Assessing the Benefits of NextGen Performance Based Navigation (PBN)

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Outline

- Project overview
- Literature review
- Assessment methodology
- Assessment results
- Conclusions and next steps
Overview

- **Next Generation Air Transportation System (NextGen)**
  - Federal Aviation Administration (FAA) effort to transform air traffic control technologies and procedures in the United States

- **Performance Based Navigation (PBN)**
  - State-of-the-art navigation technologies such as satellite-based Area Navigation (RNAV) & Required Navigation Performance (RNP)

- **Optimization of Airspace Procedures in the Metroplex (OAPM)**
  - Multi-year effort assessing implementation of RNAV and RNP at key metropoles across the National Airspace System (NAS)
  - Metroplex is collection of two or more adjacent airports whose arrival and departure operations are highly interdependent

- **Project Objective**
  - The FAA Office of Systems Analysis & Modeling is seeking to quantify the benefits of PBN
  - This work includes identification of PBN benefit mechanisms, develops explicit models of those mechanisms, and uses fast-time simulation to quantify their impacts under representative operating conditions
  - PBN benefit mechanisms include RNAV-enabled modifications to Standard Instrument Departures (SIDs) or Standard Terminal Area Arrivals (STARs) that mitigate metroplex inefficiencies
# Literature Review

Prior studies of RNAV mitigations for metroplex inefficiencies

- FAA OAPM reports for the Washington, D.C., Charlotte, Houston, North Texas, and Northern California metroplexes & other published literature

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<tr>
<th>Capability</th>
<th>Inefficiency Mitigation</th>
<th>Related References</th>
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<tr>
<td>RNAV STARs</td>
<td>• Decoupled fixes, routes or airspace</td>
<td>• Decoupling vs. coordinating use: Clarke, J.-P., et al., 2012; Saraf, A., et al., 2011; Capozzi, B., et al., 2009</td>
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<tr>
<td></td>
<td>• Additional en route transitions</td>
<td>• Airport vs. route capacity: Gilbo, E., 1997</td>
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<td>• Parallel offload STARs</td>
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<td></td>
<td>• Reduced in-trail separation minima</td>
<td>• RNAV SIT IFT vs. throughput: Mayer, R., et al., 2007; FAA OAPM-Charlotte, 2011</td>
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## Assessments

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<th>Motivation</th>
<th>• Assess impact of RNAV SIDs/STARs in mitigating metroplex inefficiencies, independent of upstream/downstream constraints</th>
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<td>Methods</td>
<td>• Queuing system models of each baseline &amp; RNAV SID/STAR mitigation</td>
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<td>• Service rates at entry, merge/diverge, exit points</td>
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<td>• Inter-queue transit times along en route transitions &amp; common route</td>
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<td></td>
<td>• Simulations to evaluate models at increasing traffic levels</td>
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<td></td>
<td>• 100% RNAV capable to get impact limit, unless specified otherwise</td>
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<td>Metrics</td>
<td>• Throughput = number of aircraft/(last a/c exit time – first a/c exit time)</td>
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<td>• Capacity = inverse of service time interval, service time interval = minimum inter-flight distance spacing/assumed transit speed</td>
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<td>• Express throughput as % of capacity of SID/STAR point previously underused due to up-/down-stream constraint eliminated/reduced in RNAV SID or STAR</td>
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<td>• E.g., Merge point of STAR with additional en route transition</td>
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<td>Analysis</td>
<td>• Generic models</td>
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<td>• Develop baseline &amp; RNAV SID/STAR models, conduct simulations to verify models and assess sensitivity to system parameters</td>
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<td>• Northern California metroplex</td>
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<td>• Analyze data to characterize current-day inefficiencies</td>
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<td>• Develop baseline &amp; RNAV SID/STAR models &amp; conduct simulations to determine throughput impact in mitigating inefficiencies</td>
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Modeling Approach

- Queuing system approach to modeling baseline & RNAV SIDs/STARs
- E.g., simplified generic STAR physical and queuing models

- Demand rate D at each entry point; service rate S at each entry, merge/diverge, exit point; transit time T along each leg
- Distinct models for baseline SID or STAR exhibiting a specific inefficiency & RNAV SID or STAR mitigating the inefficiency
Modeling Example

**Physical Models**
- Baseline STARs with Shared Fix
- RNAV STARs With Decoupled Entry Fixes

**Queuing Models**
- Baseline STARs with Shared Fix
- RNAV STARs With Decoupled Entry Fixes
Generic Model Assessments

Example
• Throughputs of STARs for baseline shared and RNAV decoupled entry fix

**Baseline STARs, Shared Entry Fix**
- 50% of STAR Traffic To Shared Entry Fix
- 75% of STAR Traffic To Shared Entry Fix

**RNAV STARs, Decoupled Entry Fix**
- 50% of STAR Traffic To Shared Entry Fix
- 75% of STAR Traffic To Shared Entry Fix

Throughput impact of RNAV SIDs/STARs sensitive to system conditions
• Traffic level & distribution among SID/STAR en route transitions
• Inter-flight separation minima values & ratios among SID/STAR entry, diverge/merge, and exit points
Northern California Metroplex Assessments

Our review of FAA OAPM reports found Northern California metroplex had broad range of inefficiencies in each flight phase

**Scope**
- Data analysis to characterize inefficiencies in baseline SIDs/STARs
- Modeling and simulation to evaluate throughput of baseline SIDs/STARs with inefficiencies & RNAV SIDs/STARs mitigating inefficiencies

**Data sources**
- Flight tracking data from FAA Aircraft Situation Display to Industry Jan. 1 to Jan. 25 2009 & SID/STAR routes from FAA National Flight Data Center Feb. 9 to Apr. 5 2012
  - Associate flight tracks with SID/STAR routes as per closest lateral proximity

**Analysis**
- Analyze traffic distribution among SID/STAR en route transitions, altitude & time distributions of traffic at shared waypoints, inter-fix transit times, other

**Modeling**
- Extend generic queuing system based models and simulation methodology to evaluate specific baseline & RNAV SIDs/STARs in the Northern California metroplex
Northern California Metroplex
Fixes Decoupling

KSFO MOD, KOAK MADN and KSJC HYP STARs share entry fixes FMG, MVA and OAL

- FAA OAPM identified this inefficiency
- Our analysis found positive indicators of interaction among the traffic flows of the three airports at fix OAL

Evaluate the impact of completely decoupling these STARs
Northern California Metroplex Decoupled Fixes Simulation

Simulations to determine throughput of baseline & RNAV KSFO MOD, KOAK MADN and KSJC HYP STARs

- Baseline: Shared entry fixes FMG, MVA, OAL
- RNAV: Decoupled entry fixes FMG-1, -2, -3; MVA-1, -2; and OAL-1, -2, -3; 100% of aircraft RNAV capable

Throughput of RNAV STARs increases over baseline STARs

- KSFO MOD by 44%
- KOAK MADN by 32%
- KSJC HYP by 23%

Service time intervals from tracking data

- 5th percentile of inter-flight time spacing values
- Bounded by [1, 10] minutes

Transit times from tracking data

- Mean of inter-fix transit times
Northern California Metroplex Additional En route Transitions

- Baseline KOAK MADN STAR has three en route transitions with entry fixes FMG, MVA and OAL
  - FAA OAPM identified this as an inefficient STAR
  - Our analysis found en route transition OAL carries 72% of KOAK MADN traffic

Evaluate impact of introducing additional en route transition OAL-2 for fractions of aircraft that are RNAV capable
Northern California Metroplex Additional Transitions Simulation

- Analyze throughput benefits of RNAV KOAK MADN STAR with additional en route transition OAL-2
  - Baseline condition: En route transitions FMG, MVA, OAL
  - RNAV condition: En route transitions FMG, MVA, OAL-1, -2; 10%-50% of OAL-bound aircraft apportioned to OAL-2

Throughput of RNAV KOAK MADN STAR with additional transition OAL-2 increased by 48% with fraction of traffic RNAV capable
Northern California Metroplex
RNAV STARs

Throughput results for RNAV STARs

<table>
<thead>
<tr>
<th>Inefficiency Mitigation</th>
<th>Modeled STAR</th>
<th>Evaluation Condition</th>
<th>STAR Capacity Utilization</th>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Baseline</td>
</tr>
<tr>
<td>Arrival Fixes Decoupling</td>
<td>KSFO MOD, KOAK MADN, KSJC HYP</td>
<td>Entry points FMG, MVA, OAL decoupled.</td>
<td>16% (MOD), 16% (MADN), 16% (HYP)</td>
</tr>
<tr>
<td>Additional ERTs</td>
<td>KOAK MADN</td>
<td>50% of en route transition OAL traffic allocated to en route transition OAL-2.</td>
<td>47%</td>
</tr>
<tr>
<td>Parallel Offload STAR</td>
<td>KSFO MOD, KSFO YOSEM</td>
<td>Traffic demand evenly distributed to both STARs. Baseline traffic distributions among en route transitions.</td>
<td>55%</td>
</tr>
<tr>
<td>Reduced In-Trail Spacing</td>
<td>KSFO GOLDN</td>
<td>20% reduction in minimum IFT at entry points FOT, RBG, RBL, FMG and merge point PYE.</td>
<td>60%</td>
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</table>

RNAV STARs may yield a significant throughput increase over the baseline STARs
Northern California Metroplex RNAV SIDs

Throughput results for RNAV SIDs

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<th>Evaluation Condition</th>
<th>SID Capacity Utilization</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Decoupled entry point REBAS and exit points ENI, RBL, CIC, SAC, LIN.</td>
<td>Baseline</td>
</tr>
<tr>
<td>Departure Routes Decoupling</td>
<td>KOAK SLNT, KSFO CUIT</td>
<td></td>
<td>55% (CUIT), 61% (SLNT)</td>
</tr>
<tr>
<td>Additional ERTs</td>
<td>KSFO PORTE</td>
<td>50% of en route transition AVE traffic allocated to en route transition AVE-2.</td>
<td>53%</td>
</tr>
<tr>
<td>Reduced In-Trail Spacing</td>
<td>KSJC SJC</td>
<td>Evaluated 12.5% and 30% reductions in IFT at entry point MOONY</td>
<td>39%</td>
</tr>
</tbody>
</table>

RNAV SIDs may yield a significant throughput increase over the baseline SIDs
Summary & Conclusions

- Literature review of metroplex inefficiencies & RNAV mitigations
- Queuing system-based modeling and simulation approach to evaluate throughput impacts of RNAV SIDs/STARs to mitigate metroplex inefficiencies
- Analysis of Northern California metroplex showed RNAV SIDs/STARs demonstrated increased throughput over baseline for different inefficiencies
  - RNAV SIDs/STARs with additional en route transitions showed greatest throughput increase, with less than 50% of traffic RNAV capable
- However, RNAV SID/STAR throughput increases may only be realized to the extent that upstream/downstream airport or airspace capacity is available
- Results can be directly applied to system-wide model representations of NAS to represent capacity impacts of PBN
  - e.g., FAA System-Wide Analysis Capability (SWAC), which represents extended terminal airspace constraints as arrival and departure fix queues
Next Steps

- Integrated airport-terminal airspace simulations to assess the airport- and metroplex-wide impacts of RNAV SIDs/STARs
- Analyze other metroplexes reviewed by FAA OAPM
- Identify & evaluate additional RNAV inefficiency mitigation mechanisms
- Extend analysis to RNP AR final approach procedures
- Evaluate effect of coupling RNAV-enabled inefficiency mitigations
  - E.g., decoupling fixes + additional en route transition
Northern California Metroplex Shared Fixes Analysis

- Analyze flight tracking data to characterize indicators of interaction among KSFO MOD, KOAK MADN and KSJC HYP at shared fix OAL

- Arrival aircraft from KSFO, KOAK, KSJC cross shared fix OAL in coincident altitude ranges & time periods

- Likely requires aircraft from each airport to be sequenced with one another prior to crossing entry fix OAL
Northern California Metroplex
En route Transitions Analysis

- Baseline KOAK MADN STAR has three en route transitions with entry fixes FMG, MVA and OAL
- Analysis of arrival traffic via KOAK MADN shows en route transition OAL carries 72 percent of KOAK MADN traffic

- Introduce additional en route transition OAL-2 for RNAV capable aircraft
PBN Overview

RNAV 1: SIDs & STARs
- Standard Instrument Departures (SIDs)
- Standard Terminal Arrivals (STARs)
- Point-to-point area navigation (RNAV) independent locations
- 1 nmi lateral accuracy 95% of flight time