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*AIAA AVIATION 2025*

*ATS-13: Advanced Air Mobility II*

# ***Initial Estimation of the Number of UAM Operations at Aerodromes to Assess Operational Limits***

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(Purdue University)*

*Michael D. Patterson, Brandon E. Sells (NASA)*

*Thursday, July 24, 2025 | 3:30pm*

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SYSTEMS<sub>IN</sub> AEROSPACE**

# Bottom Line Up Front

## Challenge

- Urban Air Mobility (UAM) faces numerous operational challenges and limits, one of which could be aerodrome throughput
- Modifying existing aviation infrastructure for UAM provides potential pathway to near-term operations, but it is unclear how many operations this infrastructure can support

## Summary of Work

- Implemented throughput modelling involving gates and Touchdown and Lift-Off (TLOF) pads in the Chicago metro area
- Explored nine aerodrome locations, with a plausible number of pads determined by spatial constraints
- Estimated number of operations that could be fulfilled under multiple operating assumptions and with a varying number of gates

## Importance

- Provides a first order estimate of number of UAM flights that existing facilities could serve
- Provides insights on infrastructure demands, temporal spread of operations, and peak capacities
- Provides a criteria to identify locations where more gates or TLOF pads may be needed

## Takeaways

- Commuter patterns tend to create periods of peak UAM flights that may require additional capacity up to 6x the usual average demand
- Per our assumptions, the Chicago nine-aerodrome network can only accommodate about 32.7% of the total unconstrained demand with existing infrastructure



# Urban Air Mobility (UAM) Overview

**UAM may potentially bring faster passenger and freight travel within urban regions**

- The concept of urban air mobility (UAM) focuses on leveraging novel aviation capabilities for transportation within metropolitan areas
  - Covers missions typically under 100 km (62 miles) in length
  - Often proposed with electric vertical takeoff and landing (eVTOL) aircraft
  - Involves multi-modal transport (i.e., combination of different transport modes, such as walking)
- Stakeholders in UAM operations include urban planners, local and regional communities, and aircraft manufacturers
- UAM is a system of systems (SoS): UAM implementation involves interactions across the realms of technology, operations, policy, and economics



# Urban Air Mobility (UAM) Operational Limits Study

## Purdue UAM Operational Limits Group Efforts To-Date

- UAM operational limits are factors that may inhibit large-scale UAM operations
- Our previous studies have focused on analyzing and quantifying UAM operational limits regarding:
  - Weather
  - CO<sub>2</sub> emissions
  - Cargo operations
  - Ridesharing considerations
- To investigate these limits, we developed a computational framework that analyzes daily trips within metropolitan areas
  - Solves for trip mode preferences
  - Compares between non-ridesharing UAM vs ridesharing-enabled UAM operations

### Evaluating Impact of Operational Limits by Estimating Potential UAM Trips in an Urban Area

Apoorv Maheshwari\*, Brandon E. Sells\*, Stephanie Harrington\*, Daniel A. DeLaurentis<sup>†</sup> and William A. Crossley<sup>†</sup>

*Research Article*

### Modeling CO<sub>2</sub> Emissions from Trips using Urban Air Mobility and Emerging Automobile Technologies

Sai V. Mudumba, Hsun Chao, Apoorv Maheshwari, Daniel A. DeLaurentis, and William A. Crossley

### Weather Impact Assessment for Urban Aerial Trips in Metropolitan Areas

Hsun Chao\*, Apoorv Maheshwari\*, Daniel A. DeLaurentis<sup>†</sup>, and William A. Crossley<sup>†</sup>

### EXPLORING RIDESHARING IN PASSENGER URBAN AIR MOBILITY: A COMPARATIVE ANALYSIS

Adler Edsel<sup>1</sup>, Somrick Das Biswas<sup>1</sup>, Michael Kilbourne<sup>2</sup>, Rishikesh Gadre<sup>2</sup>, Spruha Vashi<sup>2</sup>, Kshitij Mall<sup>3</sup>, William A. Crossley<sup>4</sup>, Daniel A. DeLaurentis<sup>5</sup>, Michael D. Patterson<sup>6</sup> & Brandon E. Sells<sup>6</sup>

### A System-of-Systems Approach to Analyzing Future Advanced Air Mobility Cargo Operations

Nicholas I. Gunady

Seejay R. Patel

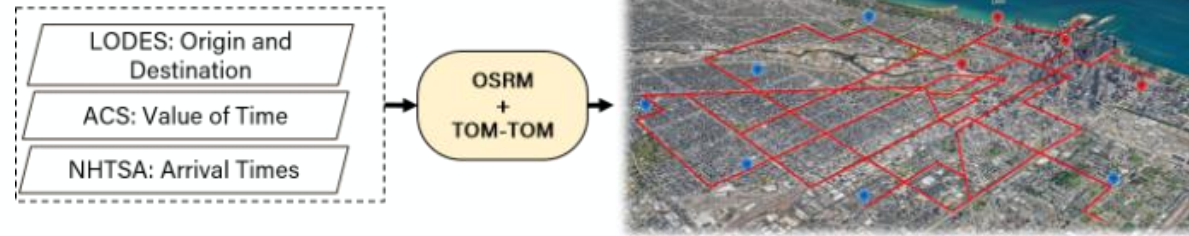
Daniel DeLaurentis



# Trip Generation

## Generating commuter trips in the Chicago Metro Area

- Commuter trips compiled using LODES, ACS, NHTSA, OSRM & TomTom

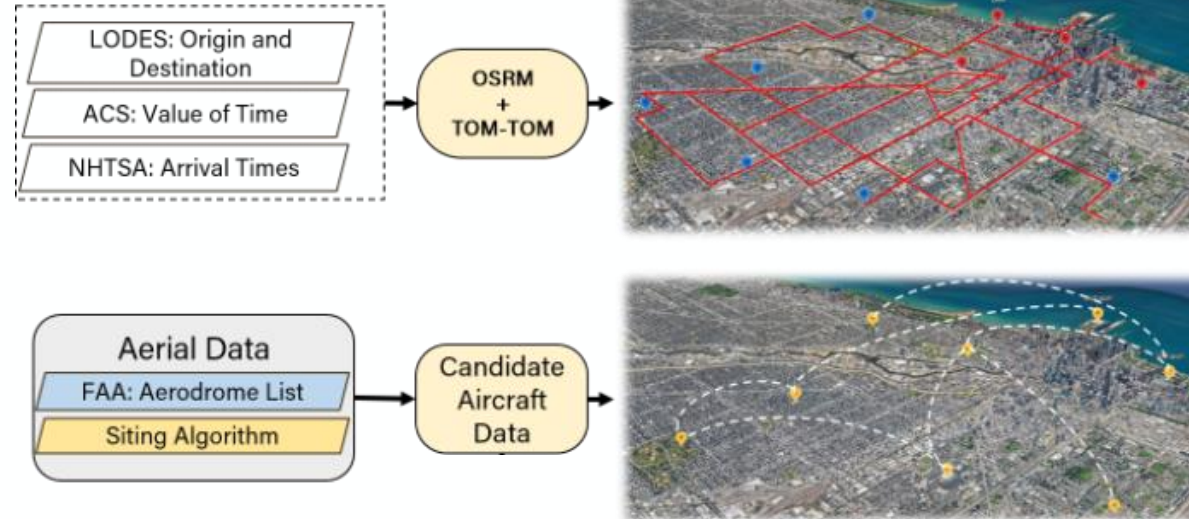


LODES: Longitudinal Employer-Household Dynamics Origin-Destination Employment Statistics  
 ACS: American Community Survey  
 NHTSA: National Highway Traffic Safety Administration  
 OSRM: Open Street Routing Machine  
 FAA: Federal Aviation Administration  
 PANVEL: Passenger Aggregation Network with Very Efficient Listing

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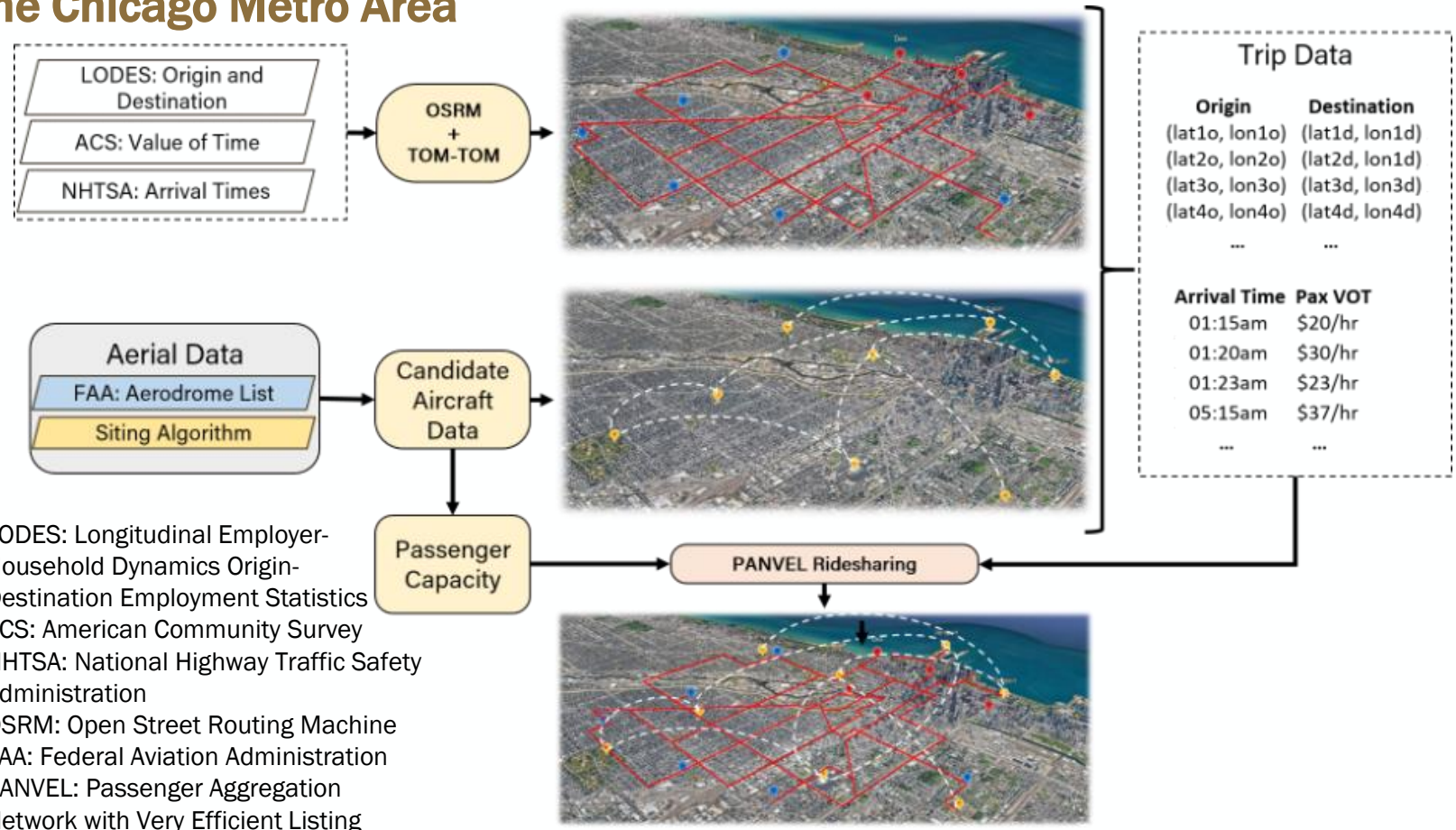


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- Commuter trips compiled using LODES, ACS, NHTSA, OSRM & TomTom
- Aerial network generated using FAA data & siting algorithm
- UAM-preferred trips created by linking road & air networks
- Ridesharing groups passengers into 23,262 daily flights



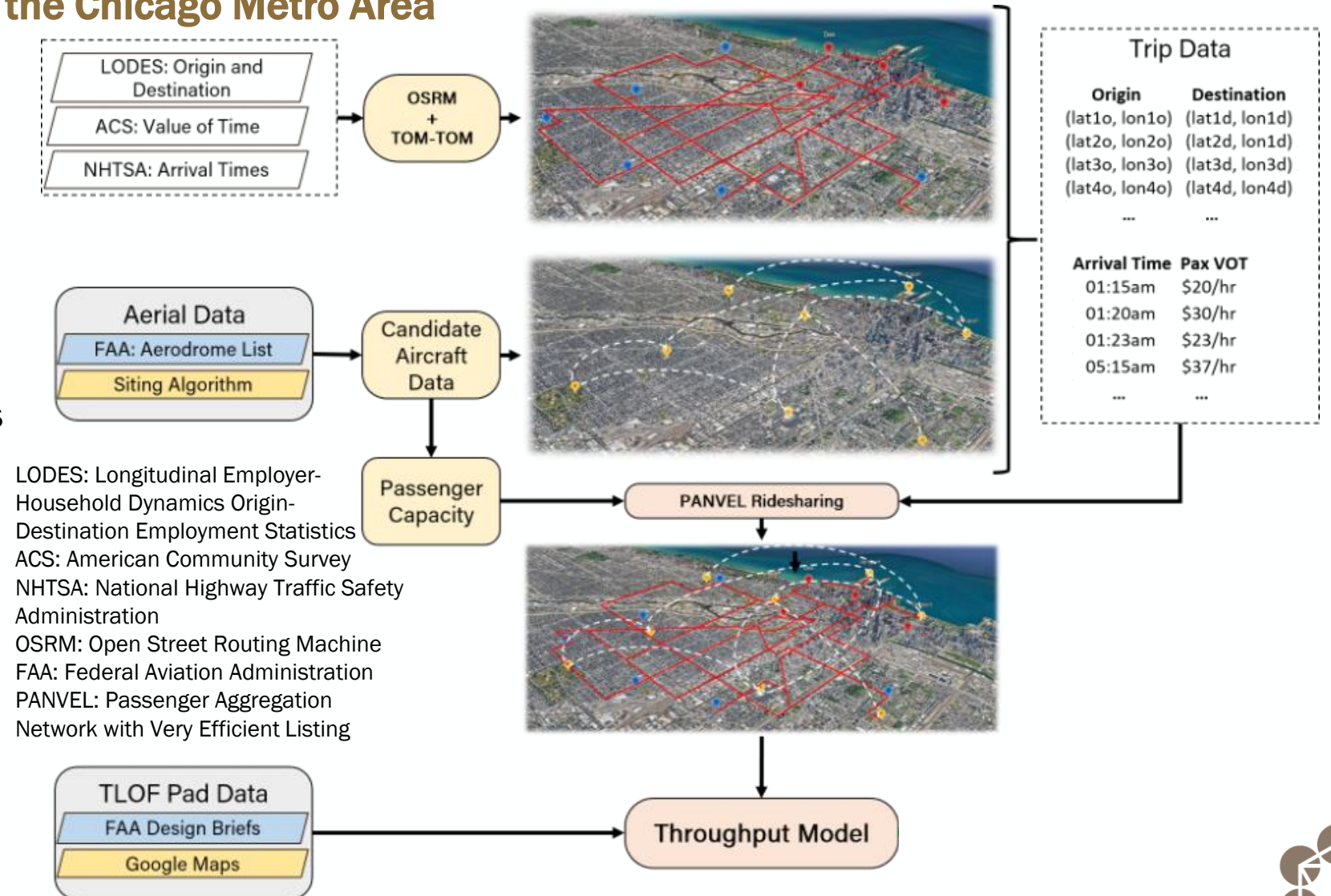
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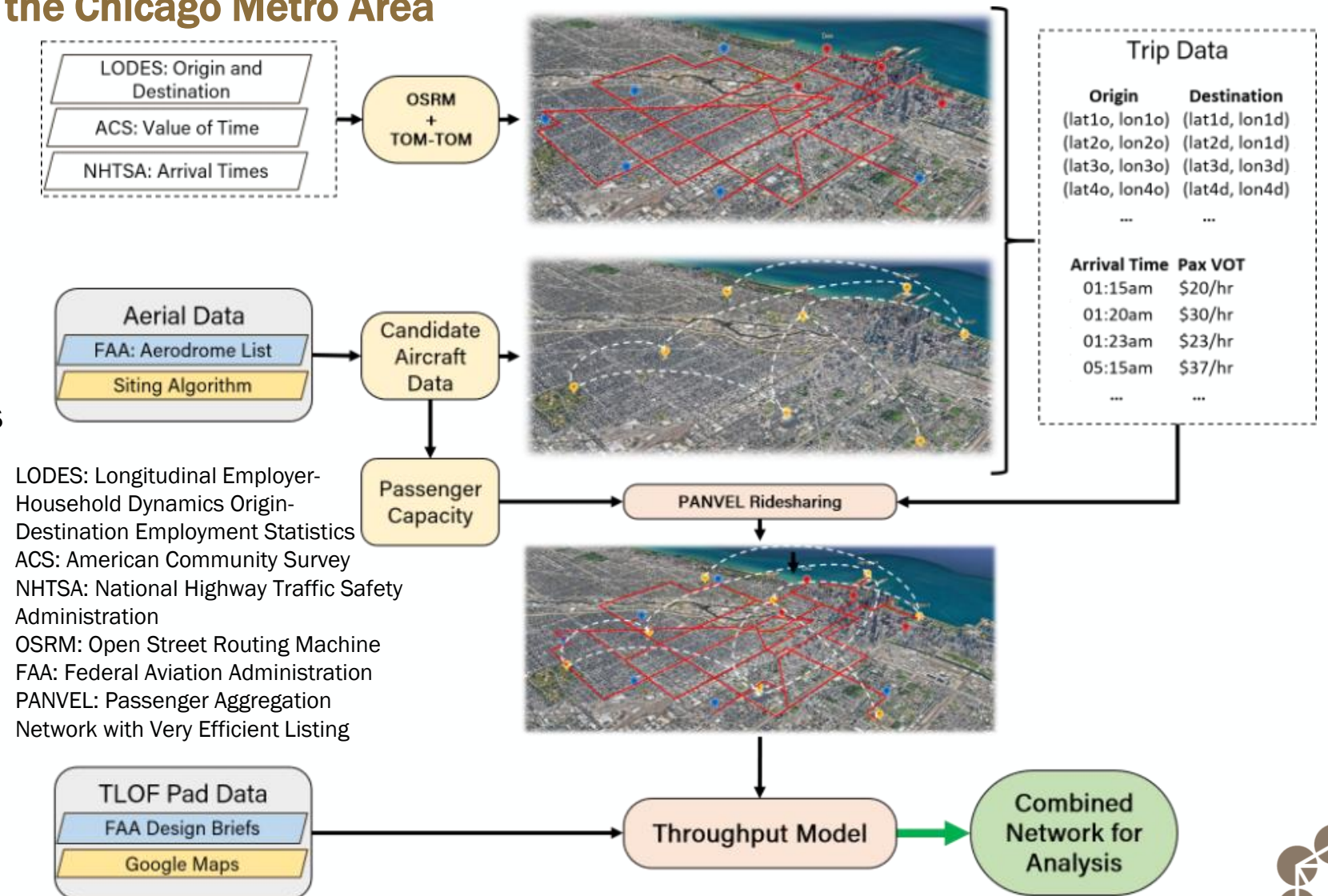
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- Flights sorted by aerodrome arrivals/departures



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- TLOF pads & gates estimated for 9 aerodromes
- Flights sorted by aerodrome arrivals/departures
- Each flight marked as 'fulfilled' or 'unfulfilled' based on pad/gate availability



# Throughput Methodology

## Flow of Operations

Assumptions made:

Enplanement: 7 mins

Taxi (Gate to TLOF pad): 2 mins

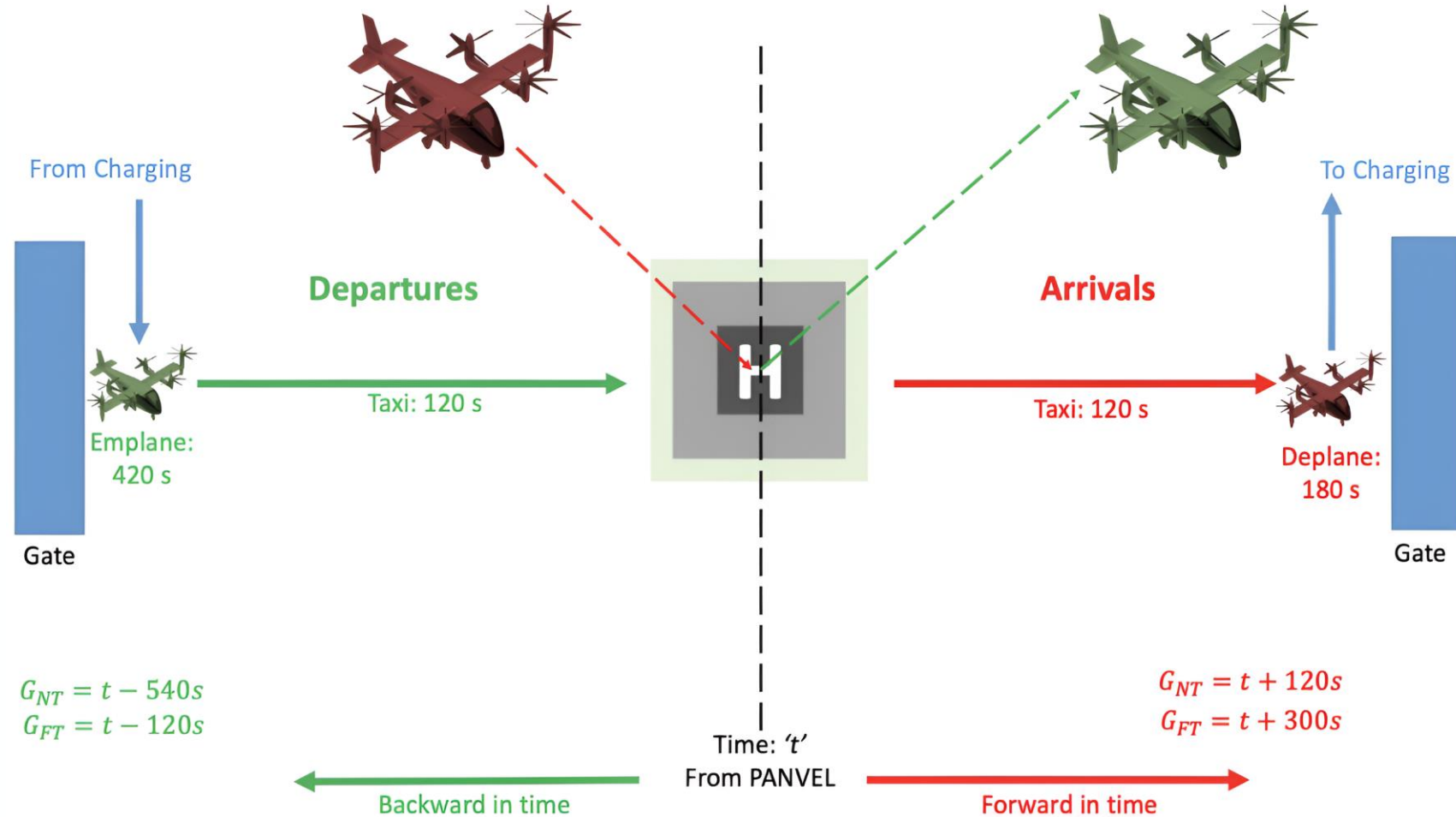
Inter-departure duration: 30s

VFR inter-arrival duration: 30s

IFR inter-arrival duration: 1min 30s

Taxi (TLOF pad to Gate): 2 mins

Deplanement: 3 mins



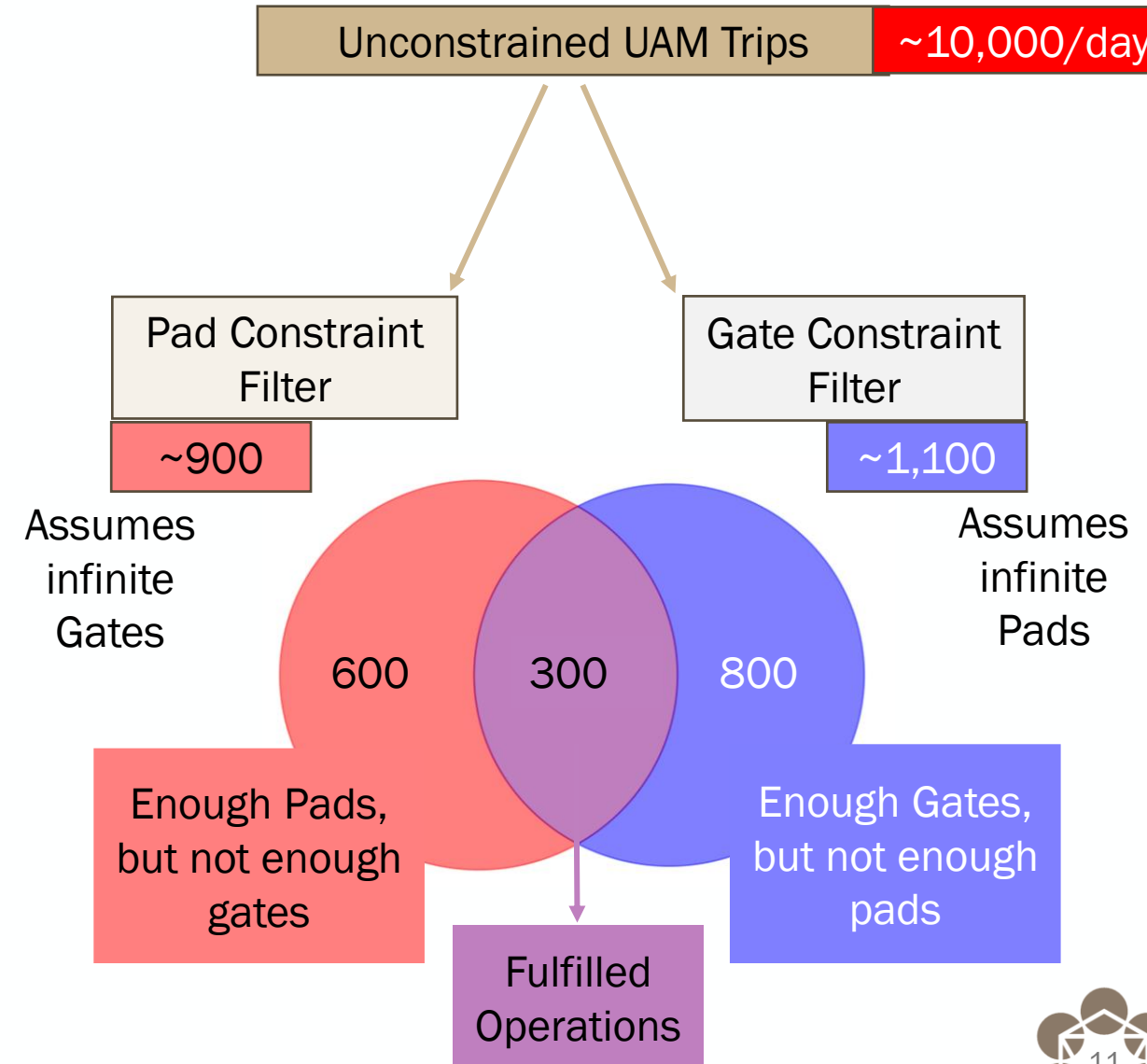
# Throughput Methodology

## Gates and TLOF pads

- Arrivals require TLOF pad first and then a gate
- Departures need a gate first and then a TLOF pad
- Reserving gates/pads exclusively for arrivals/departures would lead to non-optimal throughput)
- Gate and TLOF pad allotments happen in parallel
  - Ensures that pads and gates are allotted dynamically to meet arrival or demand surges
- Set of operations that are allotted both a gate and TLOF pad are 'fulfilled'

## Assumptions

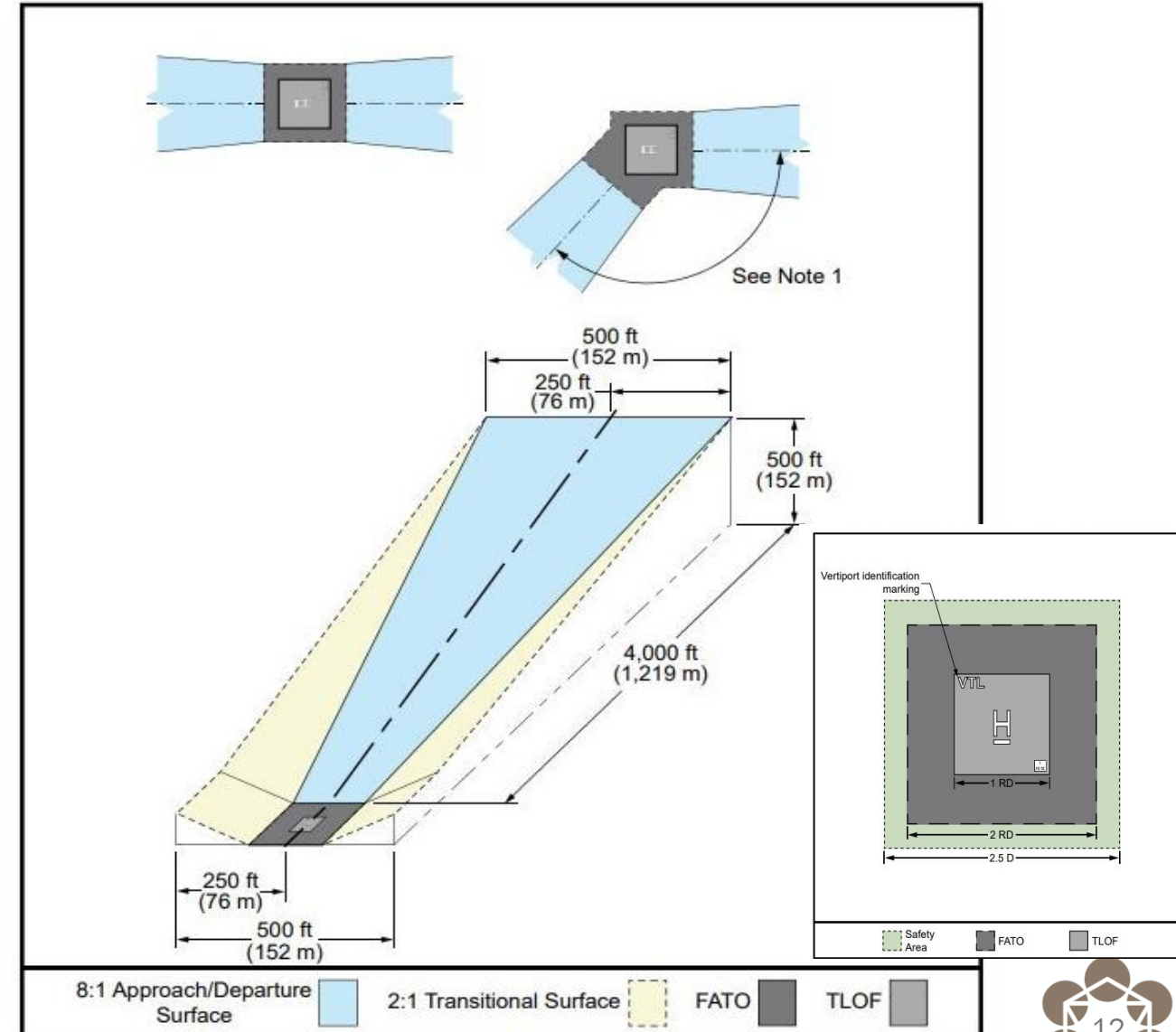
- Network and feedback effects not considered
- Delays or off-nominal effects not considered
- Deadhead flights not considered; aircraft flow is unbalanced



# Estimating Number of TLOF Pads

## FATO/TLOF Pad Guidance

- Good-faith guesstimate of TLOF pad capacity at existing aerodromes
- FAA vertiport design guidance<sup>1</sup> used to infer plausible pad counts
- Gates estimated using a 4:1 gate-to-pad heuristic
- FAA separation rules guide pad siting:
  - 500–700 ft from active runways (based on MTOW)
  - 200 ft between pad centers, 135° minimum between approach paths
  - 8:1 slope for approach/departure paths
- Satellite imagery and FAA diagrams used for siting; placements may affect taxiways or hangars



**Aim: Support high-level throughput analysis, not detailed aerodrome design**

<sup>1</sup>FAA Engineering Brief No. 105A, Vertiport Design, Supplemental Guidance to Advisory Circular 150/5390-2D, *Helicopter Design* [[https://www.faa.gov/airports/engineering/engineering\\_briefs/eb\\_105a\\_vertiports](https://www.faa.gov/airports/engineering/engineering_briefs/eb_105a_vertiports)]

# TLOF Pad Placement

## Example: Chicago Executive Airport

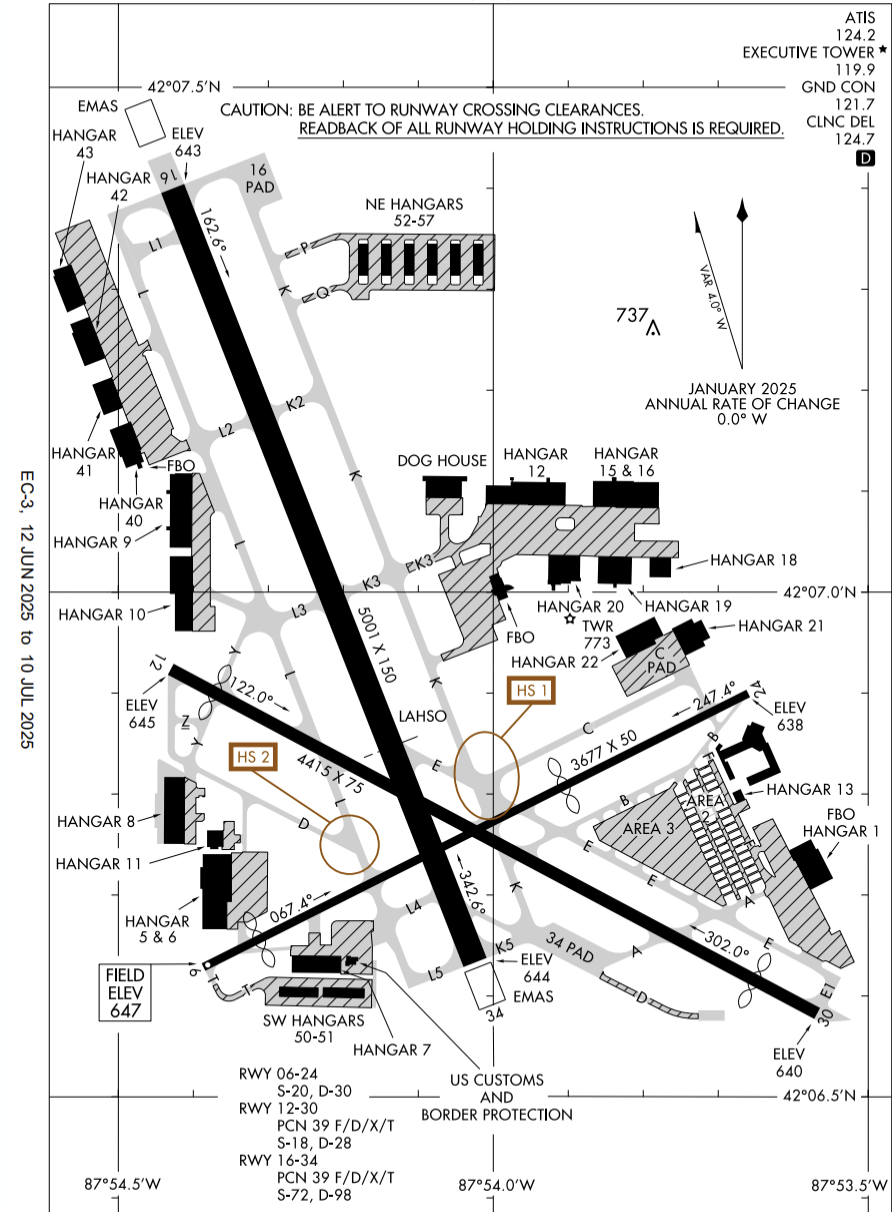
- 3 Runways: [16/34], [12/30], [6/24]

25107

AIRPORT DIAGRAM

AL-5028 (FAA)

CHICAGO EXEC (PWK)  
CHICAGO/PROSPECT HEIGHTS/WHEELING, ILLINOIS



AIRPORT DIAGRAM

CHICAGO/PROSPECT HEIGHTS/WHEELING, ILLINOIS  
CHICAGO EXEC (PWK)

25107



# TLOF Pad Placement

## Example: Chicago Executive Airport

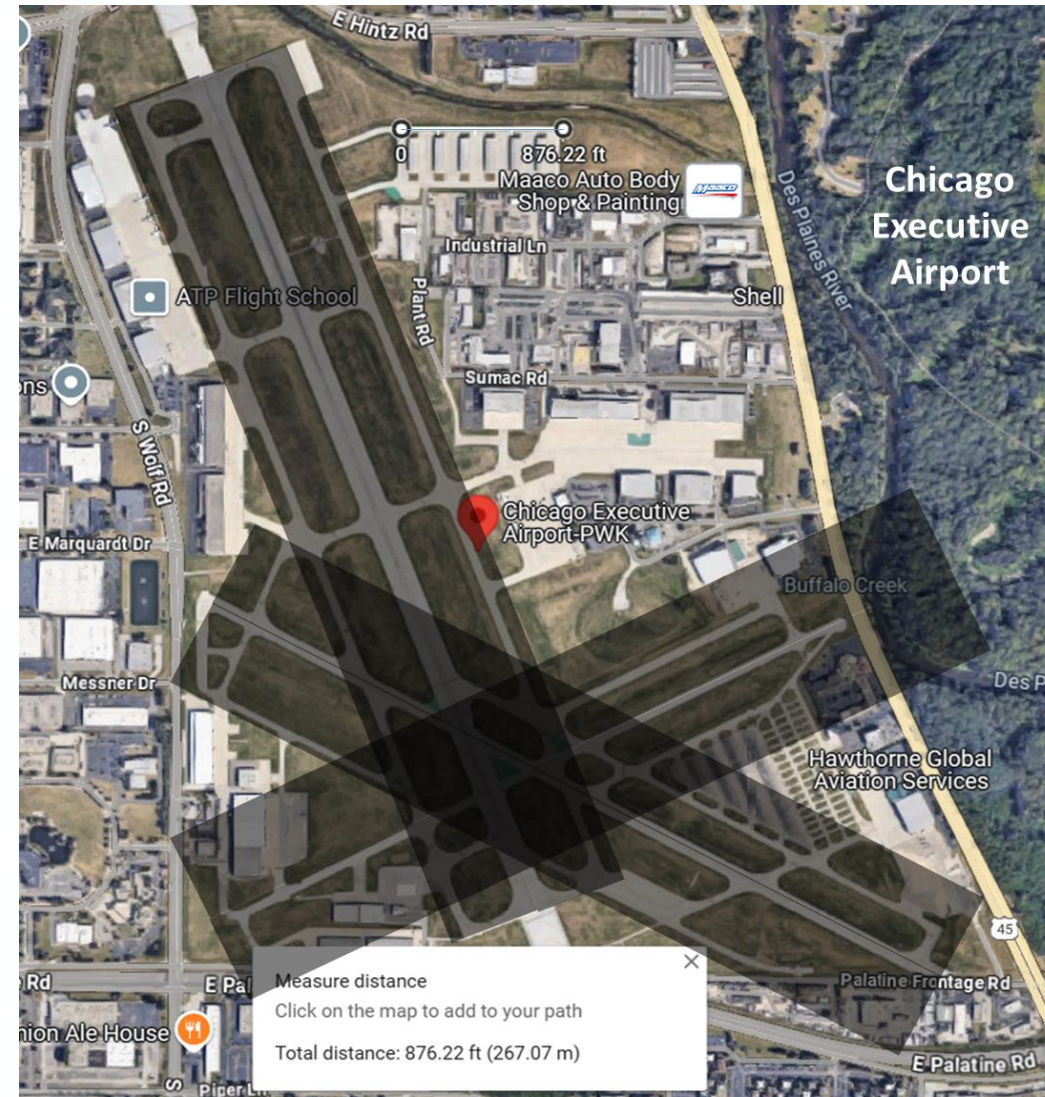
- 3 Runways: [16/34], [12/30], [6/24]
- No pads to be located within 500 ft. of the runways



# TLOF Pad Placement

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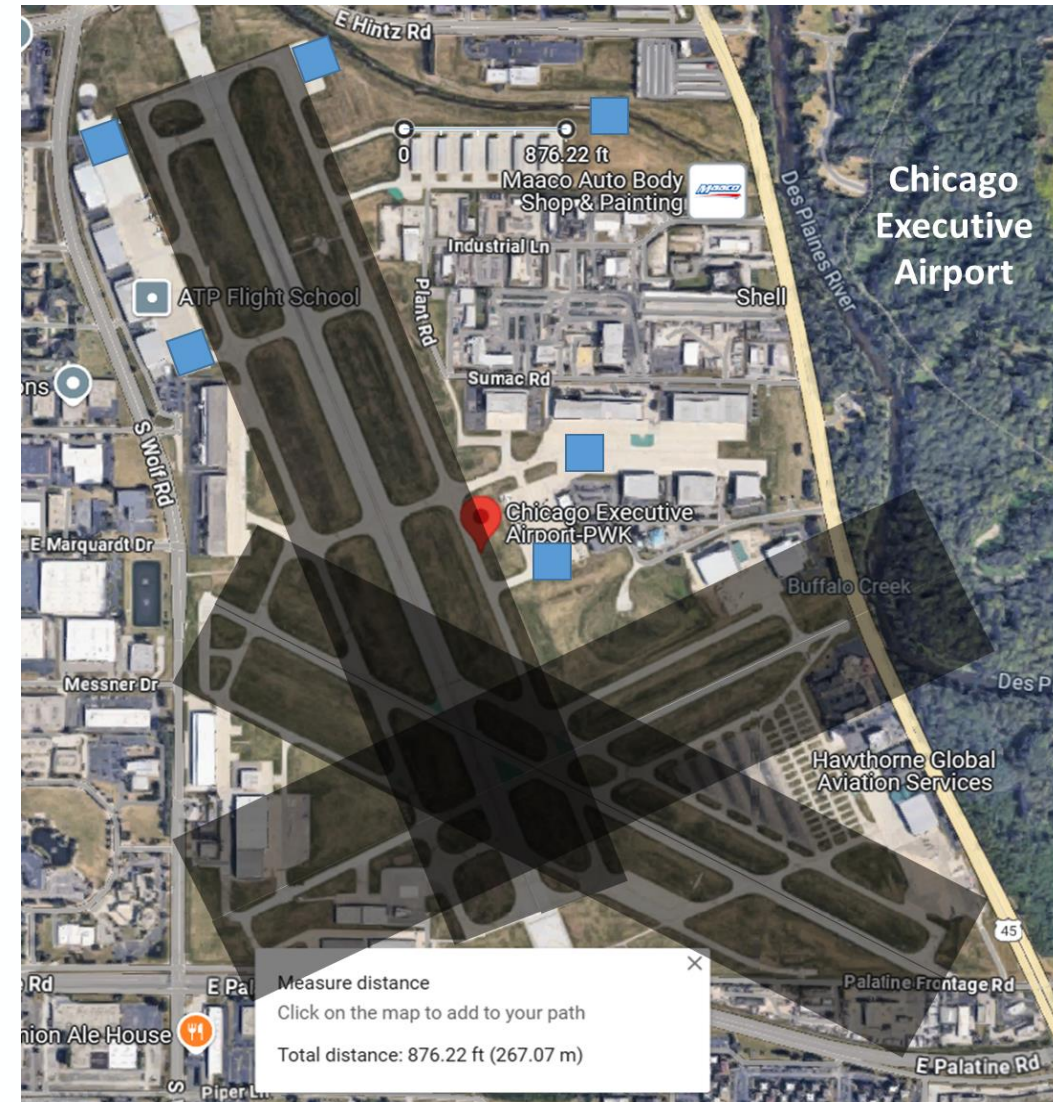
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- Runway-exclusion zones marked in black



# TLOF Pad Placement

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- 3 Runways: [16/34], [12/30], [6/24]
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- Each pad must be at least 200 feet apart



# TLOF Pad Placement

## Example: Chicago Executive Airport

- 3 Runways: [16/34], [12/30], [6/24]
- No pads to be located within 500 ft. of the runways
- Runway-exclusion zones marked in black
- Each pad must be at least 200 feet apart
- All pads have independent approach and departure vectors located at least 135 degrees apart
- Similar exercise done for all aerodromes in the Chicago network





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# *Results*

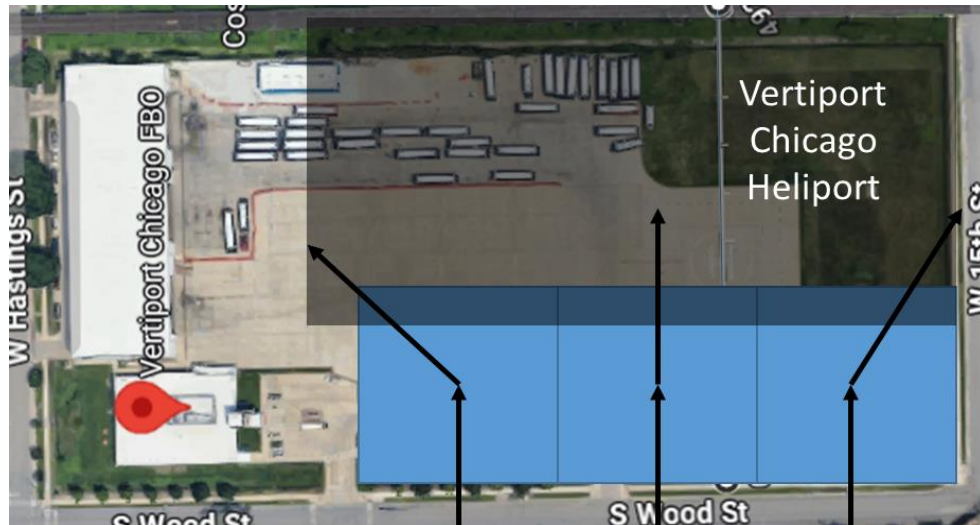


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SYSTEMS<sub>IN</sub> AEROSPACE

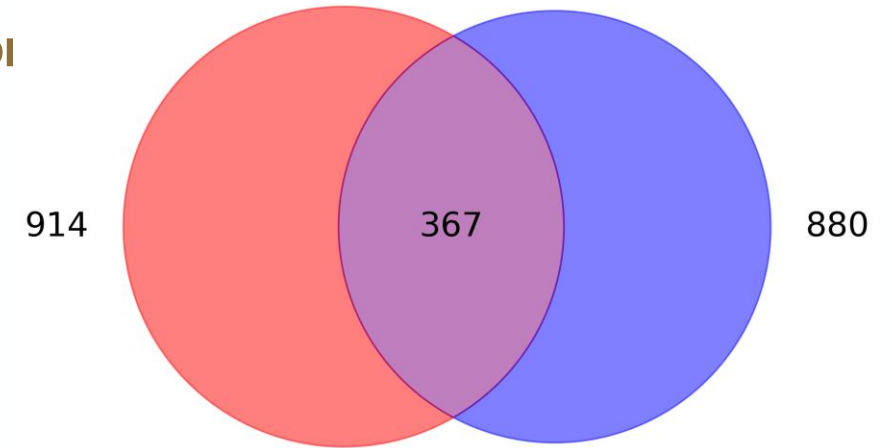
# Network Level Findings

## Vertiport Chicago Heliport (43IL) Under IFR – Flight Operation

- Intersection set indicates fulfilled flight operations under both TLOF pad and gate constraints
- 367 (10.15%) arrivals and 613 (9.56%) departures are fulfilled within the day
  - 3 TLOF pads
  - 12 gates
  - 3614 unconstrained arrivals
  - 6409 unconstrained departures

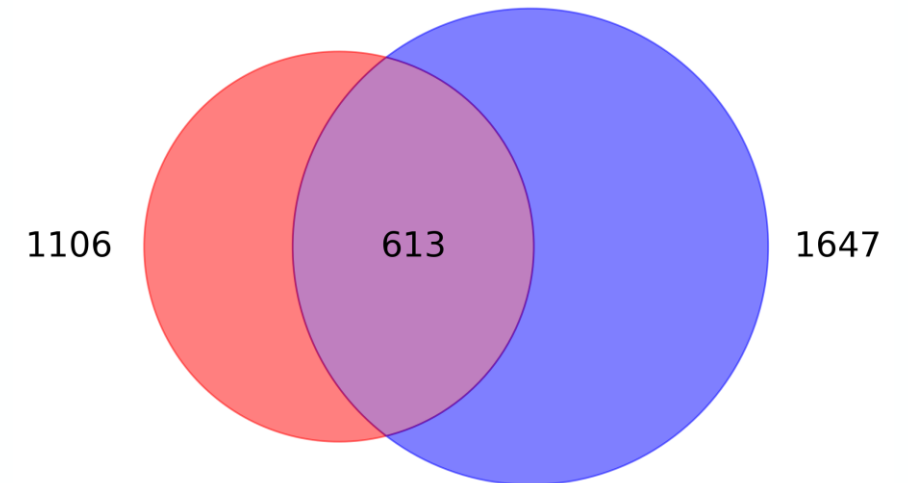


Map Data: Imagery ©2025 Google, Imagery ©2025 Airbus, Maxar Technologies, Map data ©2025



Gate Arrival Allowed

Pad Arrival Allowed



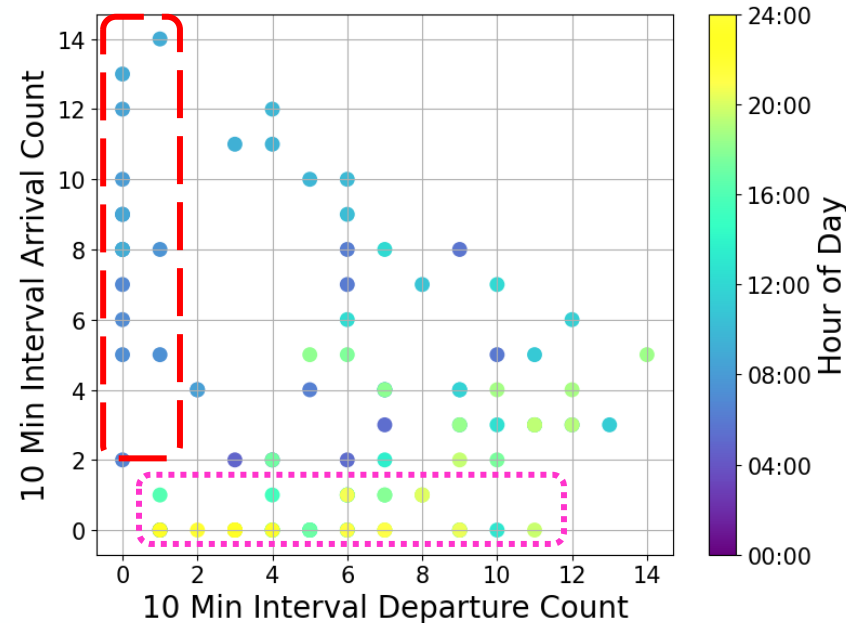
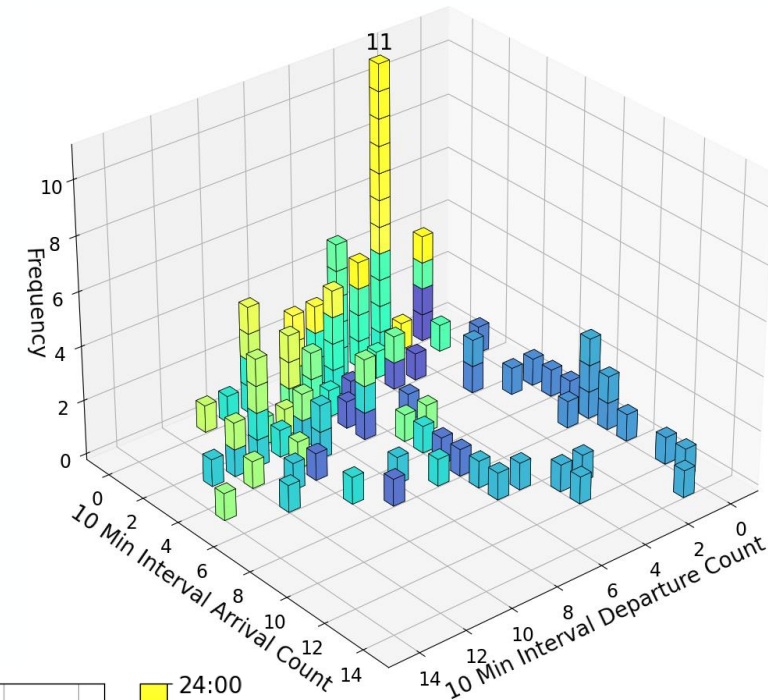
Gate Departure Allowed

Pad Departure Allowed

# Network Level Findings

## Vertiport Chicago Heliport (43IL) Under IFR - Throughput

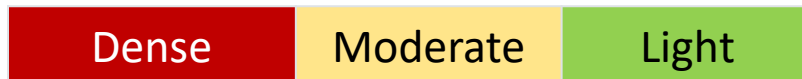
- This aerodrome sees the most unfulfilled flights due to limited infrastructure capability whilst having high demand
- High throughput activity likely stems from its central urban location, situated within the core of the metropolitan area
- Majority of flight operations occur during the rush hour period:
  - **More arrivals than departures** during the early mornings, indicative of rush hour commuting patterns to work
  - **More departures than arrivals** during the evening, indicative of rush hour commuting patterns from work



# TLOF Pad Constraints

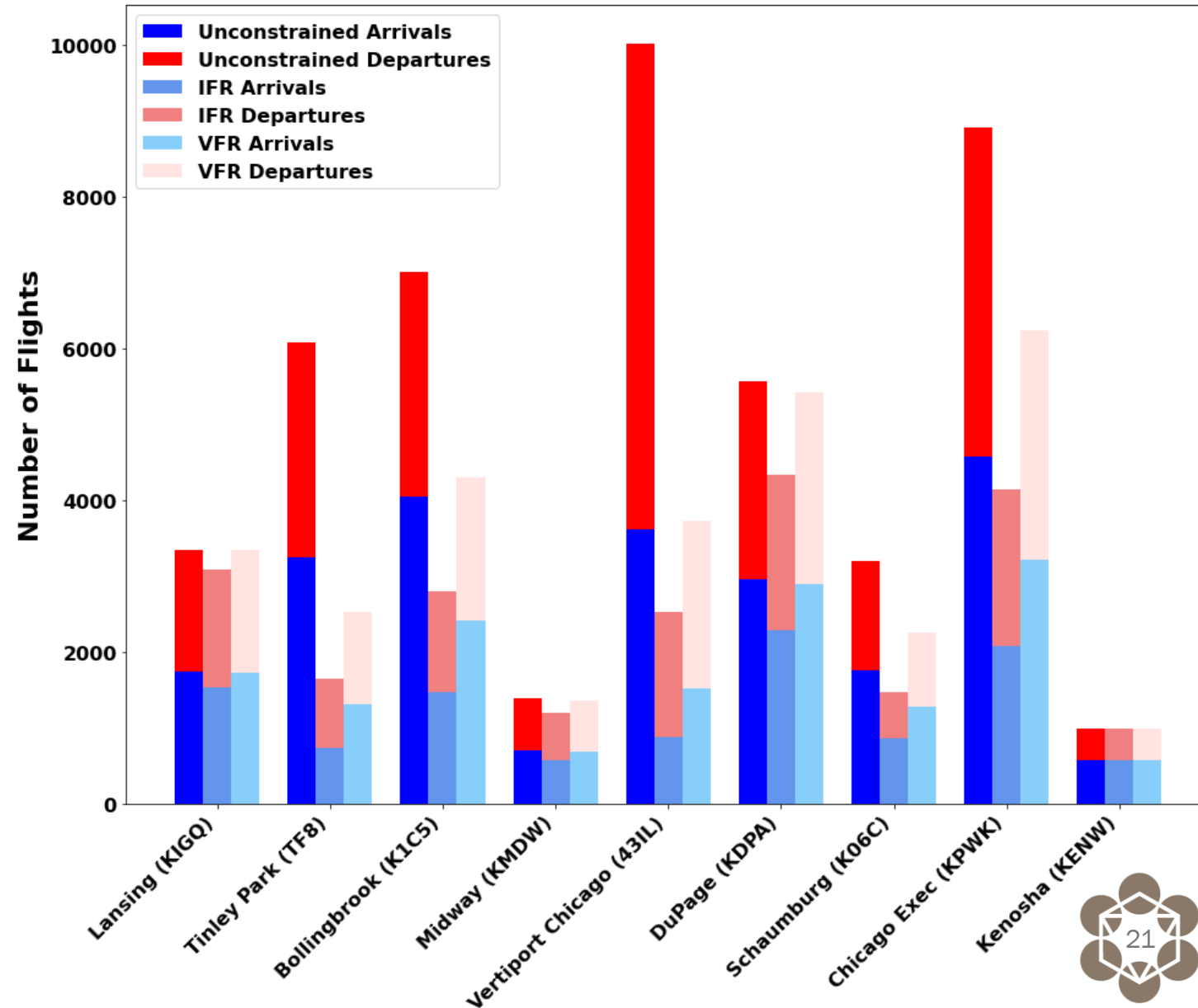
## VFR and IFR operations per day

Aerodrome Location	No. of Pads	Unconstrained Ops/Pad
Lansing (KIGQ)	9	371
Tinley Park (TF8)	2	3043
Bolingbrook (K1C5)	4	1750
Midway (KMDW)	4	348
Vertiport Chicago (43IL)	3	3341
DuPage (KDPA)	9	619
Schaumburg (K06C)	3	1067
Chicago Exec. (KPWK)	6	1484
Kenosha (KENW)	8	124

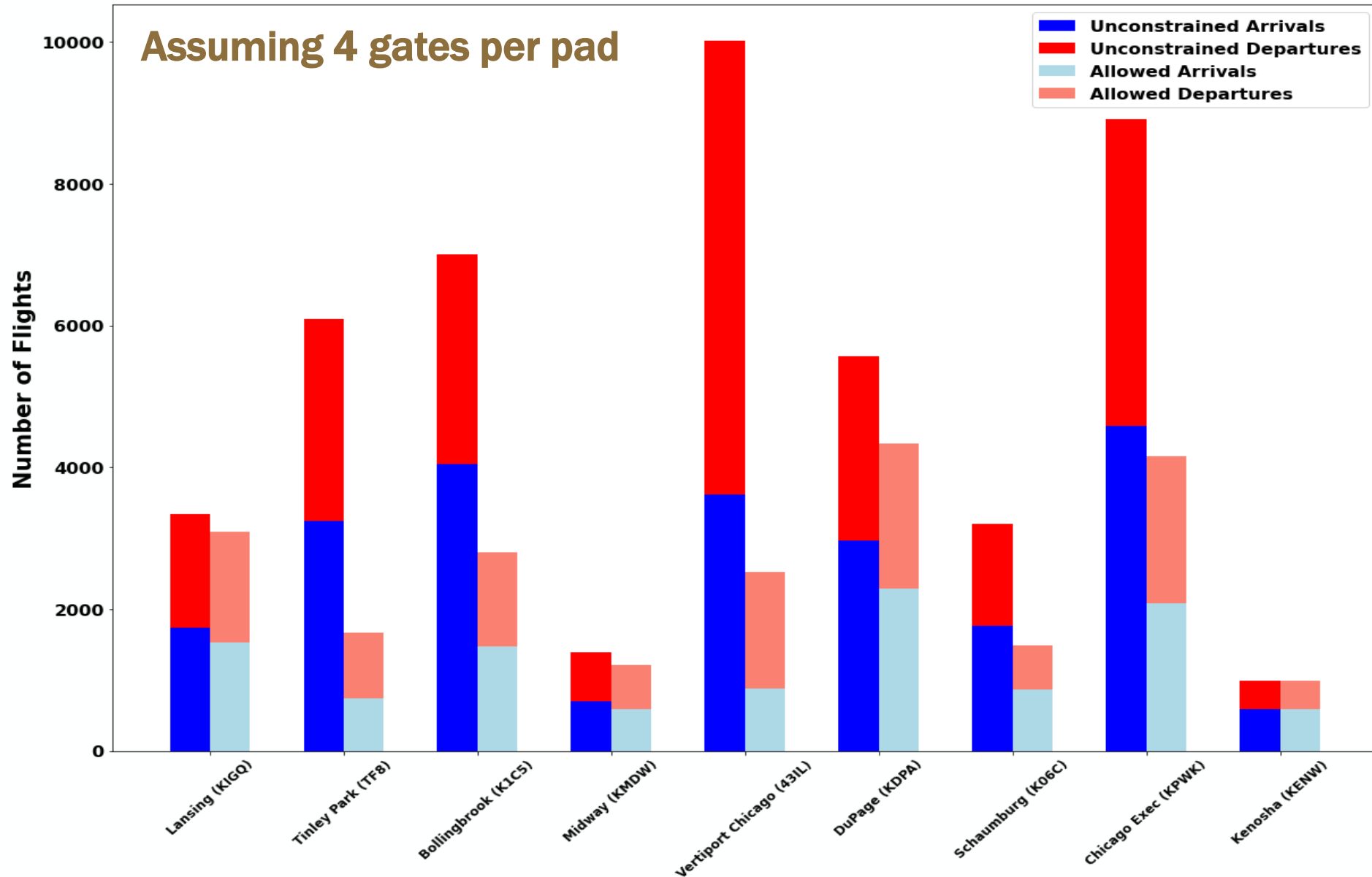


### Takeaways

- VFR (30s inter-arrival intervals) allows more operations than IFR (90s inter-arrival intervals) operations
- Dense locations see huge reductions in throughput with plausible pad constraints



# Gate Constraints



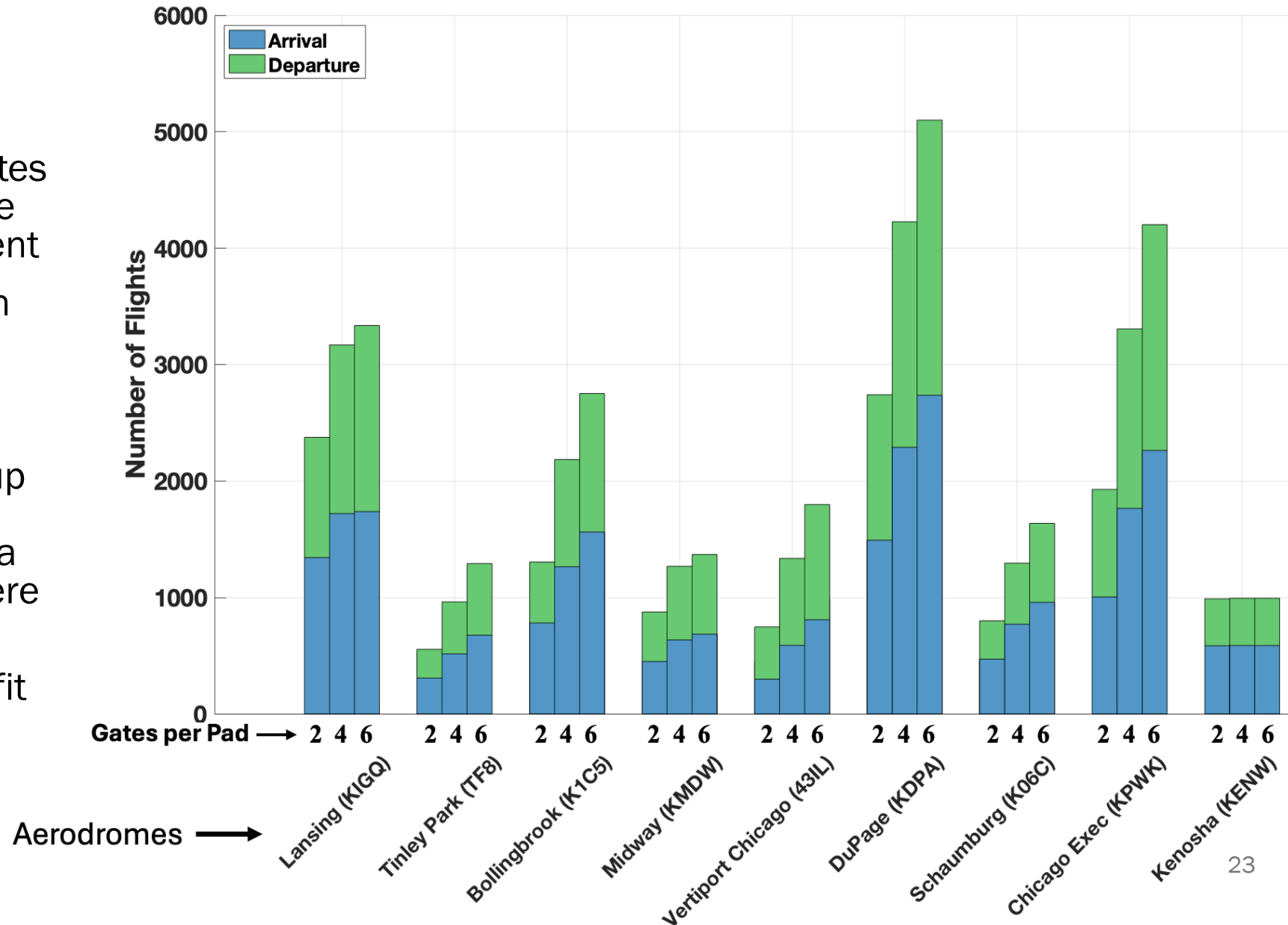
## Takeaway

Dense locations see huge reductions in throughput (like those seen with pads) with plausible gate constraints

# Varying Gates / TLOF Pads

## 50% More and 50% Less

- Baseline: 4 gates/pad
- Increasing the number of gates improves throughput at some aerodromes to a certain extent
- Increasing gates would again lead to a bottleneck, if the number of pads are not increased
- Gates are expected to take up less space than pads, so having more gates could be a viable strategy in places where there are fewer pads
- Some locations do not benefit as much from more gates

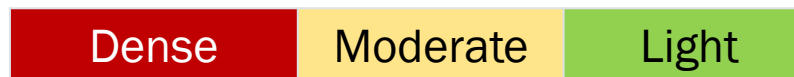


# Network Level Findings

## Throughput due to market demand

- Around 80%+ of flights are fulfilled in locations with light demand
- This metric falls to about 25% for moderate demand locations, and 10% for dense demand locations
- Over the entire network, around 37% (VFR) or 31% (IFR) of operations are fulfilled

Aerodrome Location	Unconstrained	Arrivals			Departures			Aggregate	
	Ops/Pad	Unconstrained	IFR	VFR	Unconstrained	IFR	VFR	IFR (%)	VFR (%)
Kenosha (KENW)	124	588	587	588	406	406	406	99.9	100.0
Midway (KMDW)	348	702	546	635	690	576	633	80.6	91.1
Lansing (KIGQ)	371	1741	1345	1720	1603	1393	1449	81.9	94.8
DuPage (KDPA)	619	2968	1899	2290	2603	1639	1937	63.5	75.9
Schaumburg (K06C)	1067	1769	568	770	1433	376	526	29.5	40.5
Chicago Exec. (KPWK)	1484	4581	1271	1766	4328	1192	1540	27.7	37.1
Bolingbrook (K1C5)	1750	4049	914	1264	2954	721	921	23.4	31.2
Tinley Park (TF8)	3043	3250	344	516	2836	353	447	11.5	15.8
Vertiport Chicago (43IL)	3341	3614	367	589	6409	613	747	9.8	13.3

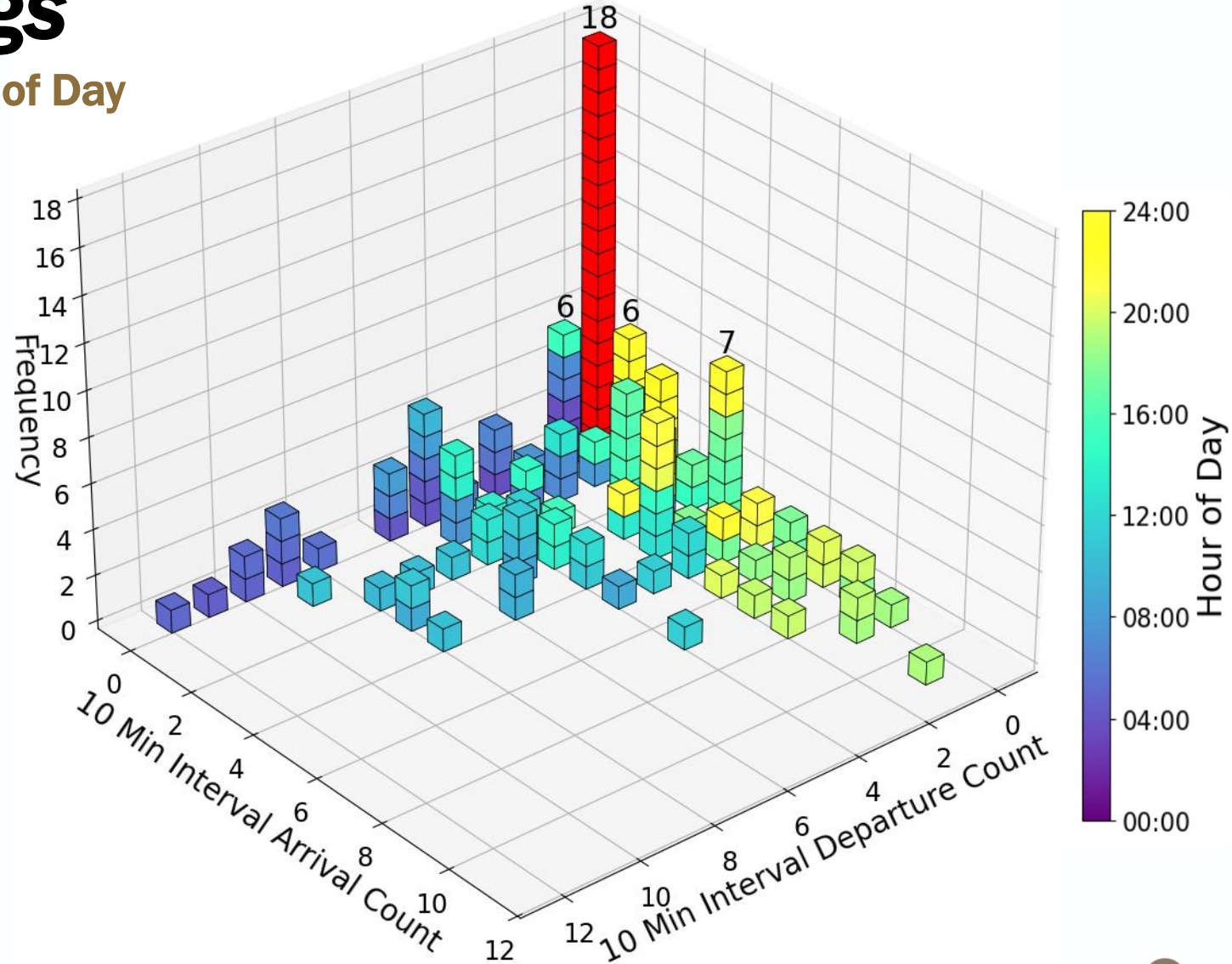


# Network Level Findings

## Temporal Results: Throughput due to Time of Day

- Commuter travel demand peaks in the mornings and afternoon
- There are instances when the aerodrome sees very frequent operations (one flight movement every 1.6 s)
- The aerodrome may also be idle during other times
- Observed peaks are about 4x-6x of average demand

**Tradeoff:** building more TLOF pads to meet demand surges during peak hours, but may remain vacant rest of the day



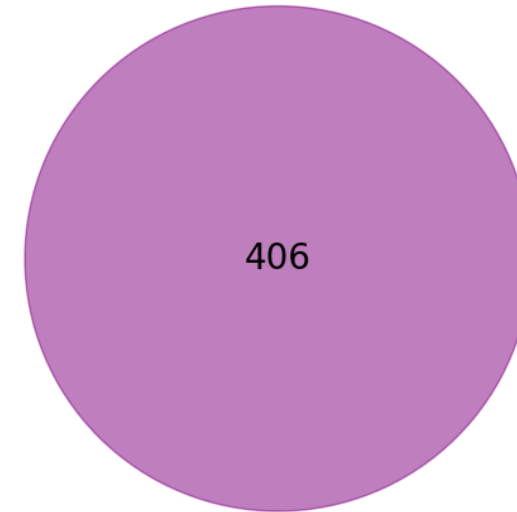
Tinley Park: Aerodrome operations (10-min intervals)

**Red:** Intervals with no operations

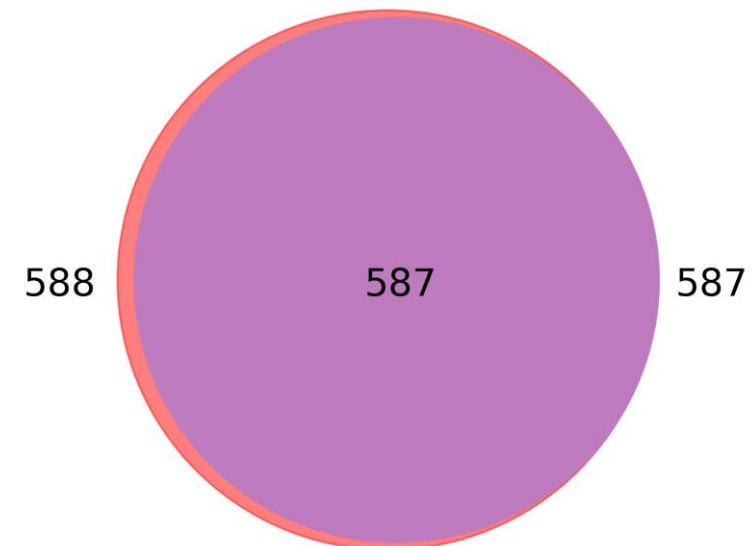
# Network Level Findings

## Kenosha Regional Airport (KENW) Under IFR – Flight Operations

- Intersection of circles indicate fulfilled flight operations under both TLOF pad and gate constraints
- 587 (99.8%) arrivals and all 406 (100%) departures are fulfilled within the day
  - 8 TLOF pads
  - 32 gates
  - 588 unconstrained arrivals
  - 406 unconstrained departures



All Departures Allowed



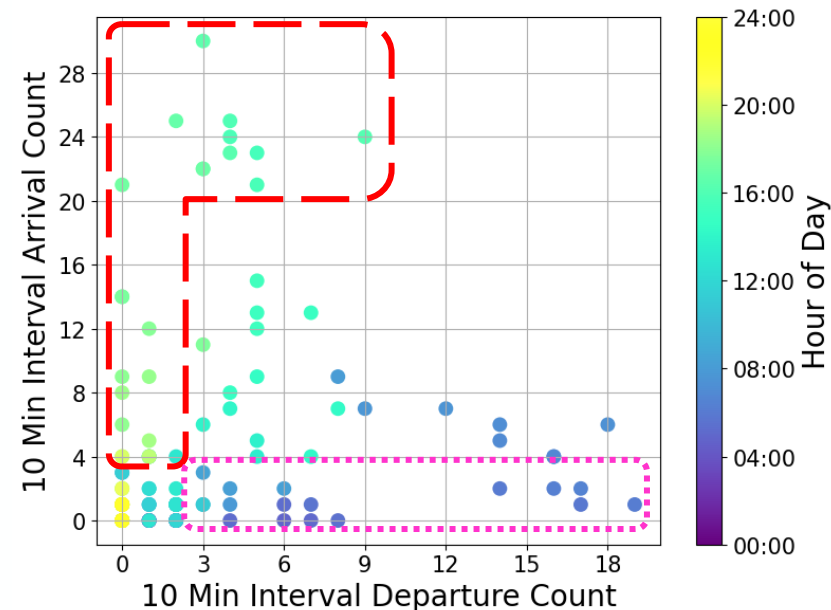
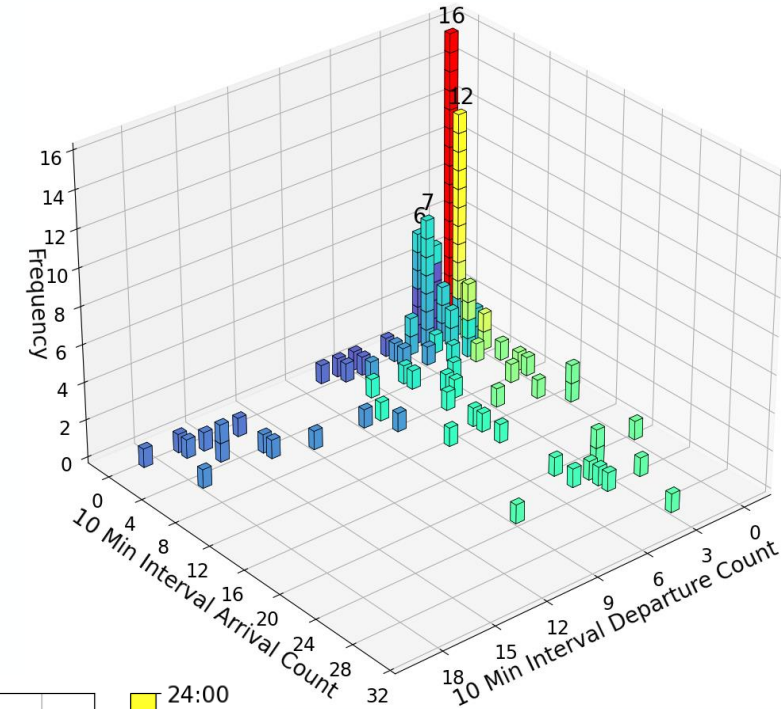
Gate Arrival Allowed

Pad Arrival Allowed

# Network Level Findings

## Kenosha Regional Airport (KENW) Under IFR - Throughput

- This aerodrome exhibits more structured and steady throughput activity, likely due to sufficient infrastructure capability
- Situated far from the core of the metropolitan area, flight operations mainly fulfilled:
  - **More departures than arrivals** during the early mornings, indicative of rush hour commuting patterns to work
  - **More arrivals than departures** during the evenings, indicative of rush hour commuting patterns from work



# Thank You!

We welcome any comments or questions!

Somrick Das Biswas

Jonah Gerardus

Kshitij Mall

Daniel A. DeLaurentis

William A. Crossley

Michael D. Patterson

Brandon E. Sells



This research is supported by the National Aeronautics and Space Administration (NASA) through the Logistics Management Institute under contract number DATSS II 80HQTR24AA004 - 80HQTR24FA095 (TO #23)



# *Backup*



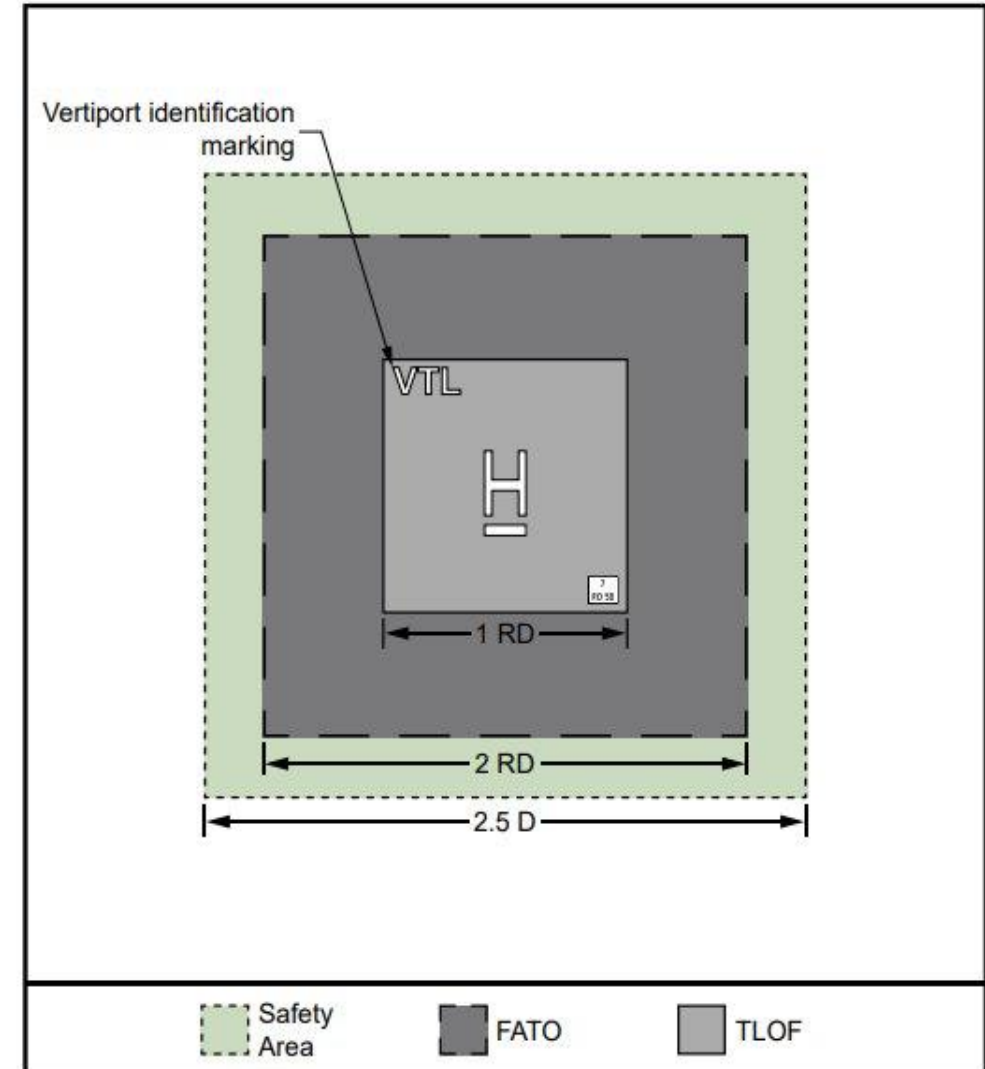
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# Estimating Number of TLOF Pads

## We do not design an aerodrome

- Throughput analysis requires estimates of available TLOF pads and gates
- We provide a **good-faith guesstimate** of pad capacity at existing aerodromes
- FAA vertiport design guidance used to infer **plausible pad counts**
- A **4 gates per pad heuristic** applied to estimate gate availability
- The approach **abstracts away operational complexities** (e.g., taxiway blockages, hangar access, weather constraints)
- Objective is not to **design** aerodromes, but to support throughput assessment with **reasonable approximations**

Figure 2-1: Relationship and Dimensions of TLOF, FATO, and Safety Area



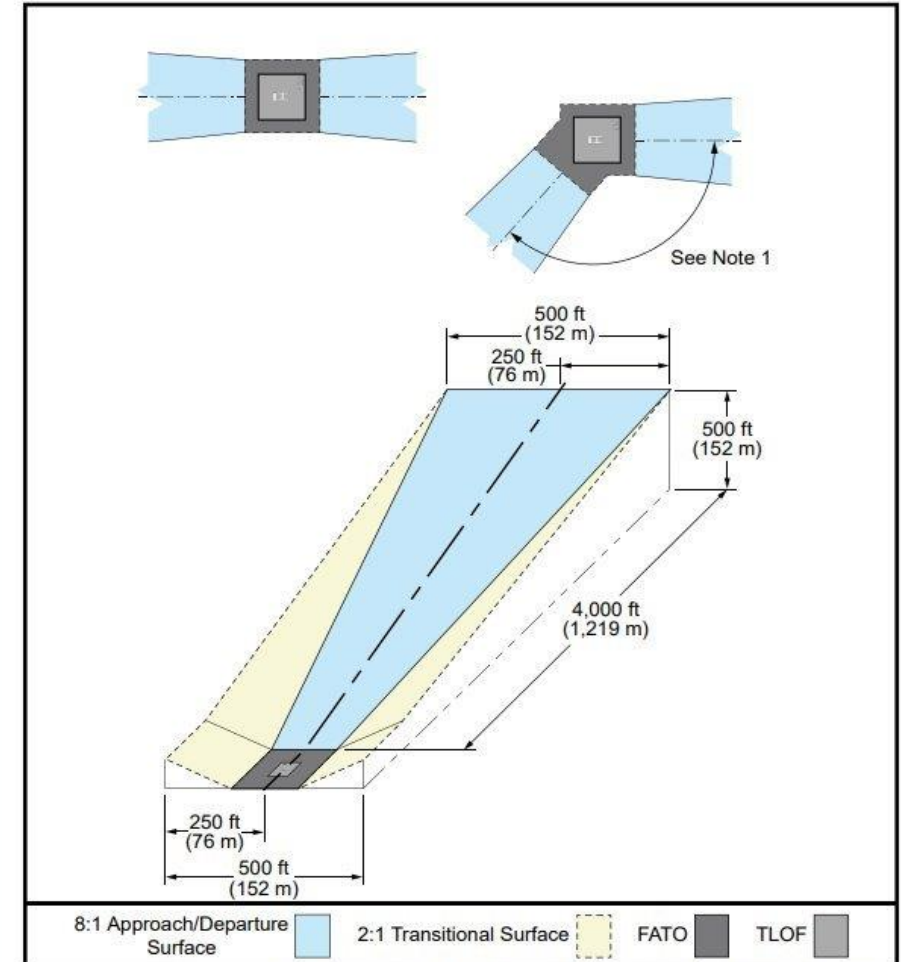
# Estimating Number of TLOF Pads

## FATO/TLOF Pad Guidance

We assume simultaneous operations in our model, so we refer to FAA guidelines for such operations:

- Approach paths to the same TLOF pad must be 135 degrees apart (minimum)
- Approach/departure paths must assure 8:1 horizontal units and vertical units
- TLOF pad centers must be 200 ft. apart
- To the extent possible, approach and departure paths must be independent and not intersect with any other flight paths

Figure 2-5: VFR Vertiport Approach/Departure Surfaces



**Note 1:** The preferred approach/departure surface is based on the predominant wind direction. Where a reciprocal approach/departure surface is not possible in the opposite direction, use a minimum 135-degree angle between the two surfaces.

# Estimating Number of TLOF Pads

## Airport Operations

FAA allows operations next to active runways, provided a minimum separation distance:

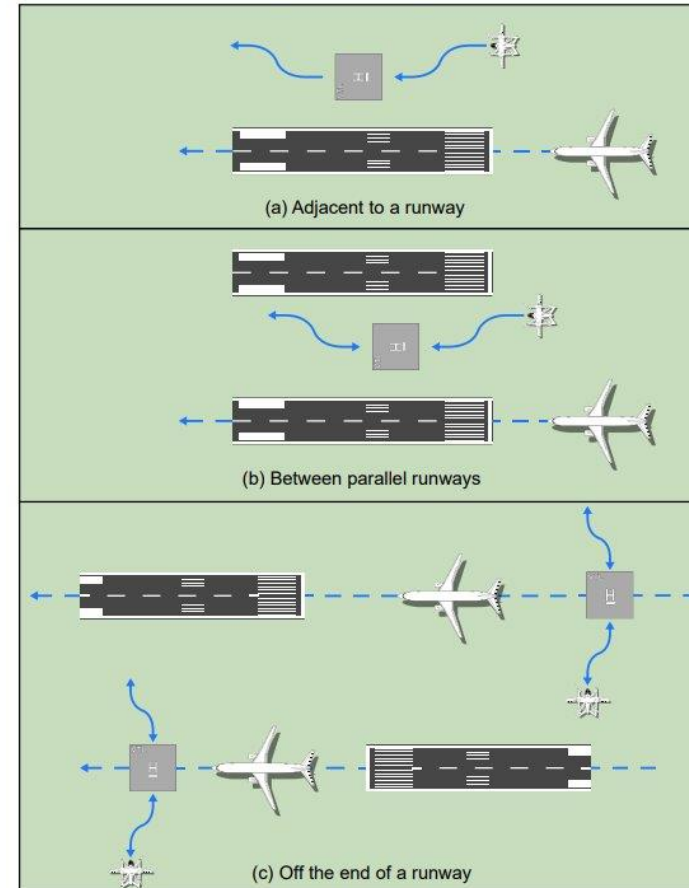
- 500 ft. for aircraft MTOW < 30000 lbs.
- 700 ft. for aircraft MTOW > 30000 lbs.

Using these rules, we consulted satellite imagery and FAA airport diagrams to locate pads, with the following caveats:

- Our placement may require taxiways to be re-routed, or may block hangar access
- TLOF pads do not take into account other practical considerations and are 'plausible'

Figure A-1. Siting Vertiports on or Near Existing Airports

(Notional depiction. Not to scale.)



Note: These notional depictions are not to scale and only illustrate the relative position of a vertiport in relation to a runway. The actual distances from the runway are critical to assessing the potential impacts.

[https://www.faa.gov/airports/engineering/engineering\\_briefs/eb\\_105a\\_vertiports](https://www.faa.gov/airports/engineering/engineering_briefs/eb_105a_vertiports)

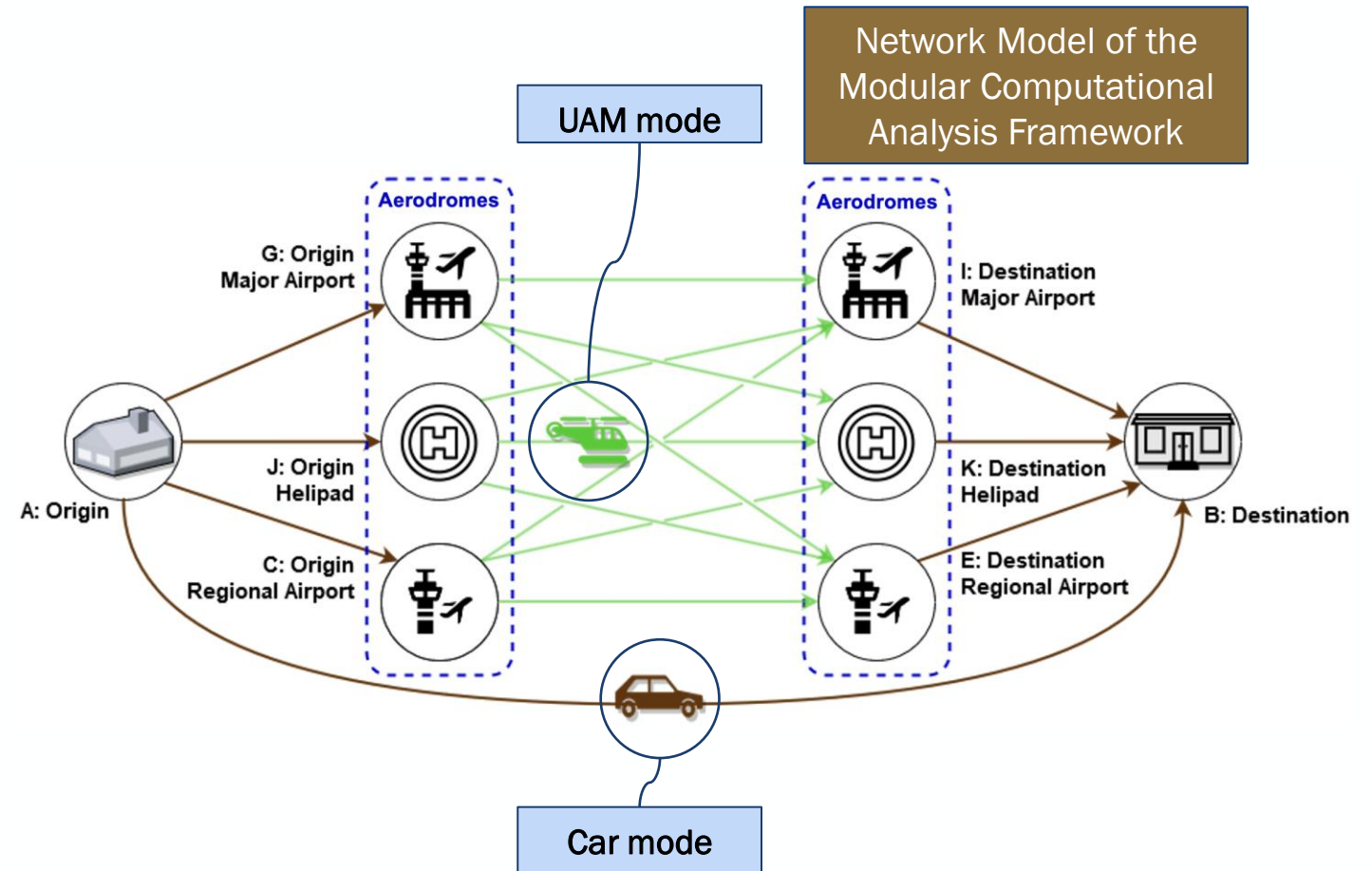
# Modeling Potential Travel Modes

## Mode choice based on the effective cost metric

- The *effective cost* measure aggregates operating cost and travel time in a single metric:

$$\text{Effective Cost } (cost_{eff}) = \text{Transport Cost} + (\text{Travel Time} \times \text{Value of Time})$$

- A trip is considered UAM-preferred when  $cost_{eff,UAM} < cost_{eff,car}$
- This indicates potential demand for UAM services



# ***Economics Operational Limits in UAM***

## **Motivation for enabling ridesharing in UAM operations**

- Examining UAM from an SoS perspective allows us to identify operational limits
- Economics (for individual travelers) identified as a significant UAM operational limit, due to high UAM operating costs compared to the alternative of driving personal vehicle
  - 605 USD/hour<sup>1</sup> assumed UAM aircraft (eVTOL) operating cost
  - 0.36 USD/km<sup>2</sup> (0.58 USD/mile) assumed driving cost
- Introducing ridesharing in UAM may reduce the cost burden for ridesharing-enabled UAM passengers vs. single-passenger UAM flights
  - We assume the UAM operating cost is divided equally among UAM passengers
  - May incentivize travelers into the UAM mode (as opposed to driving) and increase UAM mode share

[1] Holden, J., and Goel, N., “Fast-Forwarding to a Future of On-Demand Urban Air Transportation,” San Francisco, CA, 2016

[2] IRS, “Standard Mileage Rates,” <https://www.irs.gov/tax-professionals/standard-mileage-rates>, Dec 2022.

# Framework of UAM Analysis

Select assumptions:

- 25-minute total UAM mode transition duration (includes embarkation, disembarkation, mode transfers, et cetera)
- 605 USD/hour direct operating cost for aircraft divided equally among passengers

Analyzing for *unconstrained* operations:

- Not accounting for several practical constraints, such as:
  - Aerodrome throughput
  - Airspace and air traffic management
  - Aircraft availability
  - Ridesharing protocols
- Fewer trips are to be expected in real-life operations

