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

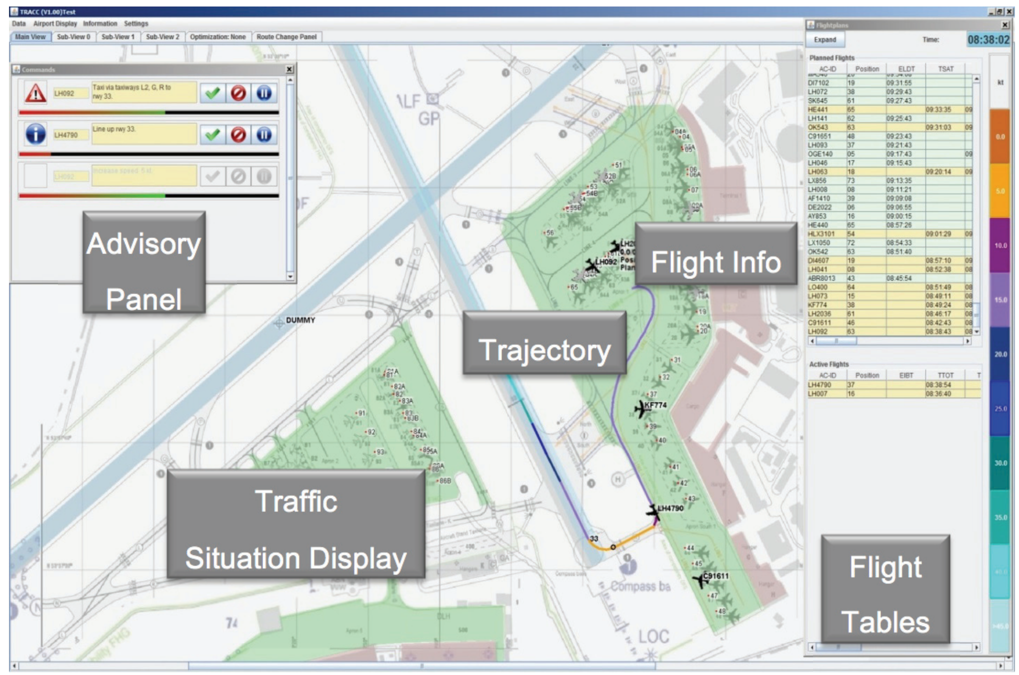
1. N. Okuniek, et al., "A Concept of Operation for Trajectory-based Taxi Operations," 16th AIAA ATIO Conference, Washington D.C, USA, June 13-17, 2016.
2. Z. Zhu et al., "Performance Evaluation of the Approaches and Algorithms for Hamburg Airport Operations," 35th DASC, Sacramento, CA, USA, September 25-29, 2016.

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

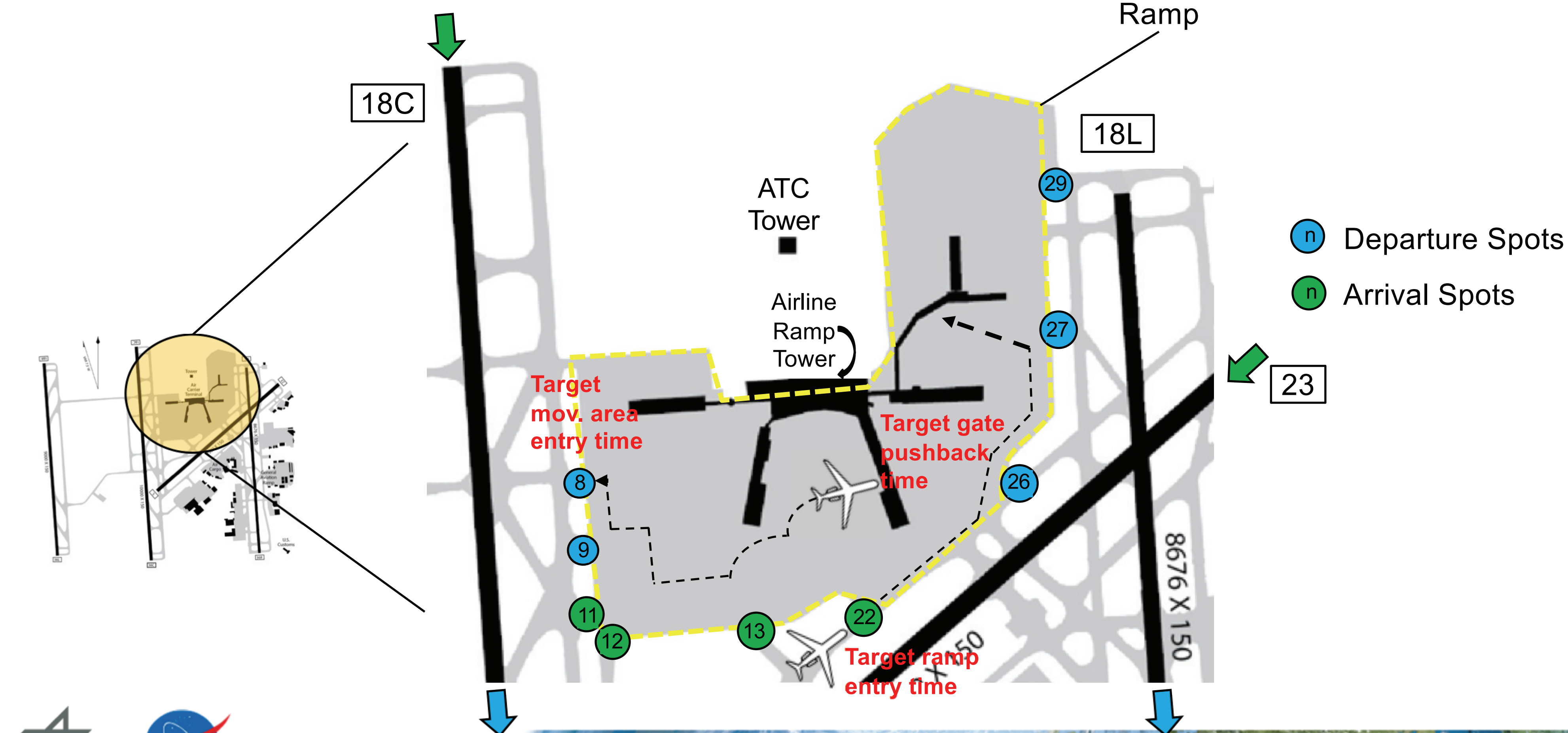


TRACC User Interface for Tower Controller (Hamburg Airport, Germany)

TRACC_PB: TRACC for Pushback Optimization

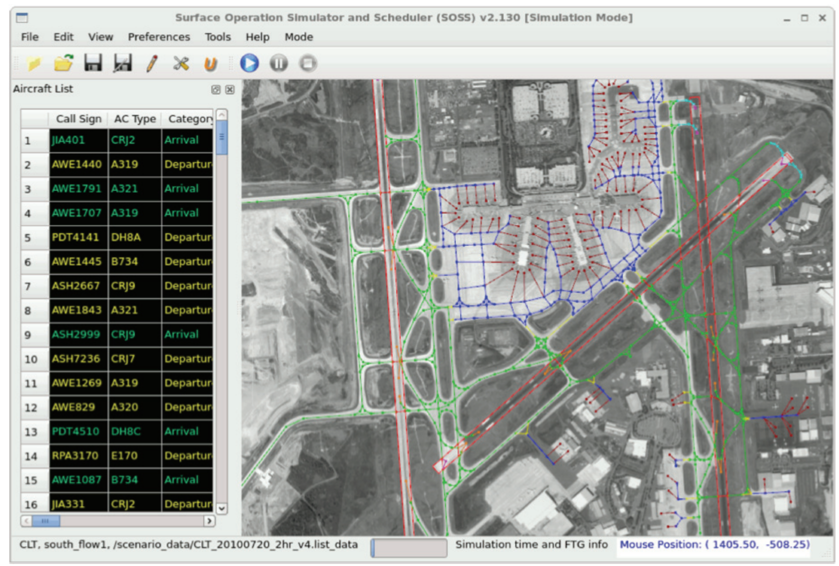
- Solve for optimized conflict-free taxi trajectories in the ramp area
- Inputs:
  - Prescribed taxi routes
  - Scheduled departure times and target movement area entry times for departures
  - Target ramp entry times for arrivals
- Outputs:
  - Optimized taxi speed profile that satisfies target times 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



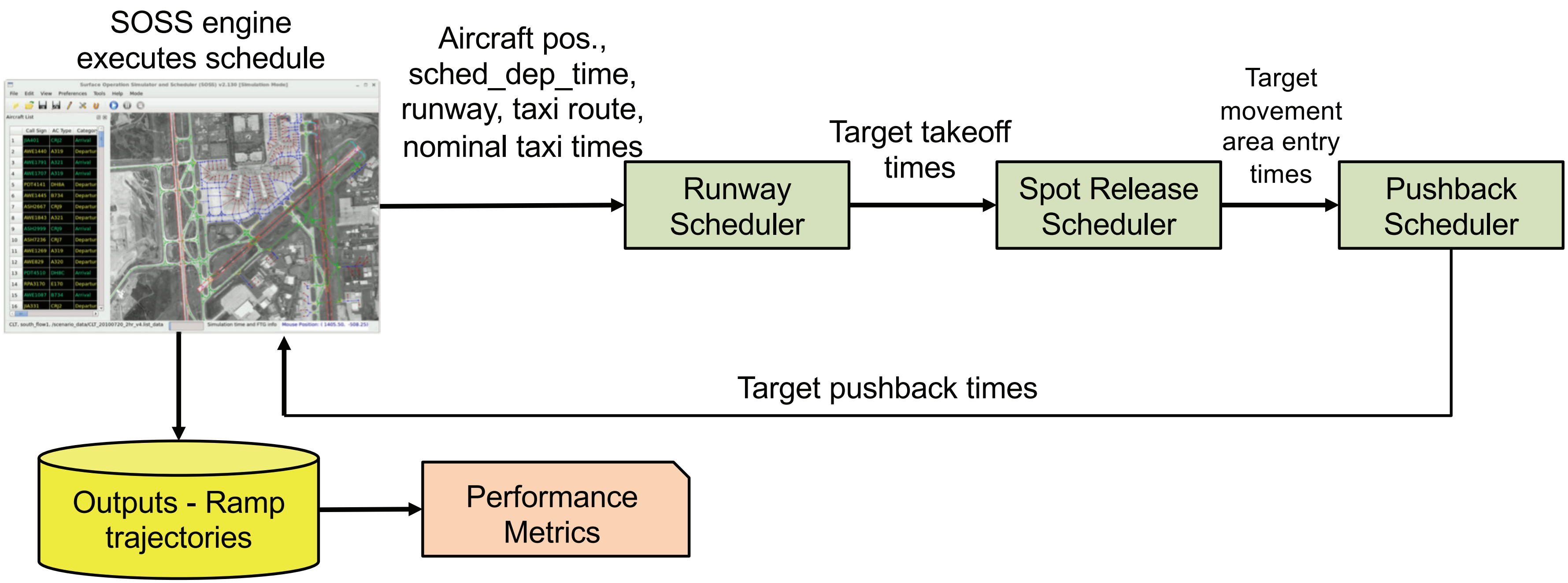
Contributing Technology - Surface Operations Simulator and Scheduler (SOSS)

- 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



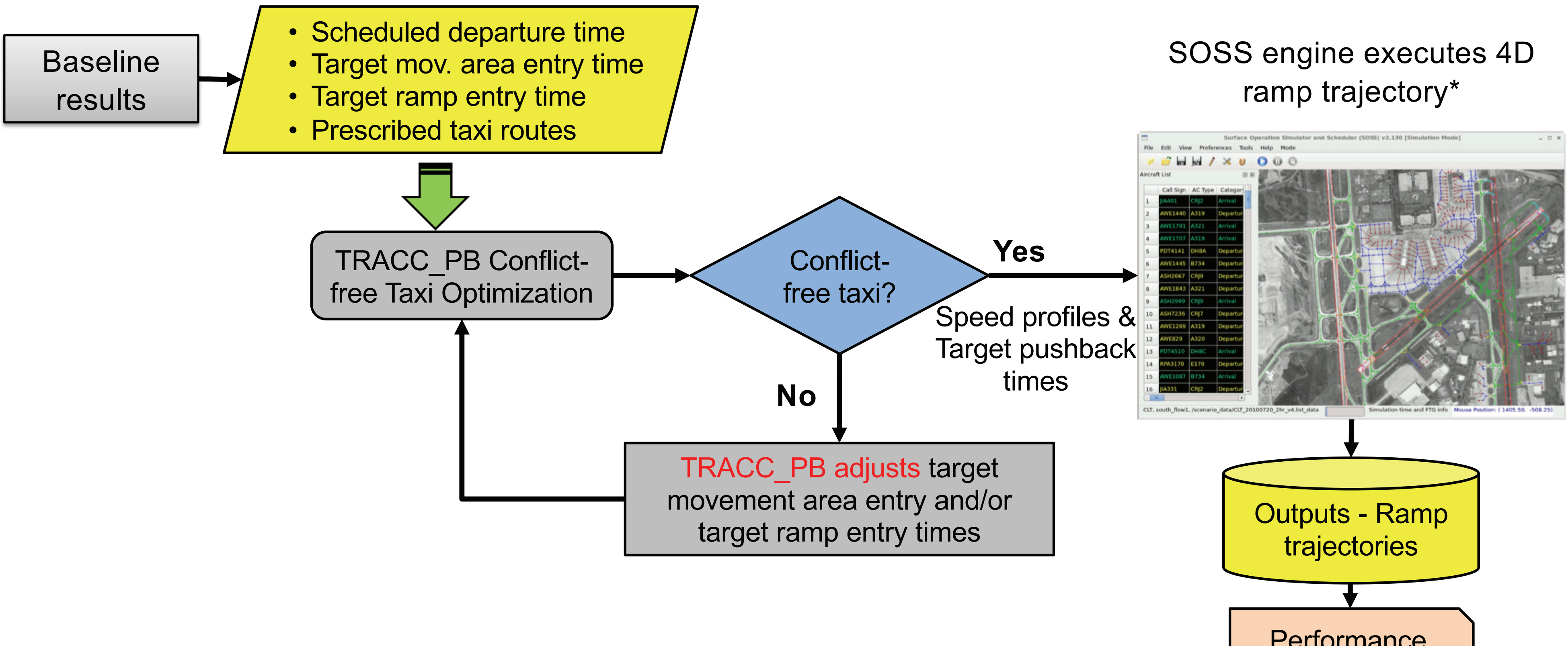
SOSS Airport Model and Traffic Scenario

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



*SOSS CD&R function is disabled

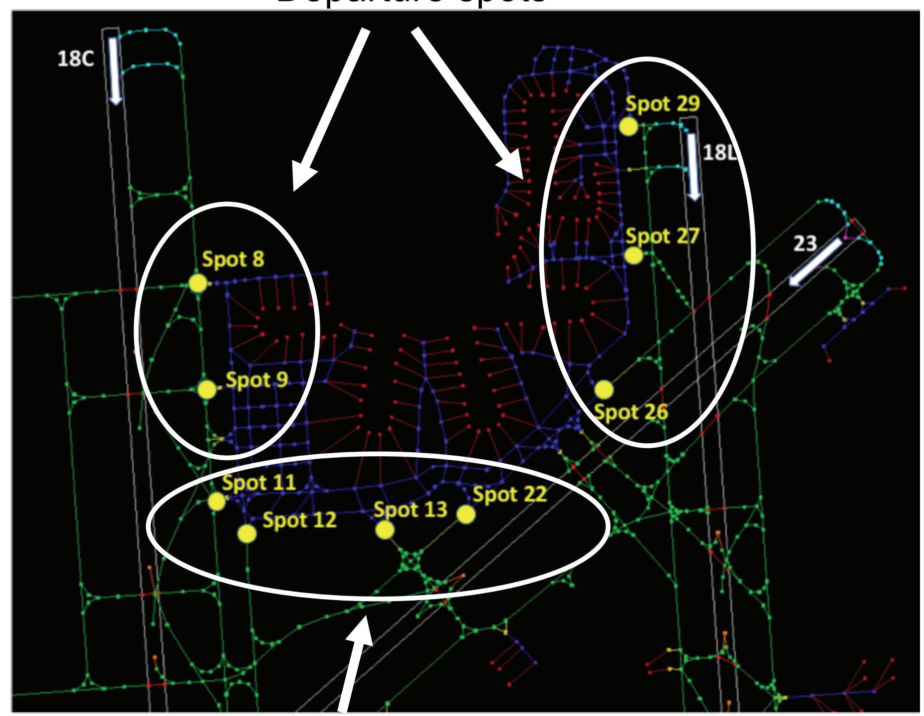
Traffic Scenario

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

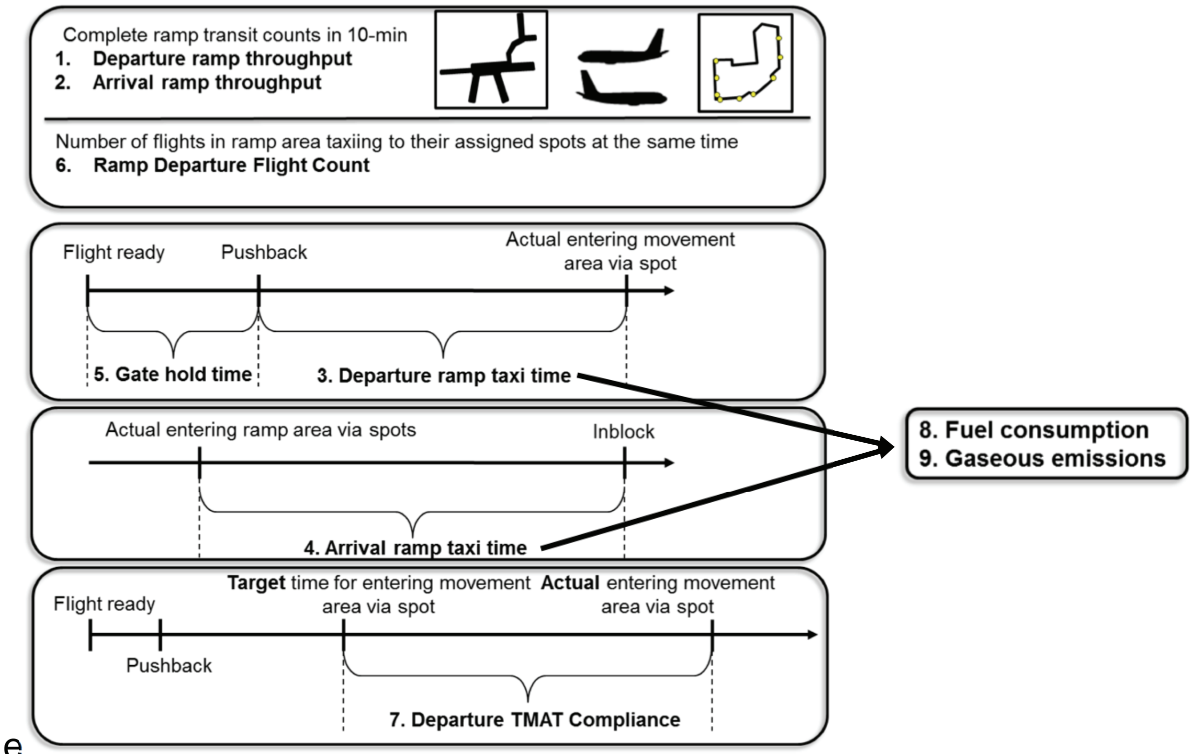
Traffic Scenario

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



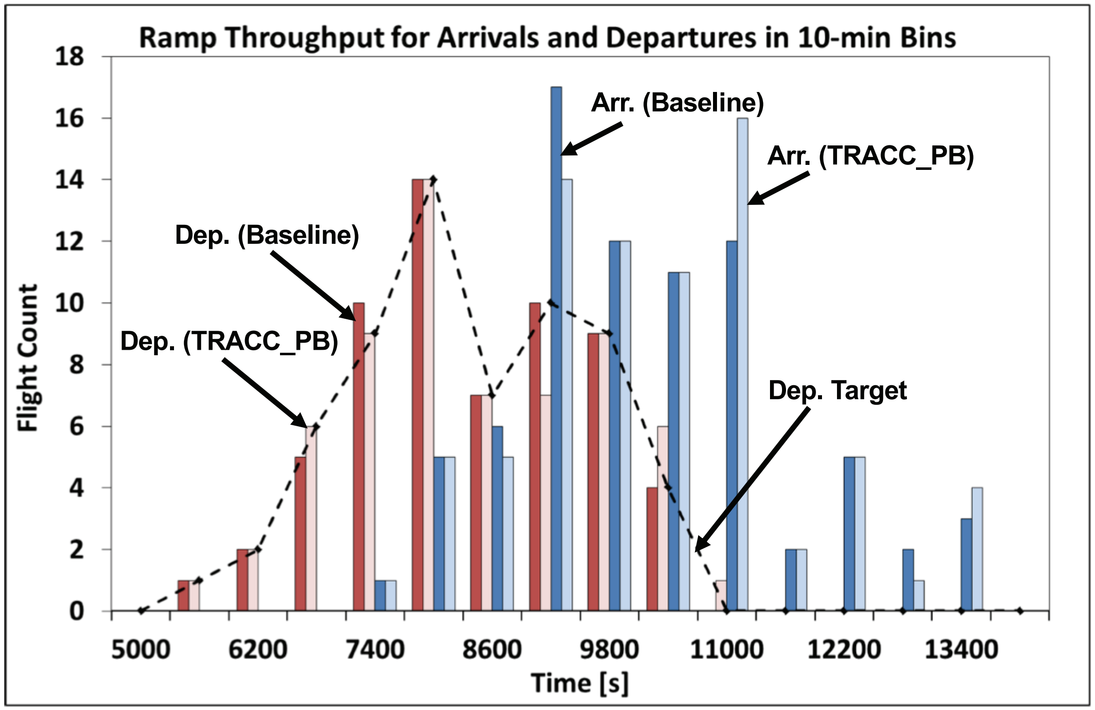
Performance Metrics

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



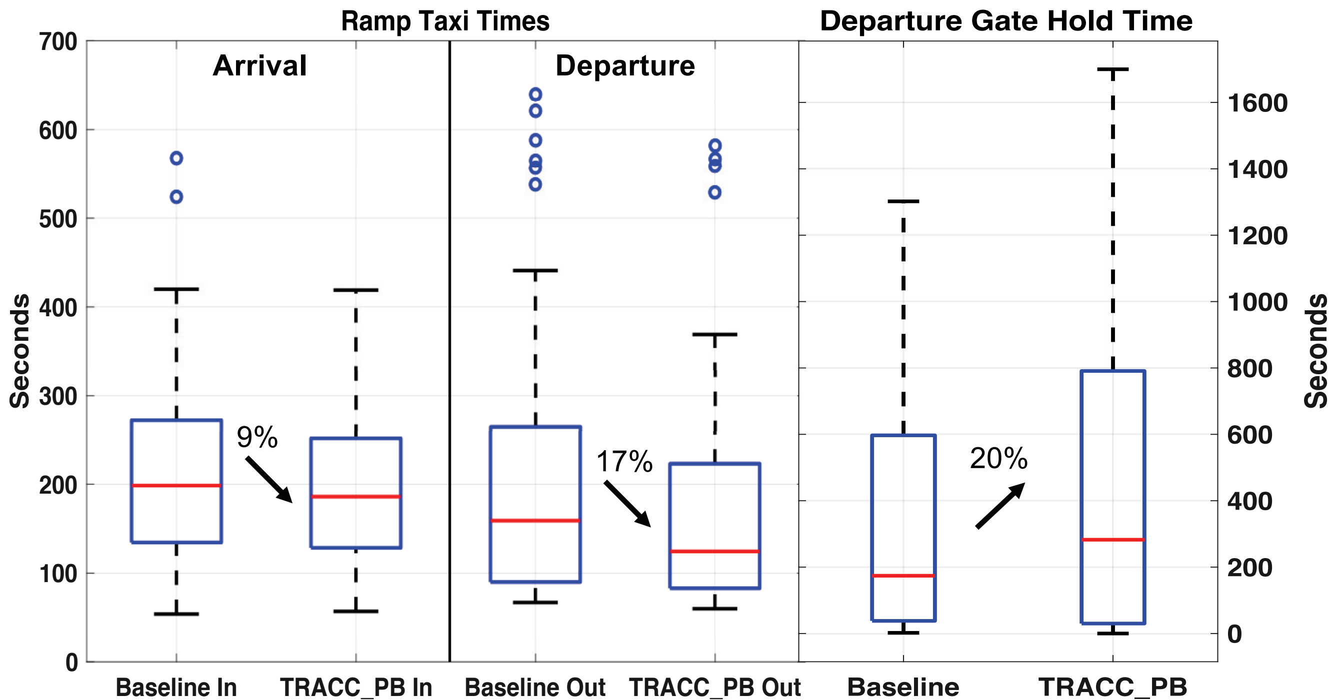
*TMAT = Target movement area entry time

Results and Analysis – Ramp Throughput



Baseline system is focused on meeting target throughput while TRACC_PB is focused on achieving conflict-free taxi

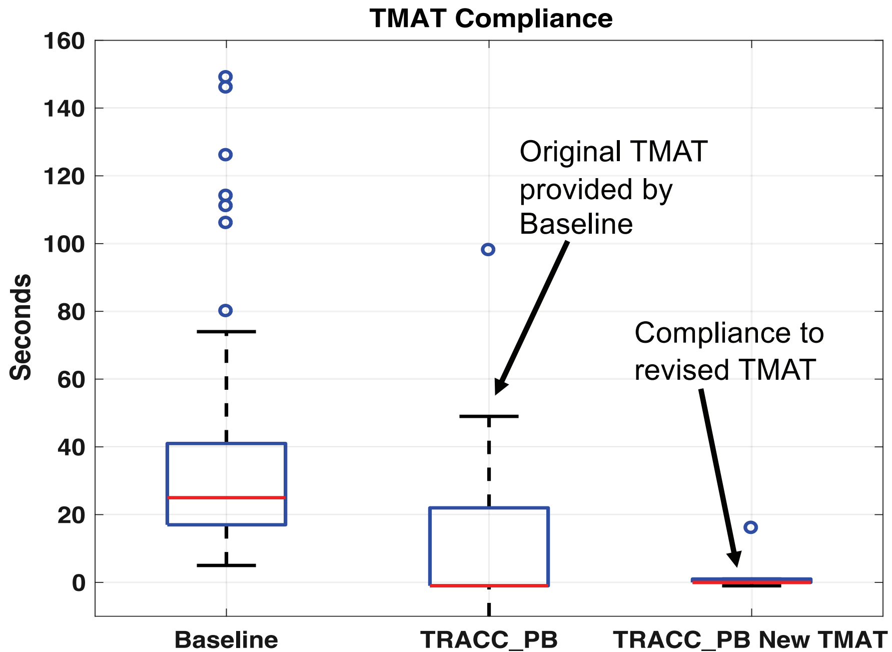
Results and Analysis – Ramp Taxi & Gate Hold Times



Numbers in % show difference in average and total

- 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

Results and Analysis – TMAT Compliance
(Actual mov. area entry time – Target mov. area entry time)



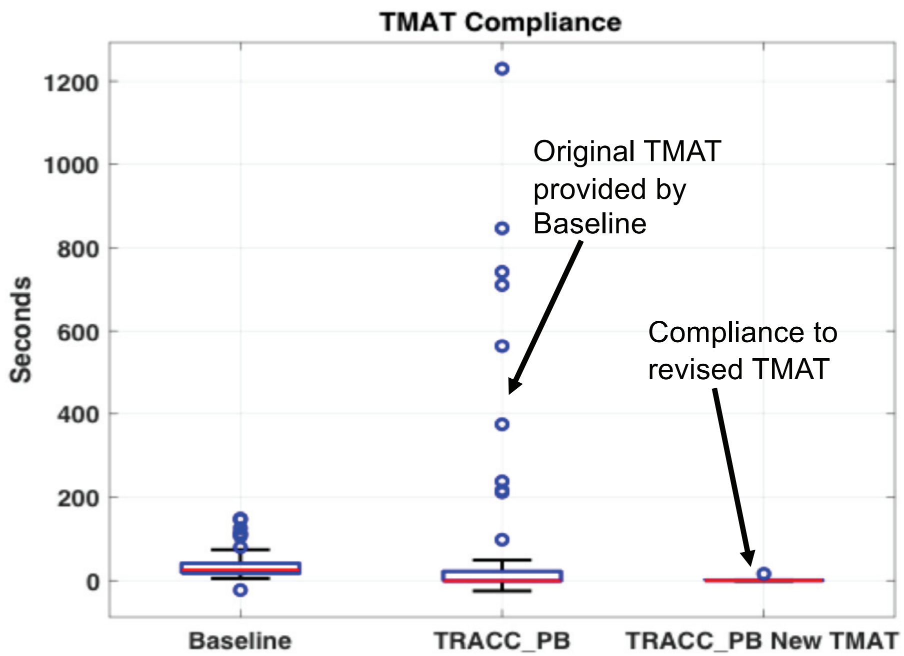
TMAT compliance at various percentiles

Percentile	25th	50th	75th	80th	90th
Baseline (Sec)	17	25	41	43	87
TRACC_PB (Sec)	0	0	22	44	279

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)



TMAT compliance at various percentiles

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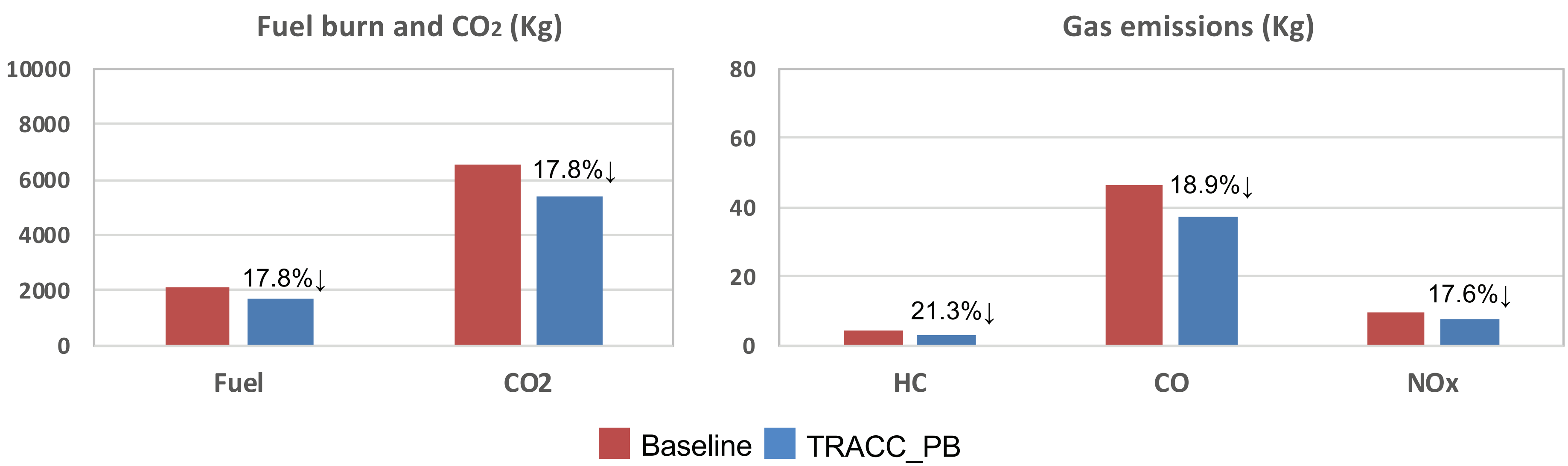
TRACC_PB (Sec)	0	0	22	44	279

Outliers of TRACC_PB's TMAT compliance is related to longer gate hold times (< 1700 secs)

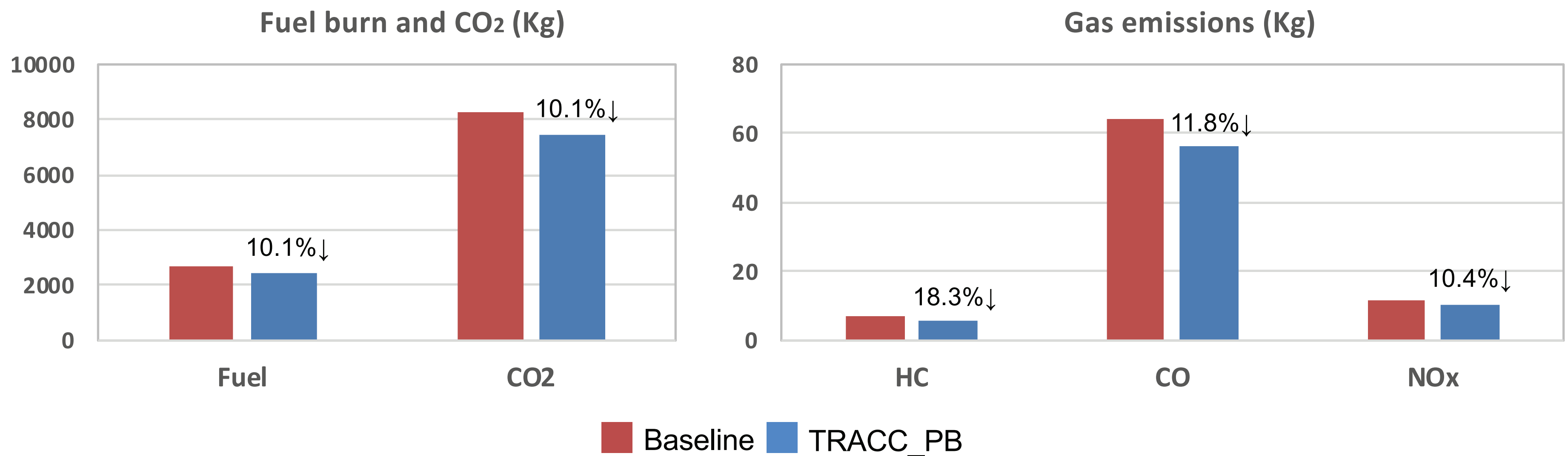
AMAT = Actual Movement Area entry Time

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)



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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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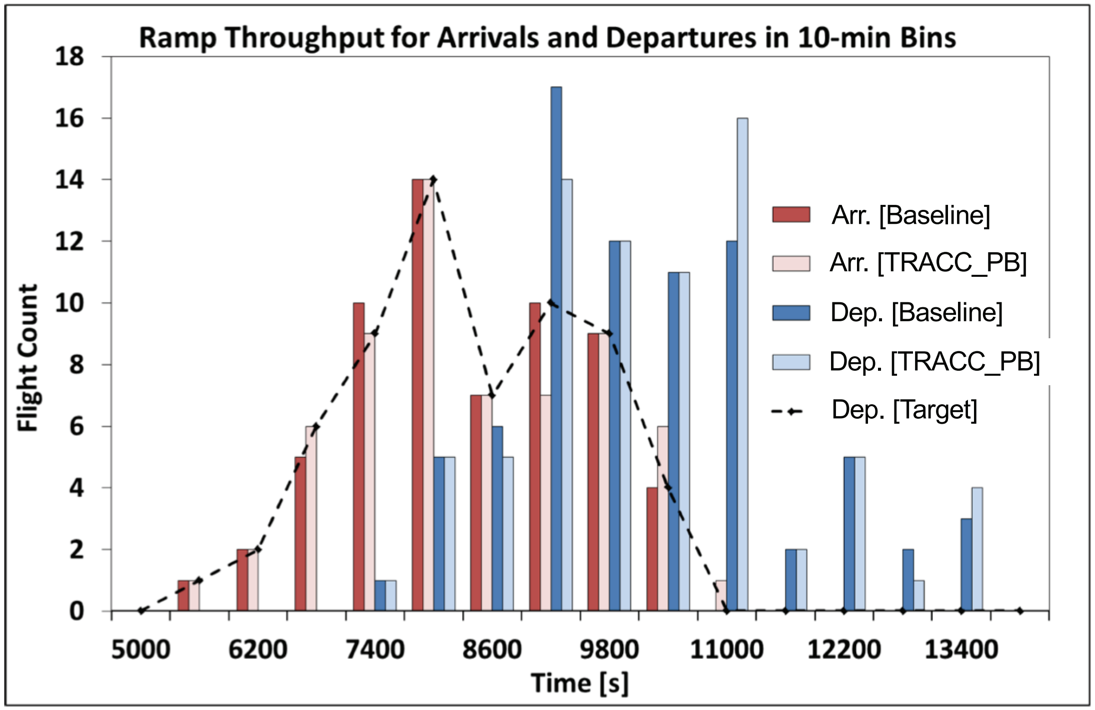
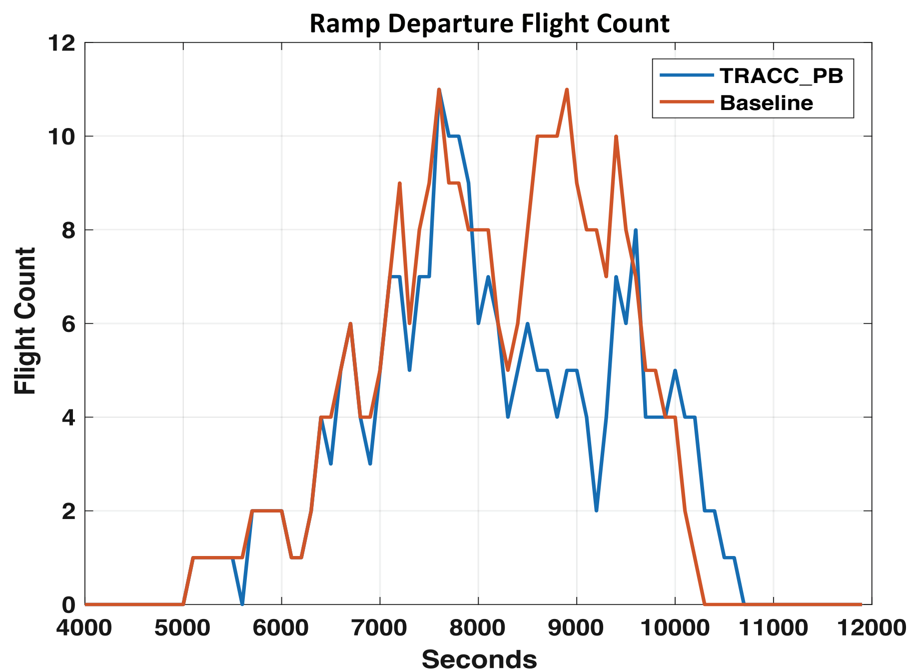
Back up slides

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

	Departures			**Arrivals**		
	Baseline	TRACC_PB	Difference %	Baseline	TRACC_PB	Difference %
Fuel (Kg)	2116.05	1739.68	17.8 ↓	2680.64	2410.19	10.1 ↓
CO_2 (Kg)	6517.43	5358.21	17.8 ↓	8256.36	7423.38	10.1 ↓
HC (Kg)	4.27	3.36	21.3 ↓	6.84	5.59	18.3 ↓
CO (Kg)	46.28	37.55	18.9 ↓	64.13	56.56	11.8 ↓
NO_x (Kg)	9.42	7.76	17.6 ↓	11.88	10.65	10.4 ↓

- 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