Overview

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  – Tool & route structure
  – Experimental design
• Results
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  – Safety
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  – Controller assessment
    • Safety, workload, reliability
• Conclusion
BACKGROUND
Motivation: Alleviate Constrained Terminal Airspace

Example: Five hours of New York area traffic. (Blue circles are airports.)
Specific Problem & Goal

• Holding departures level under arrivals
  – A source of inefficiency in NY and other terminal areas
  – Modeling studies show benefits of departures sharing airspace with arrivals, climbing through the arrival stream when there are gaps

• Can this work operationally?
• If so, how?
Predicted Issues

- Additional coordination between arrival and departure TRACON controllers—extra workload
- Difficult for controllers to assess and possibly control gaps in distant flows
- Variability in departure times and aircraft climb rate—hard to take advantage of predicted gap
- Adequate time needed for flight crews to adapt to any changes
Previous Work

• Expedite Departure Path (EDP)—earlier NASA program
  – Gave TRACON controllers vector advisories (next to aircraft data block) so could climb through arrival flows

• Other EDP goals
  – Aircraft sequencing
  – Departure fix merging
  – Departure gate balancing

• EDP algorithm calculated
  1. All possible routes to departure fix
  2. Sequence of departures based on departure fix merge
  3. Any conflicts or undue delay—if so repeat steps 1 & 2
  4. Any conflicts in zone where departures crossed arrival flows
EDP Results Mixed

• Significant inaccuracies in predicting aircraft climb rate

• However, later study showed potential benefits of departure climb
  – Simulation of Potomac TRACON traffic
    • Most EDP benefits would have come from unrestricted climb portion
Other Previous Work: Sharing of Airspace Resources (SOAR)

- Airspace Operations Lab (AOL) at NASA
- Also used scheduling algorithms but added more opportunities for human input
  - Increase controller awareness of predicted separation at the crossing point
  - Incorporate tactical options for controller to adjust for variability in departure time and climb rate
  - Specifically address coordination issues
Previous Work: SOAR 1 and SOAR 2 HITL Results

• SOAR 1
  – Best for tower to hand off departure to arrival sector
  – Point-out procedure too cumbersome
  – Controllers successfully vectored opportunistically
  – Timelines helped—but not enough
  – Needed a tool

• SOAR 2
  – Pre-arranged coordination procedure (P-ACP) worked better
  – Tie-box drawings on videomaps too static
  – Conflict probe did not give path options
  – Variation in climb speed resulted in separation violations
  – Needed new tool
    • More controller awareness
    • Path options
METHOD: SOAR 3
Selected Arrival Route with Gaps in NY Airspace

Gaps already in south LGA arrival flow to accommodate north flow merge.

Haarp (LGA arrivals)

Final (LGA arrivals)

MOFT crossing fix

Empyr (LGA arrivals)

Liberty South (departures)

EWR Departures
Developed New Departure Route Crossing Structure with Path Options

- EWR White departures
- Multiple options to turn
- Multiple crossing points
- LGA south arrival flow
Assumptions for Simulation

- RNAV/RNP arrival and departure procedures
- Terminal Scheduling and Spacing (TSS) technologies for arrivals
- Metering based on Ames Traffic Management Adviser with Terminal Metering (TMA-TM)
- New Optimal Profile Descents (OPDs)
- For flight deck
  - Alternate departure routes were published
    - Available in FMS or could be uploaded rapidly
Separation Requirements for Tool

- Separation minima in TRACON airspace is 3nm laterally or 1,000 feet vertically
  - We added 1nm buffer—so 4nm laterally
- However, minima do not apply if one aircraft has passed in front of another, i.e., routes have diverged
  - Section 5-5-7, FAA Order 7110.65V
  - We applied this "diverging separation" rule
    - When a departure followed a leading arrival
    - But not when a departure was in front of a trailing arrival, for safety purposes
• Required distance of the departure when the arrival is at the crossing fix (x) is 4nm (including buffer) (Figure A)

• Then closest point of approach (s) is 2.8nm (Figure B)
  – Allowable due to the diverging separation rule

Based on equation: If aircraft are traveling at equal speeds and at constant headings (with a course crossing angle of θ), the required separation at crossing is

\[ x = \frac{s}{\cos(\theta/2)} \]
• Required distance of the departure from the arrival is 4nm at its closest point of approach ($y_{\text{min}}$) (Figure D)
• Then minimum distance at the crossing fix is 5.6nm (Figure C)
**Developed New Route Crossing Tool**

- **Values table**
  - For each route, checks to see if desired separation exists between departure and leading & trailing aircraft
    - To leading arrivals (column 3) 4nm
    - To trailing arrivals (last column) 5.6nm
  - Takes into account forecasted winds and is updated in real time
  - Carrot indicates departure on REST4 default route just after takeoff
  - Only route that is OK is SIX (in white)
Developed New Route Crossing Tool

- Graphical display
  - Shows current route (Rest4) in yellow
  - Shows distance from leading arrival in red since it is under 4nm (3.5nm)
  - Shows distance from trailing arrival in yellow since it is over 5.6nm (10.8nm)
Controller Hovers Over Route Six in Table: Brings Up Route Six Graphic
Controller Clicks on Route Six

Datablock now shows departure is on Route SIX

Ground system is updated

Controller notifies flight deck
Controller Climbs Departure & Hands it Off
Departure Crosses MOFT6

Actual location of leading arrival

Departure now has vertical separation with arrivals as well as lateral

Actual location of trailing arrival
Departure > 4nm From Trailing Arrival at Closest Point
Experimental Design

- 3x(4x3) factorial experimental design of 12 one-hour runs; 144 departures

- 3 tool conditions
  - Baseline (no tool)
  - Single-route (MOFT4 route only)
  - Multi-route (All 5 routes)
Four Gap Sizes at MOFT

• 134 seconds needed (54 behind leading arrival & 80 seconds in front of trailing arrival)

• Gap sizes in simulation
  – 180 seconds (134 + 46 seconds)
  – 160 seconds (134 + 26 seconds)
  – 140 seconds (134 + 6 seconds)
  – 120 seconds (134 – 14 seconds)

  • I.e., “No gap” condition
Three Departure Positions *Within* Gaps

<table>
<thead>
<tr>
<th>Position in Gap</th>
<th>Gap Size in Seconds</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>180s</td>
</tr>
<tr>
<td>1) 30 seconds in back of leading arrival</td>
<td>25%</td>
</tr>
<tr>
<td>2) Middle of gap</td>
<td>50%</td>
</tr>
<tr>
<td>3) 30 seconds in front of trailing arrival</td>
<td>25%</td>
</tr>
</tbody>
</table>

Note: In 120 second (no gap) condition, all departures were 50 seconds behind the leading arrival & 70 seconds in front of the trailing arrival.
Experimental Setup & Participants

- 4-day experiment—1 day training, 3 days of data collection
- 12 one-hour runs, each with 12 WHITE Departures from EWR (48 per tool condition, 144 total)
- 3 scenarios based on actual traffic data balanced across conditions; conditions balanced across time
- Three retired controllers rotated through Empyr Arrival Sector
  - 15 year average in a TRACON
  - 24 year average in all facilities
  - 2.3 year average from retirement
Procedures

• Empyr Arrival Sector
  – Controlled arrivals to LGA (the flow to be crossed)
  – Also controlled WHITE departures from EWR
  – Departures initially cleared to 8,000,' and if decision was made to climb, cleared to 11,000' and handed off to Liberty South sector

• Traffic data blocks of WHITE departures were displayed to EWR departure, Empyr, and Liberty South sectors
RESULTS
Aircraft at Higher Average Altitude at MOFT in Multi-Route Condition

\[ F(2,132) = 10.0, \ p < .001, \] error bars = 95% Confidence Intervals
Higher Proportion of Aircraft Climbed Before MOFT in Multi-Route Condition

$F(2,132) = 6.5, \ p = .002$, error bars = 95% Confidence Intervals
Higher % of Aircraft Climbed Before MOFT in Smallest Gaps in Multi-route

\[ F(2,35) = 5.1, \ p < .01 \] for 120 second gap. Error bars = 95% CIs. (ANOVA not significant for entire sample.)
Higher % Climbed Behind Leading Arrival than in Front of Trailing Arrival

$F(2,107) = 19.93, p < .001$. Error bars = 95% CIs.
But, with Multi-Route Tool, Higher % of Aircraft Climbed Before MOFT in Front of Trailing Arrival

\[ F(4,107) = 6.3, \ p < .001. \] Error bars = 95\% CIs.
Safety: No Separation Violations—3 Aircraft Came Within Extra Buffer for Trailing Aircraft

Of three aircraft in "d" section, 2 were in Baseline Condition; 1 in Multi-Route
No Aircraft was Climbed within 4nm of Leading Arrival Before Divergence was Established

Aircraft depicted climbed before MOFTn. Departures in “a” are taking advantage of the diverging separation rule, but had a buffer of about 1 nm laterally before climbing. (Departure in "c" caused by malfunctioning aircraft simulator.)
Controllers Assessed Operations as Safe

Post-simulation question: "In this simulation, how acceptable was safety in the Empyr sector in the following conditions?"

Post-run survey means for this question were 4.8, 4.5, 4.8
Controllers Assessed the Workload as Low in All Conditions

Post-sim question: “Please describe your typical workload in the Empyr sector in the following conditions.”

![Bar chart showing workload assessment]

Note: Workload Assessment Keyboard (WAK) scores 2.2, 2.2, 2.3 in the three conditions on a scale of 1 to 6
Controllers Assessed Mental Activity as Moderate in All Conditions

Post-run question: “How much mental activity was required during the busiest time?”
However, Controllers Rated it Most Difficult to Assess Distances for Climb in Baseline

Post-run question: "In this run, how difficult was it to assess distances so that you could decide whether to climb EWR departures before they crossed the LGA arrival flow?"
Controllers Rated the Tools as Reliable

Post-simulation question: "How reliable did you find the following tools in the Empyr sector?"

One controller commented: "The crossing tool was very accurate! Better than my eyes when the aircraft were far apart."
CONCLUSIONS
Conclusions

• Multi-Route Crossing Tool enabled higher % of departures to climb through gaps in a simulated LGA arrival flow
  – Provided alternate routes to correct for variability in departure & climb rate
  – Enabled controllers to estimate distances better
    • Higher % of departures climbed within smaller gaps and in front of trailing arrivals

• Locations of climbs were safe

• Controllers rated safety, workload, & reliability as acceptable
Conclusion (cont.)

- Tool has applications wherever departure routes are held level under arrival routes
  - E.g., in U. S., Phoenix, Atlanta, Los Angeles, Dallas-Fort-Worth, Washington, DC (all 3 airports), and San Francisco

- Could be a stepping stone to further automation
  - E.g., tool could automatically select best lateral route
  - Could be automatically uplinked to flight deck
  - Controller could still make decision to climb above or cross below a given altitude
QUESTIONS?
BACK-UP SLIDE
Shared Timeline

- Time separation shown with both arrivals and departures (yellow) on the same timeline to RABBA
- Yellow departure callsigns move between arrivals depending on route chosen
- Blue gaps indicate enough space for departures to cross
  - e.g., when COM1158 is more than 4.0nm from leading arrival (AWI535) and 5.6nm from trailing arrival (AWI275), as shown on Route 6