Validation of En Route Capacity Model with Peak Counts from the National Airspace System

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Overview

• Airspace capacity estimates are important
  – sector design
  – air traffic management

• Current model accounts only for ‘transit’ workload
  – hand-offs at sector crossings

• New model adds key workload components
  – conflict avoidance
  – recurring tasks

• We have estimated capacities for 20 NAS* Centers
  – ~ 800 sectors

Capacities differ significantly center to center
Local Capacity << Inherent Capacity

* U.S. National Airspace System
Outline

- Review of Capacity Model
- Regression Process
- Center Capacities
- Conclusions
Workload Event Rates

Workload grows with three critical traffic-dependent event rates

**Transit** (boundary crossing) rate
\[ \lambda_t = \frac{N}{T} \]
sector aircraft count \( N \)
mean sector transit time \( T \)

**Conflict** rate
\[ \lambda_c = \frac{2N^2/Q}{M_h M_v V_{21}} \]
sector airspace volume \( Q \)
*miss distances* \( M_h \) and \( M_v \)
mean closing speed \( V_{21} \)

**Recurring** (scanning/monitoring) rate
\[ \lambda_r = \frac{N}{P} \]
recurrence period \( P \)
**Workload Intensity**

\[ G = G_t + G_c + G_r \]

- **Transit** \( G_t \): \( \tau_t \left[ \frac{N}{T} \right] \)
- **Conflict** \( G_c \): \( \tau_c \left[ \frac{2 \ N^2}{Q} \frac{M_h M_v V_{21}}{M_v} \right] \)
- **Recurring** \( G_r \): \( \tau_r \left[ \frac{N}{P} \right] \)

**Service Times** (empirical)

**Determining the unknown service times**

- **Live approach**
  - Measure controller performance

- **Regression approach**
  - Observe Peak daily counts \( N_p \) for many sectors
  - Calculate corresponding Model capacities \( N_m \)
  - Find service times that best fit \( N_m \) to \( N_p \) bound

**Workload Intensity** (fraction of controller time)
Conflict Distance

Conflict Workload Intensity

\[ G_c = \tau_c \left[ \left(2 \frac{N^2}{Q} \right) M_h M_v V_{21} \right] \]

Global closing speed \( V_{21} \) is also unknown

Fit the product \( \tau_c V_{21} \)

(separation lost while resolving a conflict)

\[ \tau_c V_{21} \sim 2 \text{ nautical miles (for NAS)} \]
Effect of Altitude Changes

Aircraft with vertical rates cause increased uncertainty
Adapt by increasing vertical miss distance $M_v$

- Determine fraction $F_{ca}$ of aircraft with ≥2000 ft altitude change
- As $F_{ca}$ grows, increase $M_v$ linearly from 1000 ft to $M_{vmax}$

$M_{vmax} \approx 1600$ ft
(For NAS)
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Peak Daily Counts
(790 NAS Sectors)

July and August 2007
Day with most operations for each center
Peak instantaneous count for each sector
Peak Daily Counts and Fitted Capacities
(790 NAS Sectors, July–August 2007)

Sector Volume (nm³)

Aircraft Count

NAS Model Capacity

Observed Peak Count
Asymmetric Objective Function
(Fits Model to Peak Count Bound)

Difference between Peak Count $N_p$ and Model Capacity $N_m$
Asymmetric Objective Function
(Fits Model to Peak Count Bound)

Difference between Peak Count $N_p$ and Model Capacity $N_m$

- Reward sectors with close fits

Sector Score

$N_p < N_m$

$N_p > N_m$
Asymmetric Objective Function
(Fits Model to Peak Count Bound)

Difference between Peak Count $N_p$ and Model Capacity $N_m$

- $N_p < N_m$: Close Fits
  - Reward sectors with close fits

- $N_p > N_m$: High Counts
  - Penalize sectors with high peak counts
Asymmetric Objective Function
(Fits Model to Peak Count Bound)

Difference between Peak Count $N_p$ and Model Capacity $N_m$

- Low Counts: $N_p < N_m$
- Close Fits
- High Counts: $N_p > N_m$

Low traffic demand
no score assigned

Reward sectors with close fits

Penalize sectors with high peak counts
Fitted Capacities versus Peak Counts
(790 NAS Sectors July – August 2007)
Outline

• Review of Capacity Model
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Peak Sector Counts, Seattle Center (ZSE)

July and August 2007
10 days with highest center operations
Peak sector counts for those days
28 ZSE sectors
280 ZSE sector-days
ZSE Sector Capacity from ZSE Regression

- Capacity, ZSE Regression
- ZSE Peak Daily Count

Sector Volume (nm$^3$)

Aircraft Count

0 10000 20000 30000 40000 50000 60000 70000 80000
0 5 10 15 20 25 30 25 20 15 10 5 0

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ZSE Sector Capacity from NAS Regression

- Capacity, NAS Regression
- Capacity, ZSE Regression
- ZSE Peak Daily Count

Aircraft Count vs. Sector Volume (nm$^3$)

0 10000 20000 30000 40000 50000 60000 70000 80000
0 10000 20000 30000 40000 50000 60000 70000 80000

Sector Volume (nm$^3$)
Normalized Capacity Density

- Local center capacities differ significantly
- Meaningful capacity comparisons must normalize for
  - center size
  - sector count

\[
K_{NC} = \frac{\Sigma_{CS}}{Q_Z / N_S}
\]

\[\Sigma_{CS} = \text{Sum of local capacities of all sectors}\]
\[Q_Z = \text{Center airspace volume (10,000 nmi}^3)\]
\[N_S = \text{Sector count}\]

\[(K_{NC} \text{ for Seattle is 0.11 aircraft per 10,000 nmi}^3)\]
Peak Counts
Washington DC Center

Calendar Year 2007
8 days with highest ZDC operations
(in March, April May, June, and November)

ZDC
46 sectors
$K_{NC} = 0.41$
Peak Counts
Washington DC and Miami Centers

Calendar Year 2007

ZDC 46 sectors
$K_{NC} = 0.41$

ZMA 40 sectors
$K_{NC} = 0.07$
Normalized Capacity Density
NAS En Route Centers (July – August 2007)

Normalized Capacity Density Chart

Aircraft / 10,000 nm³ / Sector

Center

ZDC ZID ZNY ZAU ZTL ZOB ZME ZFW ZKC ZOA ZJX ZLA ZAB NAS ZDV ZBW ZSE ZMP ZLC ZHU ZMA

* ZDC not restricted to July-August
Equation for NAS Sector Capacity

Sector Capacity

\[ N_m = \frac{-b + \sqrt{b^2 - 4ac}}{2a} \]

**where**

- \( a = 5.4(1 + 0.6 F_{ca})/Q, \ b = (a + 0.013 + 13/T), \ c = -0.7 \)
- \( F_{ca} \) = fraction of daily sector flights with \( \geq 2000 \) ft altitude change
- \( Q \) (\( \text{nm}^3 \)) = sector volume based on min and max daily altitudes
- \( T \) (s) = mean transit time for aircraft in sector at time of peak
Conclusions

• NAS regression provides inherent sector capacity
• Individual center regressions provide local sector capacity
  – can be significantly less than inherent capacity
• Peak count data reflect wide range of
  – Complexity
  – Demand
  – Airspace characteristics
• Single set of capacity parameters cannot capture current operations
  – Individual center regressions necessary

• July - August 2007 peaks do not give peak demand for all Centers
  – Southern operations peak in winter
• We plan to refine capacity calculations
  – Choose actual peak demand periods for all centers
  – Increase data sets in all regressions
End