Macroscopic Workload Model for Estimating En Route Sector Capacity

July 4, 2007

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Introduction

- Airspace capacity estimates are key flow management tools
  - Hot topic: complexity and dynamic capacity reductions
- How about *static, un-reduced* capacity?
  - The starting point for all dynamic density estimates
  - Should be easily determined
- But we still use subjective estimates to establish max capacity
  - Controllers “declare” parameters based on operational experience
- Unfortunately, controllers don’t really know best!
  - Low traffic demand guarantees that many large en route sectors never operate at maximum capacity
  - High local traffic densities limit many small sectors to operate well below their optimistic subjective capacity thresholds
- Fortunately, an existing simple workload model can predict the maximum capacity of any en route sector
  - Its predictions match peak US sector counts exactly
Model Overview

- Uses Schmidt’s* simple sector workload equation
- Gives workload as a function of traffic density
  - We choose parameters to minimize complexity
    - No vertical rates
    - Longitudinal flow
  - We set workload to maximum safe level
  - We invert equation to determine corresponding max traffic density
- Sector capacity depends on flow direction and sector geometry
  - Analytical model simplifies fitting to observed peak sector traffic
  - Bounds maximum sector traffic counts

Macroscopic Workload Model

\[ G = G_b + G_c + G_r + G_t \]

- **Background** \( G_b \)
- **Conflict** \( G_c \)
- **Recurring** \( G_r \)
- **Transition** \( G_t \)

\[ G_c = \tau_c [B \kappa (\kappa Q + 1)] \]
\[ G_r = \tau_r [\kappa Q/P] \]
\[ G_t = \tau_t [\kappa Q/T] \]

**Model Parameters**
- \( G_b = 0.1 \)
- \( \tau_c = 50 \text{ s} \)
- \( \tau_r = 2 \text{ s} \)
- \( \tau_t = 15 \text{ s} \)
- \( P = 300 \text{ s} \)
- \( T = 1200 \text{ s} \)
- \( M_h = 7 \text{ nm} \)
- \( M_v = 1000 \text{ ft} \)
- \( E[V_{21}] = 440 \text{ kt} \)
- \( Q = 10,000 \text{ nm}^3 \)

**Traffic limit for sector**

Determining Service Time Parameters

- **Traditional approach**
  - Observe controller performance times via *real time simulation*
    Schmidt* ($\tau_c$ and $\tau_t$), Majumdar** ($\tau_t$)

- **Macroscopic approach**
  - Invert workload equation to calculate capacity bound $N_{\text{max}}$
  - Calculate $N_{\text{max}}$ for a large number of sectors
  - Fit service times to match $N_{\text{max}}$ to observed peak sector traffic

Sector Capacities from Model

Model Capacity (455 CWIS* Sectors)

Capacity varies as $\sim (\text{sector volume})^{1/2}$

At a given volume, elongated sectors have higher capacity

**Model Parameters**

- $G_b = 0.1$
- $\tau_c = 50$ s
- $\tau_r = 2$ s
- $\tau_t = 15$ s
- $P = 300$ s
- $T = L/550$ kt
- $M_h = 7$ nm
- $M_v = 1000$ ft
- $E[V_{21}] = 440$ kt

**ZDC32**
- $Q = 10,684$ nm³
- $H = 9,900$ ft
- $L \sim 170$ nm
- $Nm = 16.3$ aircraft

**ZTL45**
- $Q = 10,297$ nm³
- $H = 13,800$ ft
- $L \sim 80$ nm
- $Nm = 12.9$ aircraft

* Corridor Integrated Weather System Domain in Northeast US
Monitor Alert Parameter ~ independent of sector volume
Model Capacities and Observed Counts
(Original Parameter Estimates)

All CIWS Sectors

- Model capacity (peak count)
- Peak clear-weather traffic count

Sector Volume (nm³)
Sector Traffic (aircraft count)

Original parameter estimates

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<td>tr</td>
<td>10</td>
</tr>
<tr>
<td>Mh</td>
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- tt = transit work time/aircraft (s)
- tc = conflict work time/aircraft (s)
- tr = recurring work time/aircraft (s)
- Mh = 5 (miles)
Fitted Model Capacities and Observed Counts

Maximum observed count at each volume fits model bound. Most sectors operate below capacity.

Fitted Model parameters:
- \( t_t = 15 \) (transit work time/aircraft (s))
- \( t_c = 50 \) (conflict work time/aircraft (s))
- \( t_r = 0.2 \) (recurring work time/aircraft (s))
- \( M_h = 3.7 \) (miles)
Observed Counts vs Model Capacities

Few sectors operate above the model bound.
Traffic Densities

Small sectors handle denser traffic (but with more controllers per aircraft)
Model Workload Components

At capacity, conflict workload dominates in smaller sectors
Observations from Model

• Most en route sectors operate below model capacity
  – lack of demand
    little-used routes
    system flow constraints
  – local deviations from model parameters
    higher airspeeds (closing, transit)
    non-longitudinal flow
    increased separation standards (horizontal, vertical)

• Large sectors improve workplace efficiency
  (aircraft/controller)

• Small sectors handle higher traffic densities
Conclusions

• Macroscopic workload model fits observed peak traffic data
  – operationally reasonable service times
  – all sector shapes and volumes

• Explains observed relationships
  – utility of small sectors in dense airspace
  – non-linear sector capacity growth with volume

• Applications
  – replacement for “declared” capacity
  – real-time sector capacity estimation
  – tool for airspace design
  – guidance for ATM research
Next Steps

• Include traffic information
  – Vertical motion
    Will increase conflict frequency
  – Mean transit time
    Will increase transit frequency (usually)

• Examine more sectors
  – U.S.
  – Europe
END