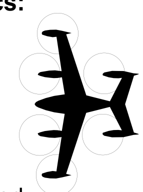
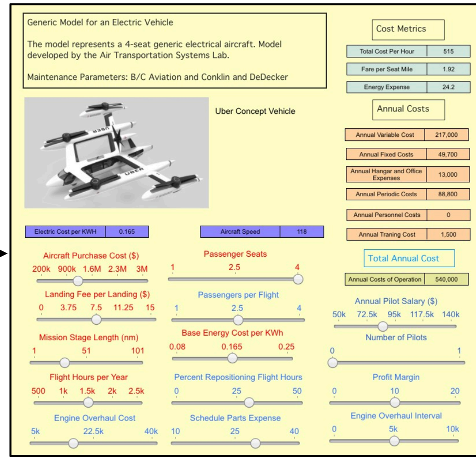
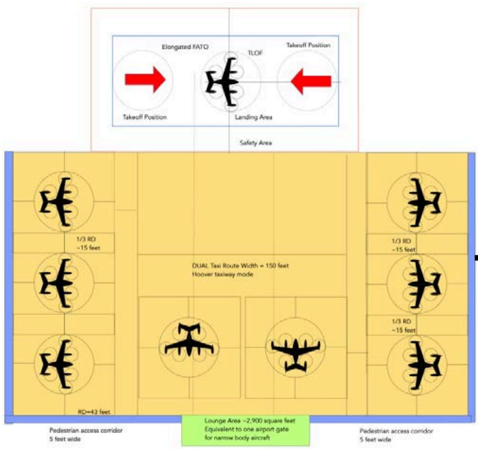
Integrated Approach to Urban Air Mobility Demand Analysis

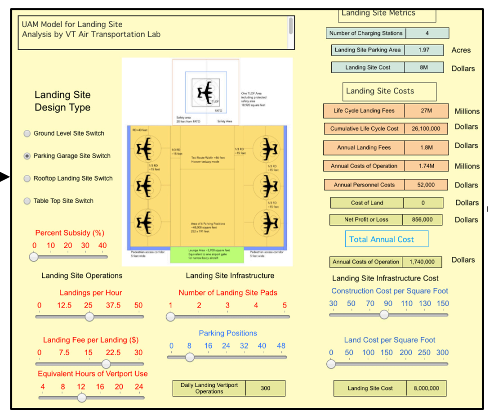
UAM vehicle characteristics:

Aircraft range
Payload
Battery life
Wing loading
Maximum speed
Aircraft size

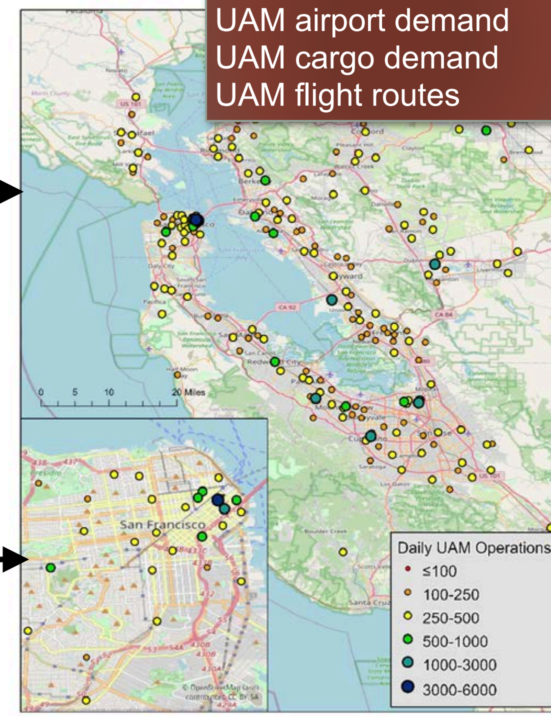








UAM commuter demand
UAM airport demand
UAM cargo demand
UAM flight routes



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May 3, 2022

Outline of the Presentation

- An integrated approach to model UAM demand
- UAM landing site models
  - Vertiport land requirements
  - Vertiport cost analysis
  - Vertiport capacity
- UAM vehicle cost models
- UAM demand generation
  - Multi-mode model calibration and applications
  - Commuter demand
  - Airport demand

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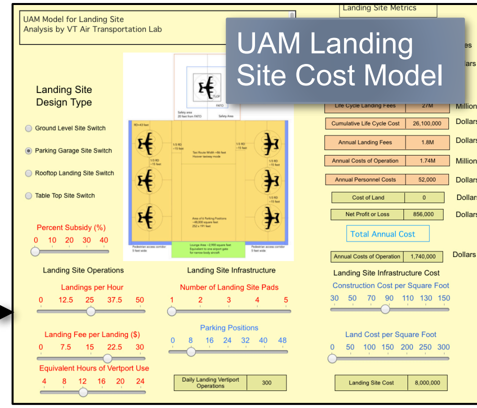
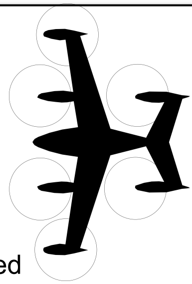
- Work funded under a National Institute of Aerospace Grant Number NNL13AA08B Task Order Number 80LARC18F0120

Integrated UAM Systems Analysis Model



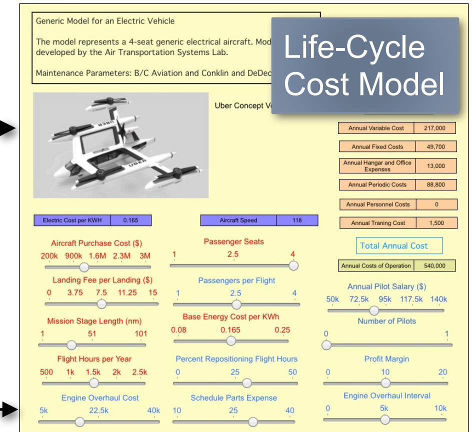
UAM vehicle characteristics:

- Aircraft range
- Payload
- Battery life
- Operational speed
- Aircraft size



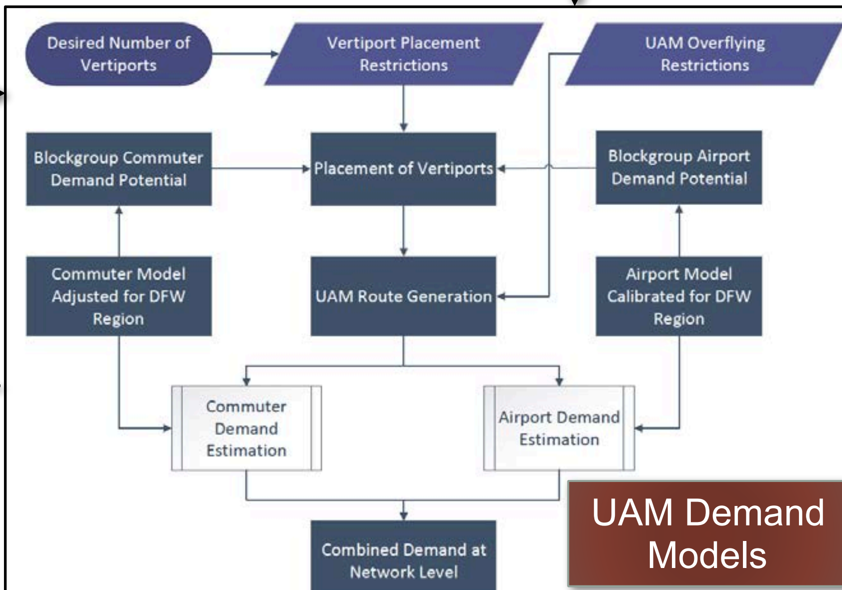
Aircraft Development Cost Model

UAM Unit Cost



Cost per passenger-mile

Airspace Restrictions in Urban Areas

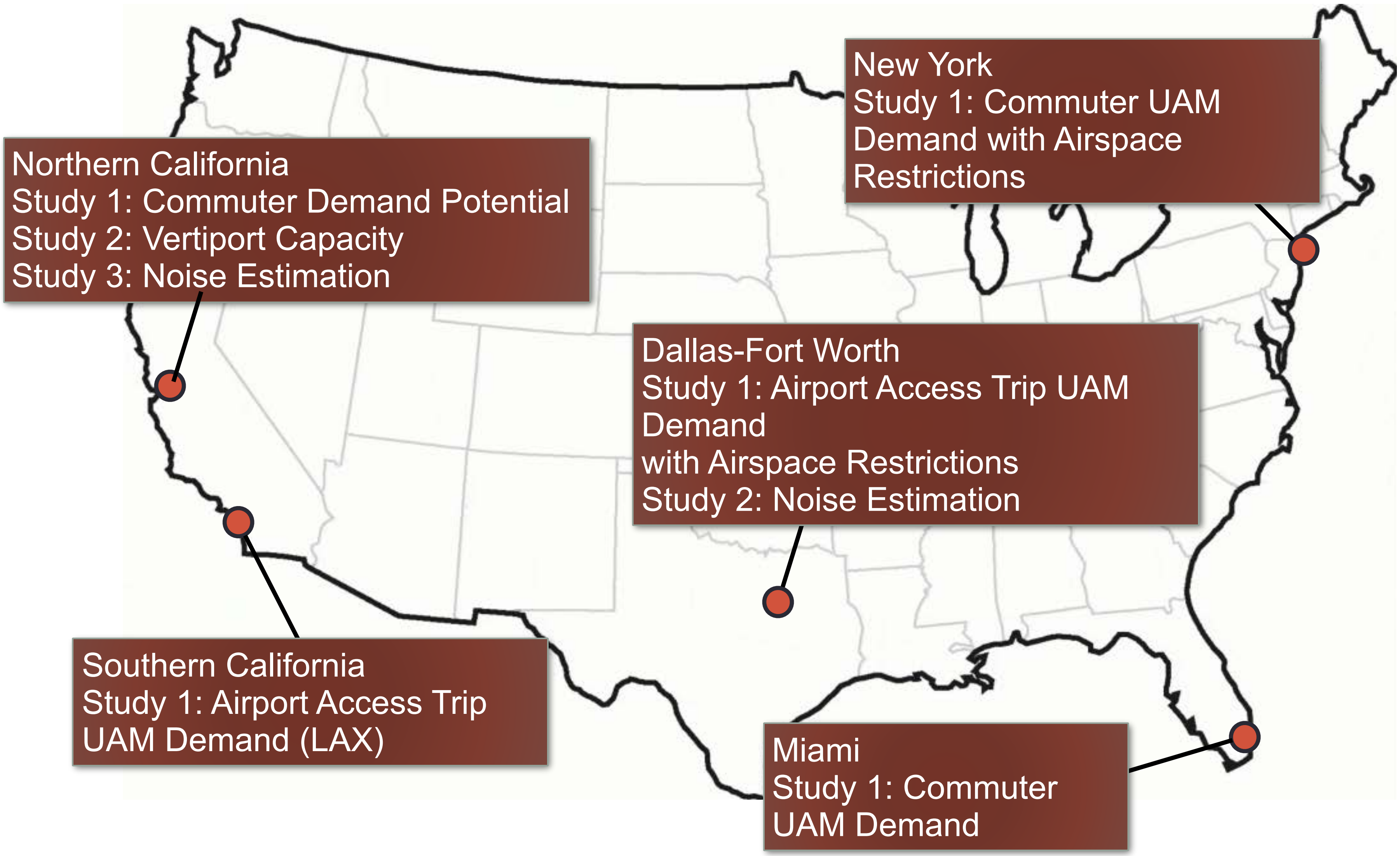


Output of Integrated UAM Model

- UAM commuter demand
- UAM airport demand
- UAM cargo demand
- UAM flight routes

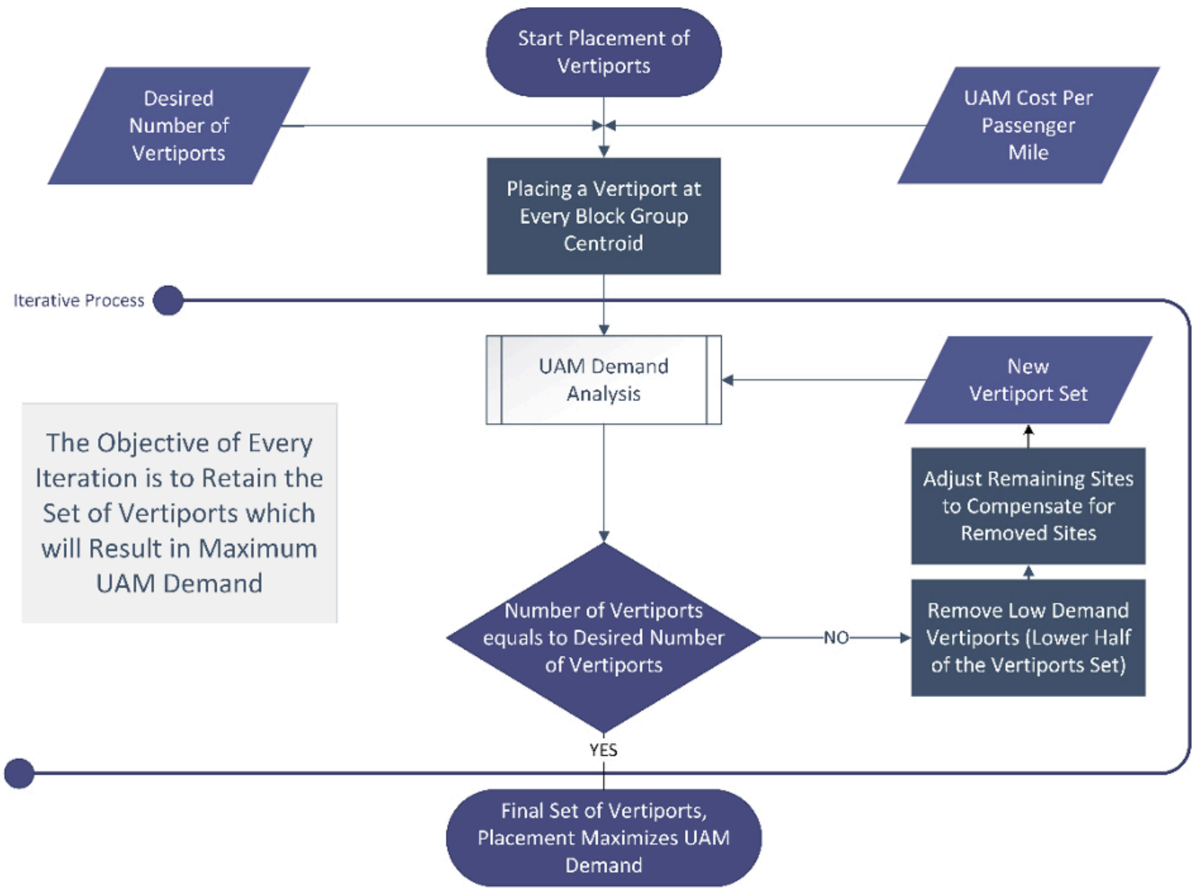
Feedback

UAM Areas of Study

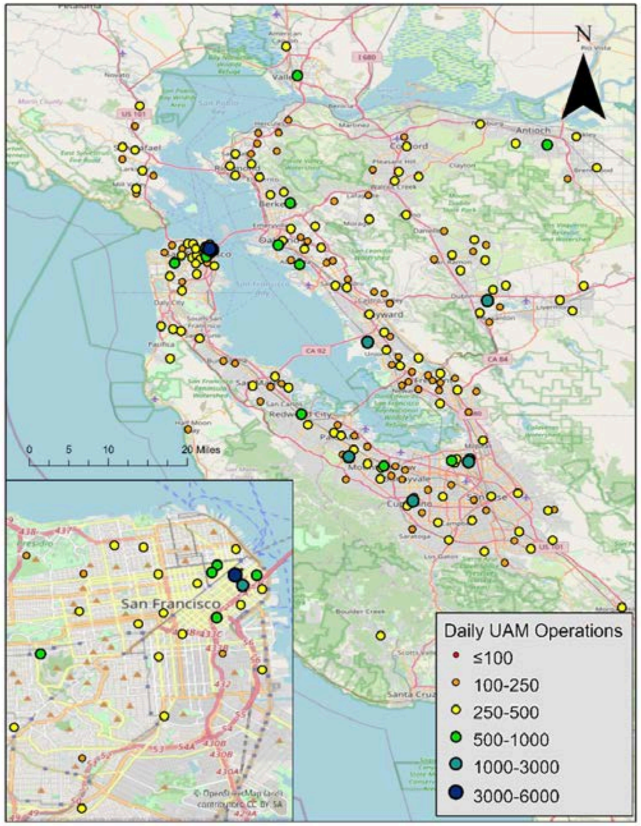


UAM Landing Site Placement Model, Landing Site Space Requirements, and Landing Site Cost Model

Demand-Driven, Iterative UAM Landing Site Vertiport Location Method

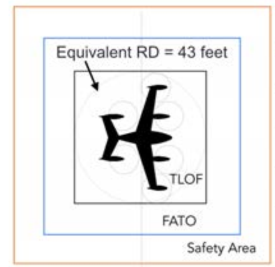


The Objective of Every Iteration is to Retain the Set of Vertiports which will Result in Maximum UAM Demand



UAM Landing Site Space Requirements

- Estimated UAM landing site requirements for various configurations
  - Number of landing pads
  - Number of parking positions



TLOF area = 1,849 ft²
FATO area = 4,160 ft²
Safety area = 10,920 ft²

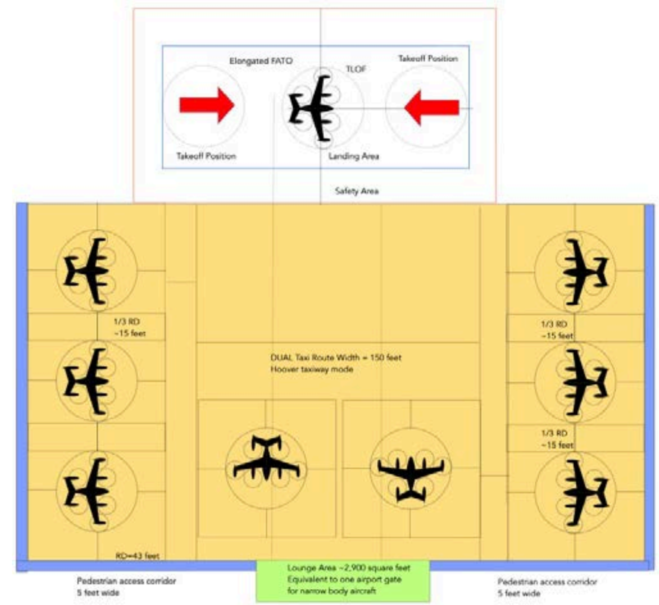
Dimension	Rule	Dimension (feet)
A- TLOF Length	1 RD	43
B- TLOF Widt	1 RD	43
C - Min. FATO Length	1.5 D	64.5
E - Min. FATO Width	1.5 D	64.5
F - Min. Distance TLOF and FATO	3/4D - 1/2RD	10.75
G - Min Safety Area Width	Table	20

D = Total length of aircraft
RD = rotor diameter of aircraft
MHR = minimum rotor height

Source: FAA 150/5390-2c (2012)

Single Pad UAM landing Site Requirements

Landing Pads	Parking Stalls	Landing Pad Safety Area (acres)	Hover Taxi Operation Parking Stall Area (acres)	Hover Taxi Operation Total Area (acres)
1	0	0.25	0.00	0.25
1	1	0.25	0.12	0.38
1	2	0.25	0.43	0.68
1	3	0.25	0.71	0.96
1	4	0.25	0.86	1.11
1	5	0.25	1.07	1.32
1	6*	0.46	1.50	1.95
1	7*	0.46	1.73	2.18
1	8*	0.46	1.96	2.41

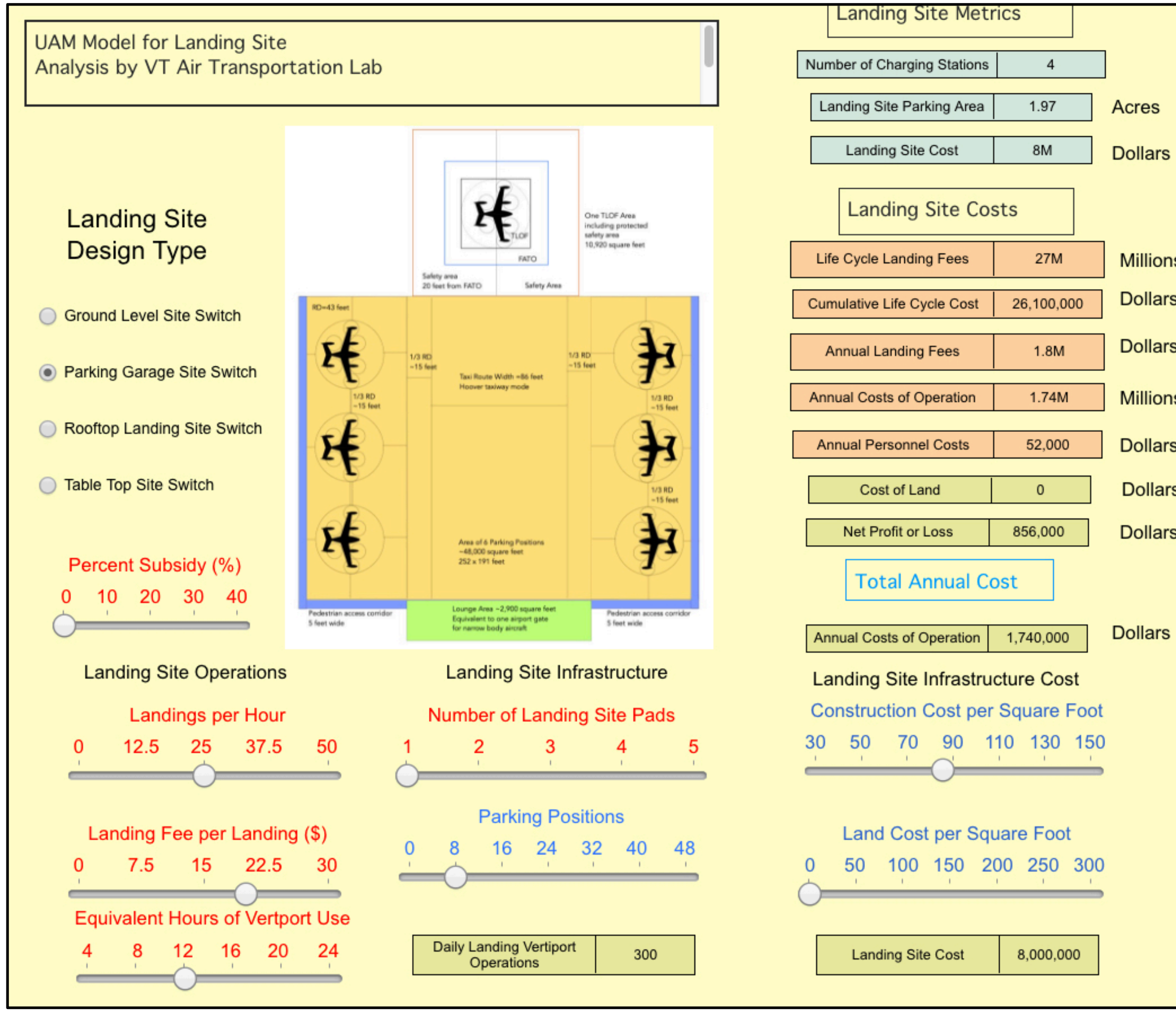


* Configurations with six or more parking stalls use dual taxi lanes and elongated FATO areas for added flexibility.
The calculations assume an equivalent rotor diameter (RD) of 43 feet.

UAM Landing Site Life-Cycle Cost Model

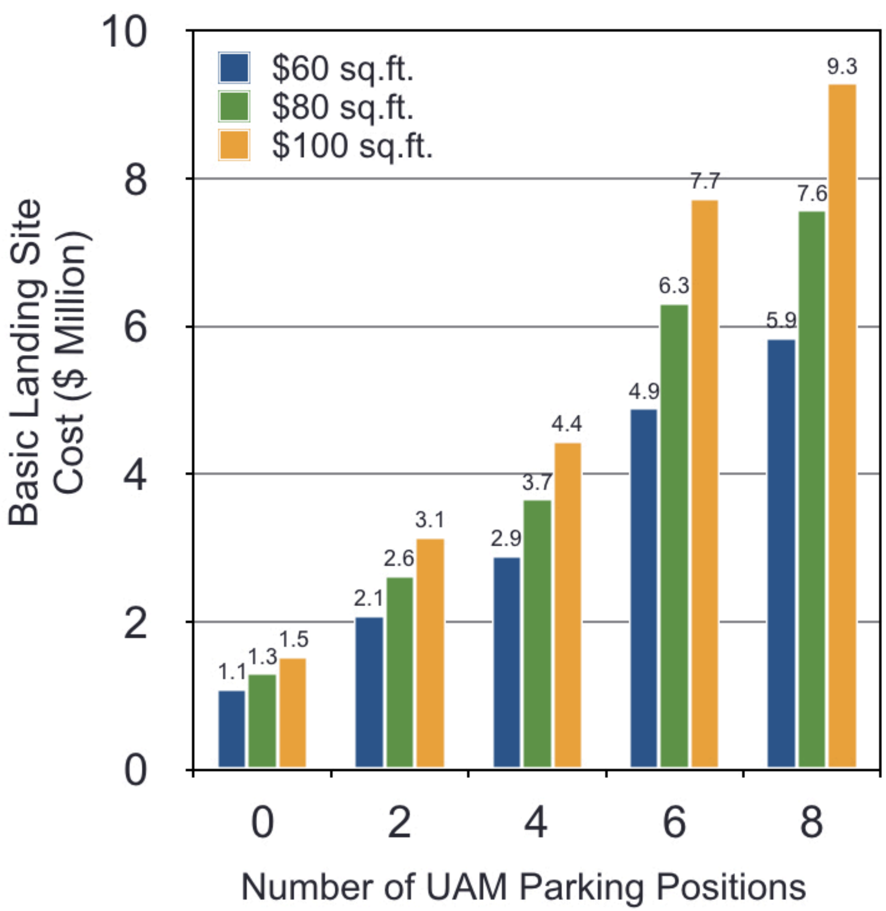
The building blocks of the life-cycle cost model include the following:

- Landing area type (vacant land, rooftop, parking lot)
- Critical vehicle dimensions
- Number of landing pads
- Number of parking stalls
- Number of charging stations
- Staffing of landing site
- Lounge areas for waiting passengers
- Lighting requirements
- Number of hours of operation per day for the landing site)
- Landing fees
- Percent subsidy to build the landing site

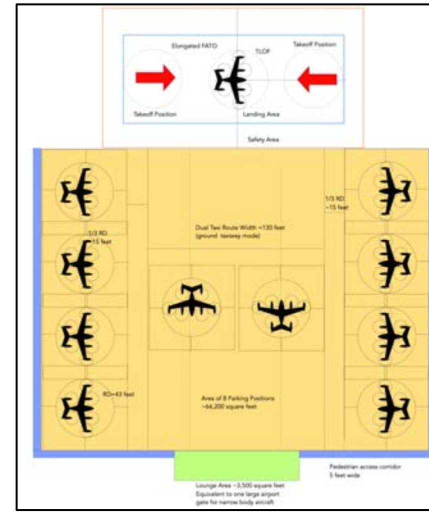


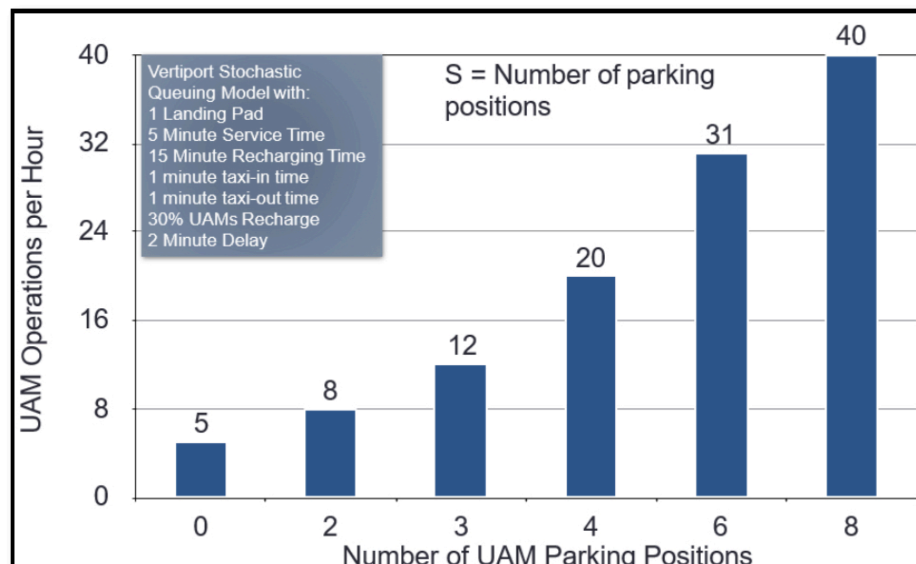
Model developed in STELLA Author

UAM Vertiport Capacity and Cost Analysis



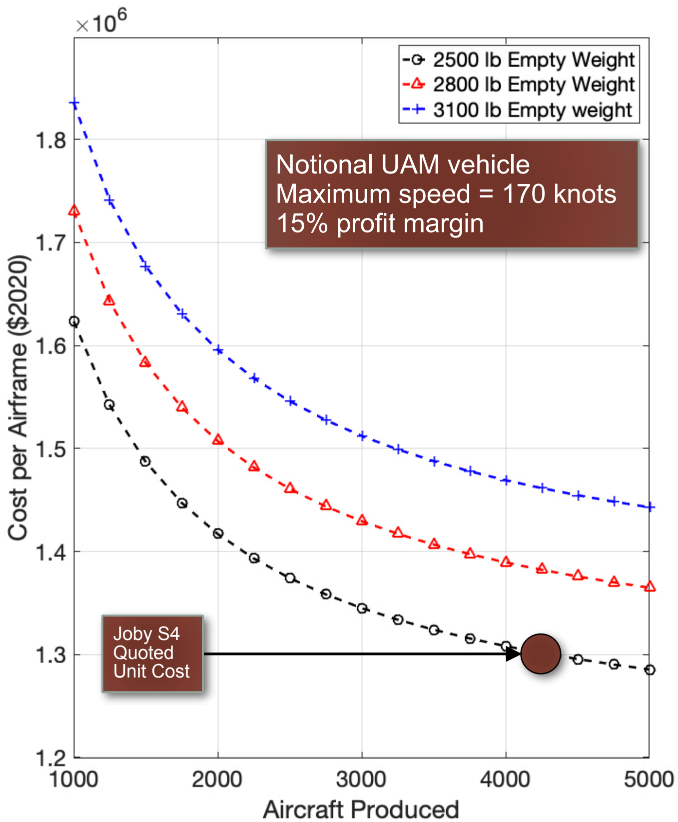
Stochastic Queueing Model with:
1 Landing Pad
8 Parking Positions
5 Minute Service Time
15 Minute Recharging Time
1 minute taxi-in time
1 minute taxi-out time



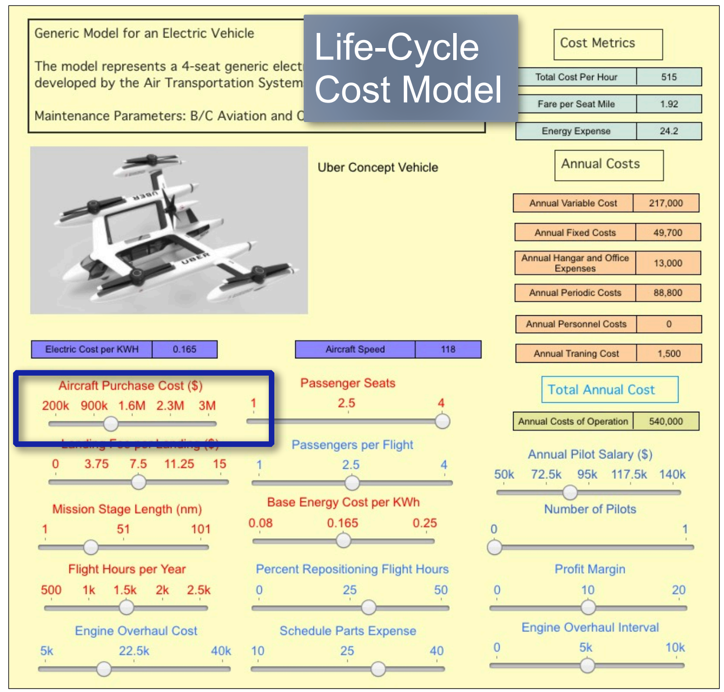


UAM Vehicle Development Cost and Operational Cost Models

UAM Vehicle Development and Operational Life Cycle Cost Models



Aircraft development cost equations adapted from Nicolai and Carichner (2012)

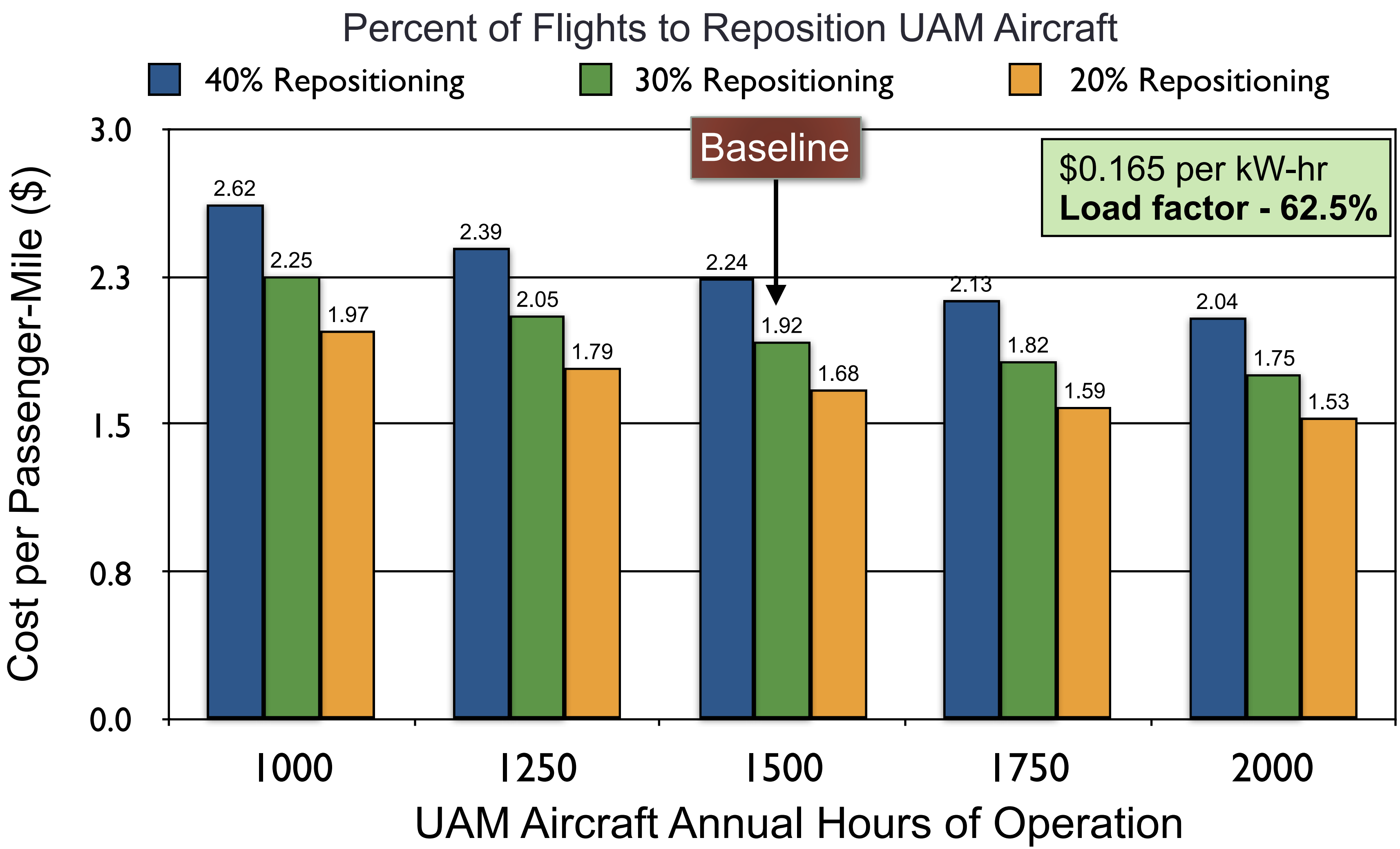


Maintenance data adapted from Conklin and deDecker (rotorcraft technology)

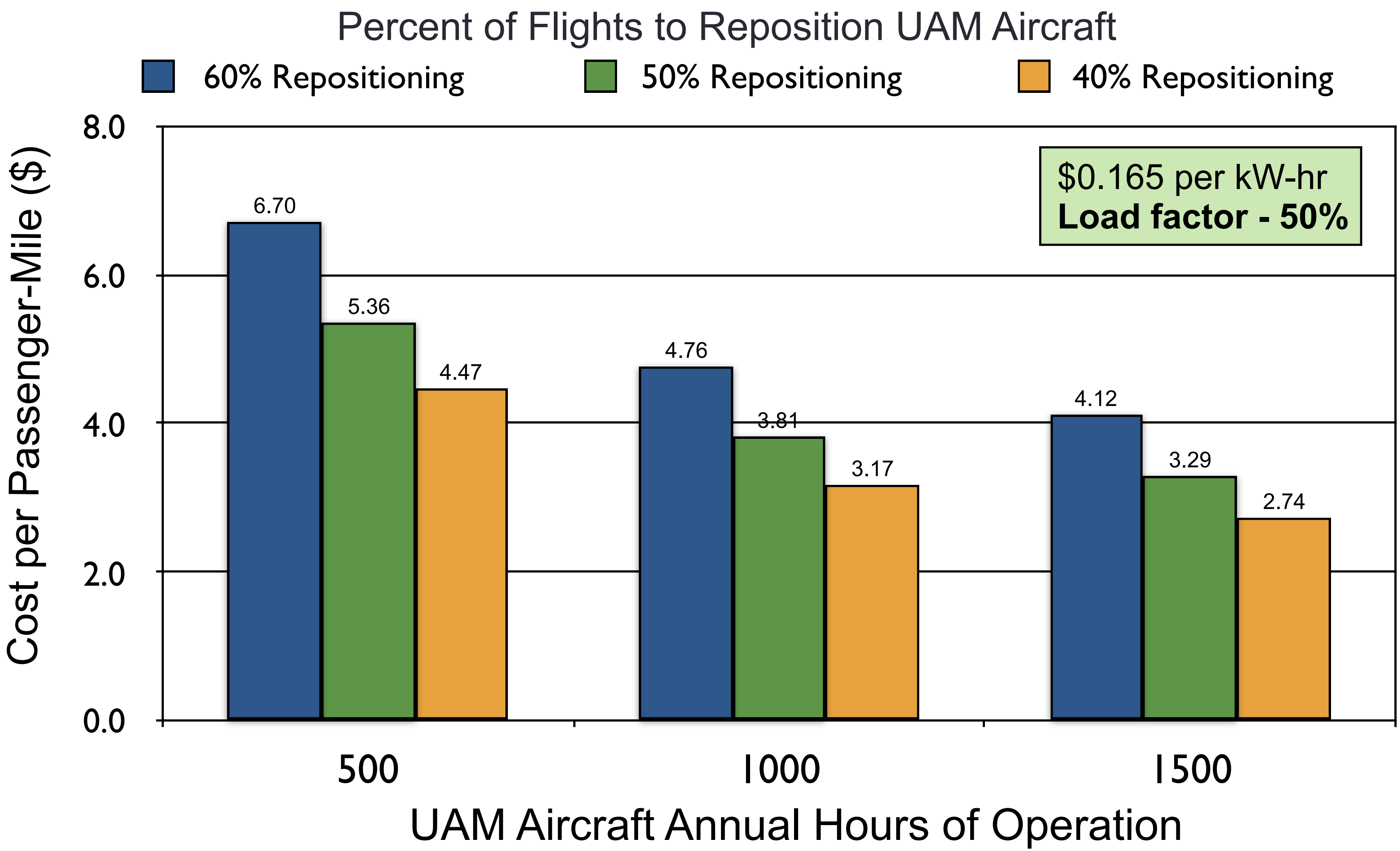
UAM aircraft life-cycle cost model include the following:

- Vehicle unit cost
- Number of annual operations
- Maintenance hours per flight hour
- Engine overhaul costs
- Time between overhauls
- Landing fee per landing
- Percent of repositioning flights
- Energy consumption performance (vs. block speed)
- Energy cost ($/kW-hr)
- Hangar cost
- Pilot vs no pilot switch
- Avionics and interior refurbishing costs
- Load factor per flight
- Depreciation
- Life-cycle time

Four-Seat UAM Vehicle Economics: High Utilization and Moderate Number of Repositioning of Flights



Four-Seat UAM Vehicle Realistic Economics



UAM Vehicle Costs in the Literature

Source		UAM Cost per Passenger Mile ($)	Trip Purpose
Lilium		$4.40	Airport
Joby Aviation		$3.80	Not Specified
Ehang		$2.28 - $2.74 Per Available Seat Mile	Not Specified
BAH (5-seat eVTOL)		$6.25 (near-term) $2.5 (long-term)	General
Goyal et al. (2021)		~$2.50 - $2.85	General
Archer		$3.0 - $4.0	Airport
LEK		$7.68 (2025) $1.76 (2040)	General
Brown and Harris (2020)	Lift + Cruise Compound Heli Tilt Wing Tilt Rotor	$4.86 $5.12 $4.33 $3.80	Not Applicable (Systems Study)
Virginia Tech UAM Life Cycle Cost Model		$3.20 to $4.63	Commuter and Airport Trips

Source: Air Traffic Management Exploration (ATM-X) UAM Demand Analysis: Deliverable 1.2

UAM Demand Models

Calibrated Logit and Mixed Logit Models to Predict UAM Demand

Metropolitan Area	UAM Model	Model Structure	Attributes Considered	Model Scope	Value of Time
Northern California	Commuter trips	Mixed Conditional Logit	In-vehicle travel time, Out-of-vehicle travel time, Number of transfers. Income level (3 categories)	4.3 million commuters 17 counties around San Francisco Bay Area	Out-of-Vehicle VOTs Low Income $15.7/hr Medium Income $18.22/hr High Income $29.30/hr
	Cargo	Parametric Market Share Model	High value goods	High-value air freight Time-sensitive shipments	Not applicable
Southern California	Commuter trips	Mixed Logit Model	Travel time, number of transfers,	9.1 million commuter trips 15 counties	
	Airport trips	Conditional Logit Models	Travel time, Travel cost, Resident, Non-resident, Business, Non-business, submodes constants	99,250 daily airport trips	Business travelers $52/hr. Non-business travelers $22/hr.
	Cargo	Parametric - Market Share Model	High value goods	High-value air freight Time-sensitive shipments	Not applicable
Dallas-Forth Worth	Commuter trips	Mixed Logit Model	Travel time, number of transfers	2.9 million commuter trips	
	Airport trips	Conditional Logit Models	Travel time, Travel cost, Resident, Non-resident, Business, Non-business, submodes constants	45,750 daily airport trips	Business travelers $57/hr. Non-business travelers $36/hr.
Miami	Commuter trips	Mixed Logit Model calibrated in Northern California	Travel time, number of transfers	2.5 million commuter trips	

Calibrated Logit and Mixed Logit Models to Predict UAM Demand

Table 8: Region-specific Calibrated Commuter Mode Choice Models

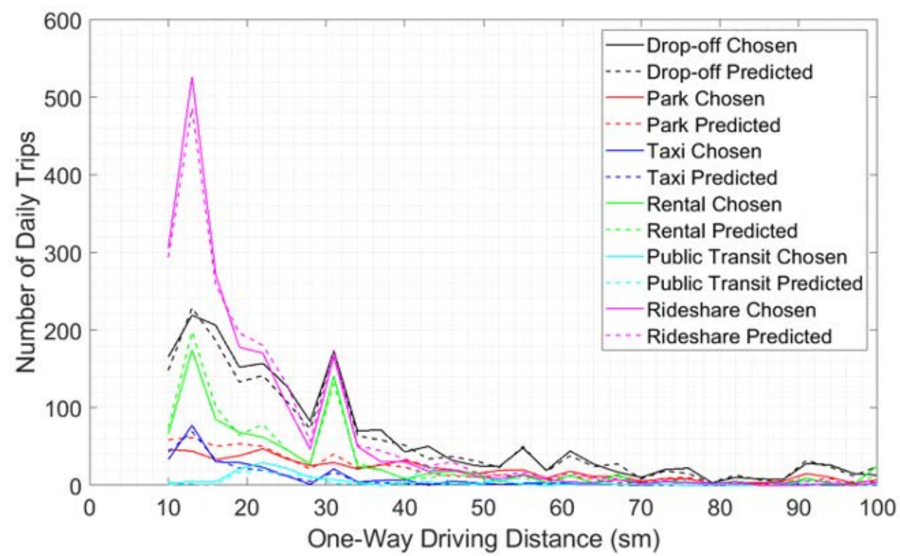
BASIC MODELS WITHOUT CONSTANTS				
	Dallas-Ft. Worth	**North California**	**South California**	**New York**
TT				
IVTT		-0.0472*	-0.0441*	-0.2027*
OVTT		-0.0845*	-0.110*	-0.2299*
Cost			-0.307*	
Transfers		0.343*	0.139*	-0.5384*
Low Income		-0.329*		-0.7157*
Lower-Mid Income				-0.6472*
Mid Income		-0.275*		
Upper-Mid Income				-0.5582*
High Income		-0.172*		-0.4187*
Transit Constant		-0.603*	-1.476*	-0.1038*
VTOL Constant		0.699	0.612	-0.7496
Pseudo-R^2		0.493		0.899
TT VOT				
IVTT VOT		\$8.6, \$10.3, \$16.5	\$8.6	\$17.0, \$18.8, \$21.8, \$29.1
OVTT VOT		\$15.4, \$18.4, \$29.5	\$21.5	\$19.3, \$21.3, \$24.7, \$33.0
Constraints			OVTT/IVTT=2.5	

Table 5: Airport-Access Models for Dallas-Fort Worth

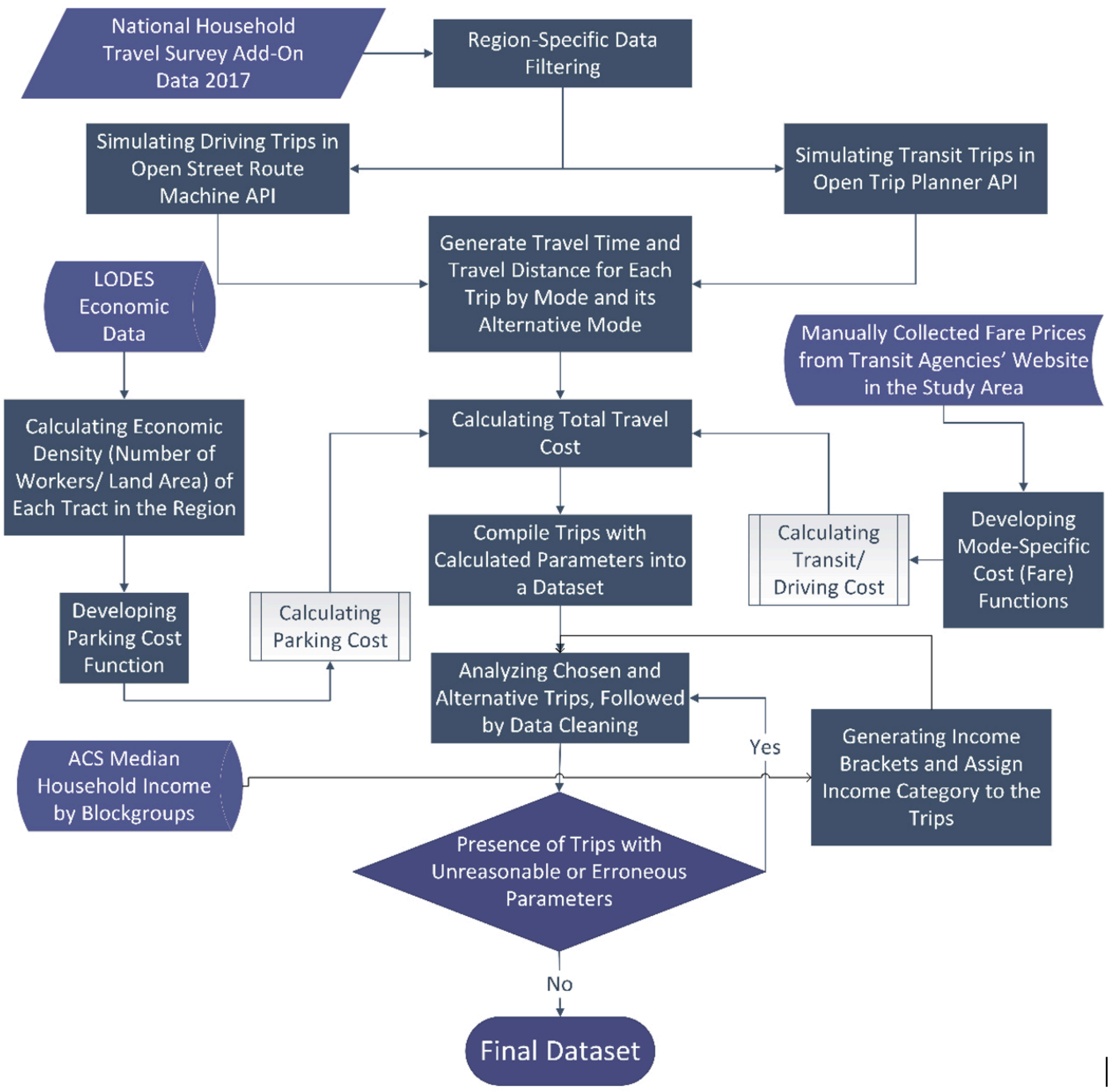
Parameter		Coefficient (or Estimate)	
		Business Trips	Non-Business Trips
Mode Constants	Drive & Park[#]	1.1613*	0.0384
	Taxi	-0.7247*	-1.4141*
	Rental Car[##]	0.5772*	-0.2281*
	Public Transit	-2.333*	-1.9685*
	Rideshare (Uber, Lyft, etc.)	-1.8706*	-1.8531*
Travel Time	Total Travel Time	-0.0207*	-0.0192*
Travel Cost	Travel Cost (Residents)	-0.0220*	-0.0353*
	Travel Cost (Visitors)	-0.0216*	-0.0316*
Transfers	Number of Transfers	-0.2277*	0.3337*
Model Fit	ρ^2 (Pseudo R^2)	0.2952	0.2763
	Prob > chi^2	0.0000*	0.0000*
Value of Time	Resident VOT (\$/hr)	56.45	32.54
	Visitor VOT (\$/hr)	57.50	36.38

*Significance: 0.01
[#]Only applicable to Resident Business Trips
[##]Only applicable to Non-Resident Business Trips

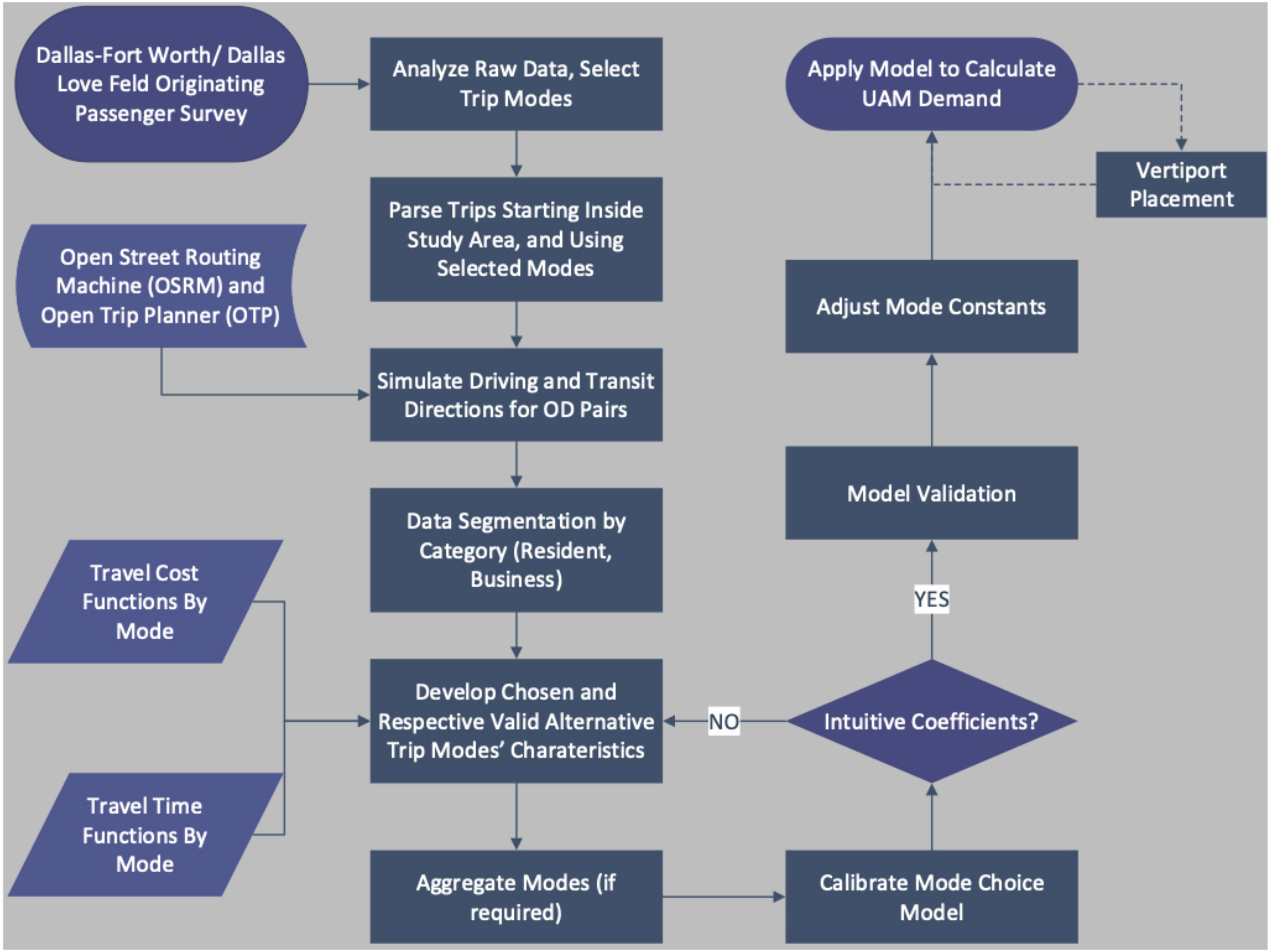
Typical Model Validation



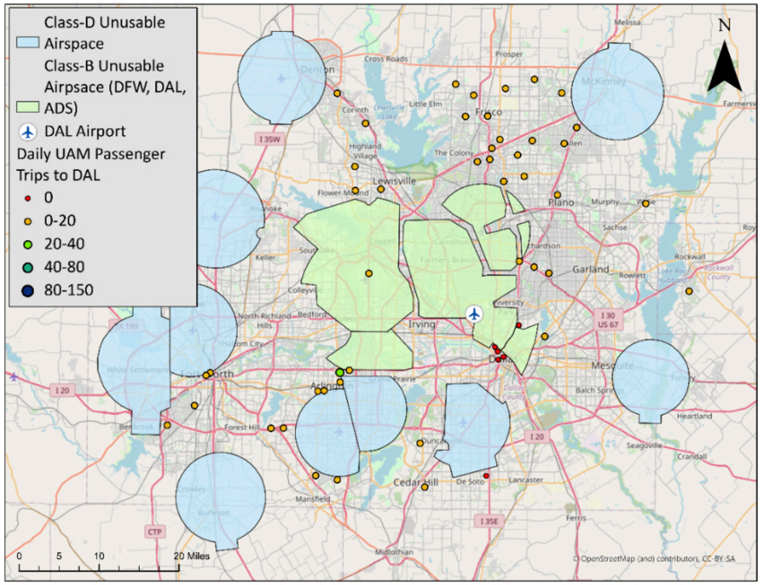
UAM Commuter Demand Data Workflow



UAM Airport Trip Demand Workflow

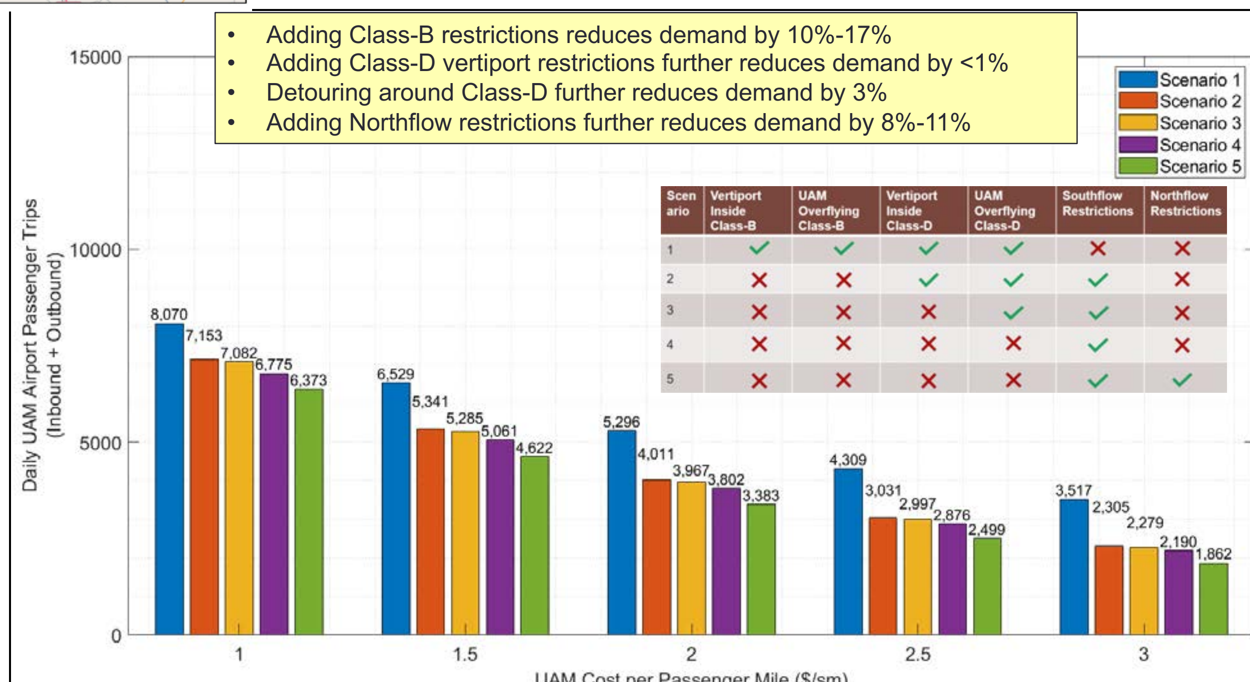


Class B Airspace Restrictions Reduce Airport UAM Trip Demand by 17% in the Dallas Area



- Longer UAM travel times due to airspace class B and D restrictions affect trip cost
- UAM vertiport placement affected by airspace restrictions

Airspace restrictions developed by NASA Ames Research Center



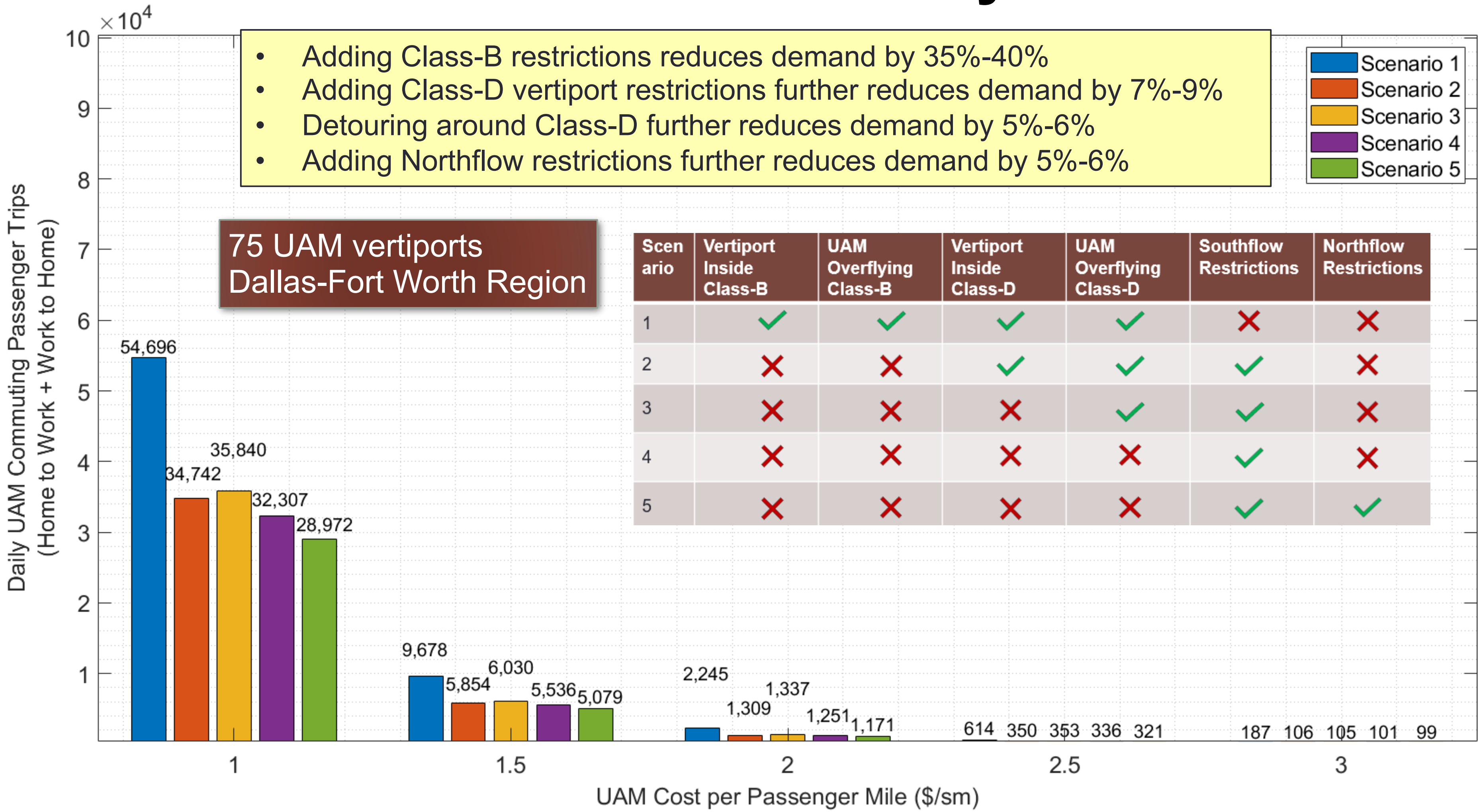
Scenario	Vertiport Inside Class-B	UAM Overflying Class-B	Vertiport Inside Class-D	UAM Overflying Class-D	Southflow Restrictions	Northflow Restrictions
1	✓	✓	✓	✓	✗	✗
2	✗	✗	✓	✓	✓	✗
3	✗	✗	✗	✓	✓	✗
4	✗	✗	✗	✗	✓	✗
5	✗	✗	✗	✗	✓	✓

Class B Airspace Restrictions Reduce UAM Commuter Demand by 40%

- Adding Class-B restrictions reduces demand by 35%-40%
- Adding Class-D vertiport restrictions further reduces demand by 7%-9%
- Detouring around Class-D further reduces demand by 5%-6%
- Adding Northflow restrictions further reduces demand by 5%-6%

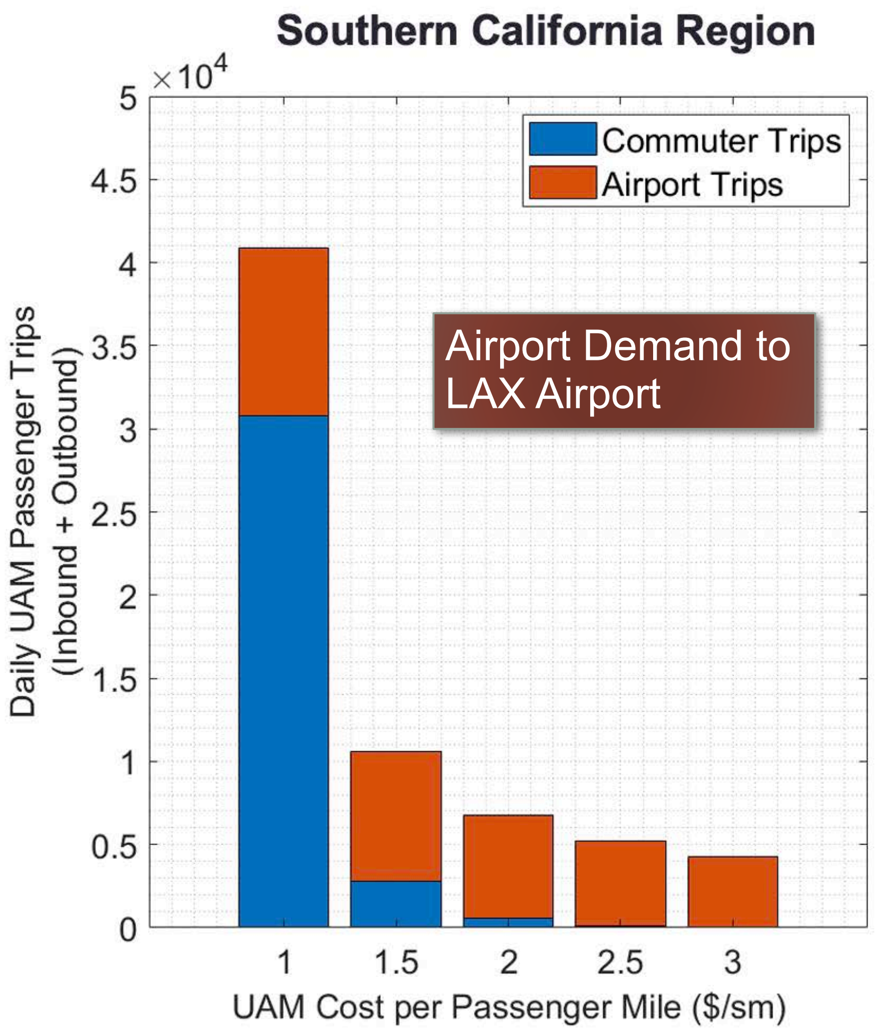
75 UAM vertiports
Dallas-Fort Worth Region

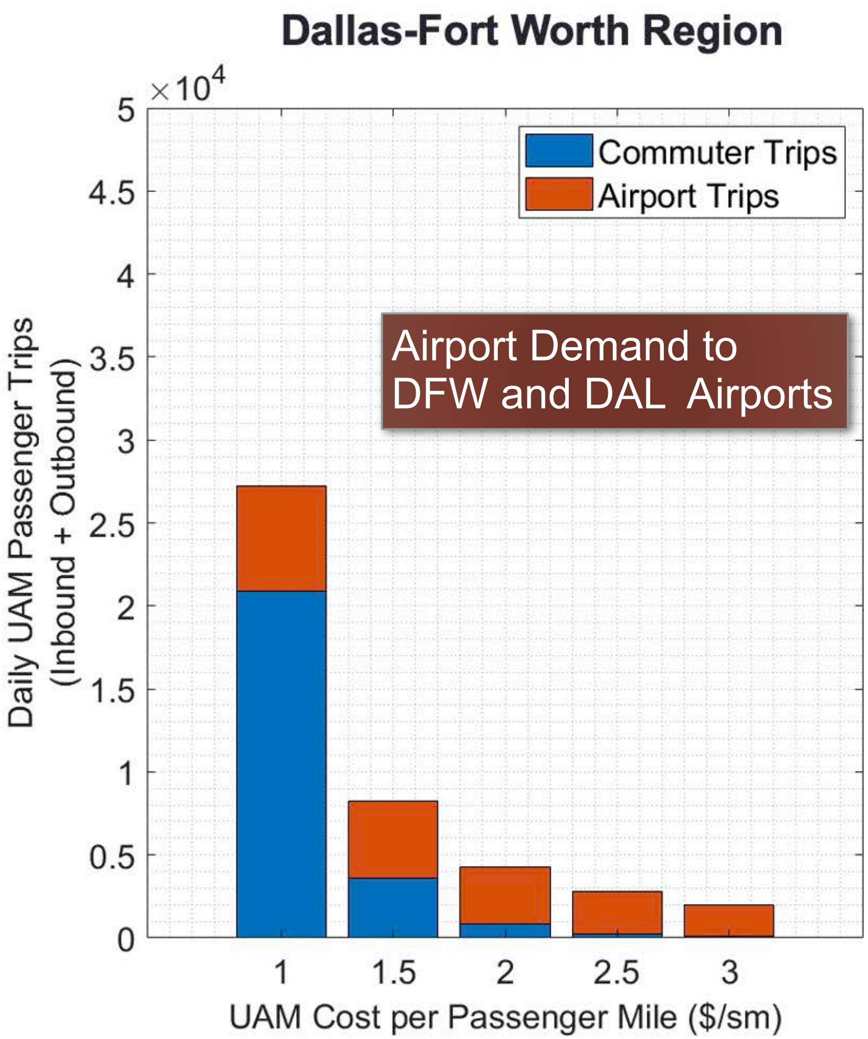
Scenario	Vertiport Inside Class-B	UAM Overflying Class-B	Vertiport Inside Class-D	UAM Overflying Class-D	Southflow Restrictions	Northflow Restrictions
1	✓	✓	✓	✓	✗	✗
2	✗	✗	✓	✓	✓	✗
3	✗	✗	✗	✓	✓	✗
4	✗	✗	✗	✗	✓	✗
5	✗	✗	✗	✗	✓	✓



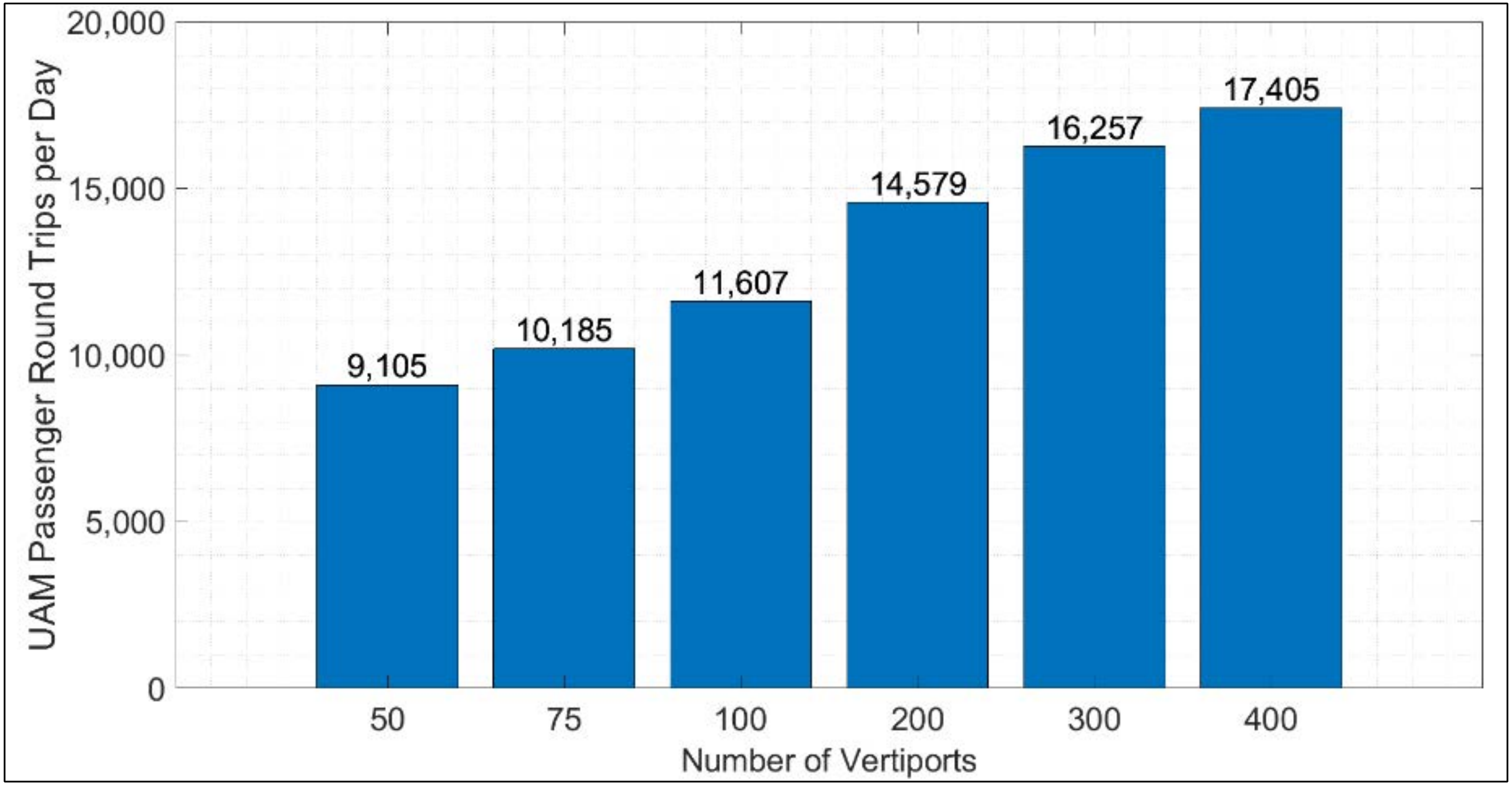
At $3 per Passenger-Mile and Airspace Restrictions UAM Trips to Airport Remain Feasible

50 UAM vertiports and airspace restrictions

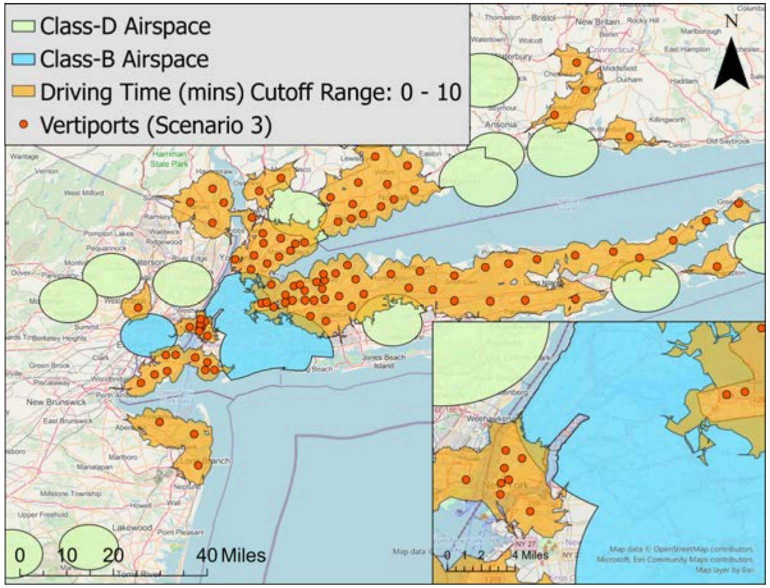




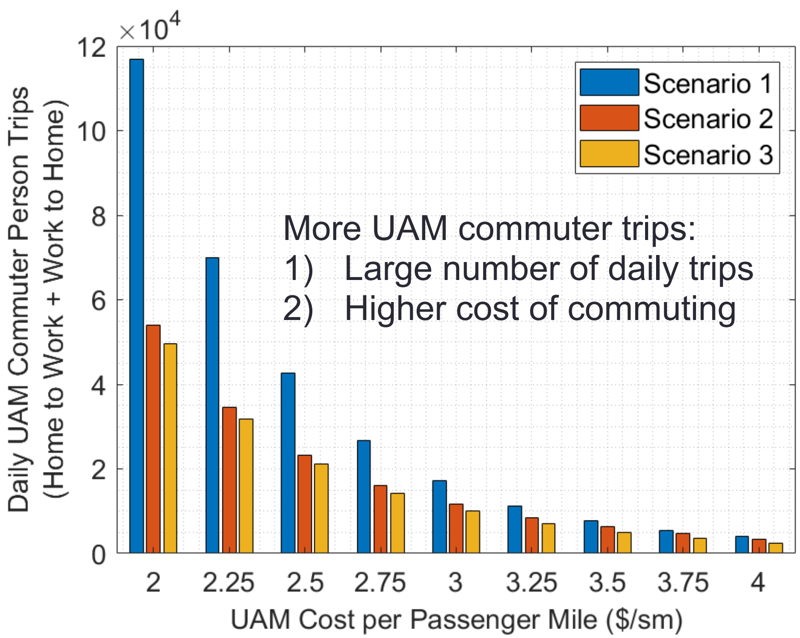
In Northern California, Doubling the Number of UAM Vertiports from 50 to 100 Increases UAM Commuter Demand by 27% at a Cost Per Mile $1.80

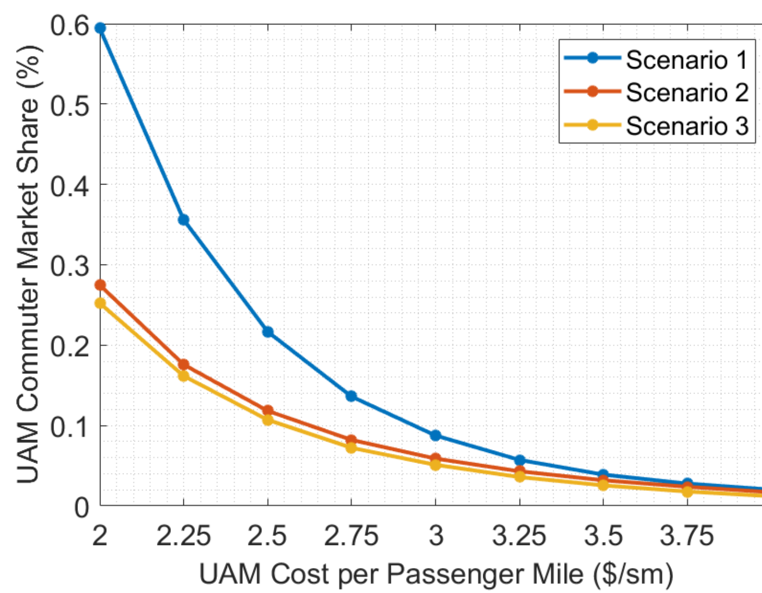


For New York Commuter Demand is Reduced by 55% if Airspace Restrictions are Applied

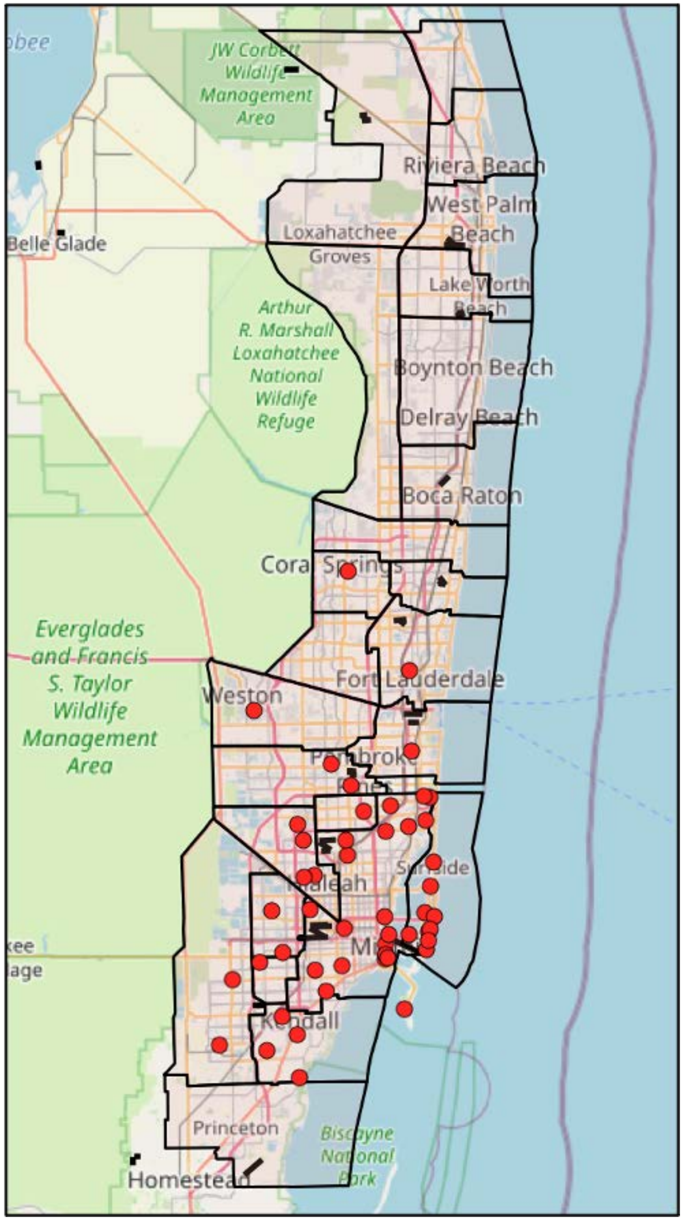


Scenario	Restrictions	
	Vertiport Placement	**UAM Overflying**
Scenario 1	None	None
Scenario 2	Only in Class-B Airspace	Only in Class-B Airspace
Scenario 3	In Class-B and Class-D Airspace	In Class-B and Class-D Airspace

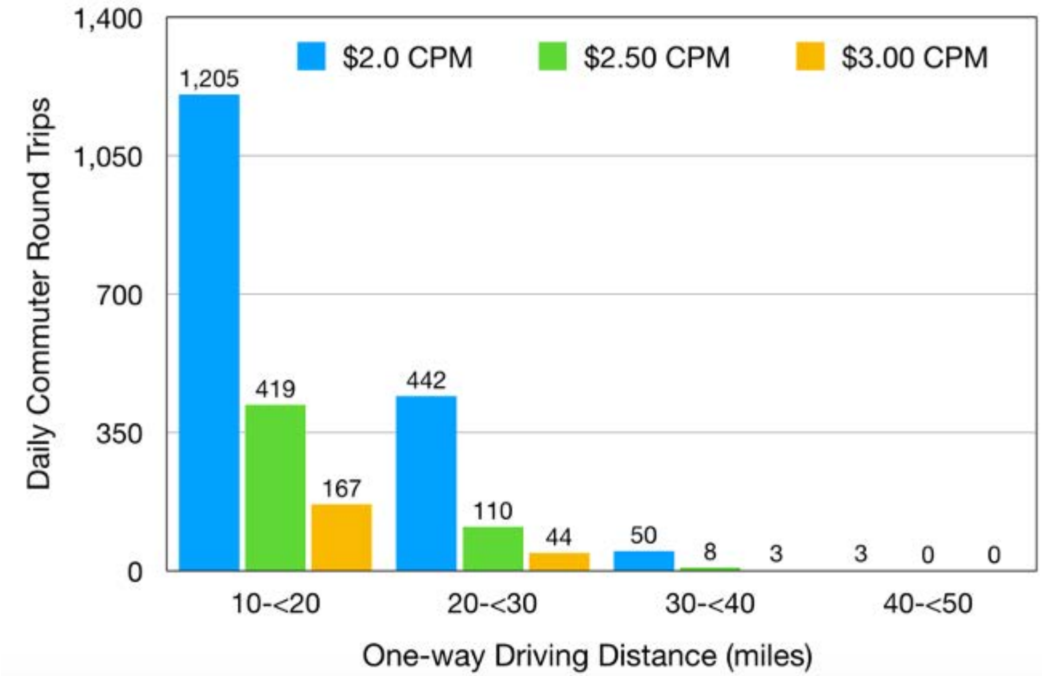




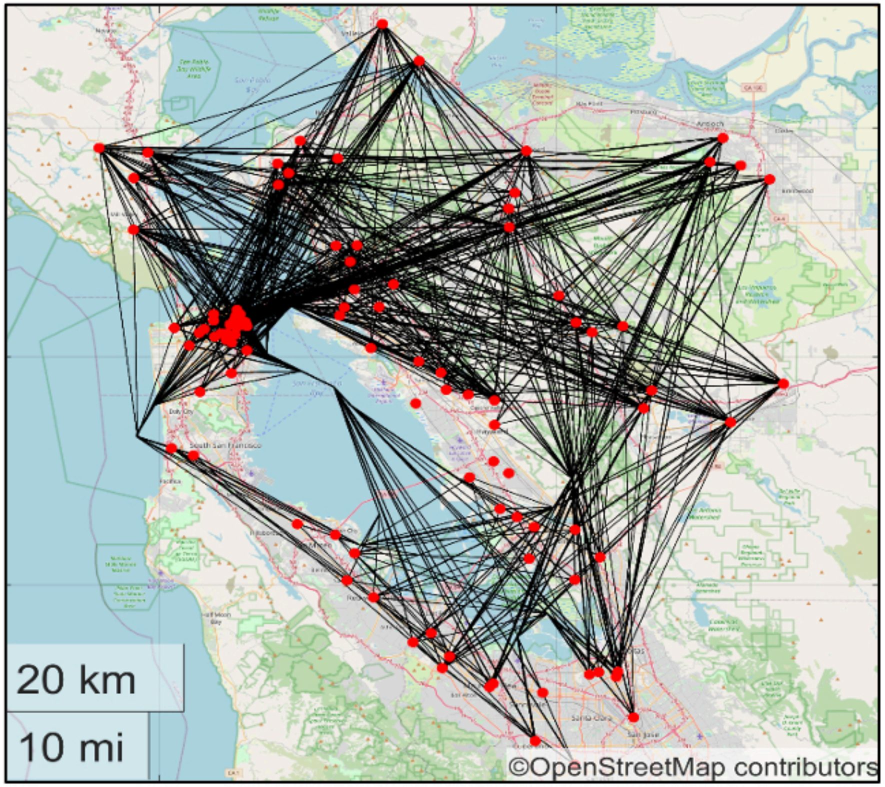
Miami Commuter Demand



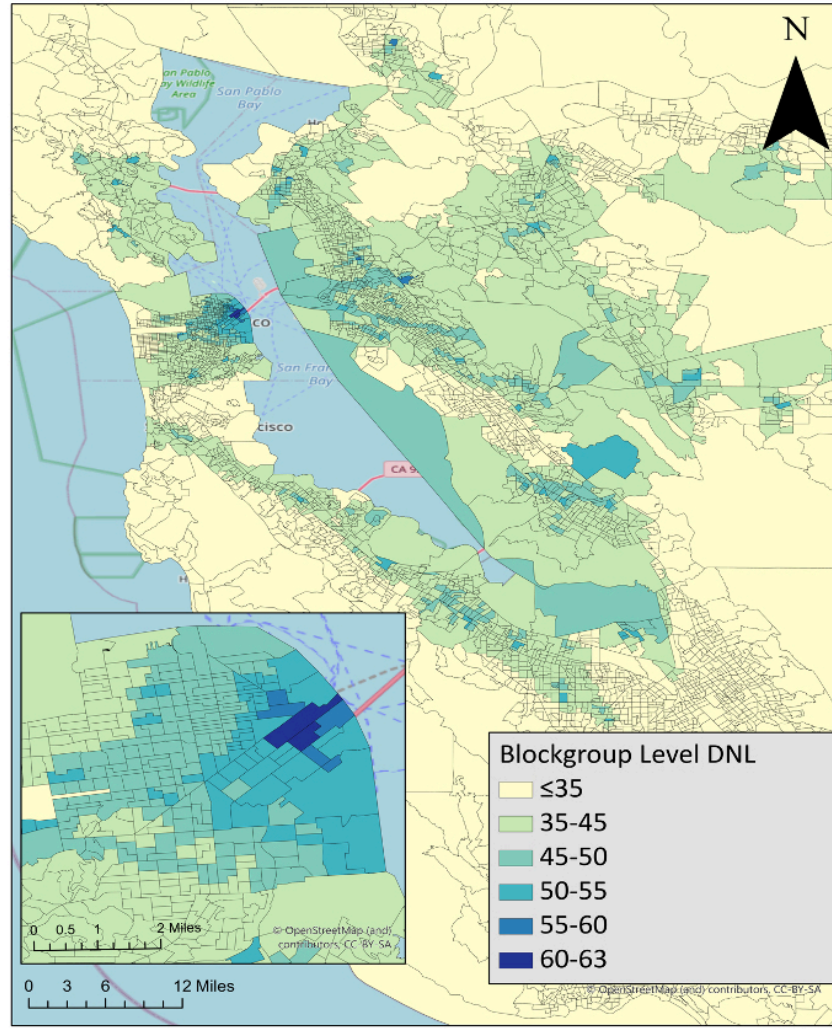
Parameter		Value
Walkable Distance To/From Vertiport		0.10 mi
Ingress[1] Time		5 min
Egress Time		5 min
Average UAM Vehicle Speed		120 mph
Average Walking Speed		3.1 mph
Minimum Trip Distance for UAM Eligibility		10 miles
Average UAM Aircraft Occupancy		2.4
UAM Fare Structure	Base Cost (per-passenger)	$15
	Landing Cost (per-vehicle)	$20
	Cost Per Mile (CPM)	Variable



Integrated UAM Demand Model Produces Flight Trajectories

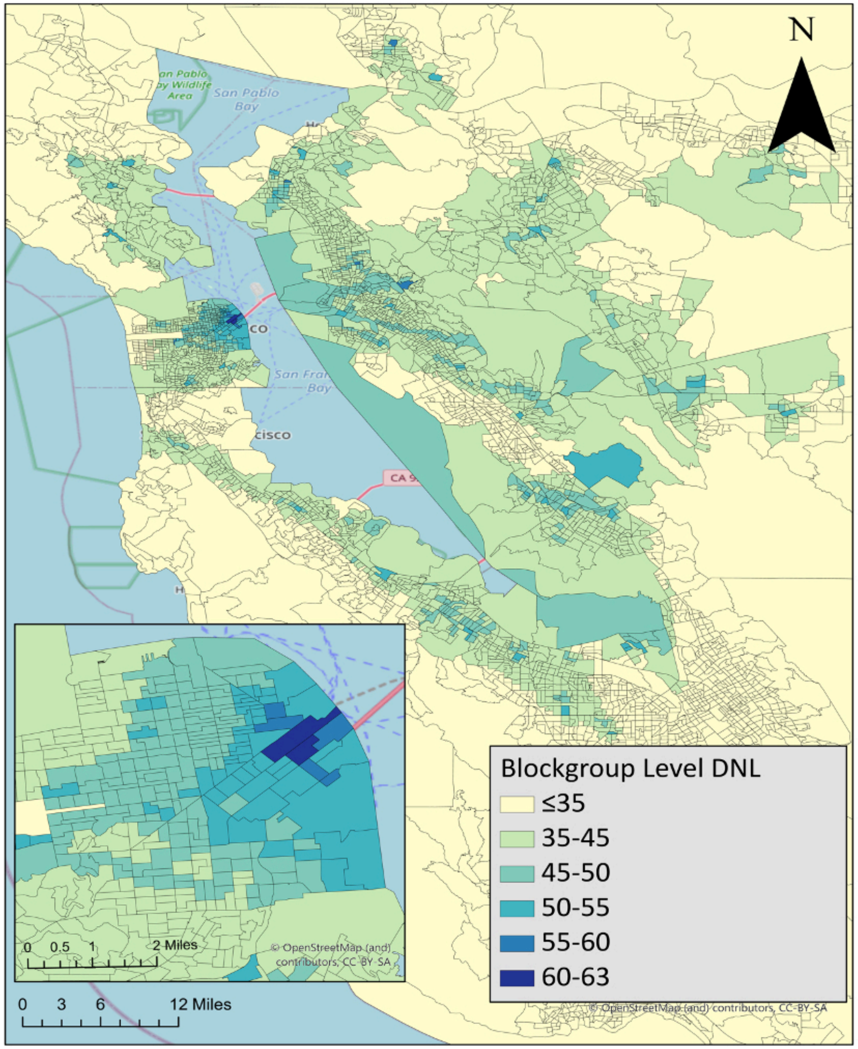


Sample Flight Tracks of UAM Aircraft in the Northern California Area

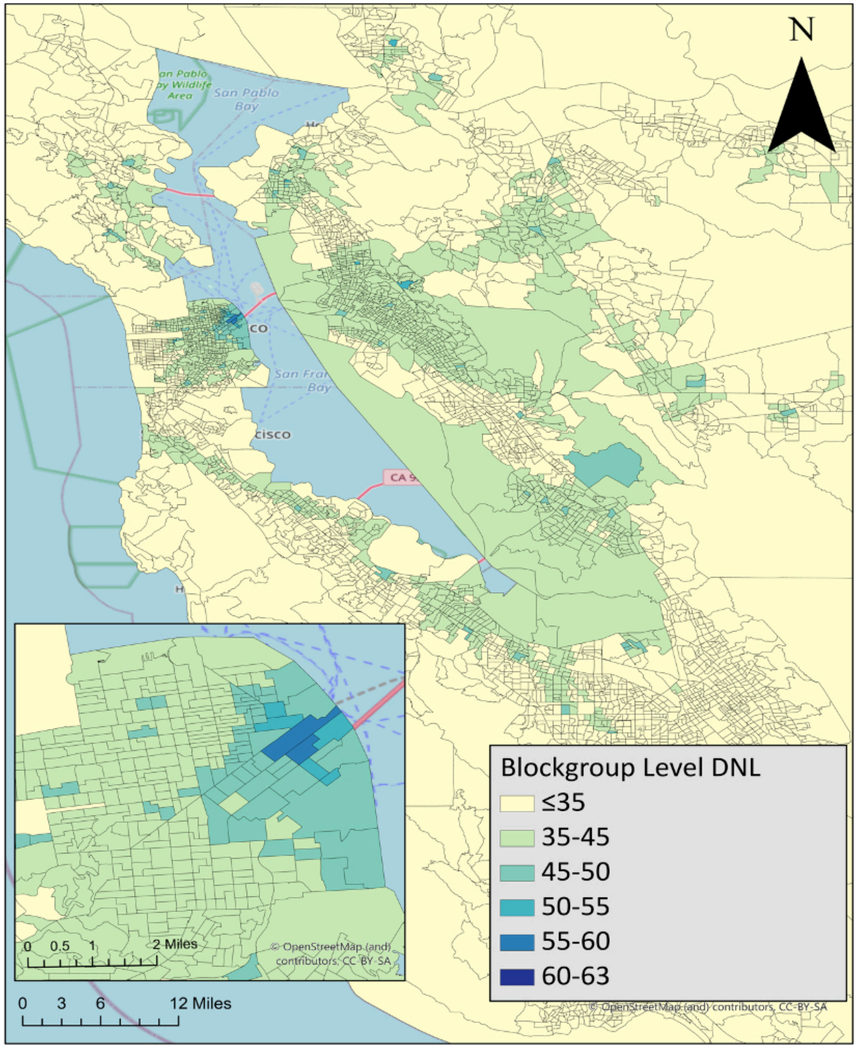


Estimated Day-Night Average Sound Level (assumes 10 dBA Reduction over Robinson R44)

Preliminary Assessment of UAM Noise (Northern California)



10 dBA Reduction compared to R44



15 dBA Reduction compared to R44

Preliminary Assessment of UAM Noise (Northern California)

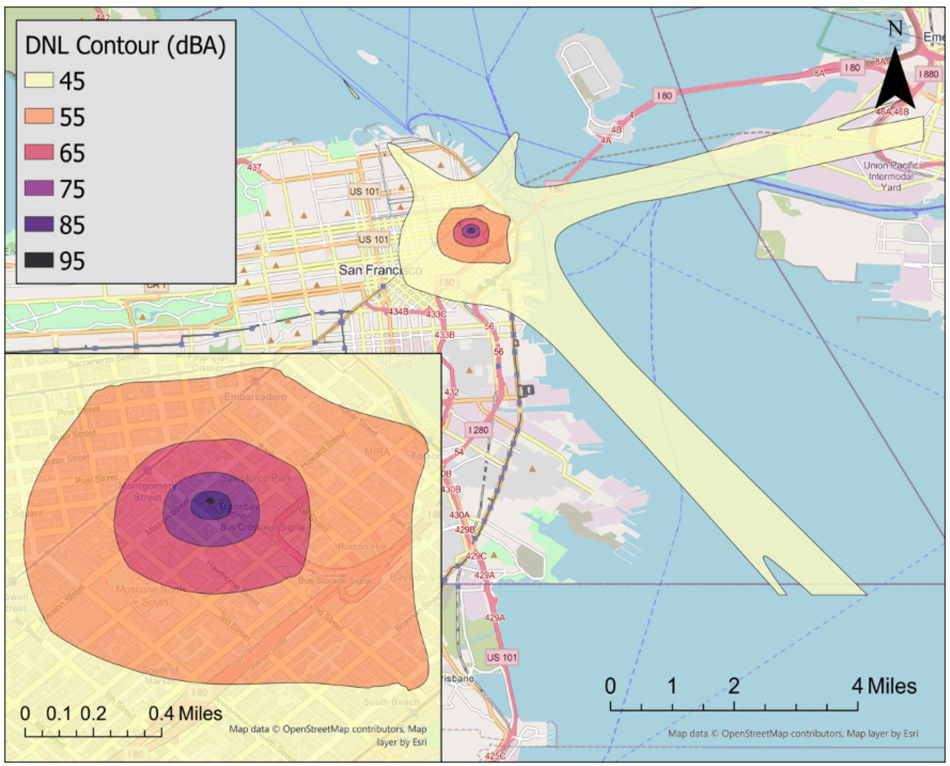
- Achieving a 15 dBA over the the reference helicopter used in the study (Robinson R22) the land area affected by noise could decrease by 80%
- The total highly annoyed population would be reduced by 80%

DNL Category	Area Impacted (sq. mi.)		Population Impacted by Noise		Highly Annoyed Population	
Reduction Scenario	10 dBA	15 dBA	10 dBA	15 dBA	10 dBA	15 dBA
45-50 dBA	97.0	22.7	657,946	159,270	87,126	21,828
50-55 dBA	22.7	1.15	159,270	12,844	38,435	2,870
55-60 dBA	1.15	0.32	12,844	3,317	4,699	1,209
60-63 dBA	0.32	0	3,317	0	1,776	0
Total	**121.2**	**24.2**	**833,377**	**175,431**	**132,036**	**25,907**

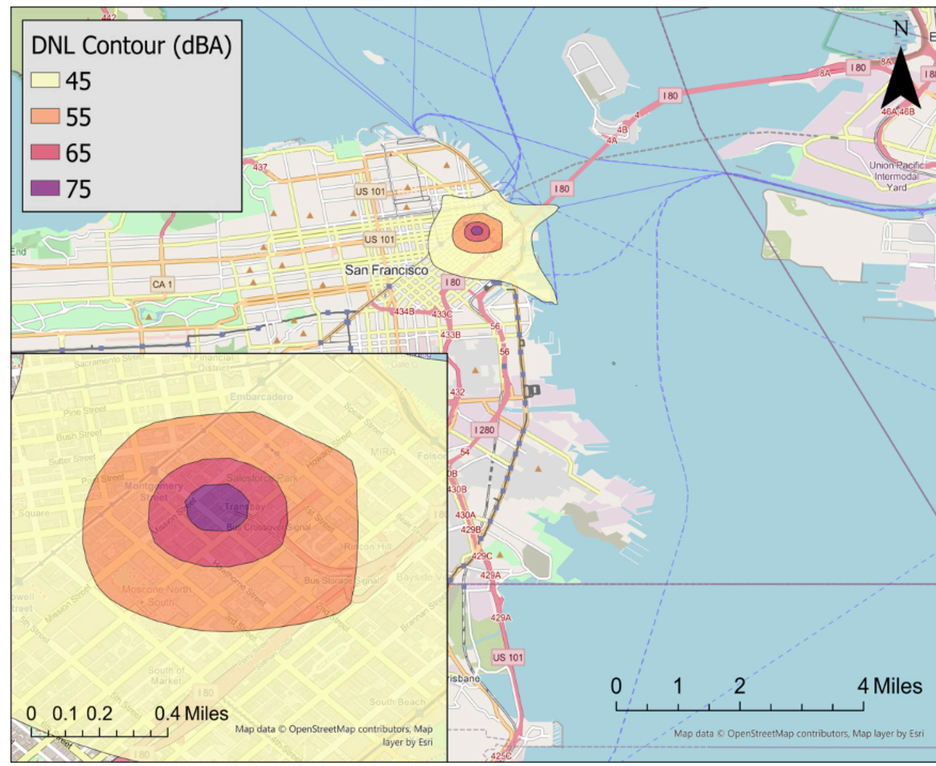
Noise Impacts Using the FAA Aviation Environmental Design Tool Analysis

900 daily UAM operations

DNL	Area under DNL Contour (sq. mi.)		Population under DNL Contour		Highly Annoyed Population	
Reduction Scenario	10-dBA	15-dBA	10-dBA	15-dBA	10-dBA	15-dBA
45	10.89	1.81	110,811	28,764	21,133	5,485
55	0.70	0.33	11,655	4,213	5,687	2,055
65	0.16	0.08	1,596	677	1,267	537
75	0.03	0.0155	272	93	256	87
85	0.006	-	2	-	2	-
95	0.0002	-	-	-	-	-



15 dBA Reduction compared to R44



10 dBA Reduction compared to R44

Conclusions

- An integrated approach to study UAM operations has been developed
  - Model considers landing site placement, landing site cost and capacity limits
  - UAM demand is estimated using Conditional Logit or Mixed Logit models
- For UAM to be successful, the analysis shows cost per passenger mile needs to be contained below $3 per passenger-mile
- Beyond $3 per passenger mile, the commuter demand is relatively low (except in New York)
- Airspace restrictions add 6-12% more distance to UAM trips
- Airspace restrictions result in 20-55% fewer demand trips compared to unrestricted scenarios investigated

Relevant Technical Publications

1. Rimjha, M., A., Trani, and S. Hotle, Urban Air Mobility: Preliminary Noise Analysis of Commuter Operations, AIAA 2021, July28, 2021, American Institute of Aeronautics and Astronautics, https://doi-org.ezproxy.lib.vt.edu/10.2514/6.2021-3204
2. Rimjha, M., Hotle, S., A., Trani, A.A, Hinze, N. and J. Smith, Urban Air Mobility Demand Estimation for Airport Access: A Los Angeles International Airport Case Study, Integrated Communications, Navigation and Surveillance Conference, ICNS, v 2021, April 19-23, 2021, Institute of Electrical and Electronics Engineers Inc.
3. Rimjha, MA. And A.A. Trani, Urban Air Mobility: Factors Affecting Vertiport Capacity, Integrated Communications, Navigation and Surveillance Conference, ICNS, v 2021, April 19-23, 2021, Institute of Electrical and Electronics Engineers, Inc.
4. Rimjha, M., Hotle, S., Trani, A.A, and Hinze, N., Commuter Demand Estimation and Feasibility Assessment for Urban Air Mobility in Northern California, Transportation Research Part A: Policy and Practice, Volume 148, June 2021, Pages 506-524, Elsevier (https://doi.org/10.1016/j.tra.2021.03.020).
5. Sayantan, T., Rimjha, M., Hinze, N., Hotle, S. and Trani, A. A. Urban Air Mobility Regional Landing Site Feasibility and Fare Model Analysis in the Greater Northern California Region, Integrated Communications, Navigation and Surveillance Conference, ICNS, v 2019-April, April 2019.
6. Rimjha, M., Tarafdar,S.,Hinze, N., Trani, A.A., Swingle, H., Smith, J., Marien, T., and S. Dollyhigh., On-Demand Mobility Cargo Demand Estimation in Northern California Region, Integrated Communications, Navigation and Surveillance Conference, v 2020-September, September 2020, Institute of Electrical and Electronics Engineers, Inc.
7. Syed, N., Rye, M., Ade, M., Trani, A., Hinze, N., Swingle, H., Smith, J., Dollyhigh, S. & Marien, T. (2017). Preliminary Considerations for ODM Air Traffic Management based on Analysis of Commuter Passenger Demand and Travel Patterns for the Silicon Valley Region of California. In 17th AIAA Aviation Technology, Integration, and Operations Conference (p. 3082), https://doi.org/10.2514/6.2017-3082