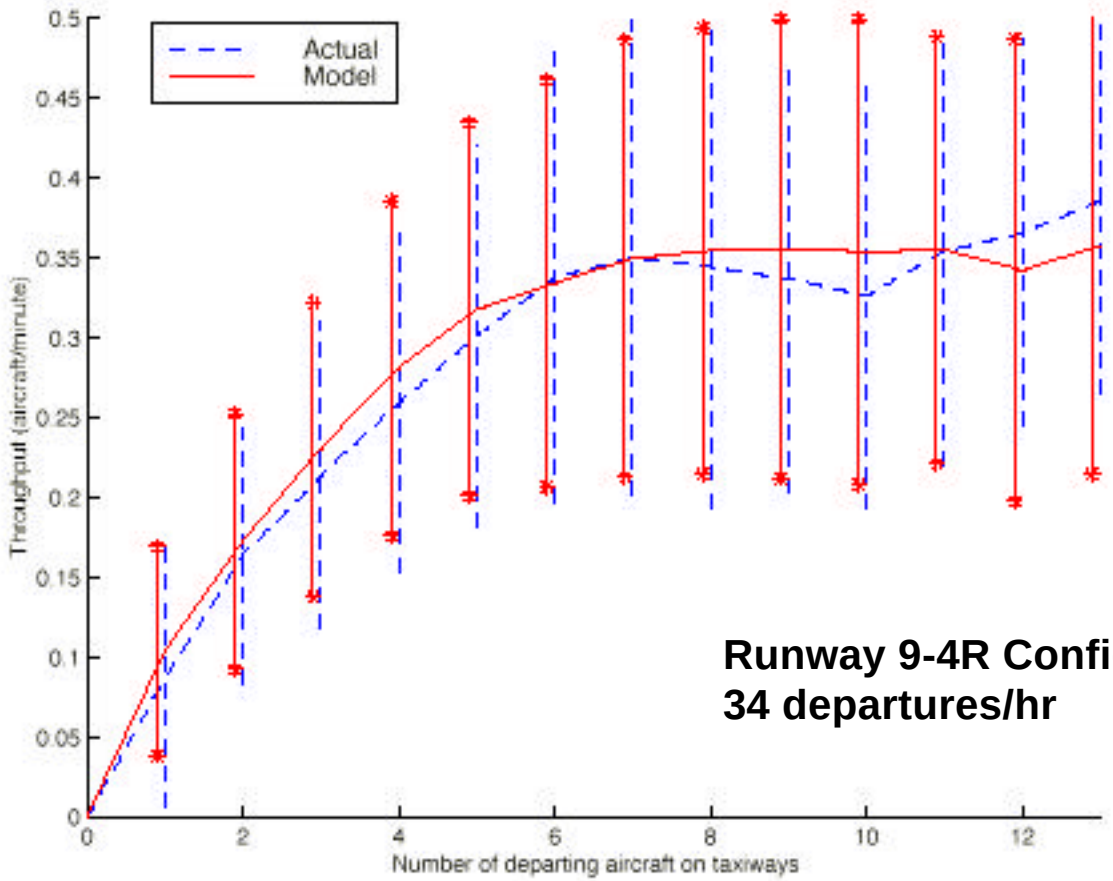
- **Example: Louisville Runway**
  - 30 > 70 ops/hr
  - Runway
    - $447 M
  - Property within 65 DNL
    - $350 M



BOS (4R Departure)

Runway Saturation Effect (N Control)

$\overline{T}_5(t+6\ min.)$ *as a function of* $N_{dep}(t)$ *in configuration 9* *(ASQP data, Boston Logan , 1996)*



Runway 9-4R Configuration
34 departures/hr

Runway Departure Queue Costs
Boston, Logan Airport

- 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.

Pollutant	Runway queue Emissions per year	Equivalent car miles per year	Equivalent car round trips per day
HC	28.0 tons	9.7 million	14,710
CO	136.4 tons	6.2 million	9,440
NO_x	22.0 tons	14.7 million	22,330

Table 6: Environmental impact of current runway queueing.

Obstacles: DOT Performance Reporting, Gates, Culture

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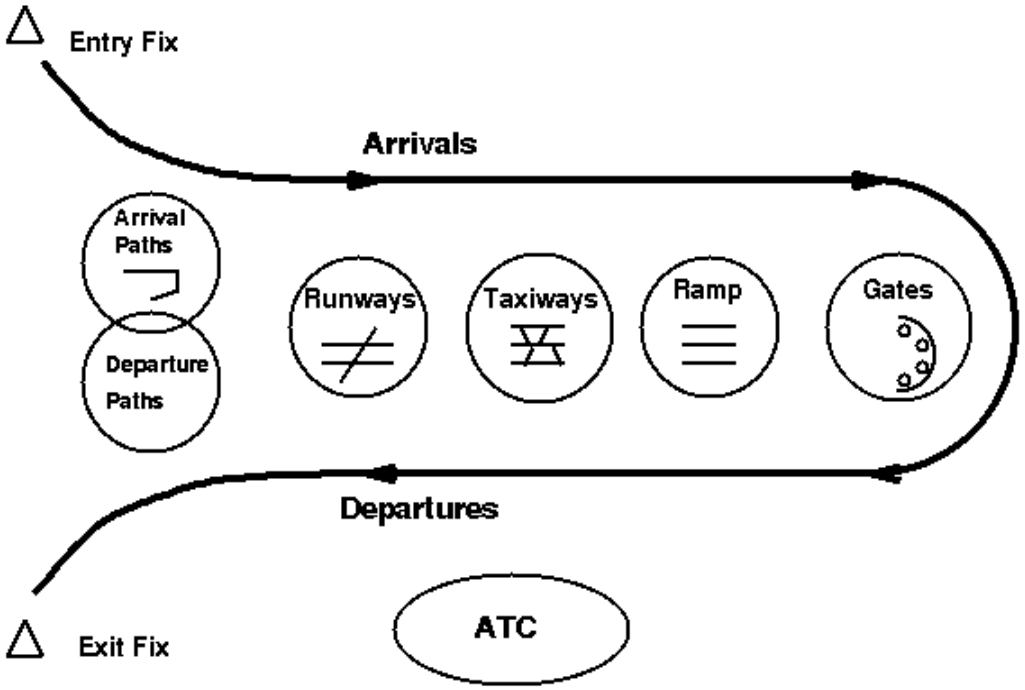
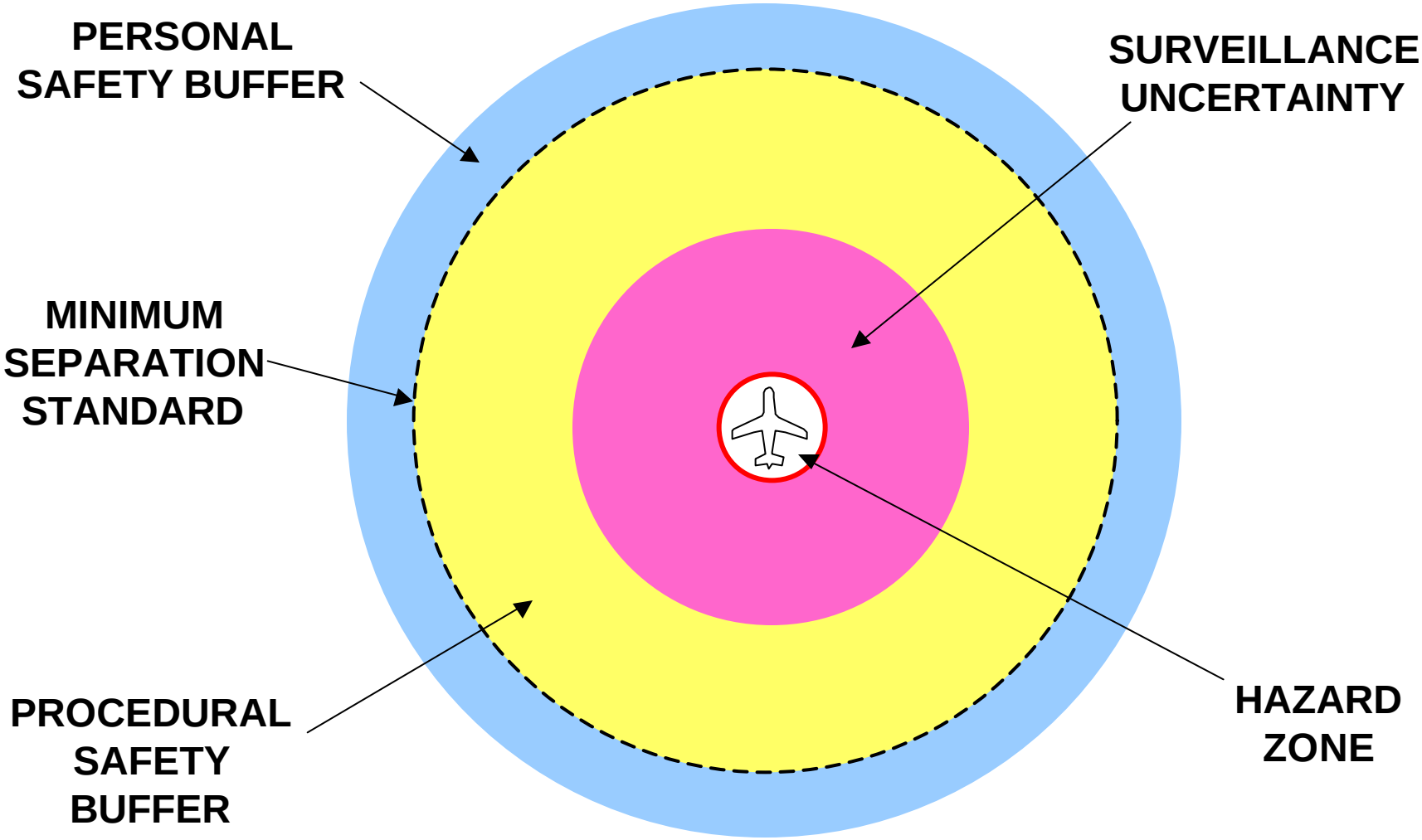
  - Road Access
- **Environmental**
  - Community Noise
  - Emissions
- **Safety**



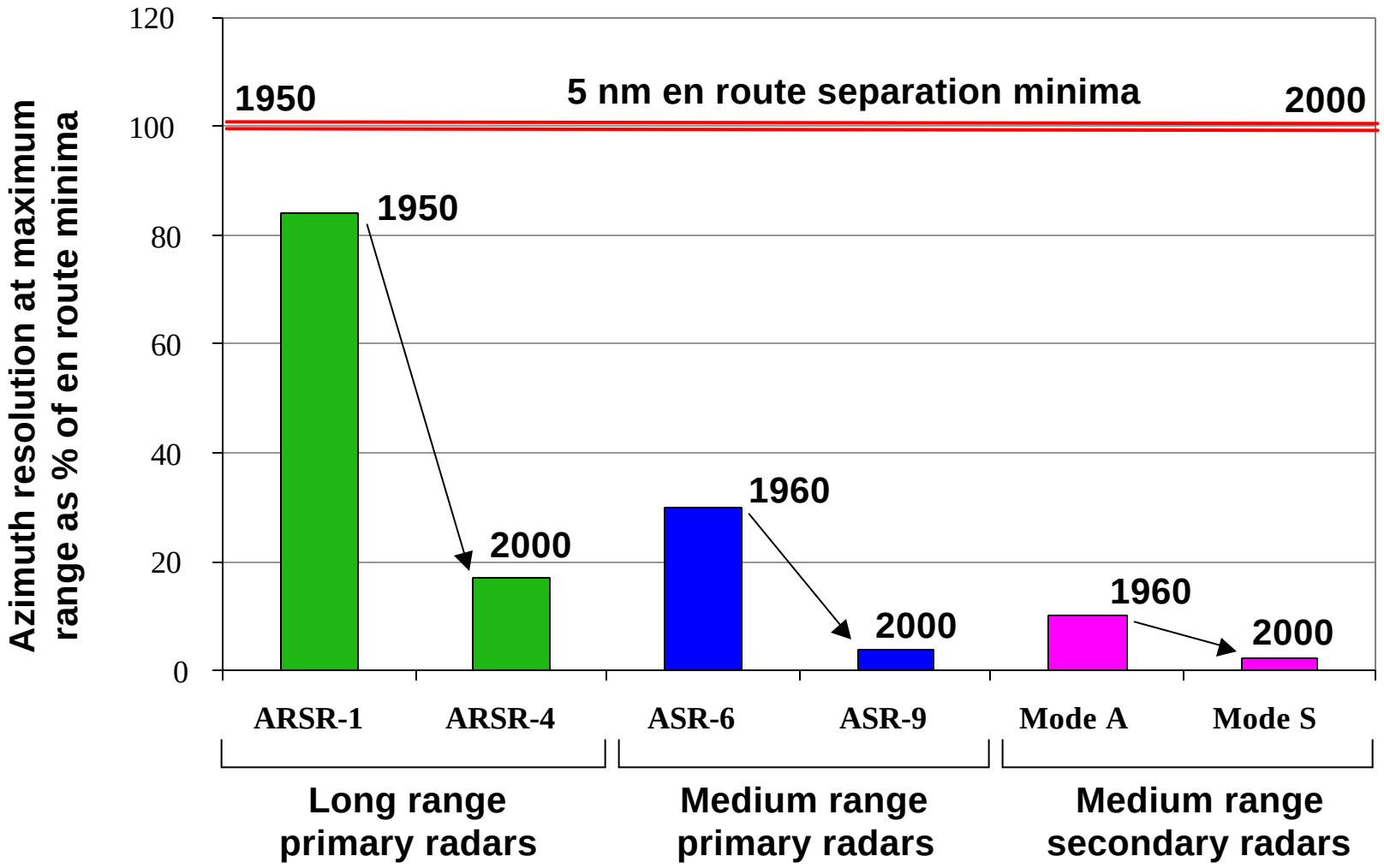
Safety vs Capacity

- **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**

SEPARATION ASSURANCE CONSIDERATIONS



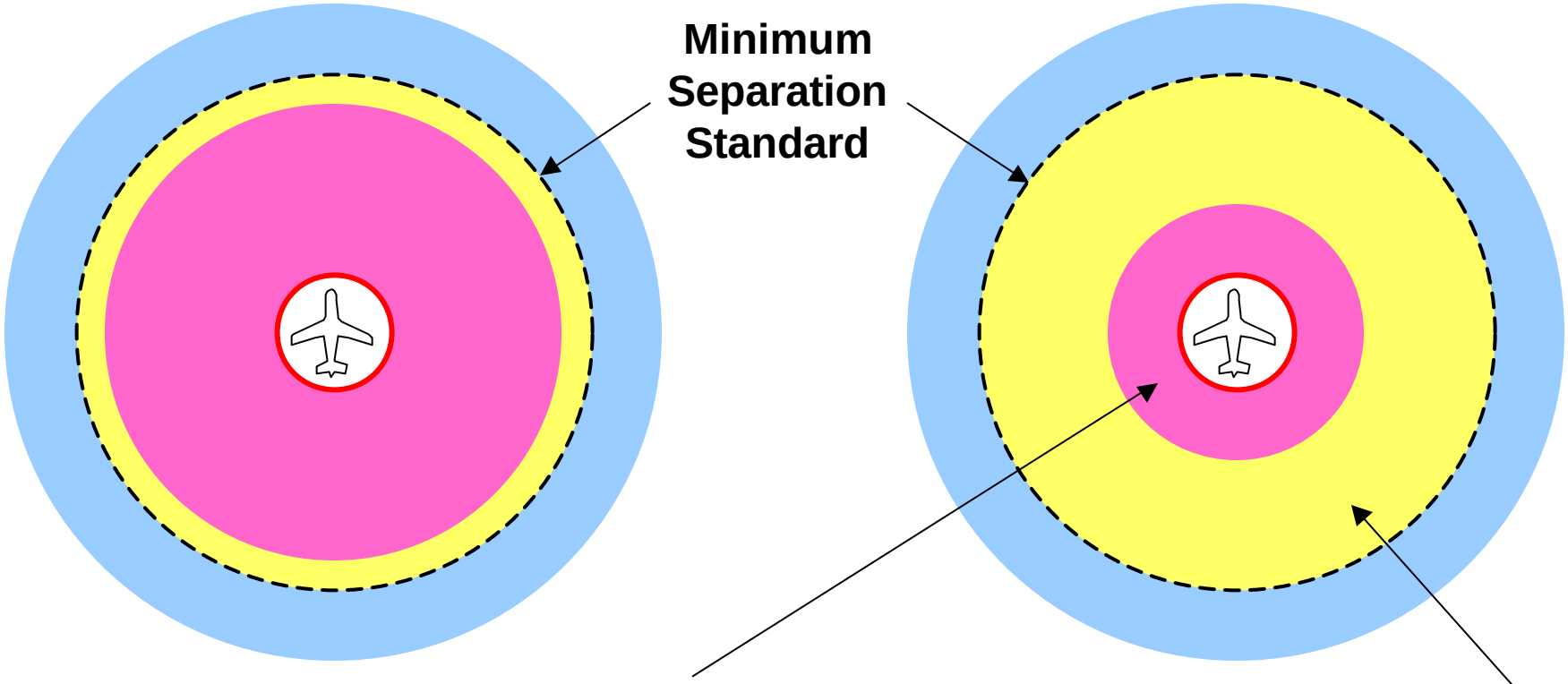
EN ROUTE MINIMA HAVE NOT CHANGED DESPITE 5 x IMRPOVEMENT IN RADAR PERFORMANCE



IMPROVED SURVEILLANCE HAS NOT LED TO REDUCED EN ROUTE MINIMA

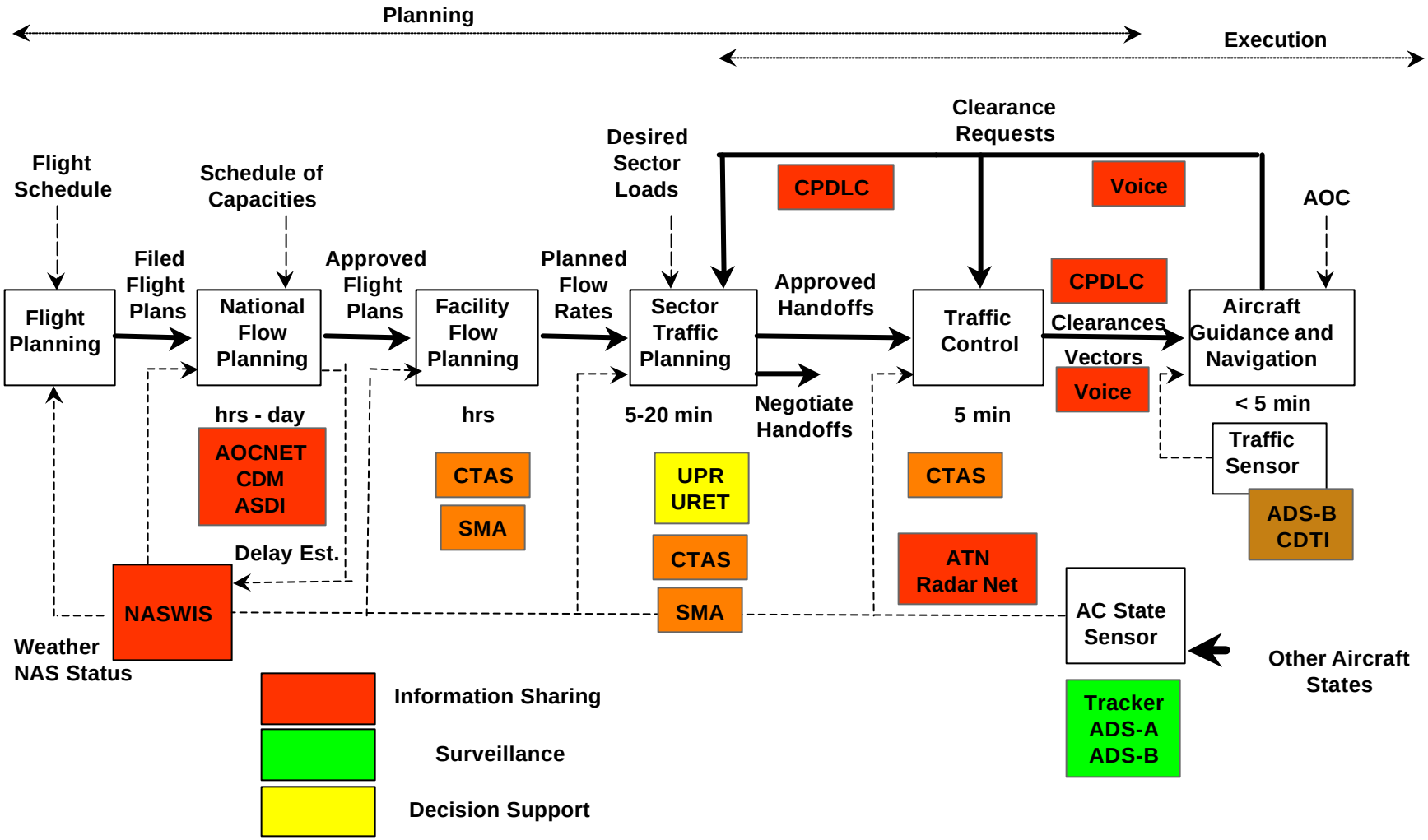
WHEN STANDARDS WERE DEVELOPED (e.g. 1950s for en route radar)

IMPROVED SURVEILLANCE ENVIRONMENT (e.g. today for en route radar)



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

Proposed CNS/ATM Information Technologies



Adapted from; A. Haraldsdottir Boeing

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%)
- **Surface Movement Advisor**
  - Limited Gate Coordination
- **Controller Pilot Datalink Communication (CPDLC)**
  - No Direct Impact

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**
- **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
  - Increased Traffic at Secondary Airports
  - High Frequency Service
- **Overall system response is not clear**
- **Protection of Airport and Spectrum Resources**
- **Need more runways in critical locations**
- **Need for new ATM paradigms**
- **Need for leadership**