AAM/UAM Research at USF

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Smart Urban Mobility Laboratory

Future of Aviation

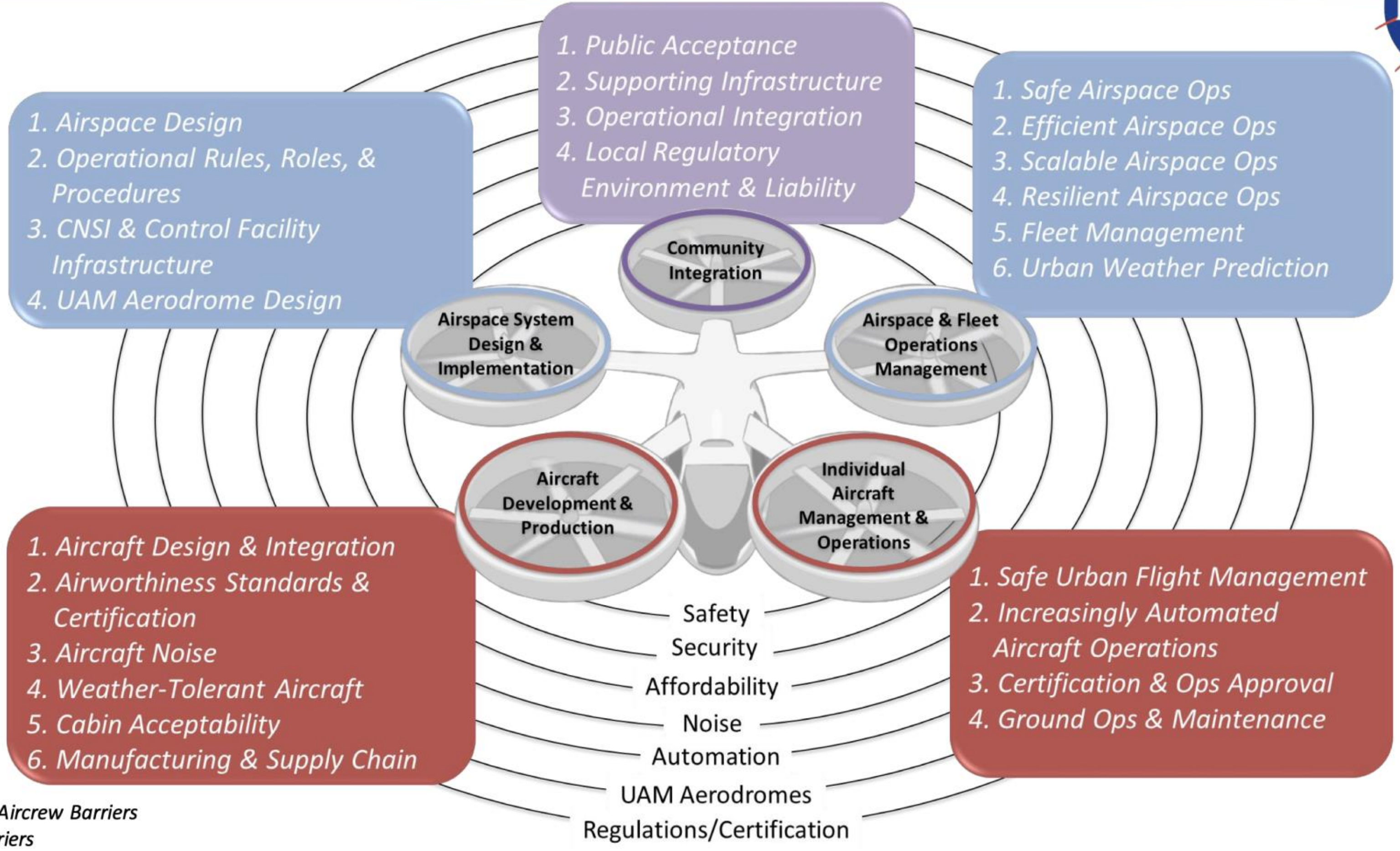
San Francisco, August 4, 2022

UNIVERSITY of SOUTH FLORIDA

Smart Urban Mobility (SUM) Lab at USF

- **Shared Micromobility, Ridesourcing, and Shared Automated Vehicles:** Efficient and Equitable Micromobility Program Design and Evaluation; Impacts of Shared AV; Multimodal Connections with Emerging Technologies and Business Models; Learning-based prediction of demand of different modes.
- **Advanced Aerial Mobility:** Network Design and Multimodal Planning; Airspace Management of Integrated National Airspace System; Automated Air Traffic Management System; Community Integration, equity, and sustainability; Multimodal Connections with Emerging Technologies and Business Models.
- **Air Transport Management:** Applications of Machine Learning in Air Traffic Management; Air Traffic Flow Management; Air Transport Economics; Integrated Airspace with New Entrants; Green Aviation.
- **Resilient Cities:** Criticality Analysis of Roadway Network and Freight Transportation System; Integrated Mitigation and Restoration Planning for Transportation and Freight Movement; Resiliency of Interdependent Critical Infrastructures.

UAM Framework and Barriers



1. Public Acceptance
2. Supporting Infrastructure
3. Operational Integration
4. Local Regulatory Environment & Liability

1. Airspace Design
2. Operational Rules, Roles, & Procedures
3. CNSI & Control Facility Infrastructure
4. UAM Aerodrome Design

1. Safe Airspace Ops
2. Efficient Airspace Ops
3. Scalable Airspace Ops
4. Resilient Airspace Ops
5. Fleet Management
6. Urban Weather Prediction

Community Integration

Airspace System Design & Implementation

Airspace & Fleet Operations Management

Aircraft Development & Production

Individual Aircraft Management & Operations

1. Aircraft Design & Integration
2. Airworthiness Standards & Certification
3. Aircraft Noise
4. Weather-Tolerant Aircraft
5. Cabin Acceptability
6. Manufacturing & Supply Chain

1. Safe Urban Flight Management
2. Increasingly Automated Aircraft Operations
3. Certification & Ops Approval
4. Ground Ops & Maintenance

Safety
Security
Affordability
Noise
Automation
UAM Aerodromes
Regulations/Certification

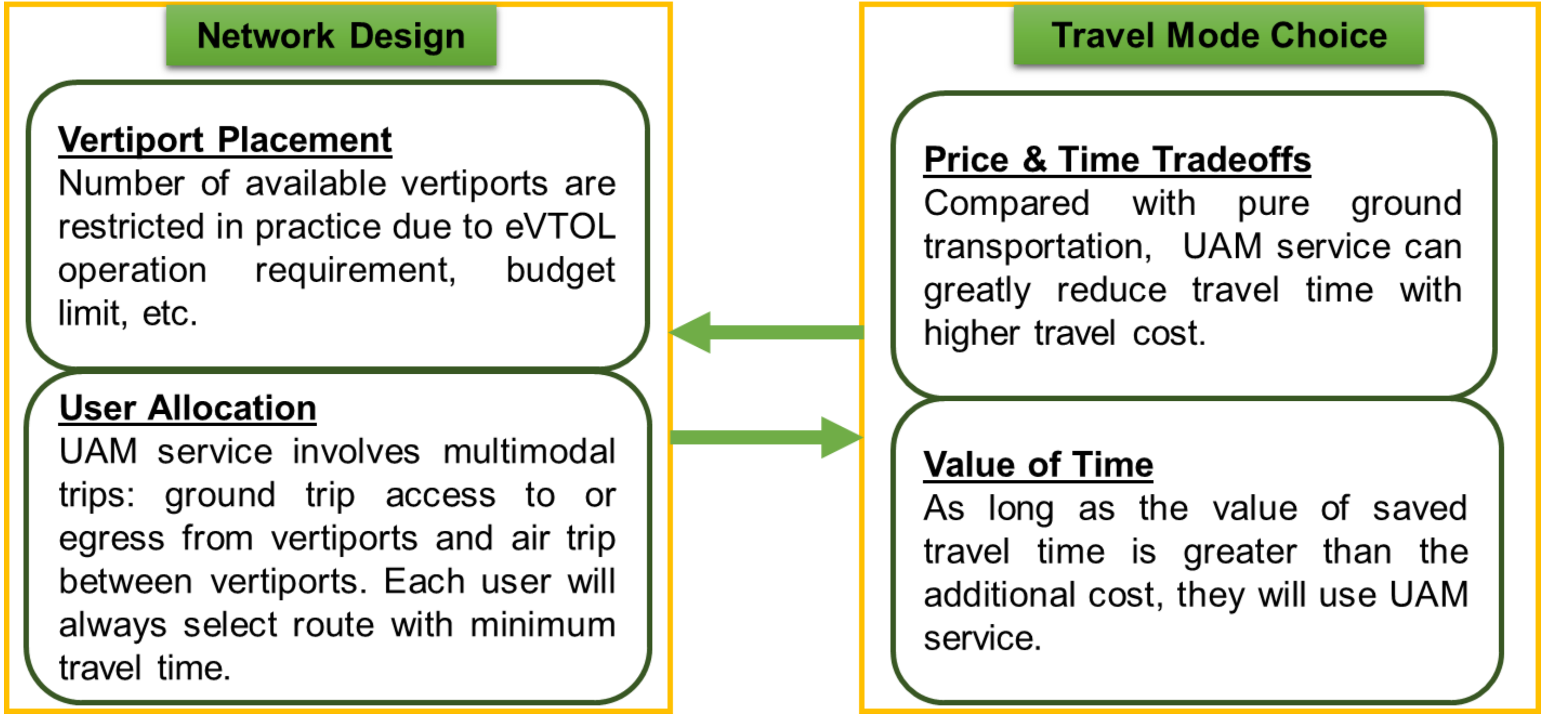
🟥 *Aircraft and Aircrew Barriers*
🟦 *Airspace Barriers*
🟪 *Community Integration Barriers*

M1: Integrated Network Design and Demand Estimation for On-Demand UAM

Zhiqiang Wu and Yu Zhang

Zhiqiang Wu, **Yu Zhang^** (2021). Integrated Network Design and Demand Estimation of on-Demand Urban Air Mobility. Engineering, https://doi.org/10.1016/j.eng.2020.11.007.

Network Design and Travel Mode Choice



Network Design

Vertiport Placement
Number of available vertiports are restricted in practice due to eVTOL operation requirement, budget limit, etc.

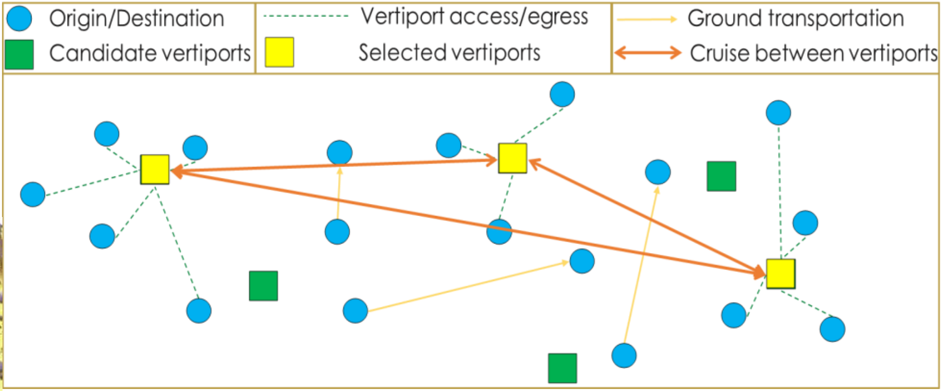
User Allocation
UAM service involves multimodal trips: ground trip access to or egress from vertiports and air trip between vertiports. Each user will always select route with minimum travel time.

Travel Mode Choice

Price & Time Tradeoffs
Compared with pure ground transportation, UAM service can greatly reduce travel time with higher travel cost.

Value of Time
As long as the value of saved travel time is greater than the additional cost, they will use UAM service.

Vertiport Siting - Extended Single Allocation Hub-Spoke Problem



Decision Variables
$\boldsymbol{y_k} \in \{0,1\}$, takes a value of 1 if k is selected as a vertiport, 0 otherwise.
$\boldsymbol{z^p} \in \{0,1\}$, takes a value of 1 if trip $\boldsymbol{p}$ is through pure ground transportation, 0 otherwise.
$\boldsymbol{x}_{\boldsymbol{kd}}^{\mathrm{p}} \in \{0,1\}$, takes a value of 1 if trip p use multimodal UAM through vertiport k and d $(k \rightarrow d)$, 0 otherwise.
$\boldsymbol{g_{ak}^p}$ & $\boldsymbol{h_{ed}^p} \in \{0,1\}$, takes a value of 1 if trip $\boldsymbol{p}$ access (egress) vertiport $\boldsymbol{k}$ $(\boldsymbol{d})$ using travel mode $\boldsymbol{a}$ $(\boldsymbol{e})$, 0 otherwise.

Optimal Vertiport Locations and Trip Allocations in The Tampa Bay Region

532 trips
of = 0.20%
266,734

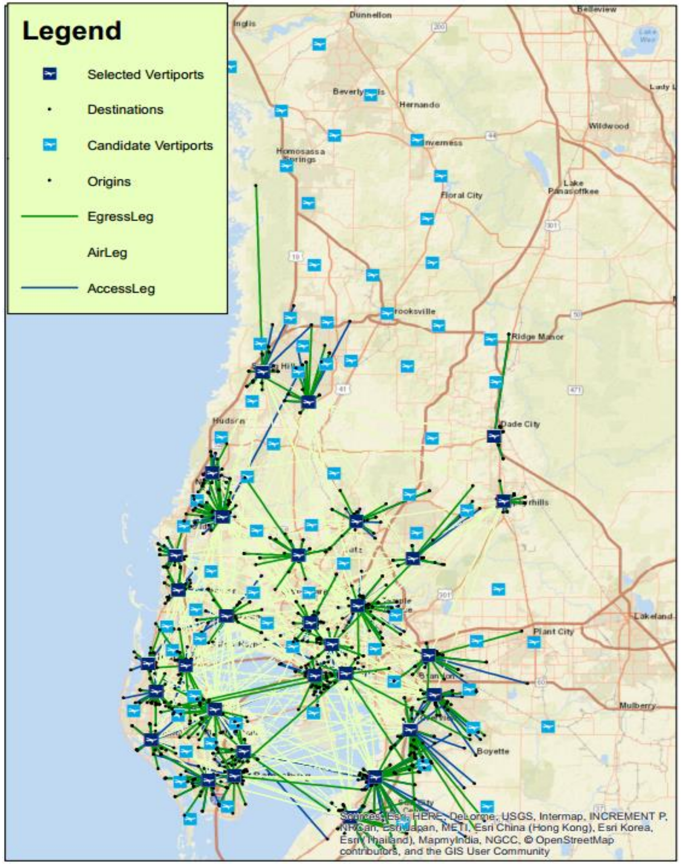
- Vertiport demand unevenly-distributed
- Northern region under-served

Number of trips served by each vertiport

Vertiport Index	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Demand	52	64	39	45	21	25	35	39	64	48

Vertiport Index	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Demand	31	43	27	30	41	20	34	26	33	42

Vertiport Index	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
Demand	26	36	54	25	21	25	32	13	65	27



Sources: Esri, HERE, DeLorme, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), MapmyIndia, NGCC, © OpenStreetMap contributors, and the GIS User Community

Outcomes of the Research

- Optimal locations of vertiports and diverted passenger demand
- Passenger allocation to vertiports
- Access and egress modes of each passenger
- Saved travel time and reduced system generalized cost
- Sensitivity analysis results:
  - Optimal number of vertiports to serve the region
  - Impacts of pricing schemes
  - Impacts of intermodal efficiency

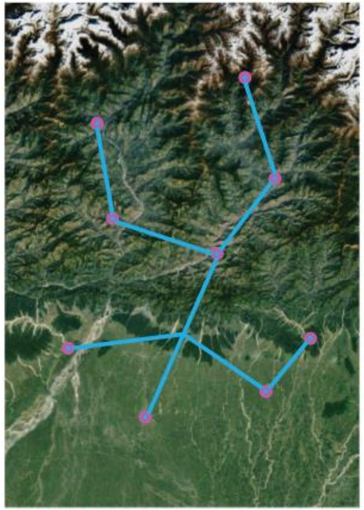
M2: Automated Flight Planning of High-Density Urban Air Mobility Operations

- Hualong Tang, **Yu Zhang^,** Hualong Vahid Mohmoodian, Hadi Charkhgard (2021). Automated Flight Planning of High-Density Urban Air Mobility. Transportation Research Part C: Emerging Technologies, Volume 131, October 2021, https://doi.org/10.1016/j.trc.2021.103324.
- Amazon Research Award 2021, "Design of an automated advanced air mobility flight planning system (AAFPS)”.
- Tang, H., Zhang, Y., Post, J., (2022). Pre-departure flight planning to minimize operating cost for urban air mobility. AIAA Aviation Forum 2022.
- https://www.youtube.com/watch?v=zF8tQGn-lhI

Research Objectives

- Provide pre-departure flight planning services to commercial service providers.
  - ✓ Medium to high density (UML 4 and above[1])
  - ✓ Conflict-free operation
  - ✓ Minimal operating cost

- **Two critical questions:**
  1. How should airspace be constructed?
  2. How are conflicts resolved at pre-departure planning stage?



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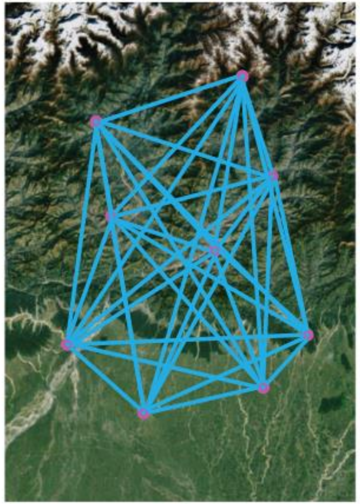
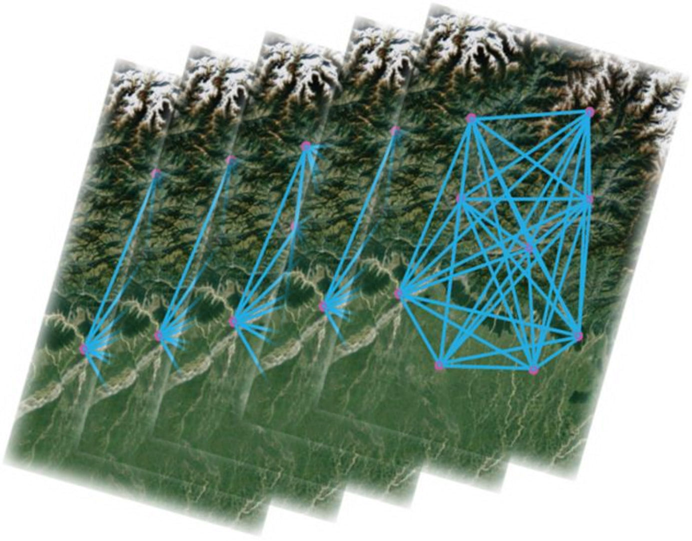


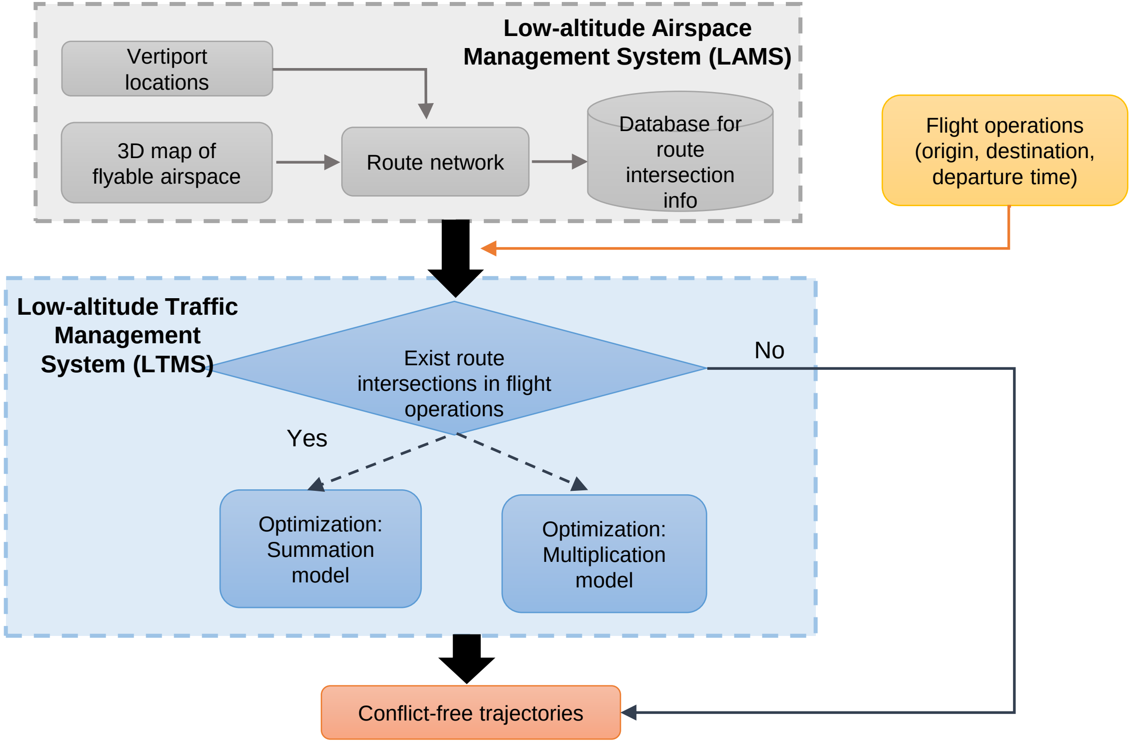
Airspace Structure

- Structured airspace can greatly reduce the airspace complexity and lessen the ATC workload[1].
- Low-structured architecture, especially free flight, spreads the traffic over the airspace so as to reduce the number of potential conflicts[2].
- A layered concept with minimal structure at each layer was optimal in capacity, safety, and efficiency[3]



[1] Hunter, G. and P. Wei. Service-oriented separation assurance for small UAS traffic management. in 2019 Integrated Communications, Navigation and Surveillance Conference (ICNS). 2019. IEEE.
[2] Jardin, M.R., Analytical relationships between conflict counts and air-traffic density. Journal of guidance, control, and dynamics, 2005. 28(6): p. 1150-1156.
[3] Sunil, E., et al. Metropolis: Relating airspace structure and capacity for extreme traffic densities. in Proceedings of the 11th USA/Europe Air Traffic Management Research and Development Seminar (ATM2015), Lisbon (Portugal), 23-26 June, 2015. 2015. FAA/Eurocontrol.

Automated UAM Flight Planning System



Low-altitude Airspace Management System (LAMS)

Vertiport locations

3D map of flyable airspace

Route network

Database for route intersection info

Flight operations (origin, destination, departure time)

Low-altitude Traffic Management System (LTMS)

Exist route intersections in flight operations

No

Yes

Optimization: Summation model

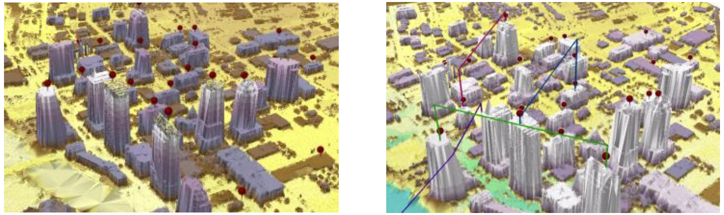
Optimization: Multiplication model

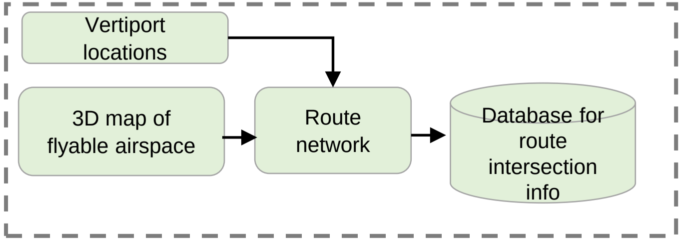
Conflict-free trajectories

- **Low-altitude Airspace Management System (LAMS): route network generation**
- **Low-altitude Traffic Management System (LTMS): conflict detection and resolution**

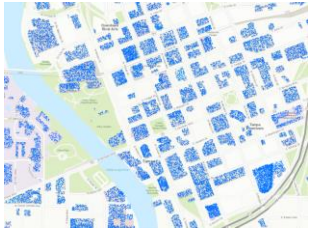
Low-altitude Airspace Management System (LAMS)

1) Construct a 3D GIS map of the region of interest with geographic and LIDAR data. A flyable airspace can be determined by the map and corresponding regulations.





LAMS

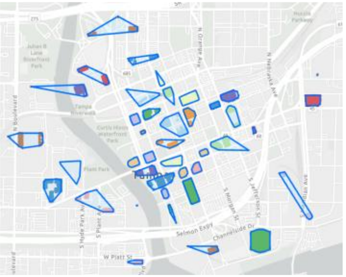


Points

Raster

Points with same density

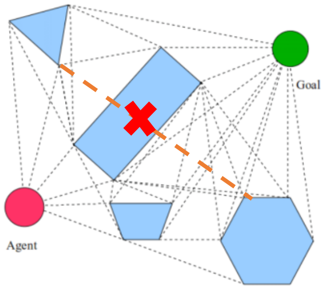
K-means clustering



UAM Operations Environment (UOE)

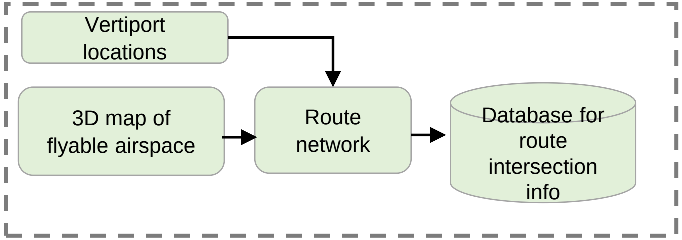
Low-altitude Airspace Management System (LAMS)

2) Construct visibility graphs for each origin-destination pair at different flight levels.



Why visibility graphs?

- Minimal nodes and edges
- The shortest path is among the candidate paths on visibility graph



Vertiport locations

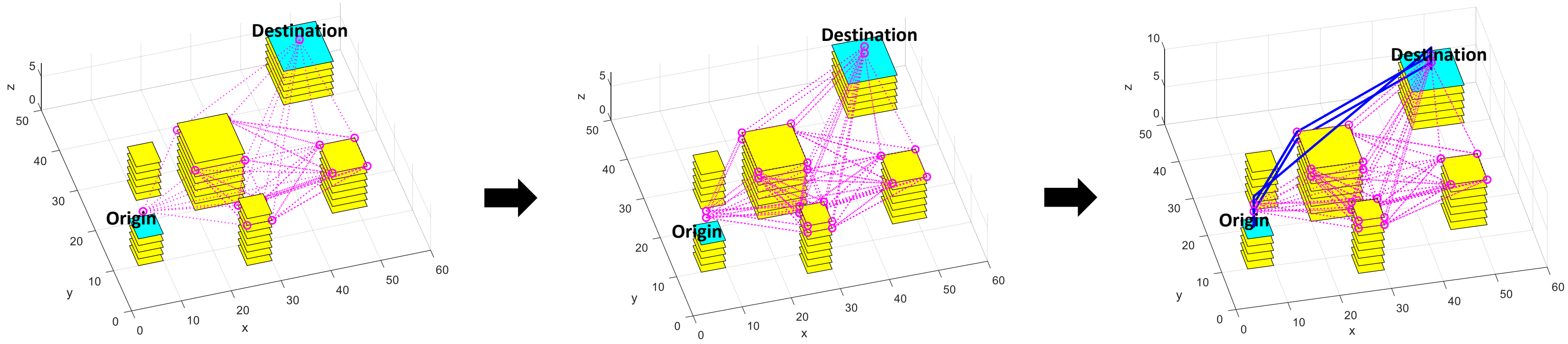
3D map of flyable airspace

Route network

Database for route intersection info

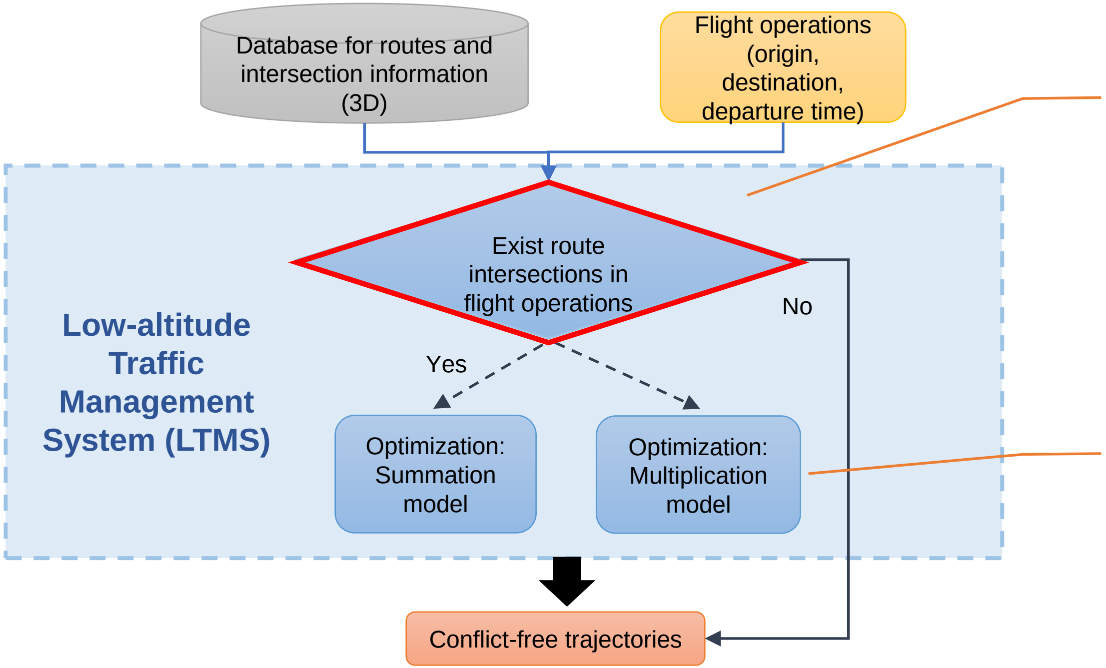
LAMS

3) Obtain the shortest path of each OD pair at each flight level.



Low-altitude Traffic Management System (LTMS)

➢ LTMS is designed for detecting and resolving conflicts.



Conflict Detection

- Optimal shortest paths (3D) intersects with each other?
- If Yes, check whether 4D trajectories intersect with each other?

Conflict Resolution

- Mathematical programming
- Summation model vs. Multiplicatio9n model
- Efficient solution algorithm

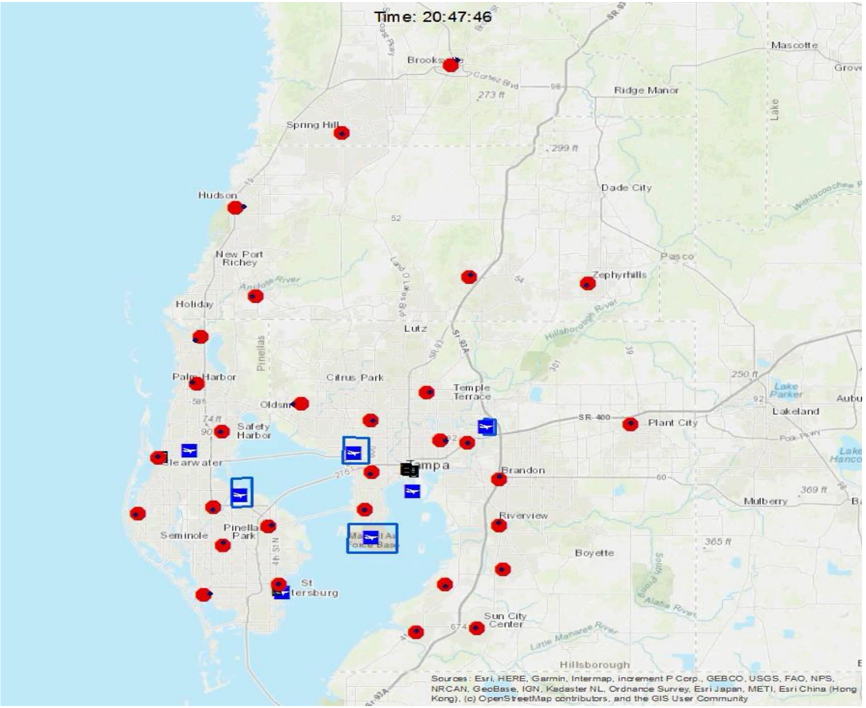
Nash Social Welfare Program (NSWP)

AAFPS

Low-Altitude Airspace Management System (LAMS): automatically generate the route network, identify and storage shortest paths of vertiport pairs on different levels.

Low-Altitude Traffic Management System (LTMS): detect and resolve conflicts, ensuring pre-departure conflict-free flight trajectory.

Nash Social Welfare Program (NSWP) is introduced to maintain fairness among different operators.



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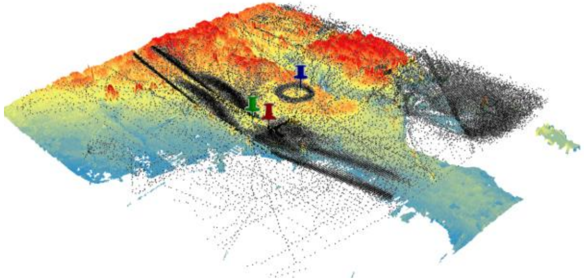
https://www.youtube.com/watch?v=zF8tQGn-lhI

Outcomes of the Research

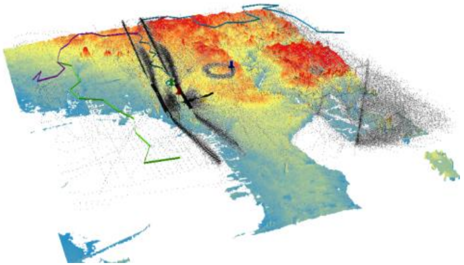
- Pre-departure conflict free 4D trajectories for high-density UAM operations
  - Flight level assignment
  - Departure delay (limited)
  - Local speed control

- Ensure the fairness among different operators
  - Market share
  - Flight distance
  - Operational times

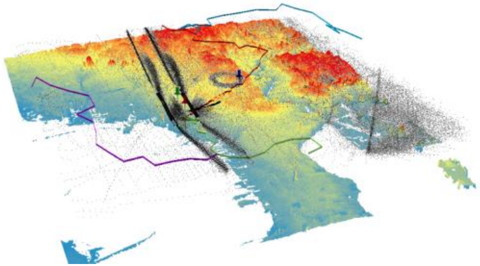
M2.A. Dynamic Procedures for the Integration of UAM at Commercial Airports



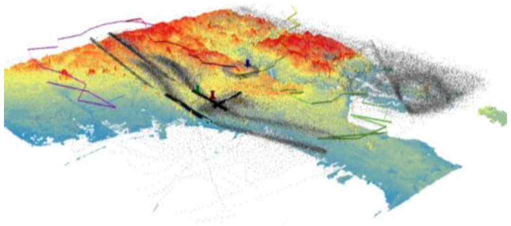
Three vertiports at Tampa International Airport



VTOL Routes from/to Vertiport 2 - Clearance 100 ft



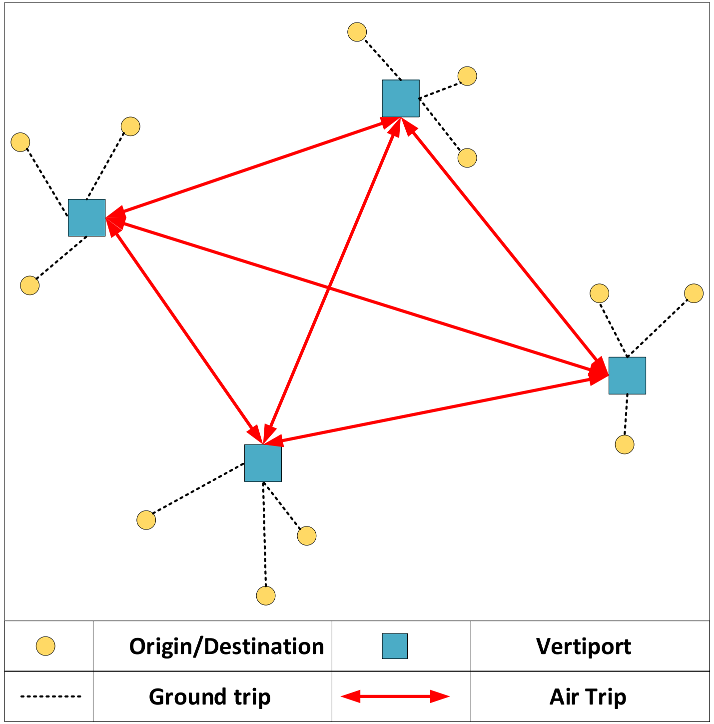
VTOL Routes from/to Vertiport 1 - Clearance 75 ft



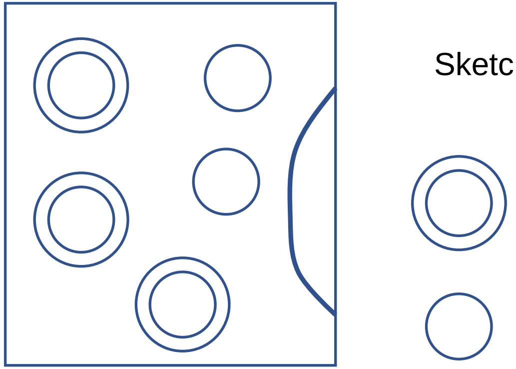
VTOL Routes from/to Vertiport 3 - Clearance 100 ft

- Identify vetiports on or near airport
- Airport Modeling of Current Manned Operations
- VTOL Route Design – Rapidly Exploring Random Tree RRT Algorithm
- Case study - Tampa International Airport (TPA)

M3: A Simulation Platform for eVTOL Operation Performance and Service Quality Evaluation of the On-Demand Advanced Air Mobility (AAM-SIM)

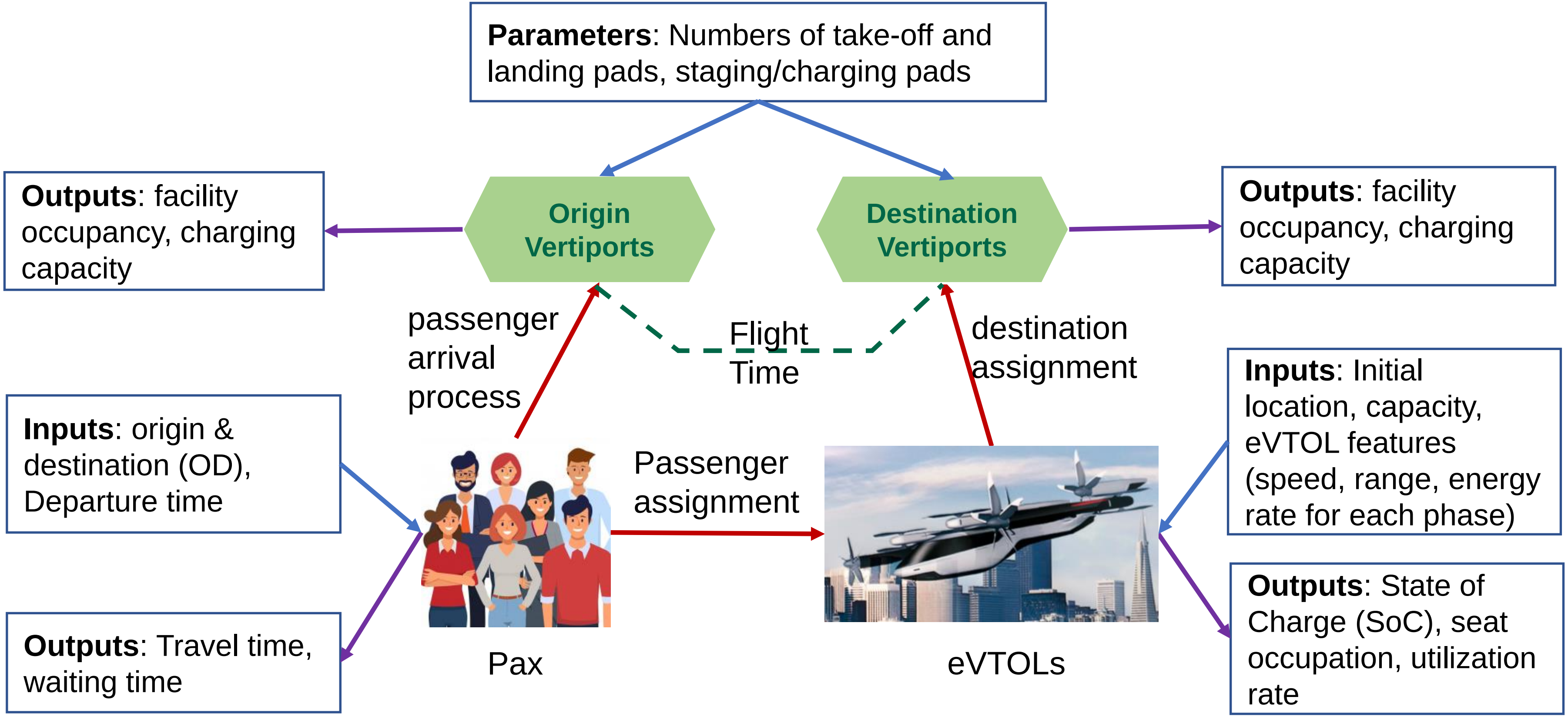


Sketch of a Vertiport



- Passenger arrivals to vertiports
- Passenger assignments to eVTOLs

Illustration of Simulation



Parameters: Numbers of take-off and landing pads, staging/charging pads

Outputs: facility occupancy, charging capacity

Outputs: facility occupancy, charging capacity

Inputs: origin & destination (OD), Departure time

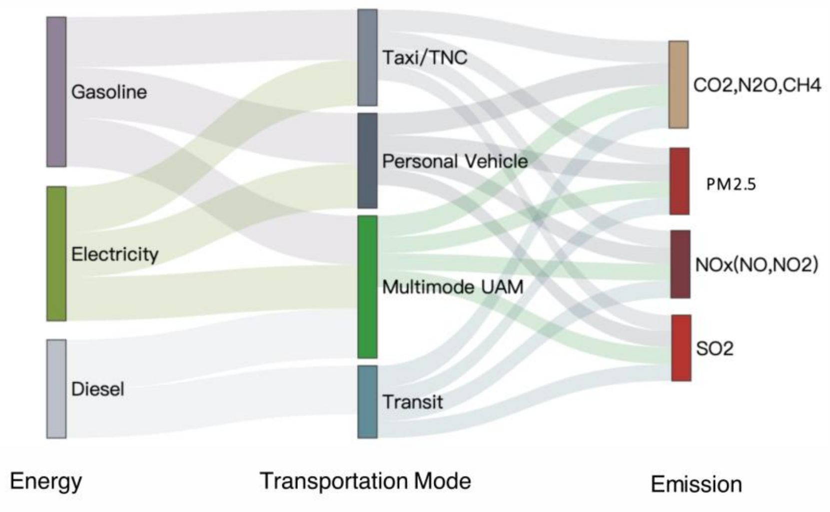
Inputs: Initial location, capacity, eVTOL features (speed, range, energy rate for each phase)

Outputs: Travel time, waiting time

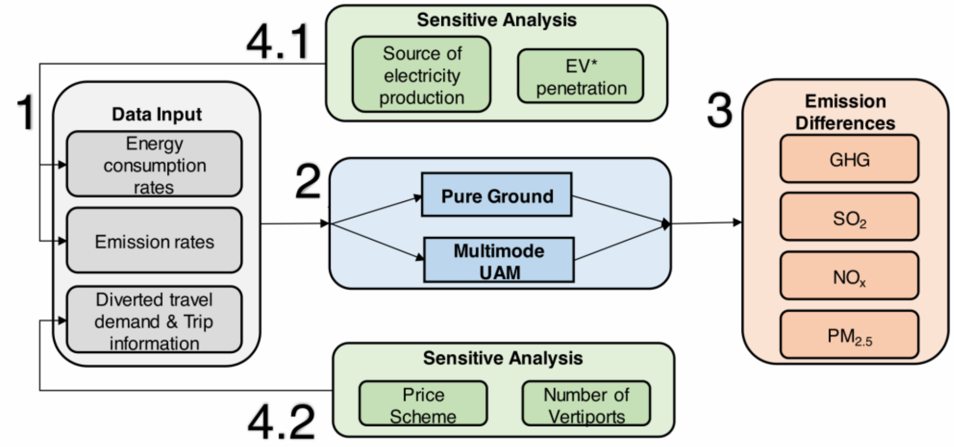
Outputs: State of Charge (SoC), seat occupation, utilization rate

M6: Environmental Impact Analysis of Future on-Demand UAM

Energy to Emission



Research Approach

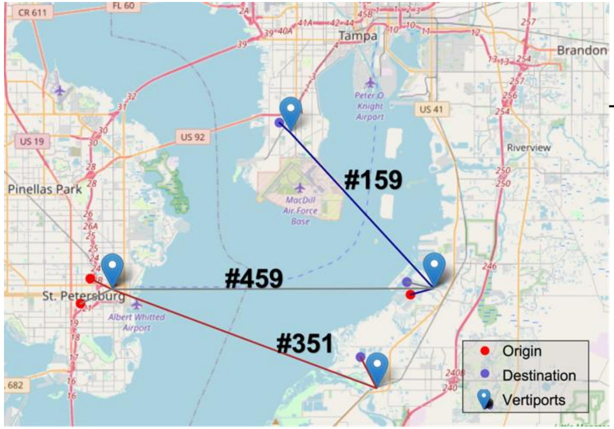


Comparison Outcome of Case Study Region

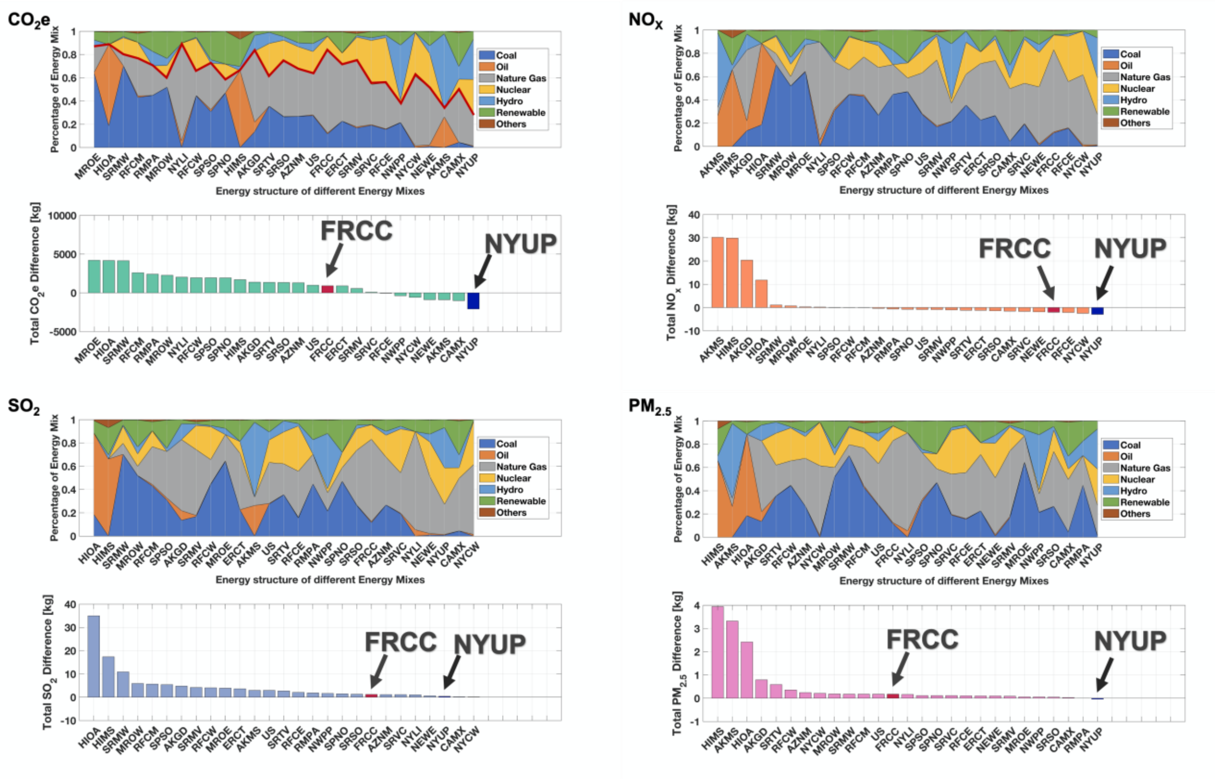
		CO_2	CH_4	N_2O	CO_2e	NO_x	SO_2	$PM_{2.5}$
Pure Ground		4,147.739	0.179	0.037	4,163.329	4.276	0.020	0.132
Multi modal UAM	**eVTOL**	4,090.459	0.290	0.039	4,109.176	1.558	1.219	0.281
	Access	451.109	0.020	0.004	452.810	0.391	0.002	0.013
	Egress	499.995	0.022	0.005	501.875	0.339	0.002	0.013
	In Total	5,041.564	0.332	0.047	5,063.956	2.288	1.224	0.306
Difference		893.825	0.152	0.010	900.627	-1.987	1.204	0.174
% Difference		21.55%	84.99%	26.95%	21.63%	-46.48%	5957.19%	131.33%

Demonstration of Selected Trips

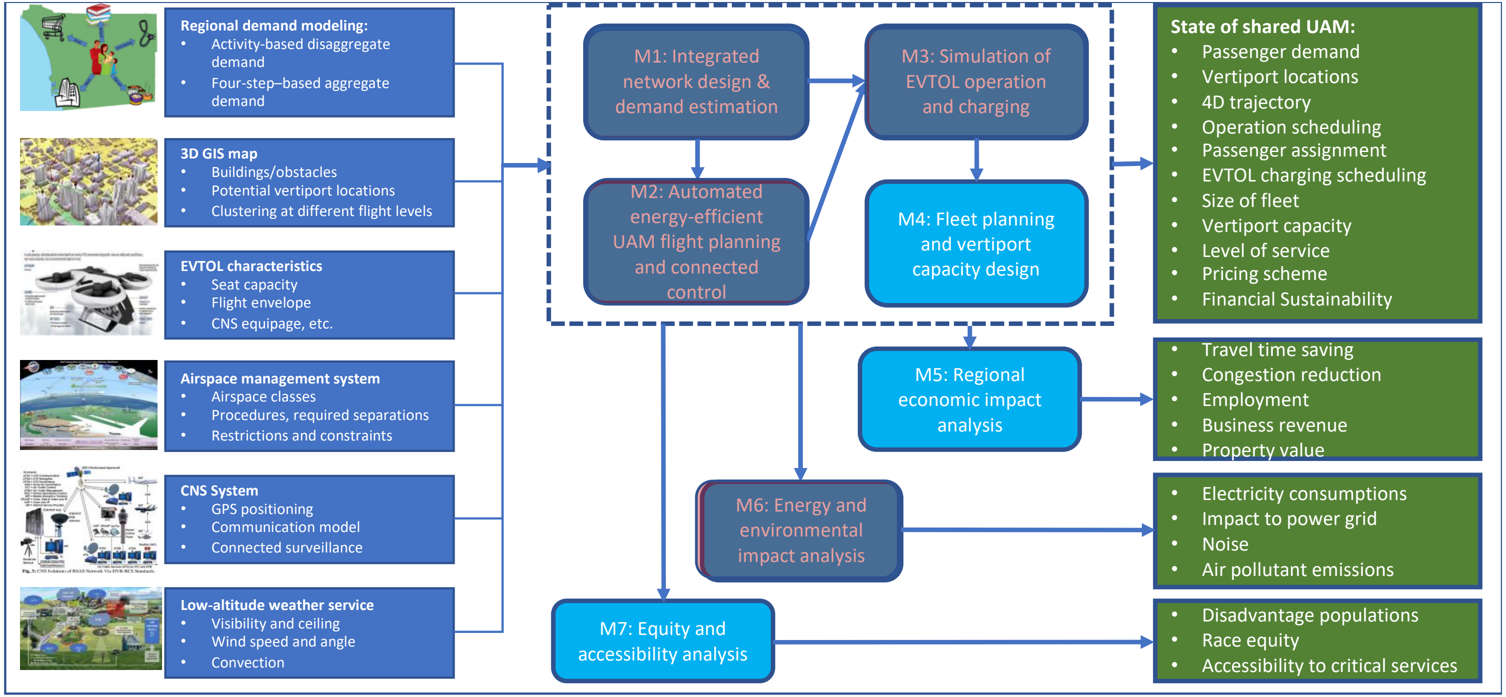
Trip ID	Items	Distance (mi)	Time (min)	CO_2e	NO_x	SO_2	$PM_{2.5}$
#159	Pure ground mode	26.2	43.9	6257.41	4.90	0.03	0.17
	Multimodal UAM	12.5	18.8	6019.42	4.03	1.52	0.40
	Difference	-13.7	-25.1	-238.00	-0.88	1.49	0.24
	Percent change	-52.42%	-57.22%	-3.80%	-17.89%	5484.71%	142.21%
#351	Pure ground mode	35.5	44.4	8484.18	6.65	0.04	0.22
	Multimodal UAM	17.2	17.6	7121.33	2.93	1.85	0.45
	Difference	-18.3	-26.8	-1362.85	-3.72	1.81	0.22
	Percent change	-51.63%	-60.31%	-16.06%	-55.91%	4911.42%	98.17%
#459	Pure ground mode	44.4	47.5	10605.83	8.31	0.05	0.28
	Multimodal UAM	19.2	17.9	7771.54	3.23	2.03	0.49
	Difference	-25.2	-29.6	-2834.29	-5.09	1.98	0.21
	Percent change	-56.78%	-62.41%	-26.72%	-61.20%	4302.60%	73.90%



Highly Dependent on Energy Sources for Electricity Generation



Summary of AAM/UAM Research at USF



Regional demand modeling:
- Activity-based disaggregate demand
- Four-step–based aggregate demand

3D GIS map
- Buildings/obstacles
- Potential vertiport locations
- Clustering at different flight levels

EVTOL characteristics
- Seat capacity
- Flight envelope
- CNS equipage, etc.

Airspace management system
- Airspace classes
- Procedures, required separations
- Restrictions and constraints

CNS System
- GPS positioning
- Communication model
- Connected surveillance

Low-altitude weather service
- Visibility and ceiling
- Wind speed and angle
- Convection

M1: Integrated network design & demand estimation

M2: Automated energy-efficient UAM flight planning and connected control

M3: Simulation of EVTOL operation and charging

M4: Fleet planning and vertiport capacity design

M5: Regional economic impact analysis

M6: Energy and environmental impact analysis

M7: Equity and accessibility analysis

State of shared UAM:
- Passenger demand
- Vertiport locations
- 4D trajectory
- Operation scheduling
- Passenger assignment
- EVTOL charging scheduling
- Size of fleet
- Vertiport capacity
- Level of service
- Pricing scheme
- Financial Sustainability

- Travel time saving
- Congestion reduction
- Employment
- Business revenue
- Property value

- Electricity consumptions
- Impact to power grid
- Noise
- Air pollutant emissions

- Disadvantage populations
- Race equity
- Accessibility to critical services

Shared Urban Air Mobility Evaluation Tool (SUAMET)

Ongoing Efforts

- (M4) Enhancing simulation tool by including eVTOL dynamic rebalancing
- (M1+) Understanding induced demand of emerging UA: Stated preference survey & Natural language processing
- (M7+) Opportunities of improving transportation equity with emerging UAM

Implementation

- Impacts of emerging AAM/UAM to regional transportation system (Tampa Bay Region)

Thank you for your attention!

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http://www.sum-lab.org