OPTIMIZING INTEGRATED ARRIVAL, DEPARTURE AND SURFACE OPERATIONS UNDER UNCERTAINTY

ATM Seminar 2015

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MOTIVATION

• Terminal airspace
• Airport surface

• Integrated arrivals and departures
• Integrated taxiway and runway operations

• Uncertainty
RESEARCH OBJECTIVE

Develop and evaluate a fast-time decision support algorithm that bridges terminal airspace and surface operations in the presence of uncertainty.
OUTLINE

• Background

• Problem Setup and Formulation

• Solution Methodology

• Case Study: Los Angeles Terminal Airspace and Airport

• Closing Remarks
BACKGROUND

• Previous scheduling research in Terminal Operations:
  – Arrival scheduling
  – Departure scheduling
    [Atkin et al., 2008][Gupta et al., 2009][Rathinam et al., 2009]
  – Integrated departures and arrivals
    [Capozzi et al., 2009][Chen et al., 2011][Xue et al., 2013, 2014][Bosson et al., 2014]

• Previous scheduling research in Airport Operations:
  – Taxiway scheduling
    [Smeltink et al., 2004][Balakrishnan and Jung, 2007][Roling and Visser, 2008]
    [Rathinam et al., 2008]
  – Runway sequencing and scheduling
    [Deau et al., 2009][Sölveling, 2012]
  – Integrated taxiway and runway operations
    [Clare and Richards, 2011] [Lee and Balakrishnan, 2012][Yu and Lau, 2014][Heidt et al., 2014]
BACKGROUND

• How do we integrate uncertainty?
  – Buffering technique
  – Regression
  – Sampling methods

• Machine job-shop scheduling problem:
  – “Problem that consists of assigning and scheduling jobs to machines at particular times”
  – Variations:
    • Temporal and/or sequencial constraints on jobs and/or machines
    • Known/unknown input schedule for job to be processed
BACKGROUND

• Machine job-shop – aviation analogy:
  – Job = Aircraft
  – Machine = Route node (waypoint, surface node)
  – Release time
  – Due date

• Previous applications in aviation research:
  – Deterministic aircraft sequencing [Beasley et al., 2000]
  – Airport runway scheduling framework with uncertainty [Sölveling, 2012]
  – Integrated departures and arrivals with probabilistic release times and probabilistic due times [Bosson et al., 2014]
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PROBLEM SETUP

- Integrated terminal airspace operations scheduler:
  - Temporal separation strategy
  - Computes optimal flight schedules and routings
  - Waypoints are shared by arrivals and departures
  - Uncertainty added to flight times

- Integrated terminal airspace and airport operations:
  - Extends previous research to airport surface operations
  - Connects formulation at the runway
  - Uncertainty added to gate and taxi times
PROBLEM SETUP

Modeling – machine job shop analogy:

- Job = aircraft (weight $[\text{H,7,L,S}]$ and operation $\{\text{A,D}\}$)
- Machine =
  - Surface waypoint
  - Air waypoint
- Sequence =
  - Surface route
  - Flight plan
- Processing times = aircraft separation times
- Release times =
  - For arrivals: entry air waypoint time
  - For departures: gate pushback time
- Due dates =
  - For arrivals: gate arrival time
  - For departures: exit air waypoint time
PROBLEM FORMULATION

Inputs
Set of aircraft, schedule scenarios, network model

Objective
Minimize the total travel time (surface + air) of a set of aircraft and maximize their on-time performance such that the impact of uncertainty is minimized subject to:
- Waypoint precedence constraints
- Speed constraints
- Waypoint capacity constraints
- Runway constraints
- Schedule constraints

Outputs
Optimal air and surface routings and schedules
SOLUTION METHODOLOGY

• Multistage stochastic programming

• Sample Average Approximation
Pool of aircraft types

Stage 1: compute runway aircraft type slots

Stage 2: assign flights to slots

Stage 3: schedule and route aircraft on the surface at each waypoint

Due date schedule \( j \)

Release time schedule \( i \)

\[ j=m \]?

\[ i=n \]?

\[ j=m? \]

\[ i=n? \]

Delay

Schedules and routings

MULTISTAGE STOCHASTIC PROGRAMMING
Sample Average Approximation

- Number of scenarios affects:
  - Quality of computed solutions
  - Computational tractability

- Solution:
  - Sample Average Approximation method
  - Multi-threading technique

- Approximate true stochastic problem by sample average approximation (SAA)
- Solve several SAA problems with smaller sample size
- Merge solutions into a single set of routings and schedules
- Choose the solution that has the minimal objective
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CASE STUDY: LA TERMINAL AIRSPACE AND AIRPORT

Terminal airspace flows:
28% arrivals
10% departures

Airport traffic:
West flow arrival preference on 24L
CASE STUDY: LA TERMINAL AIRSPACE AND AIRPORT

Reference timelines constructed for December 4, 2012 from historical data

<table>
<thead>
<tr>
<th>Operations</th>
<th>Weight</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Departures</td>
<td>1 S + 5 L</td>
<td>6</td>
</tr>
<tr>
<td>Arrivals</td>
<td>1 H + 6 L</td>
<td>7</td>
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<table>
<thead>
<tr>
<th>Location</th>
<th>Min Speed</th>
<th>Max Speed</th>
</tr>
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<tbody>
<tr>
<td>Surface</td>
<td>8 kts</td>
<td>16 kts</td>
</tr>
<tr>
<td>Air</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Departures</td>
<td>180 kts</td>
<td>250 kts</td>
</tr>
<tr>
<td>Arrivals</td>
<td>280 kts</td>
<td>350 kts</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Location</th>
<th>Separation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface</td>
<td>Taxiway</td>
</tr>
<tr>
<td></td>
<td>Runway</td>
</tr>
<tr>
<td>Air</td>
<td></td>
</tr>
</tbody>
</table>

Reference due date = reference release time + unimpeded operation time
Uncertainty affects departure and arrival schedules.

**Departures**

- Reference release times
- Error $i$ drawn from probabilistic distribution of departure delay
- Release times schedule
- $i=n$?
  - yes
  - no

**Arrivals**

- Reference due dates
- Error $j$ drawn from probabilistic distribution of arrival delay
- Due dates schedule
- $j=m$?
  - yes
  - no

*ln* $N(20.4, 166.8)$

*$N(−265.8, 708.6)$*
Uncertainty affects departure and arrival schedules.

\[ N(0, 30) \]

\[ N(0, 15) \]
EXPERIMENTATION

• Goals:
  - Demonstrate methodology effectiveness
  - Compare computed solution with a First Come First Served (FCFS) baseline solution

• FCFS:
  - Aircraft are treated in the temporal order of the reference schedule
  - Aircraft are forced to use the shortest path
  - Uncertainty is integrated

• Experiment setup: [Bosson et al, 2014]

<table>
<thead>
<tr>
<th>Stochastic experiment</th>
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</thead>
<tbody>
<tr>
<td>Release time schedules</td>
<td></td>
</tr>
<tr>
<td>Due time schedules</td>
<td></td>
</tr>
<tr>
<td>Number of Stage 2 scenarios</td>
<td>100</td>
</tr>
<tr>
<td>Number of Stage 3 scenarios</td>
<td>100</td>
</tr>
<tr>
<td>Number of SAA repetitions</td>
<td>50</td>
</tr>
</tbody>
</table>
RESULTS

MILP vs FCFS: results for optimal repetition

Reduced schedule makespan (22.7%)
RESULTS

MILP vs FCFS: results for optimal repetition

Reduced average taxi times (11s for departures, 8s for arrivals)

Reduced gate delay (overall 55%)
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**CONCLUSION**

- **Solution approach**: efficient methodology that:
  - Bridges terminal airspace and airport surface operations
  - Produces a real-time feasible decision support tool (240s to solve a 30-minute --13-flight scenario)

- **Study case conducted for the LA terminal airspace and airport**: computed runway sequence that leads to:
  - Flight time savings, more direct routings
  - Taxi time savings and reduced gate delays for departures
• Perform further simulations with diverse traffic scenarios
• Investigate different uncertainty models

• Include all traffic of the LAX airport
• Include all traffic in the LA TRACON
Thank you!

Questions?

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