Quantifying the Effects of Departure and Flight Time Uncertainty on Urban Air Mobility Operations

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INTRODUCTION

Background

Advanced Air Mobility (AAM) [1]

- Initiative of the FAA, NASA, and industry partners to integrate new aircraft into the current Air Traffic Management (ATM) system
- Connect local, regional, and urban locations using modern aircraft, technologies, and operations

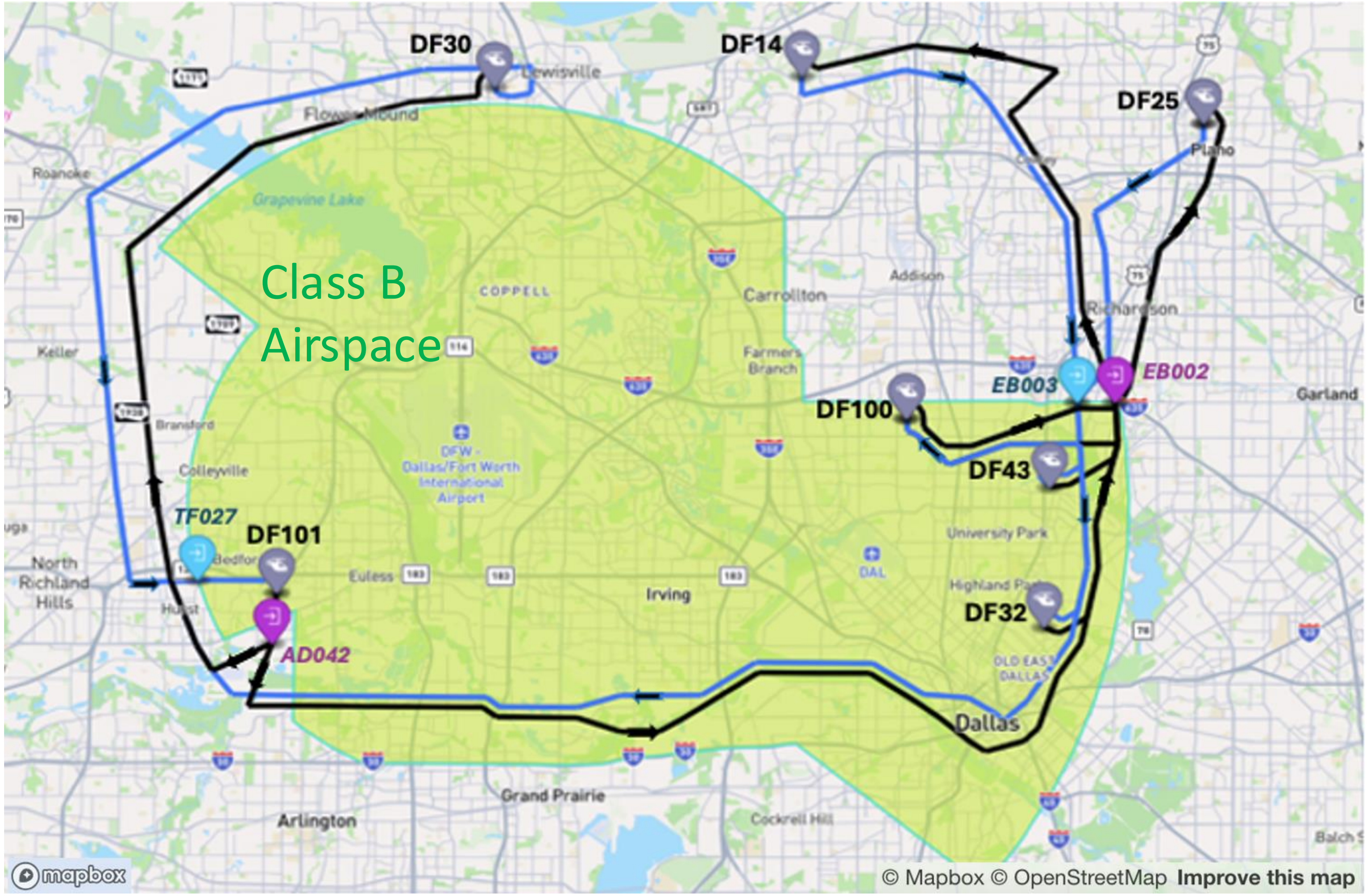
Urban Air Mobility (UAM) [1]

- Enable high density air traffic operations into, out of, and within an urban area
- A more **efficient** and **safe** air traffic management system for a new generation of aircraft
- Understand and reduce the conflict risks for this new generation of air traffic in the national airspace

[1] Federal Aviation Administration (FAA), “Urban Air Mobility: Concept of Operations v2.0,” version 2.0, April 2023.

Example UAM Route Map

Dallas-Fort Worth Metropolitan Area



Vertiports

Waypoints

Research Topic of Interest

Strategic conflict management

- Determine how to manage traffic throughout the entire route network and increase adherence to safety constraints, while maintaining traffic flow volume
- Expected to account for and manage uncertainty such as pre-departure delay

Uncertainty

- Pre-departure delays caused by late passengers, technical issues, and congestion at the vertiport
- Flight time variation can be caused by wind or other environmental factors
- Can negatively impact the safety and efficiency of air traffic, and can lead to conflicts, if not managed properly

Motivations & Objectives

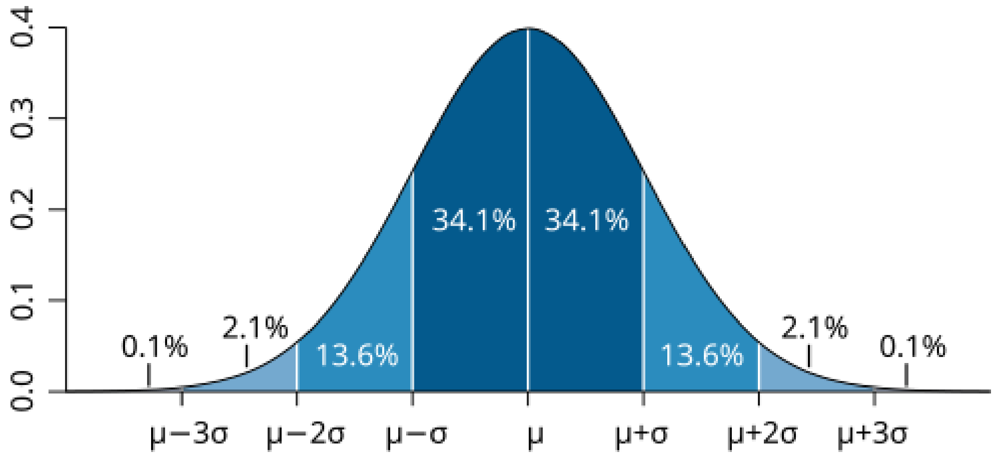
- Motivations
  - The study of uncertainty is an integral part of creating a new ATM system for UAM operations
  - Research in the space is lacking and incomplete

- Objectives
  1. Understand how to incorporate these delays within an existing UAM architecture
  2. Quantify the impact of departure time uncertainty and flight time uncertainty on the safety and efficiency of UAM operations
  3. Establish future research directions and provide basis for advanced scheduling algorithms for UAM

Uncertainty in Urban Air Mobility Operations

UNCERTAINTY METHODOLOGY

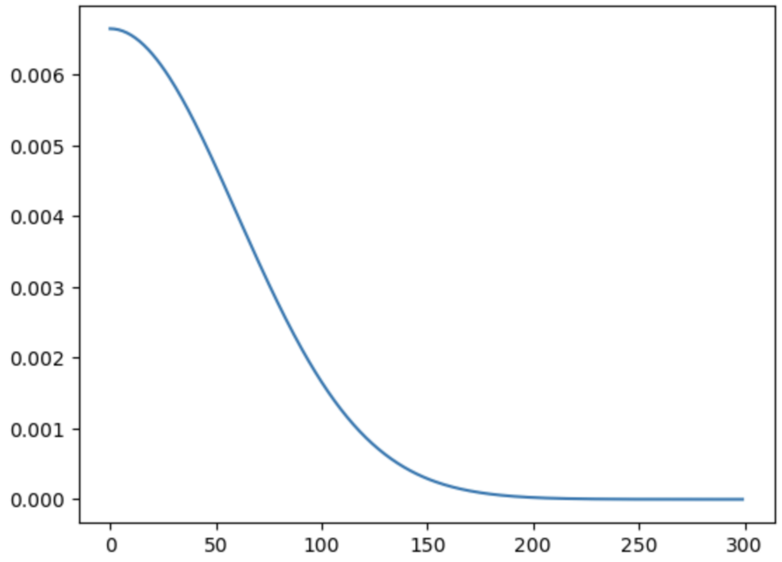
Normal Distribution



One method for understanding uncertainty for cases with limited real-world data is to model uncertainties using **normal distributions**

Normal Distributions are widely used for modeling continuous data and are a good form of modeling pre-departure delays, especially when there are no significant external factors causing delays

One-sided Normal Distribution



Study Setup

Uncertainty Study

- Simulate a large urban network of seven vertiports
- Run each scenario simulation 100 times
- Focus on the effects of departure & flight time uncertainty at peak network traffic to compare with the theoretical limits without uncertainty

Simulation Software

- The simulations presented use a fast-time simulation tool developed by NASA to support the testing and verification of new airspace services and platforms that may be used in UAM operations
- This software allows users to separately test any new airspace system or capability

UAM Simulation Tool for Airspace services Research (USTAR)

Purpose

UAM Simulation Tool for Airspace services Research (USTAR) is a **fast-time simulation tool** written in Python for conducting various simulations of UAM system architecture

Main Components[1]

FO

The Fleet Operator (FO) selects flights and performs dispatch duties

PSU

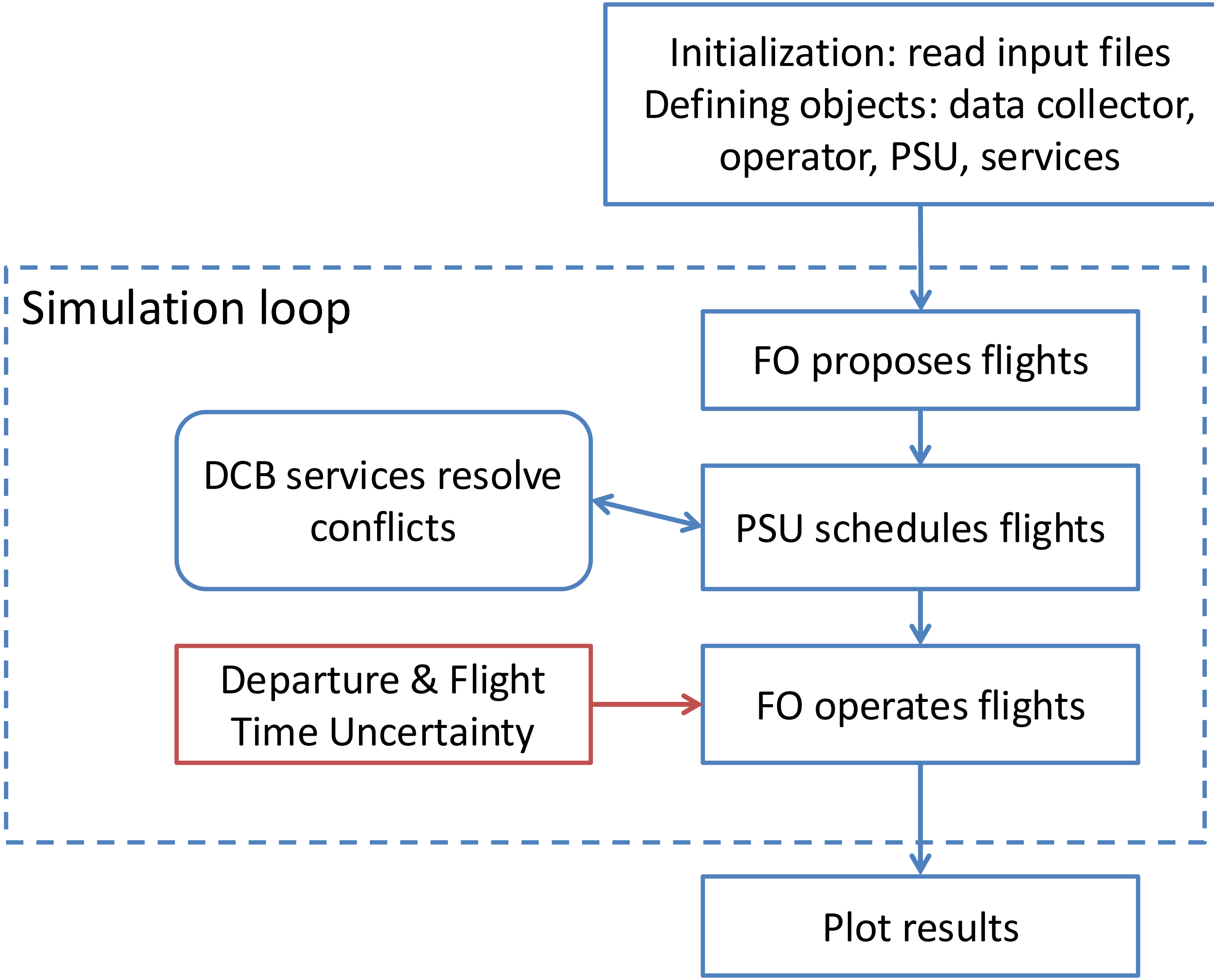
A Provider of Services for UAM (PSU) is the primary service/data provider for UAM stakeholders and the interface between federated UAM actors in the UAM ecosystem

DCB

The Demand-Capacity Balancing (DCB) algorithm ensures that predicted demand does not exceed the capacity of a resource

[1] *Federal Aviation Administration,* "Urban Air Mobility (UAM) Concept of Operations v2.0", April 2023, www.faa.gov/air-taxis/uam_blueprint.

Simulation Flowchart



PSU – Provider of Services for UAM

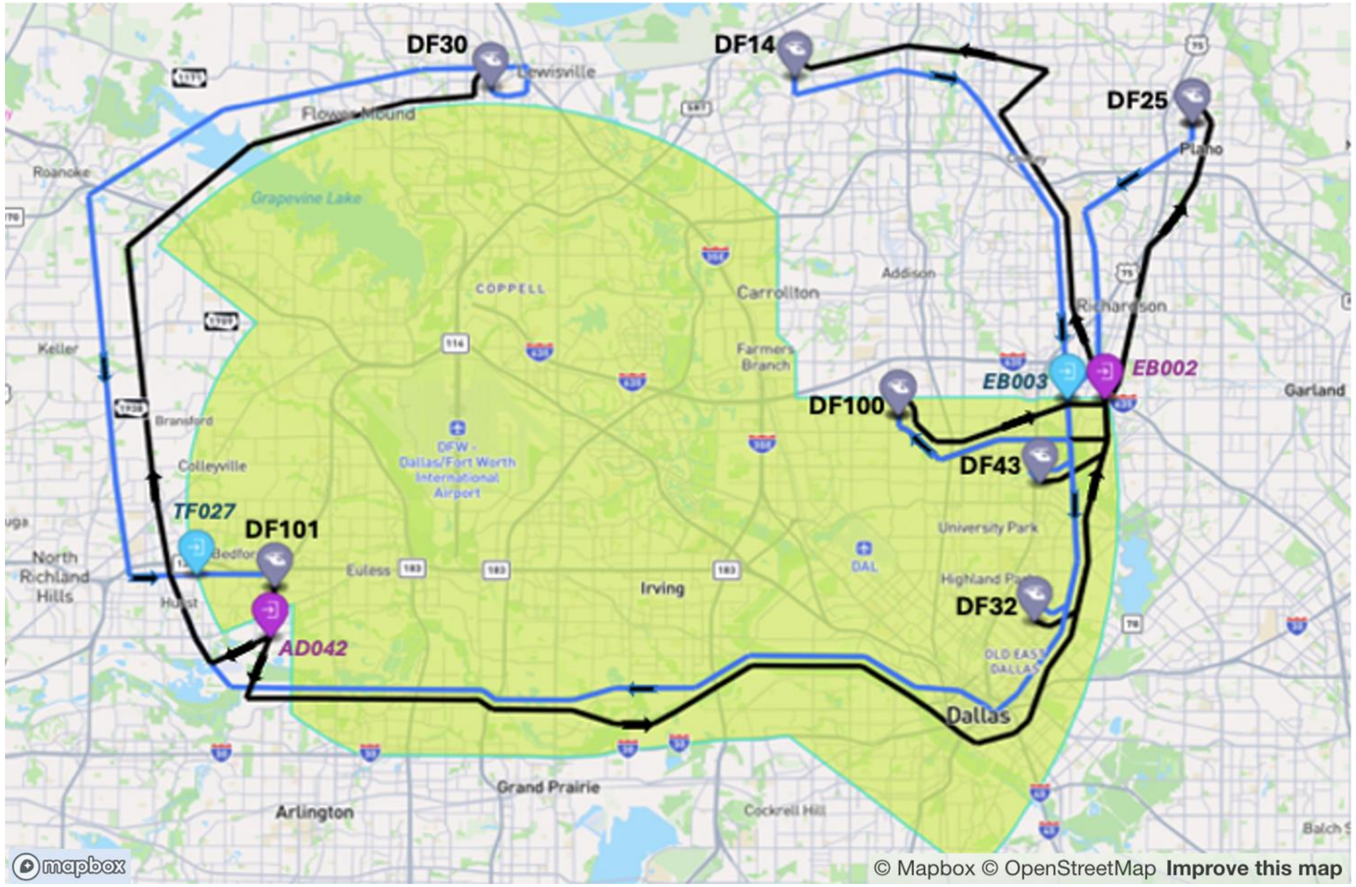
FO – Fleet Operator

DCB - Demand Capacity Balancing

Experimental Setup

Target Urban Area for Case Study

Dallas-Fort Worth Metropolitan Area



Scenario Parameters

7 Vertiports (indicated by prefix DF)

Each vertiport has a capacity of 2 operations per time bin

Each time bin represents a 12-minute time interval

60 flights in scenario (same aircraft types)

Methodology

Metrics and Measurement

Efficiency

Measured as the amount of **total delay** for all flights in a simulation

Safety

Measured as the number of observed **demand capacity imbalances** in a scenario

Methodology

One-sided Normal Distribution	Used to simulate departure time uncertainty with only late departures
Normal Distribution	Used to simulate departure time uncertainty with late and early departures
Departure + Flight Time Uncertainty	Normal distribution for departure time delay and flight time varied using a uniform distribution

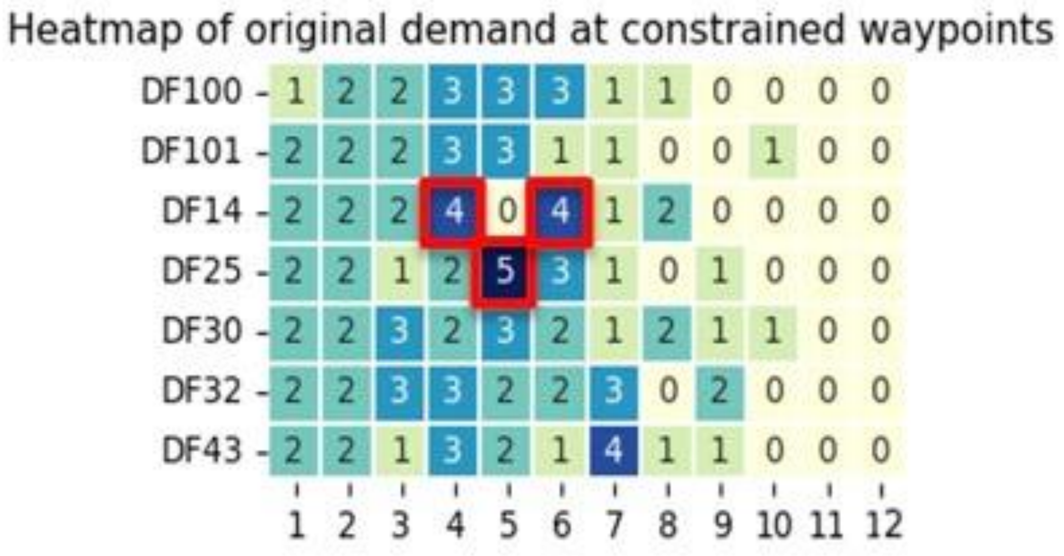
- Each scenario was run with varied standard deviations for the normal distribution of 60, 90, or 120 seconds
- Each of those instances were run 100 times and averaged out

Safety

RESULTS

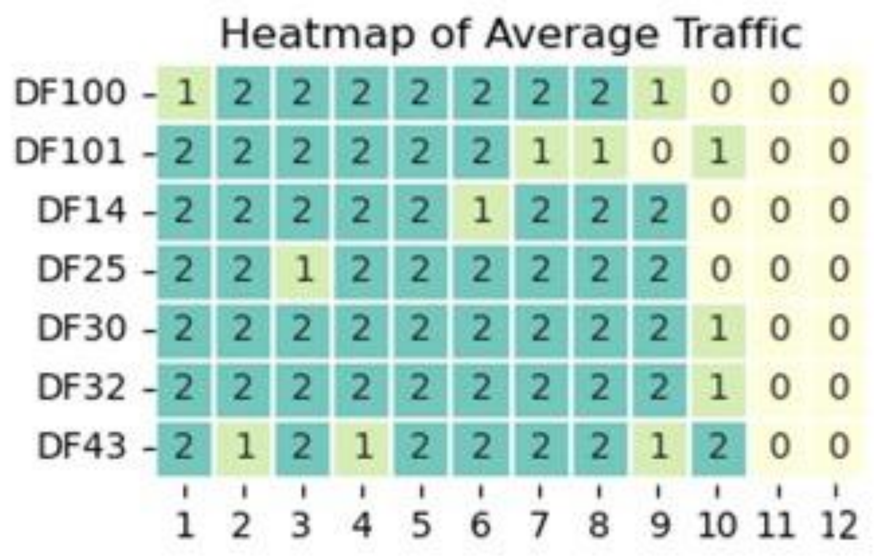
Traffic Distribution without Uncertainty

Original Demand



Demand at vertiports **before** DCB algorithm resolves conflicts

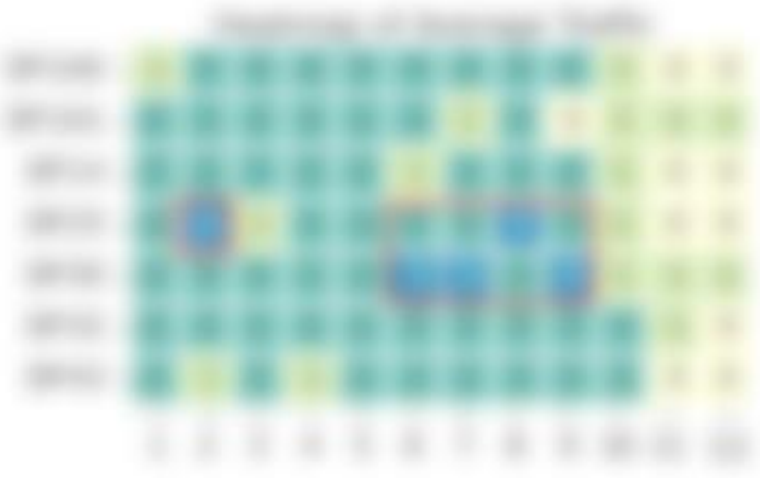
After Balancing

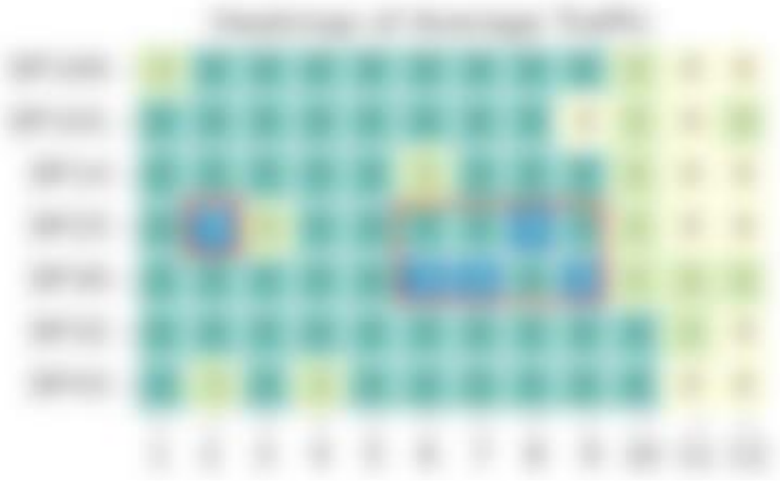


Demand at vertiports **after** DCB algorithm resolves conflicts

Demand Distribution Heatmaps for One-Sided Normal

Only Late Pre-Departure Uncertainty





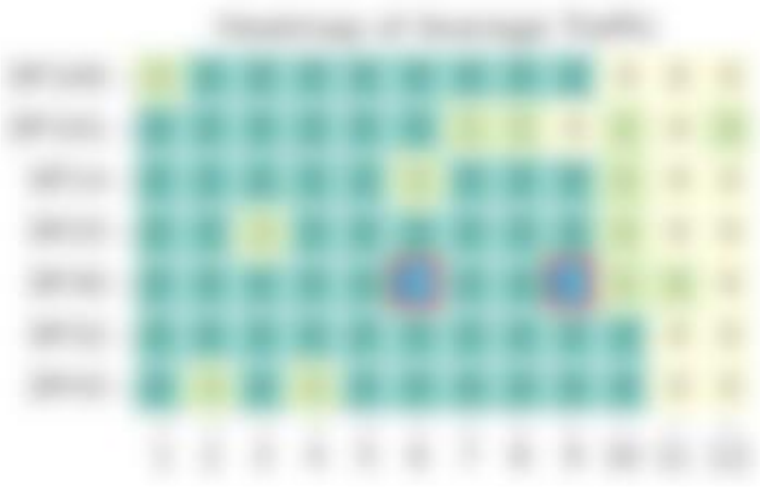
Standard deviation of 60 seconds

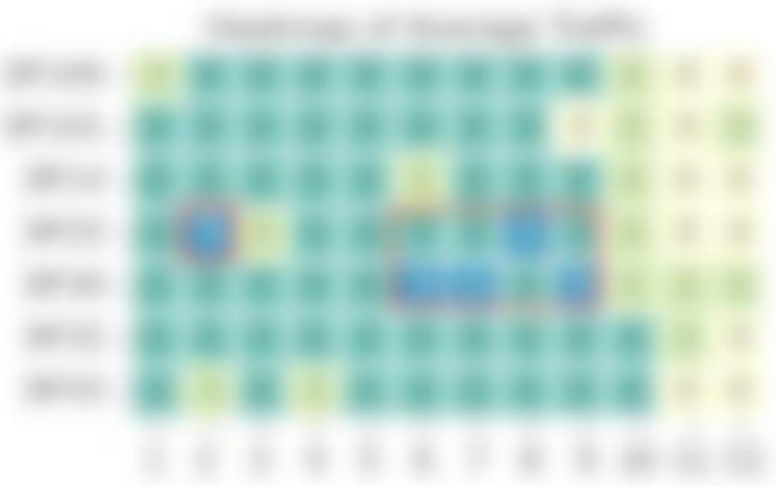
Standard deviation of 90 seconds

Standard deviation of 120 seconds

Demand Distribution Heatmaps for One-Sided Normal

Only Late Pre-Departure Uncertainty





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Standard deviation of 120 seconds

Demand Distribution Heatmaps for One-Sided Normal

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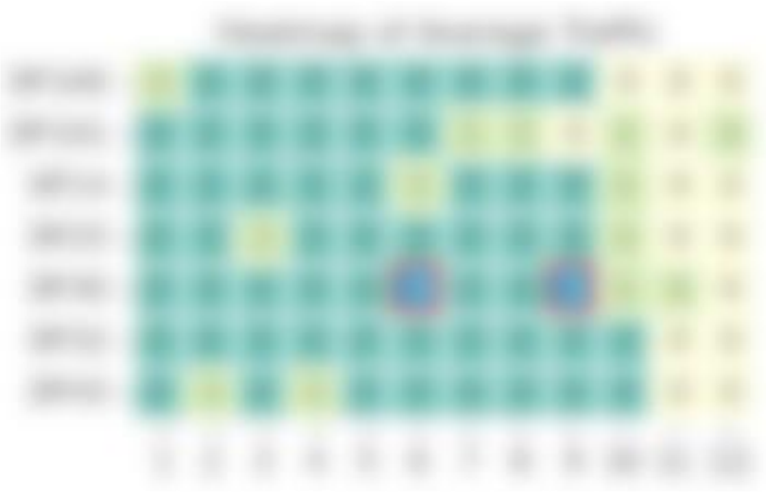
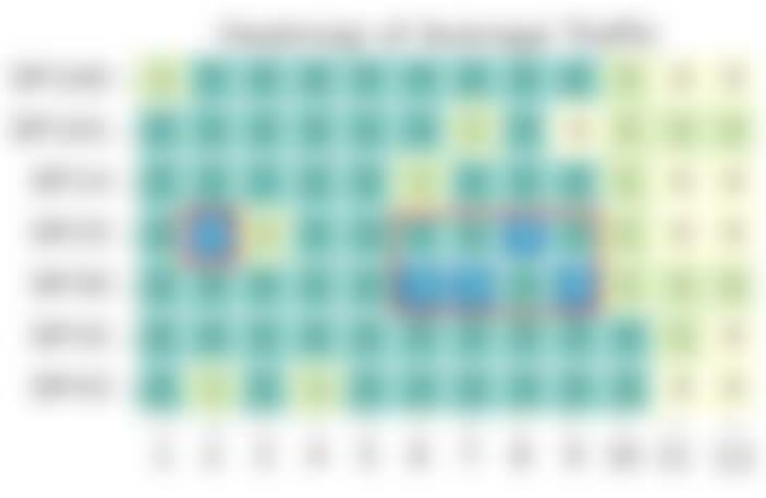


Standard deviation of 60 seconds

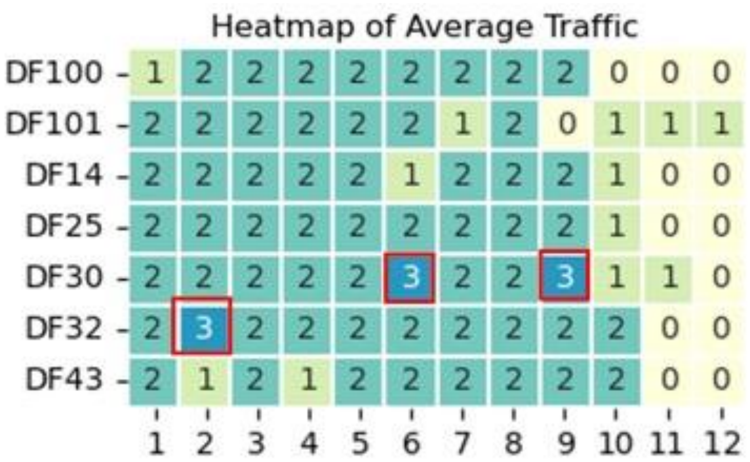


Standard deviation of 90 seconds

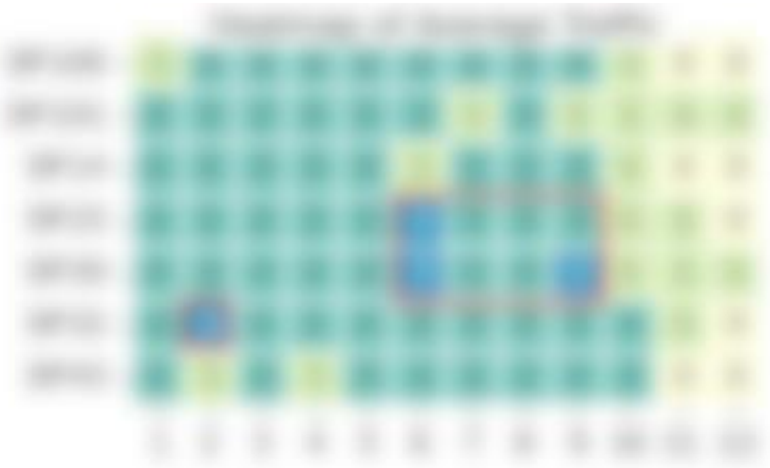
Standard deviation of 120 seconds

Demand Distribution Heatmaps for Full Normal Distribution

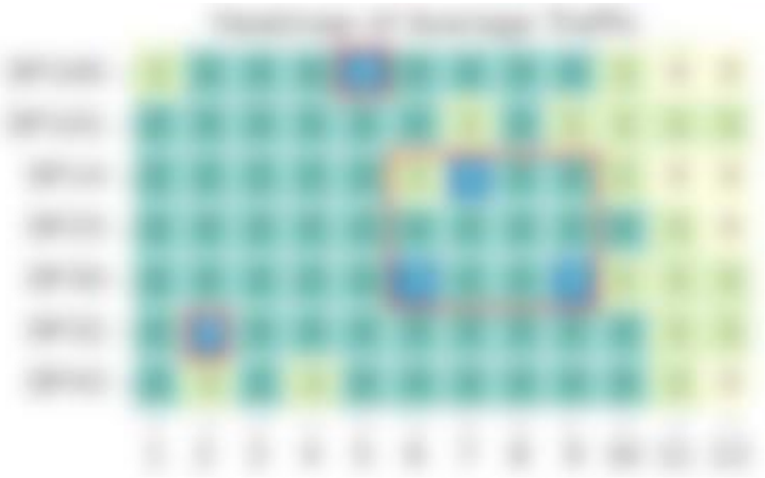
Both Early and Late Pre-Departure Uncertainty



Standard deviation of 60 seconds



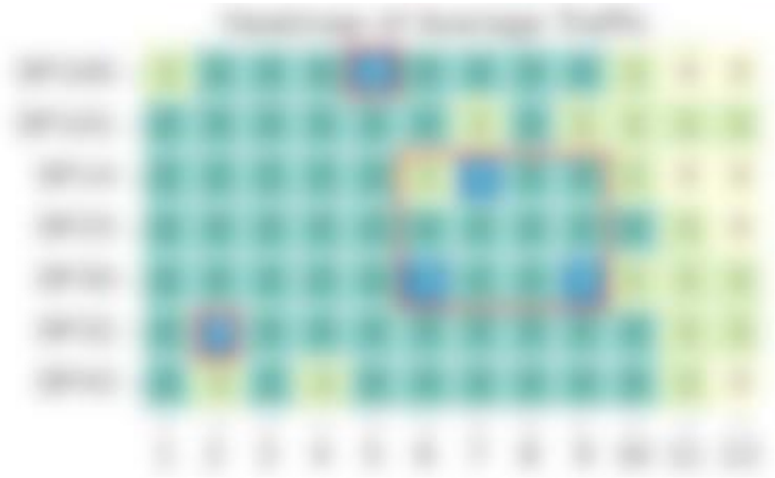
Standard deviation of 90 seconds



Standard deviation of 120 seconds

Demand Distribution Heatmaps for Full Normal Distribution

Both Early and Late Pre-Departure Uncertainty



Standard deviation of 60 seconds

Standard deviation of 90 seconds

Standard deviation of 120 seconds

Demand Distribution Heatmaps for Full Normal Distribution

Both Early and Late Pre-Departure Uncertainty

Standard deviation of 60 seconds

Standard deviation of 90 seconds

Standard deviation of 120 seconds

Demand Distribution Heatmaps for Departure + Flights Time Uncertainty

Pre-Departure and Flight Time Uncertainty

Standard deviation of 60 seconds

Standard deviation of 90 seconds

Standard deviation of 120 seconds

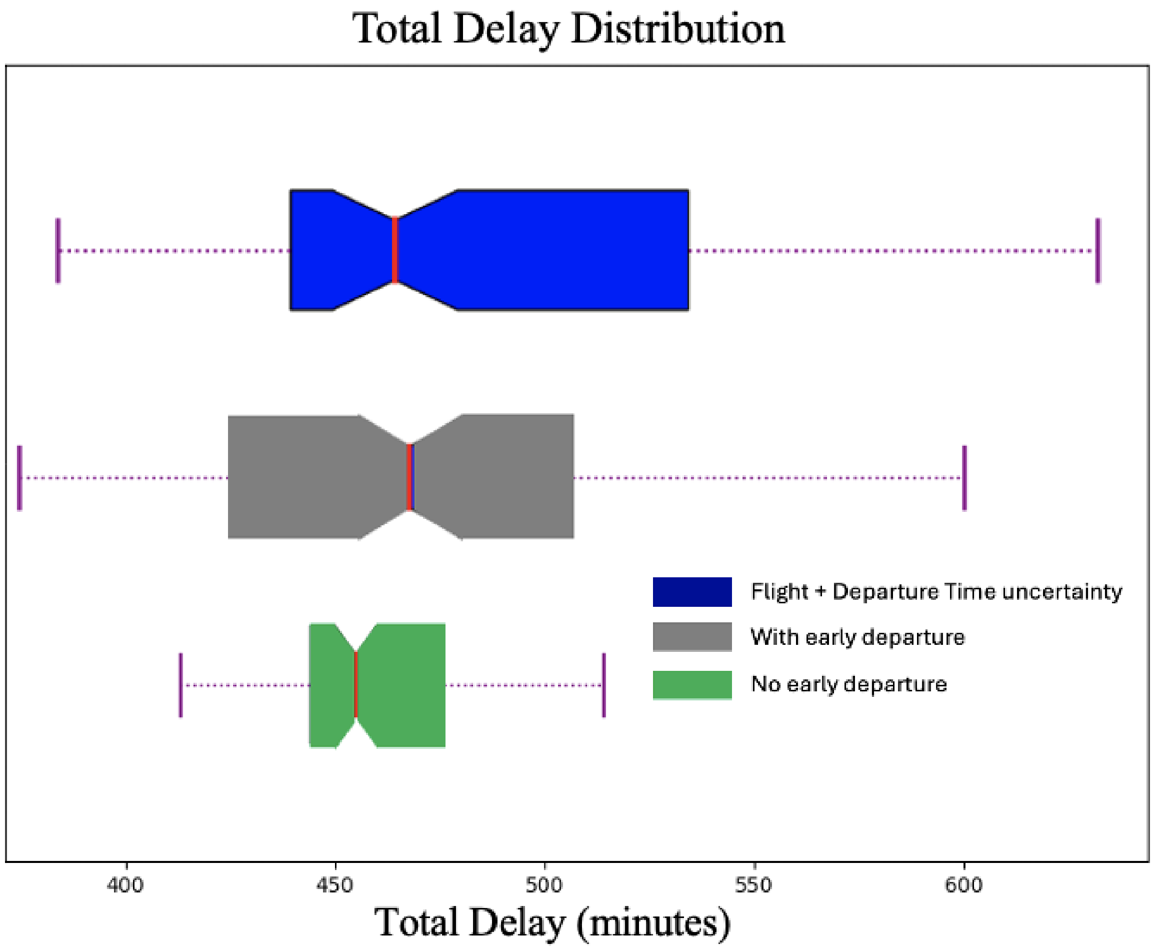
Impact

These demand capacity imbalances will cause safety issues that can lead to potential collisions and further delays to the route network

Efficiency

RESULTS

Distribution of Delays from Final Simulations



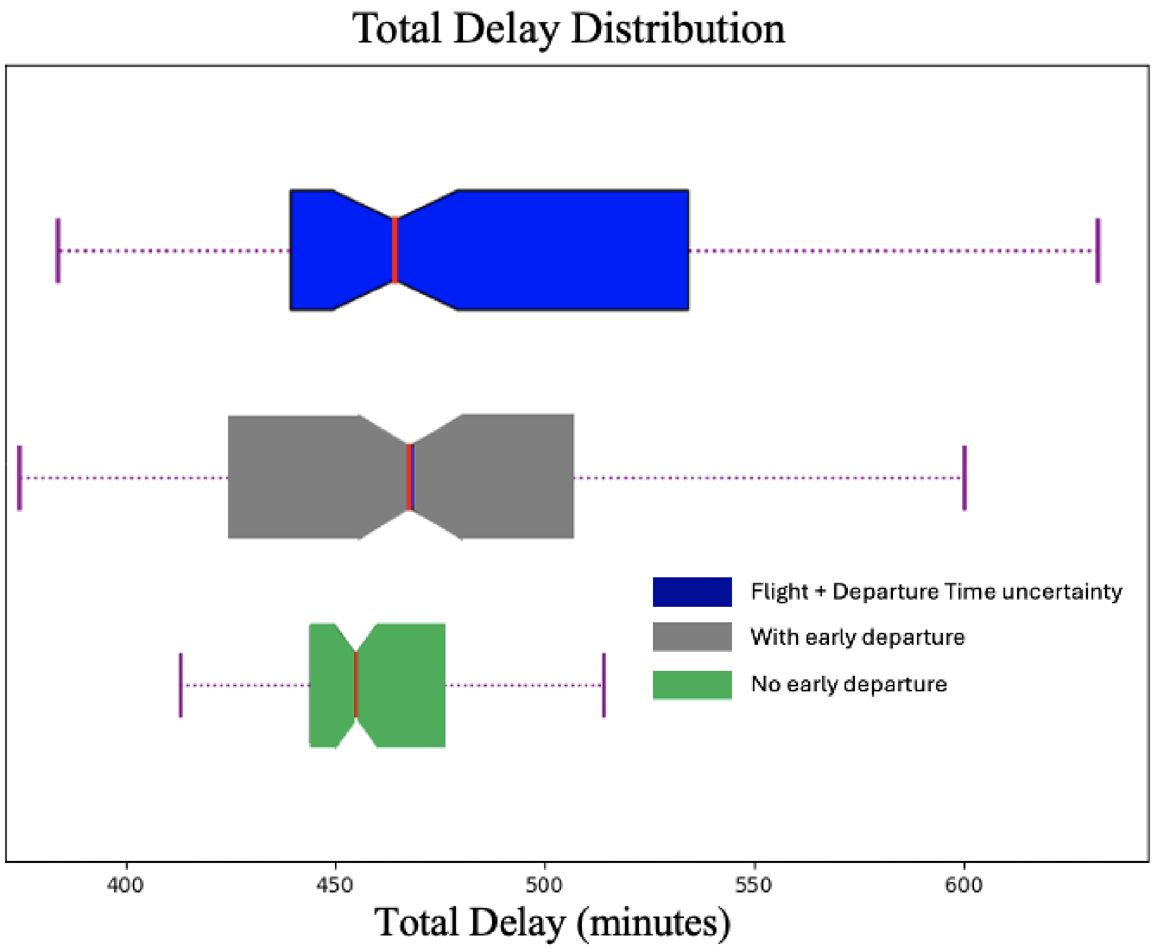
Distribution of Total Delay from Each Trial with Standard Deviation of 120 seconds

Distribution of total delay of 100 trials for each scenario

According to a one way analysis of variance (ANOVA) test, the means are statistically similar

Large maxima and 3rd quartile

Distribution of Delays from Final Simulations



Distribution of Total Delay from Each Trial with Standard Deviation of 120 seconds

Distribution of total delay of 100 trials for each scenario

According to a one way analysis of variance (ANOVA) test, the means are statistically similar

Large maxima and 3rd quartile

Impact

As high levels of uncertainty are introduced to the scenario, the range of possible outcomes increases and raises serious efficiency questions

Results for Uncertainty Simulations

Results of Departure Time Error Simulations					
Description	Standard Deviation (seconds)	With Early Departure Time	Mean of Total Delay (minutes)	Standard Deviation of Delay (minutes)	Increase in Total Delay
No Uncertainty	N/A	N/A	387.07	N/A	N/A
Departure Time Uncertainty (late departures only)	60	No	430.28	18.83	11.16%
	90	No	447.26	23.68	15.55%
	120	No	461.59	28.87	19.25%
Departure Time Uncertainty (with late and early departures)	60	Yes	420.63	24.36	8.67%
	90	Yes	448.08	46.75	15.76%
	120	Yes	472.80	56.46	22.15%
Departure + Flight Time Uncertainty	60	Yes	425.68	27.43	9.97%
	90	Yes	444.46	43.56	14.83%
	120	Yes	468.38	60.94	21.01%

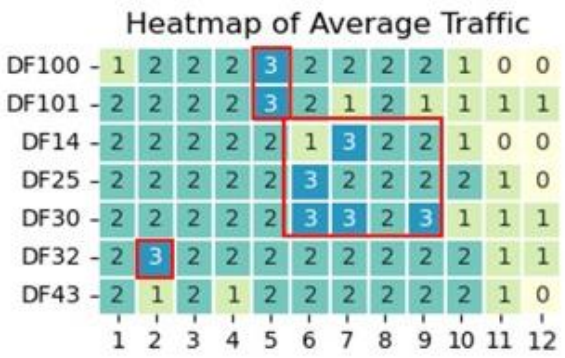
9-21% increase

Quantifying Uncertainty for UAM Operations

CONCLUSIONS

Analysis of Results

Safety



As shown in the results as delay was increased through various means the number of imbalances increased

Indicates uncertainty created demand capacity imbalances potentially leading to unsafe operational conditions

Efficiency

Results of Departure Time Error Simulations

Description	Simulation	Standard Deviation (seconds)	Increase in Total Delay
No Uncertainty	Base Scenario	N/A	N/A
Departure + Flight Time Uncertainty	#7	60	9.97%
	#8	90	14.83%
	#9	120	21.01%

Efficiency, as measured by total delay, was significantly decreased in the presence of uncertainty

There were increases in total delay between 9 - 21%

The decrease in efficiency will lead to higher costs of operation, and longer wait times

Summary

- Motivations
  - The study of uncertainty is an integral part of creating a new ATM system for UAM operations
  - NASA has identified this research as a topic of focus

- Main Objective
  - To quantify the impacts of departure and flight time uncertainty on UAM operations

- Results / Impact
  - Created a methodology to simulate uncertainty in existing UAM architectures
  - Quantified demand capacity imbalances which can lead to safety issues

- Contribution
  - Improve current solutions to mitigate these uncertainty effects
  - Help enhance overall UAM simulation capabilities

Future Work

Next Steps

1. Further uncertainty studies
    - Varied parameters (vertiport capacity, time bins, etc.)
    - Different traffic demand levels

2. Mitigation
    - Use the simulation results to create mitigation strategies

3. Implementation
    - Test and implement these mitigation strategies in strategic deconfliction algorithms

Thank You

Q&A

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