Performance Evaluation of Conflict-Free Trajectory Taxiing in Airport Ramp Area Using Fast-Time Simulations

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Outline

- Background
- Research Objective and Technical Approach
- Simulation Setup
- Results and Analysis
- Summary and Future Research
Background - DLR & NASA Collaboration

Collaborate in the area of airport surface operations to jointly investigate advanced ATM concepts/tools:

- Started in 2013

- Investigate a harmonized concept of operations for surface operations\(^1\)

- Conduct simulations: independent\(^2\) and integrated

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Research Objective and Technical Approach

- Objective: Investigate conflict-free, time-based taxi optimization capability applied to *ramp operations* using integrated fast-time simulations

- Technical Approach
  - Adapt the existing conflict-free surface traffic optimization tool to ramp operations
  - Integrate with a fast-time simulation tool
  - Develop common performance metrics in efficiency, throughput, predictability, and environmental benefits
  - Compare the simulation results with the baseline simulation
Contributing Technology - Taxi Routing for Aircraft: Creation and Controlling (TRACC)

- Coupled with a Departure Management System (DMAN) determines the optimal surface movement plans
- Generates conflict-free 4D taxi (4DT) trajectories and calculates Target Start-up Approval Time (TSAT)
- Transfers 4DT trajectories into a speed profile with corresponding advisories for controllers and pilots
- Tested the prototype tool in a human-in-the-loop simulation environment

TRACC User Interface for Tower Controller (Hamburg Airport, Germany)
TRACC_PPB: TRACC for Pushback Optimization

• Solve for optimized conflict-free taxi trajectories in the ramp area

• Inputs:
  - Prescribed taxi routes
  - Scheduled departure times and target movement area entry times for departures
  - Target ramp entry times for arrivals

• Outputs:
  - Optimized taxi speed profile that satisfies target times for departures and arrivals
  - Target pushback times for departures

• Target movement area entry time and target ramp entry time are adjusted if there is no conflict-free trajectory available
TRACC_PB for Ramp Operations

- Departure Spots
- Arrival Spots

Target ramp entry time
Target gate pushback time
Target mov. area entry time

ATC Tower
Airline Ramp Tower
Ramp
Contributing Technology - Surface Operations Simulator and Scheduler (SOSS)

- Fast-time airport surface simulation tool based on a node-link model
- Capable of modeling uncertainties, including taxi speeds, pushback process
- Common Algorithmic Interface (CAI) allows for testing schedulers independent of the model
- Has a built-in Conflict Detection and Resolution (CD&R) function to prevent loss of separation
- Used for development/testing of schedulers that can be plugged in a real-time system
Simulation Setup – Baseline System

- SOSS CD&R function is used to maintain separation of traffic on the surface
- Target movement area entry and target ramp entry times are saved for TRACC_PB simulation
Simulation Setup - TRACC_PB System

Baseline results

- Scheduled departure time
- Target mov. area entry time
- Target ramp entry time
- Prescribed taxi routes

TRACC_PB Conflict-free Taxi Optimization

Conflict-free taxi?

Yes

Speed profiles & Target pushback times

No

TRACC_PB adjusts target movement area entry and/or target ramp entry times

Outputs - Ramp trajectories

Performance Metrics

*SOSS CD&R function is disabled
Traffic Scenario

Airport
- Charlotte Douglas International Airport (CLT)
- Four runways in a south flow configuration
  - RWY 18L (departure only)
  - RWY 18R, 23 (arrival only)
  - RWY 18C (dual usage)
- Arrival spots: 11, 12, 13, 22
- Departure spots: 8, 9, 26, 27, 29

Traffic Scenario
- 138 flights (medium traffic density)
  - 62 departures, 76 arrivals
- Scenario duration: about 2.5 hours
Performance Metrics

- Ramp throughput
- Ramp Taxi time
- Gate Hold Time
- Ramp Departure Flight Count
- TMAT* Compliance
- Environmental Benefits

*TMAT = Target movement area entry time
Results and Analysis – Ramp Throughput

Baseline system is focused on meeting target throughput while TRACC_PB is focused on achieving conflict-free taxi
Results and Analysis – Ramp Taxi & Gate Hold Times

- TRACC_PB reduces ramp taxi time through optimized speed profile enabling conflict-free taxi
- TRACC_PB holds aircraft longer at the gate than the Baseline

Numbers in % show difference in average and total
Results and Analysis – TMAT Compliance
(Actual mov. area entry time – Target mov. area entry time)

TMAT compliance at various percentiles

<table>
<thead>
<tr>
<th>Percentile</th>
<th>25th</th>
<th>50th</th>
<th>75th</th>
<th>80th</th>
<th>90th</th>
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<tr>
<td>Baseline (Sec)</td>
<td>17</td>
<td>25</td>
<td>41</td>
<td>43</td>
<td>87</td>
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<tr>
<td>TRACC_PB (Sec)</td>
<td>0</td>
<td>0</td>
<td>22</td>
<td>44</td>
<td>279</td>
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</tbody>
</table>

TRACC_PB’s TMAT compliance outperforms the Baseline in ~80% of situations

AMAT = Actual Movement Area entry Time
Results and Analysis – TMAT Compliance
(Actual mov. area entry time – Target mov. area entry time)

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<td>279</td>
</tr>
</tbody>
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Outliers of TRACC_PB’s TMAT compliance is related to longer gate hold times (< 1700 secs)
Results and Analysis - Environmental Benefits (Departures)

- Metrics were computed following ICAO standards with the assumption of both engines running
- TRACC_PB results showed better performance in fuel and emissions than the Baseline
Results and Analysis - Environmental Benefits (Arrivals)

- Metrics were computed following ICAO standards with the assumption of both engines running.
- TRACC_PB results showed better performance in fuel and emissions than the Baseline.
Summary

- Both Baseline and TRACC_PB systems
  - used gate holding to shift excess taxi time in the ramp to the gate
  - sought to comply with target movement area entry times

- The conflict-free taxi solution by TRACC_PB led to less taxi times, longer gate holding, and less environmental impact than the Baseline system

- TRACC_PB result showed a slight decrease in ramp departure throughput due to larger gate holding

- Both systems showed a good compliance to target movement area entry time
  - Meets current Surface Collaborative Decision Making (CDM) suggestion: ±5 min around target
  - However, TRACC_PB result shows a better compliance than Baseline in 80% of situations
Suggested Future Research

• Investigation of uncertainties in taxi process to provide robust taxi schedules

• Investigation of off-nominal conditions

• Flight deck analysis will be refined to balance the research between ground-based decision support tools and the flight deck automation
Thank you!

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Results and Analysis – Ramp Throughput

Baseline system is focused on meeting target throughput while TRACC_PB is focused on achieving conflict-free taxi.
Results and Analysis – Ramp Departure Flight Count

TRACC_PB’s conflict-free trajectories contribute to less ramp congestion, but takes more time to flush out departures
## Results and Analysis - Environmental Benefits

<table>
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<tr>
<th></th>
<th>Departures</th>
<th>Arrivals</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Baseline</td>
<td>TRACC_PB</td>
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<tr>
<td>Fuel  (Kg)</td>
<td>2116.05</td>
<td>1739.68</td>
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<tr>
<td>CO₂   (Kg)</td>
<td>6517.43</td>
<td>5358.21</td>
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<tr>
<td>HC    (Kg)</td>
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<tr>
<td>CO    (Kg)</td>
<td>46.28</td>
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</tr>
<tr>
<td>NOₓ   (Kg)</td>
<td>9.42</td>
<td>7.76</td>
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- Metrics were computed following ICAO standards with the assumption of both engines running.
- TRACC_PB results showed better performance in fuel and emissions than the Baseline.