Integrated Network Design and Demand Estimation for On-Demand Urban Air Mobility

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UNIVERSITY of SOUTH FLORIDA

Smart Urban Mobility Lab at USF

- **Advanced Aerial Mobility*:** Network Design and Multimodal Planning; Integrated National Airspace System; Automated Air Traffic Management System; Trajectory Planning
- **Shared Mobility/Micromobility** and Shared Automated Vehicles:** Efficient and Equitable Micromobility Program Design and Regulation; Performance Evaluation of Micromobility Program; Emerging of Shared Automated Vehicles.
- **Air Transport Management:** Airport Planning and Management, Air Transport Economics, Air Traffic Management, Emerging Technologies, Environmental Issues in 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

http://www.sum-lab.org

**Advanced aerial mobility involves the emergence of transformative and disruptive new airborne technology supporting an ecosystem designed to transport people and things to locations not traditionally served by current mode of air transportation, including both rural and the more challenging and complex urban environment." --Advancing Aerial Mobility: A National Blueprint*

***Micromobility: namely docked and dockless sharing programs with bike, electric bikes and electric scooters.*

Center for Transportation, Environment, and Community Health (CTECH)

- The Center for Transportation, Environment, and Community Health (CTECH) pursues research and innovation to support **sustainable mobility** of people and goods while **preserving the environment and improving community health**. It leverages behavioral and economic sciences, epidemiology, information technology, and environmental and transportation sciences and technologies to address critical issues falling under the FAST Act's priority area of Preserving the Environment: greenhouse gas reduction, use of alternative fuels and energy technologies, environmentally responsible planning, and impacts of freight movement.

CTECH
CENTER FOR TRANSPORTATION
ENVIRONMENT AND COMMUNITY HEALTH

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UTEP

UCDAVIS
UNIVERSITY OF CALIFORNIA

https://ctech.cee.cornell.edu

Center for Urban Transportation Research

- In 1988, the Florida Legislature created the Center for Urban Transportation Research at the University of South Florida. CUTR is a part of the College of Engineering at the University of South Florida in Tampa, Florida.
- Since its inception, CUTR has become internationally recognized in transportation research, education and technology transfer/training/outreach center, with a focus on producing products and people.

CUTR
CENTER FOR URBAN TRANSPORTATION RESEARCH

National Institute of Congestion Reduction

- The National Institute for Congestion Reduction (NICR) will emerge as a national leader in providing multimodal congestion reduction strategies through real-world deployments that leverage advances in technology, big data science and innovative transportation options to optimize the efficiency and reliability of the transportation system for all users.

What is Urban Air Mobility?

Future UAM Network

Photo Source:
https://www.nasa.gov/sites/default/files/thumbnails/image/uam-3-4x3-v2-sm.jpg

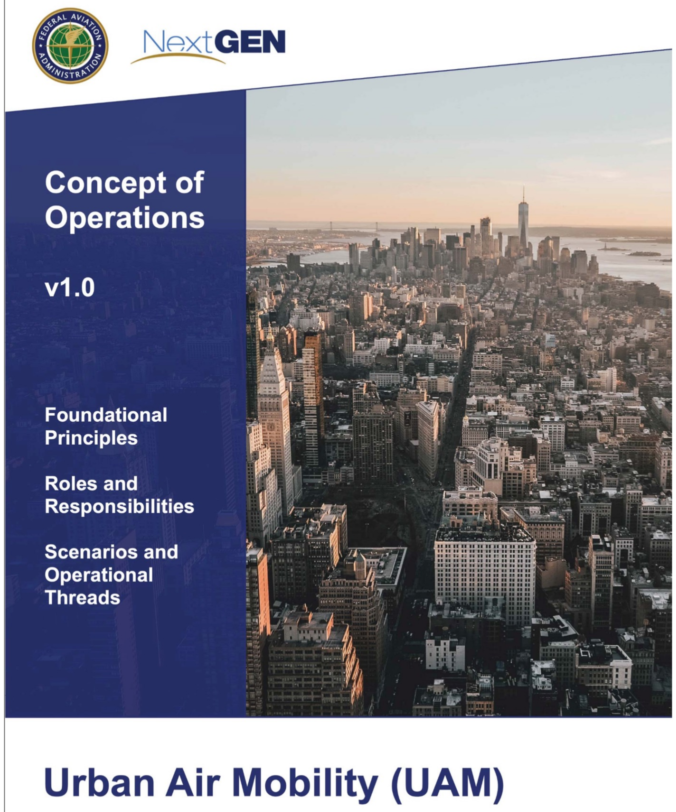
Urban Air Mobility (UAM) envisions a **safe** and **efficient** aviation transportation system that will use **highly automated** aircraft that will operate and transport passengers or cargo at **lower altitudes** within urban and suburban areas.

UAM will be composed of an **ecosystem** that considers the evolution and safety of the aircraft, the framework for operation, access to airspace, infrastructure development, and community engagement.

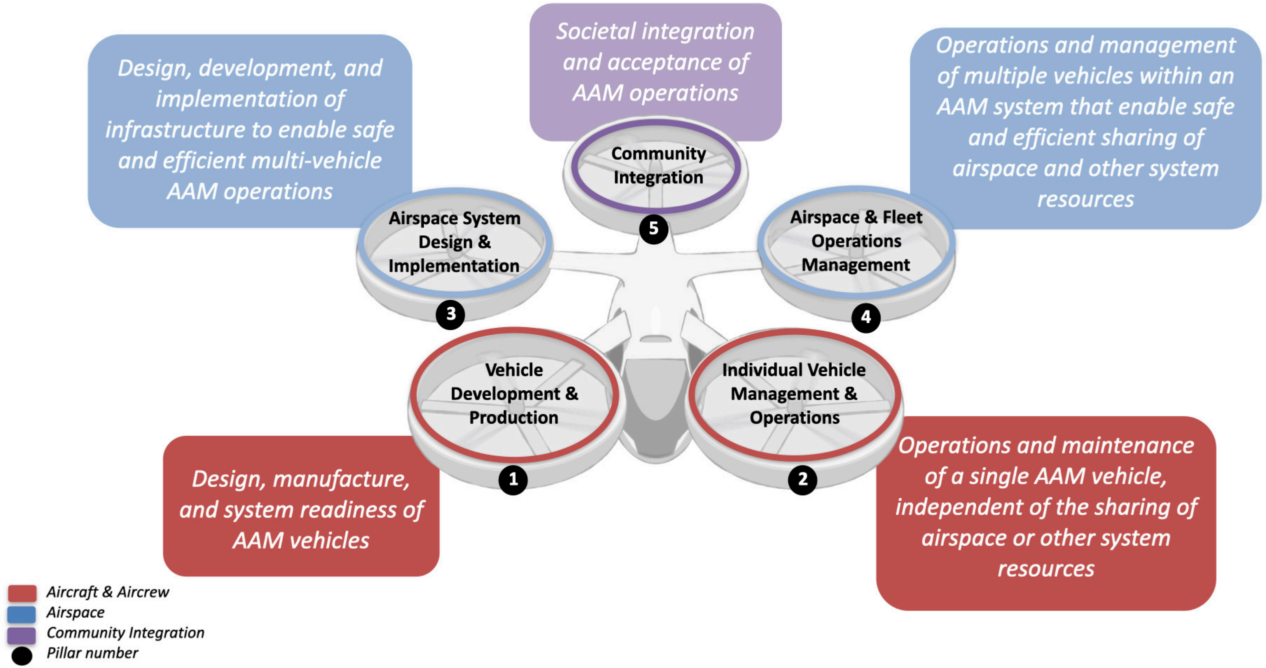
https://www.faa.gov/uas/advanced_operations/urban_air_mobility/

FAA - Five Areas of Activities and Challenges

“The FAA is including AAM and UAM in our planning efforts, and our work is organized around five areas of activity – **aircraft, airspace, operations, infrastructure, and community**.”



NASA Advanced Air Mobility Ecosystem Working Groups



Source: https://nari.arc.nasa.gov/aam-portal/

NASA UAM Maturity Levels and Barriers

UAM Maturity Levels (UMLs)

UAM Framework and Barriers

Vehicles | Airspace | Community

INITIAL STATE

UML-1
- **Late-Stage Certification Testing and Operational Demonstrations in Limited Environments**
  - Aircraft certification testing and operational evaluations with conforming prototypes; procedural and technology innovation supporting future airspace operations (e.g., UTM-inspired); community/market demonstrations and data collection

UML-2
- **Low Density and Complexity Commercial Operations with Assistive Automation**
  - Type-certified aircraft; initial Part 135 operation approvals; limited markets with favorable weather and regulation; small UAM network serving urban periphery; UAM routes supporting self-managed operations through controlled airspace

INTERMEDIATE STATE

UML-3
- **Low Density, Medium Complexity Operations with Comprehensive Safety Assurance Automation**
  - Operations include urban core; operational validation of advanced airspace operations & management, including 3rd party provided ATM services, CNSI, C^2, & automation for scalable, weather-tolerant operations; few high-capacity aerodromes; noise compatible w/ urban soundscape; model local regulations

UML-4
- **Medium Density and Complexity Operations with Collaborative and Responsible Automated Systems**
  - 100s of simultaneous operations; expanded networks including closely-spaced high throughput UAM aerodromes; many federated ATM services available, simplified vehicle operations for credit; low-visibility operations

MATURE STATE

UML-5
- **High Density and Complexity Operations with Highly-Integrated Automated Networks**
  - 1,000s of simultaneous operations; large-scale, highly-distributed networks; high-density, federated ATM; autonomous aircraft and remote, M:N fleet management; high-weather tolerance including icing; high-volume manufacturing

UML-6
- **Ubiquitous UAM Operations with System-Wide Automated Optimization**
  - 10,000s of simultaneous operations (capacity limited by physical infrastructure); ad hoc landing sites; noise compatible with suburban/rural operations; private ownership & operation models enabled; societal expectation

FAA UAM ConOps 1.0 – UAM Corridor

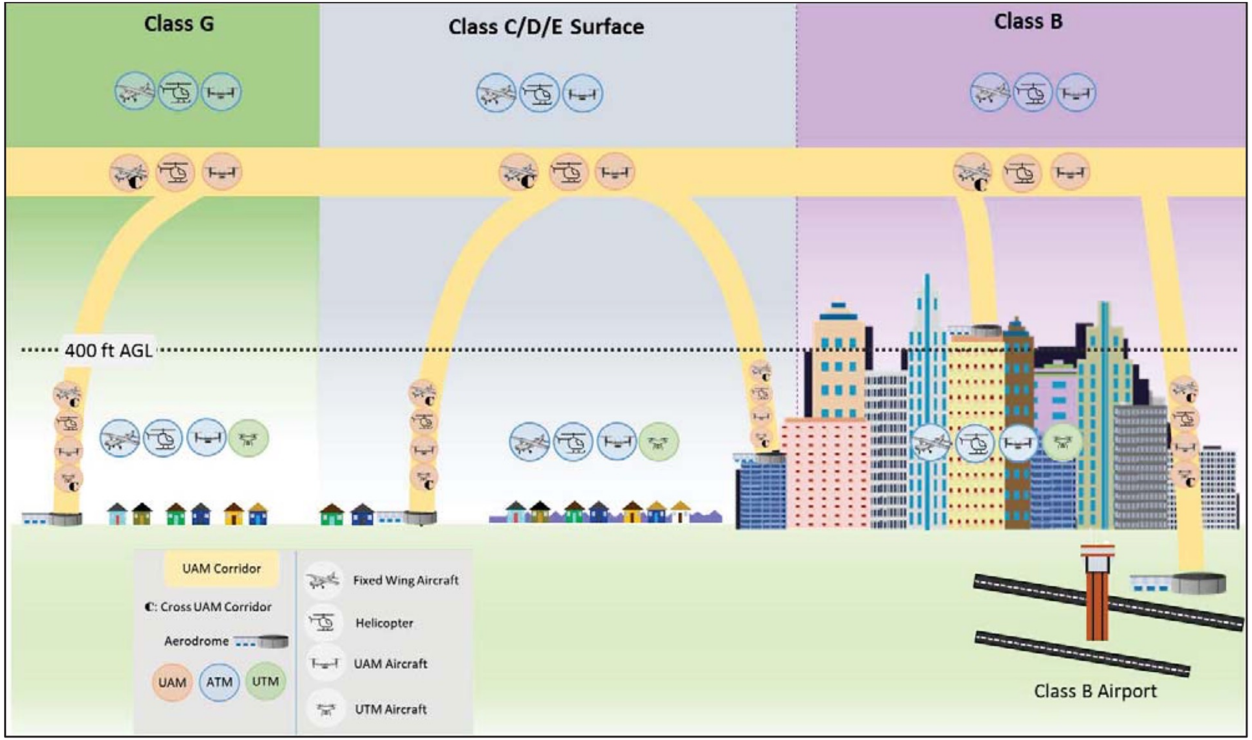


Figure 1-2: UAM, UTM, and ATM Operating Environments

UAV Research at SUM Lab

CSAA

Chinese Journal of Aeronautics

Volume 32, Issue 6, June 2019, Pages 1504-1519

Collision free 4D path planning for multiple UAVs based on spatial refined voting mechanism and PSO approach

Yang LIU [a, b], Xuejun ZHANG [b], Yu ZHANG [c, d], Xiangmin GUAN [e]

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https://doi.org/10.1016/j.cja.2019.03.026

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Hindawi
Journal of Advanced Transportation
Volume 2018, Article ID 4731585, 11 pages
https://doi.org/10.1155/2018/4731585

WILEY | Hindawi

Research Article

Safety Assessment and Risk Estimation for Unmanned Aerial Vehicles Operating in National Airspace System

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Ongoing Research Project:

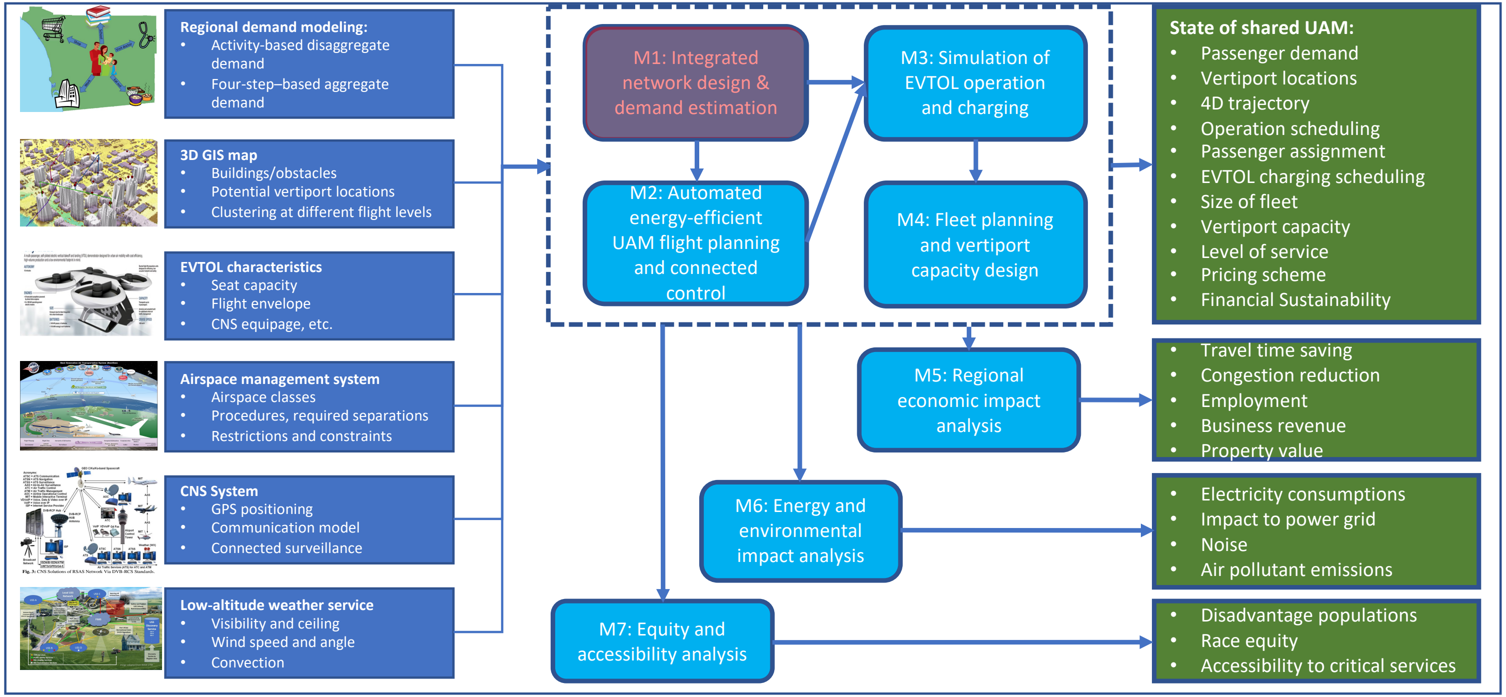
Multimodal strategies for mitigating congestion from urban parcel delivery

Major Challenges of Embracing UAM

- Aircraft: Certification
- Airspace: Integrated airspace with existing users
- Operations: Flight planning, Flight connectivity, Collision detection and resolution
- Infrastructure: Aerodrome (vertiport), charging, communication
- Community: Awareness, Multimodal transportation integration, Equity, Environmental impacts

Photo source: https://www.avweb.com/news/embraer-introduces-evtol/

UAM Research at USF



Shared Urban Air Mobility Evaluation Tool (SUAMET)

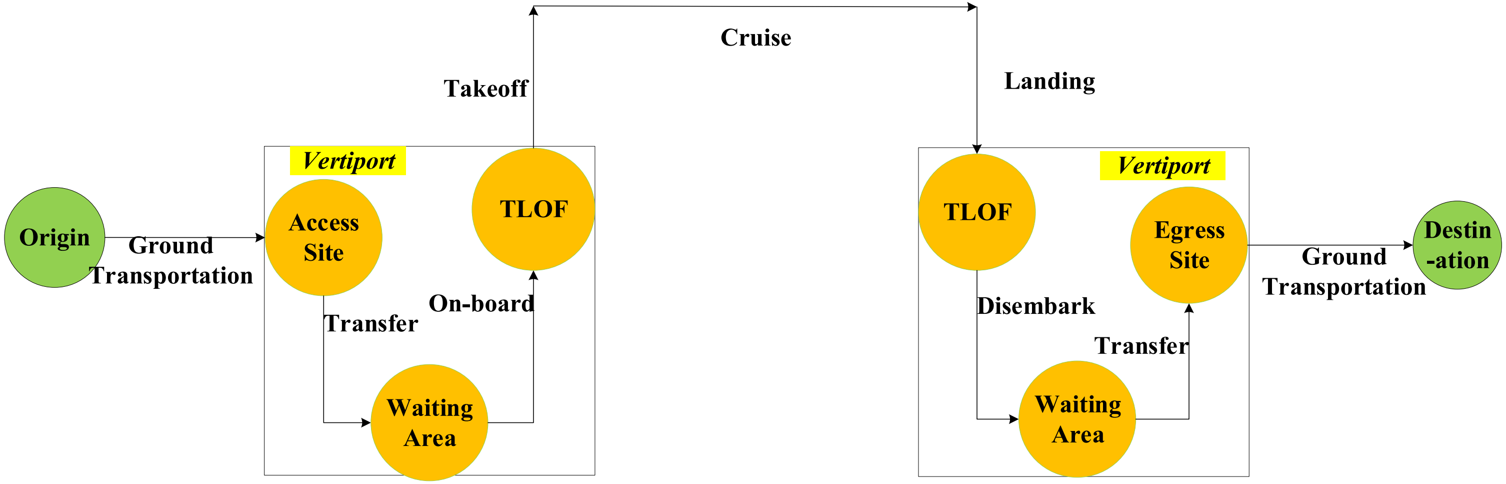
Integrated Network Design and Demand Estimation for On-Demand Urban Air Mobility

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.

Literature Review

A. Multimodal UAM



Multimodal UAM Service Process

Reference: (Antcliff et al., 2016; Vascik & Hansman, 2017; Vascik & Hansman, 2019)

Literature Review

B. UAM Potential Adoption

- **Travel Time**
- **Travel Cost**
- Trip Purpose
- Current travel pattern

(Fu & Rothfeld, 2018; Eker, U., et al., 2019)

- Reduce to **1/3** of ground transportation (a case study in Los Angeles) (Anticliff, K.R., et al., 2016)

- Pay about **2-2.5 times** of the **taxi price** for **50% travel time reduction** in U.S. and Germany (Rath & Chow, 2019)

- Accessibility to vertiports

(Vascik & Hansman, 2017; Fu & Rothfeld, 2018; Rothfeld, R., et al., 2018; Eker, U., et al., 2019)

- …

Literature Review

C. Vertiport Placement

- Well-distributed & co-located with areas of customer demand (Uber, 2016)
- Physical constraints
  - Helicopter operation regulation (Anticliff, K.R., et al., 2016)
  - Co-locate with existing infrastructures (Vascik & Hansman, 2017)
- Travel demand distribution
  - K-means clustering algorithm (Lim & Hwang, 2019)
  - Analysis of existing demographic information (Fahdil, D.N., 2018)
- Optimization model
  - Hub-and-Spoke Structure (Rath & Chow, 2019)

Silicon Valley highway cloverleaf

Top level of parking garage at Los Angeles airport

Summary of Literature Review

1. Lack of research studying the mutual effects between vertiport locations and potential UAM adoption.

2. Lack of research integrating travelers' mode choice in a multimodal transportation network into vertiport placement modeling.

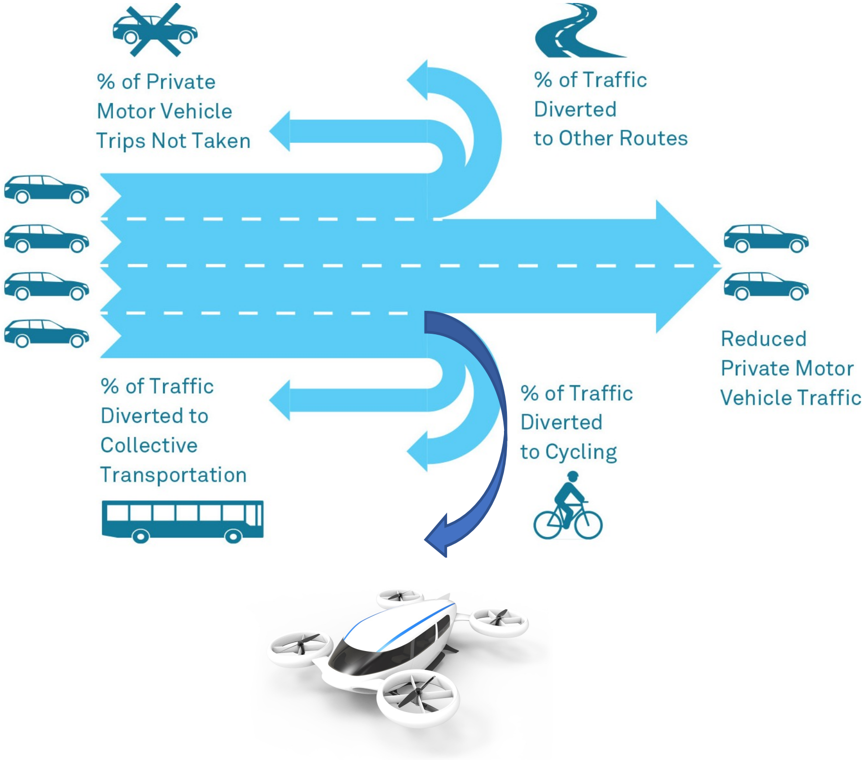
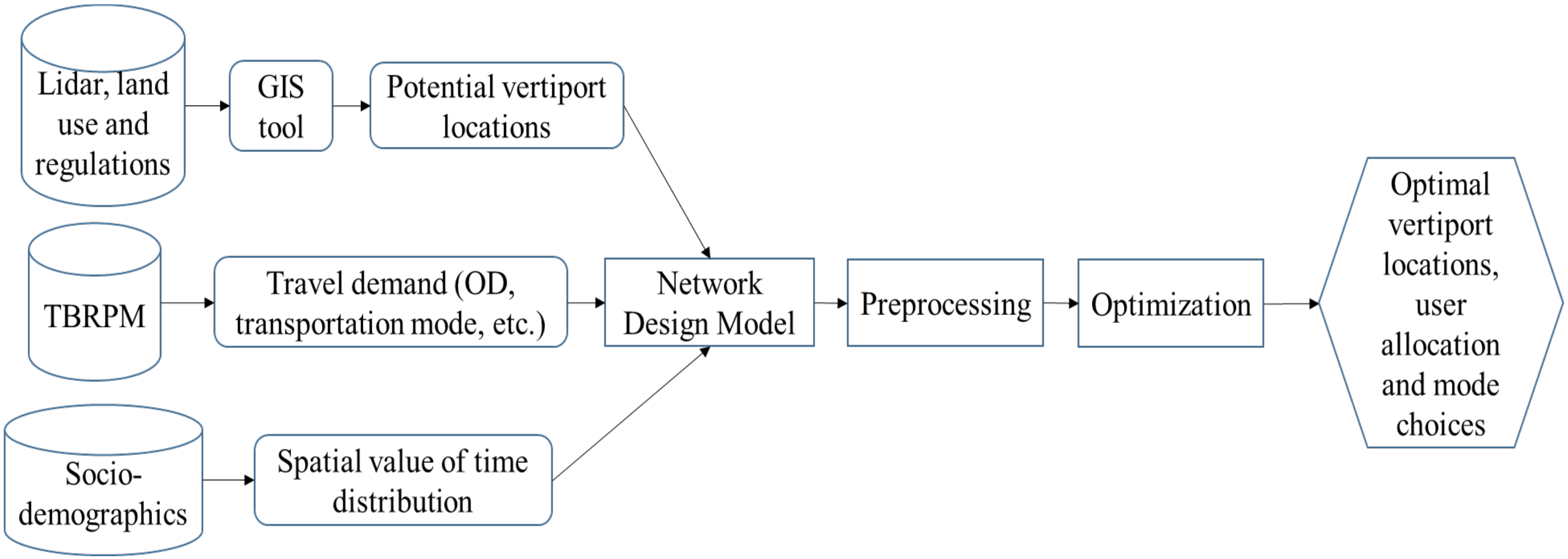


Photo sources: https://globaldesigningcities.org/publication/global-street-design-guide/design-controls/design-year-modal-capacity/

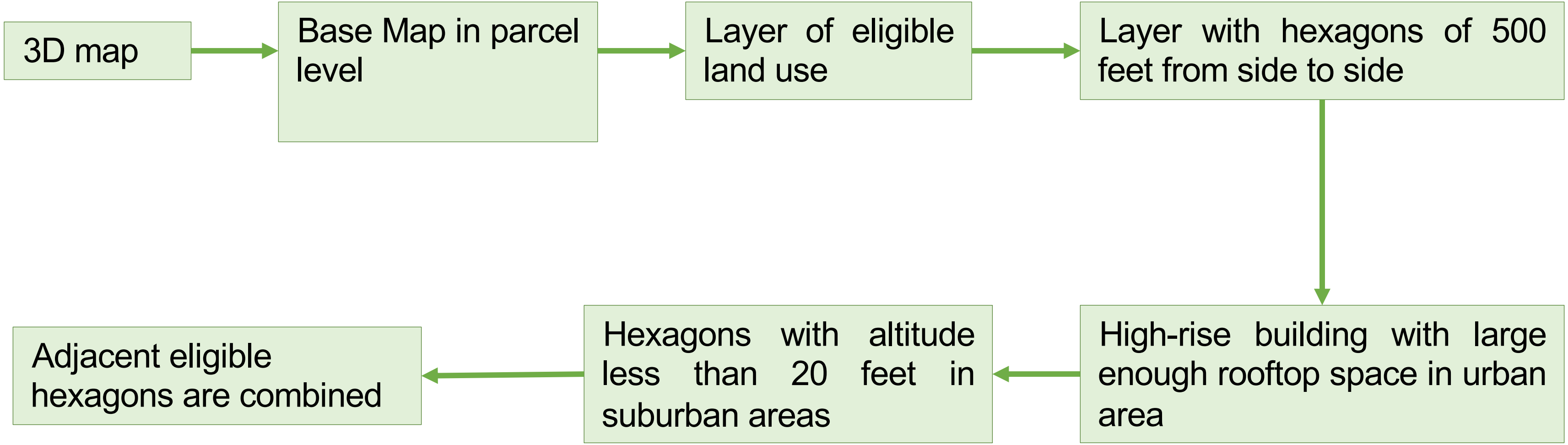
Problem Setting and Assumptions

- Assume that the total trips will not increase due to the introduction of UAM service.
- Uncapacititated network design problem, i.e. vertiport capacity is not constrained. *(Capacity constraints will be studied in future research).*
- Transshipment of travelers at vertiports is not considered.
- Transportation modes available for vertiport access or egress include driving personal vehicles, using public transit, using for-hire service, shared micormobility, and walking. The speed of access and egress modes are assumed constant. *(Uncertainties of travel time for UAM service will be further studied in robust optimization)*
- Users will choose to switch to multimodal UAM service if the value of saved travel time (compared to pure ground transportation) than the additional cost of choosing multimodal UAM.

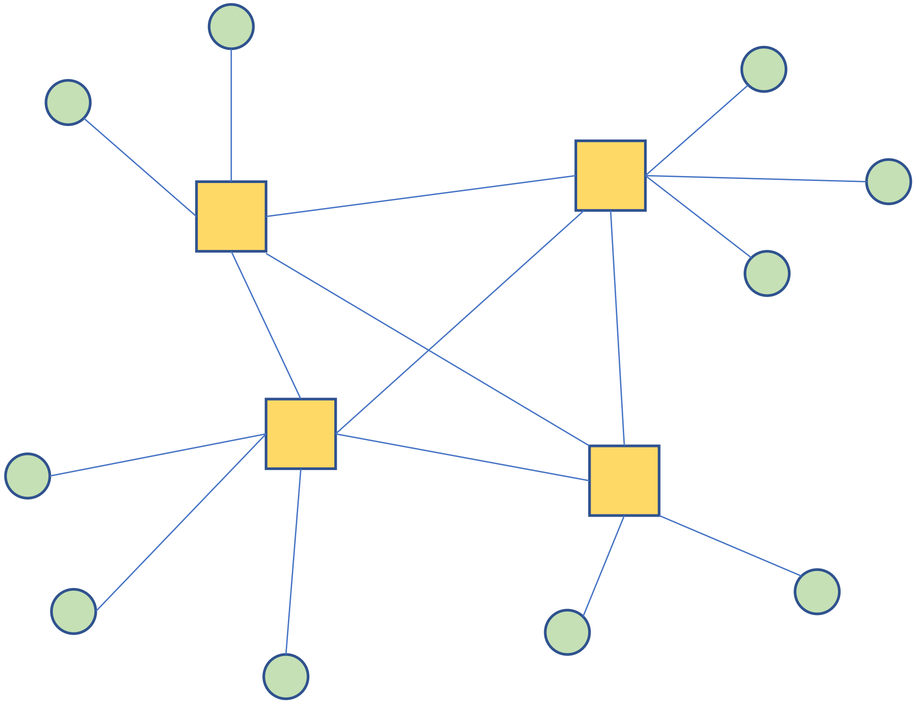
Modeling Framework



Potential Vertiport Identification



Typical Single Allocation Hub-and-Spoke Air Transport Network

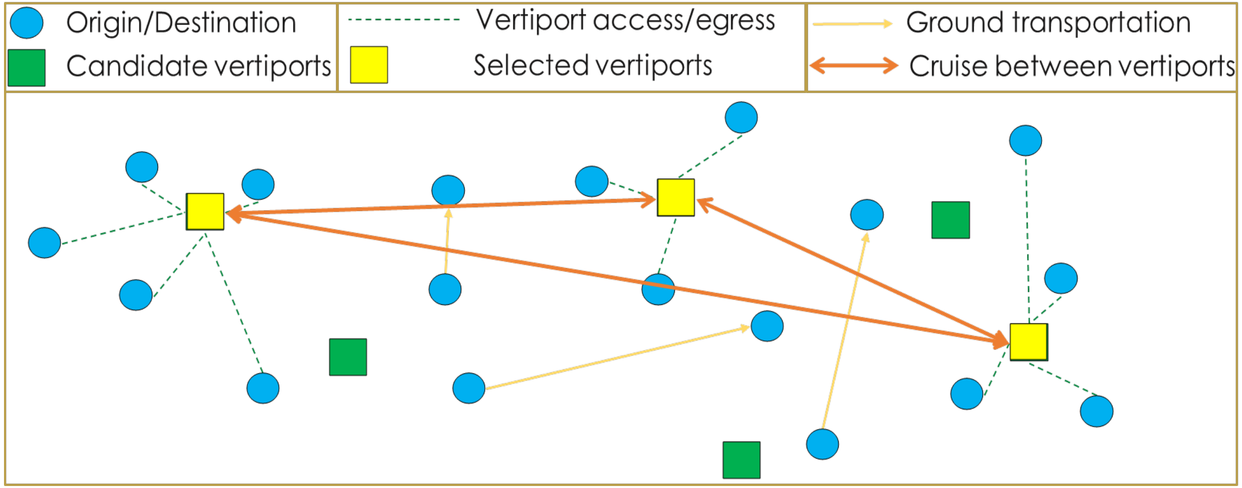


O/D Matrix

	A	B	C	D	E	Ti
A	0	0	50	0	0	50
B	0	0	60	0	30	90
C	0	0	0	30	0	30
D	20	0	80	0	20	120
E	0	0	90	10	0	100
Tj	20	0	280	40	50	**390**

- Demand is given and does not change according to the siting of hubs.
- Single transportation mode.

Vertiport Siting - Extended Single Allocation Hub-Spoke Problem



- Candidate vertiports location may or may not contain potential UAM demand
- Demand of using UAM is dependent on the siting of vertiports
- Multiple transportation modes between spoke (origin or destination) and vertiports

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.

$\boldsymbol{x^{\mathrm{p}}_{kd}} \in \{0,1\}$, takes a value of 1 if trip p use multimodal UAM through vertiport k and d $(k \rightarrow d)$, 0 otherwise.

$\boldsymbol{g^p_{ak}}$ & $\boldsymbol{h^p_{ed}} \in \{0,1\}$, 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.

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.

MIP of Integrated Modeling

$$\min \sum_{p\in P}\Big\{(t^p * \gamma^p + c^p) * z^p + \sum_k \sum_{d\neq k} (c_{kd} + (t_{kd} + t_{tw} + t_{tl})\gamma^p) * x_{kd}^p + \sum_a \sum_k g_{ak}^p (t_{ak}^p * \gamma^p + c_{ak}^p\Big) + \sum_e \sum_d h_{ed}^p (t_{ed}^p * \gamma^p + c_{ed}^p)\Big\}$$

Minimize System Generalized Cost

$s.t.$

$$\sum_k y_k = u, \forall k \in M$$

$$z^p + \sum_k \sum_{d\neq k} x_{kd}^p = 1, \forall\, p \in P$$

$$\sum_{d\in M, d\neq k} x_{kd}^p + \sum_{d\in M, d\neq k} x_{dk}^p \leq y_k, \forall k \in M, \forall\, p \in P$$

Hub-and-spoke modeling structure: limit the number of vertiports and restrict each UAM trip transferred through selected vertiports.

$$\sum_k \sum_{d\neq k} x_{kd}^p = \sum_a \sum_k g_{ak}^p, \forall p \in P$$

$$\sum_k \sum_{d\neq k} x_{kd}^p = \sum_e \sum_d h_{ed}^p, \forall p \in P$$

$$2x_{kd}^p \leq \sum_a g_{ak}^p + \sum_e g_{ed}^p, \forall k, d \neq k \in M, \forall p \in P$$

Vertiport access and egress mode choice related constraints.

$$\Big[t^p - \sum_k \sum_{d\neq k} (t_{kd} + t_{tw} + t_{tl}) * x_{kd}^p - \sum_a \sum_k g_{ak}^p t_{ak}^p - \sum_e \sum_d h_{ed}^p t_{ed}^p\Big] * \gamma^p \geq \sum_k \sum_d c_{kd}^p * x_{kd}^p + \sum_a \sum_k g_{ak}^p c_{ak}^p + \sum_e \sum_d h_{ed}^p c_{ed}^p - c^p, \forall p \in P$$

Travel mode choice: users will switch to UAM service if the value of saved travel time is more than the additional cost.

$$z^p \in \{0,1\}, y_k \in \{0,1\}, x_{kd}^p \in \{0,1\}, g_{ak}^p \in \{0,1\}, h_{ed}^p \in \{0,1\}$$

$$k, d \in M, p \in P, a, e \in F$$

Solution Technique - Probing

Observation 1:

Minimize the system generalized cost ⟺ Maximize saved generalized cost of diverted demand

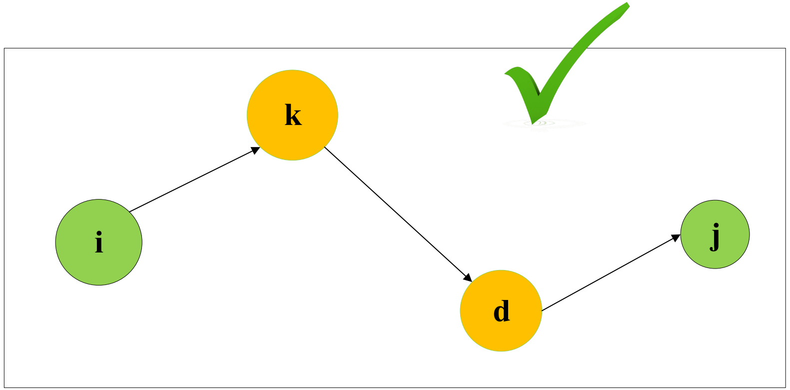
⇒ Focus on potential trips that satisfy value of time constraints

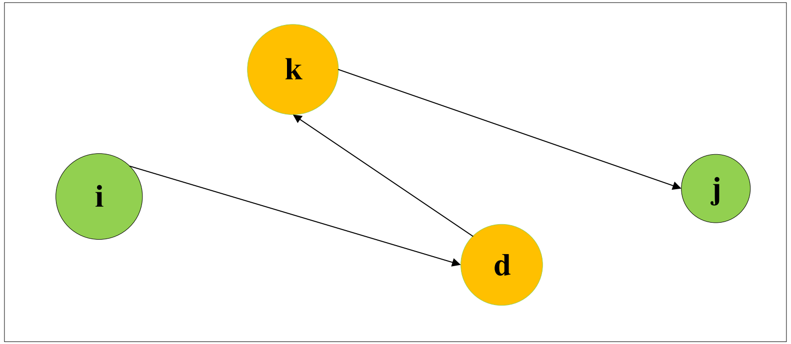
Solution Technique – Probing (Cont'd)

Observation 2:

Users will always select the trip route with the shorter trip distance for any given vertiport ($i \rightarrow k \rightarrow d \rightarrow j$ in this case)

$$d_{kd}^{p} \geq d_{dk}^{p} * x_{dk}^{p}, (p, k, d) \in W$$





Reformulation of MIP of Integrated Modeling

$\max \sum_{p\in P}\{\sum_k \sum_{d\neq k}(c_{kd} + (t_{kd} + t_{tw} + t_{tl})\gamma^p - t^p * \gamma^p - c^p) * x^p_{kd} + \sum_a \sum_k g^p_{ak}(t^p_{ak} * \gamma^p + c^p_{ak}) + \sum_e \sum_d h^p_{ed}(t^p_{ed} * \gamma^p + c^p_{ed})\}$

Maximize saved generalized cost (travel cost + monetarized travel time)

$s.t.$

$\sum_k y_k = u,\ \forall k \in M$

$\sum_k \sum_{d\neq k} x^p_{kd} \leq 1, \forall\ (p,k,d) \in W$

$\sum_{d\in M, d\neq k} x^p_{kd} + \sum_{d\in M, d\neq k} x^p_{dk} \leq y_k, \forall (p,k,d) \in W$

- *Limit the number of vertiports*
- *Passengers will select between UAM service and pure ground trip*
- *Each UAM trip transferred through selected vertiports.*

$\sum_k \sum_{d\neq k} x^p_{kd} = \sum_a \sum_k g^p_{ak}, \forall (p,k,d,a,e) \in W$

$\sum_k \sum_{d\neq k} x^p_{kd} = \sum_e \sum_d h^p_{ed}, \forall (p,k,d,a,e) \in W$

$2x^p_{kd} \leq \sum_a g^p_{ak} + \sum_e g^p_{ed}, \forall (p,k,d,a,e) \in W$

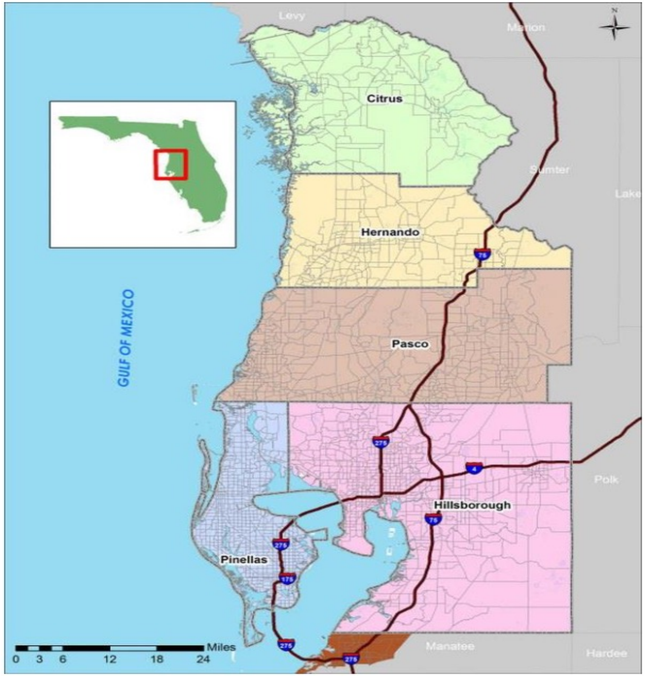
- *Restrict relations between UAM selection and vertiport access/egress mode choice.*

Reduced One constraint

$z^p \in \{0,1\}, y_k \in \{0,1\}, x^p_{kd} \in \{0,1\}, g^p_{ak} \in \{0,1\}, h^p_{ed} \in \{0,1\},$
$(p,k,d,a,e) \in W$

Case Study: Tampa Bay Area

- **Study Area:** Hillsborough , Pinellas, Pasco, Hernando, and Citrus Counties of Florida.
- **Data**: Travel demand data from the Tampa Bay Regional Planning Model (TBRPM) is at the parcel level and focuses on trips from each individual traveler as a result of the TBRPM running a simulation for 24 h for a typical weekday.
- **Individual Data Info:** Origin and destination coordinates, travel time, travel distance, travel mode, trip purpose, departure time, etc.
- **Filtering Criteria :** Travel time $\geq$ 30 min and distance $\geq$ 10 miles.



Tampa Bay Regional Planning Model Study Area

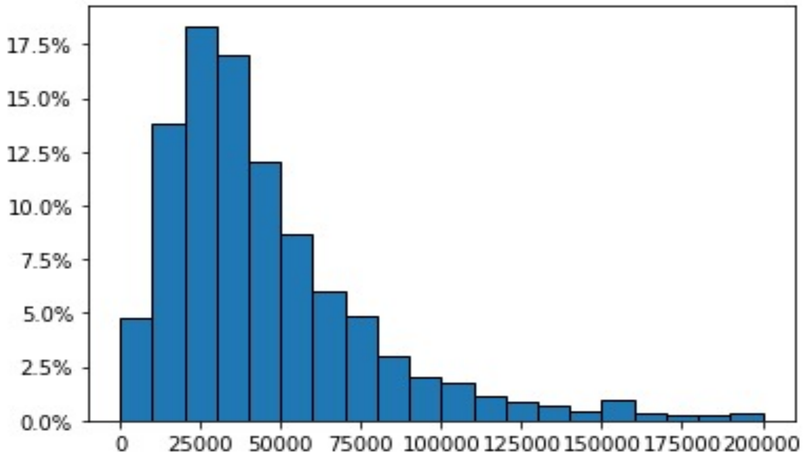
Descriptive Statistics of Candidate Trips

Statistics	Travel time (min)	Travel distance (mi)
Mean	38.48	25.95
Standard deviation	8.79	7.41
Minimum value	30	10
25th percentile	32.40	20.52
50th percentile	35.80	24.44
75th percentile	41.74	29.46
Maximum value	179.85	103.10

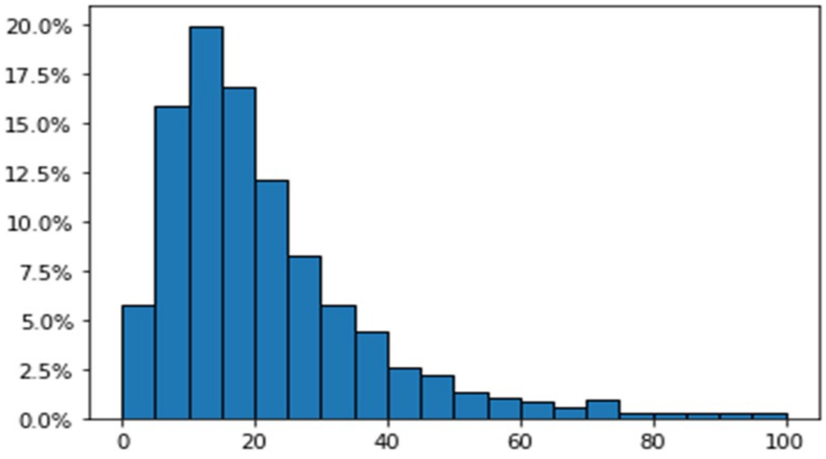
Pricing Scheme and Costs of Different Modes

Travel Mode	Pricing Scheme	Values
EVTOL	Base cost + unit distance cost * trip distance	Base cost: $30, unit distance cost: $2
Transit	With transit pass	$1
	Without transit pass	$2
Personal Vehicle	Gasoline cost per mile * trip distance + parking cost	Gasoline cost per mile: $0.11
For-hire Service	Base cost + unit time cost * trip time + unit distance cost * trip distance	Base cost: $2.3, unit time cost: $0.28 per minute; unit distance cost: $0.8
Bike Sharing	Base cost + unit time cost * trip time	Base cost: $1, unit time cost: $0.25
E-scooter Sharing	Unit time cost * trip time	Unit time cost: $0.29

Value of Time Distribution of Travelers



Average wage distribution of travelers in study region($)



Value of time distribution of travelers in study region($/hour)

Other Parameters for Case Study

Parameters	Value	Parameters	Value
Average bus speed	12.1	Number of vertiports to be built	30
Average e-scootering speed (mph)	6	Transfer time at vertiport (min)	5
Average biking speed (mph)	5.09	Aircraft operation at vertiport (min)	2.5
Average walking speed (mph)	3.13	Coefficient to transfer straight line to driving distance	1.4
Cruise speed of eVTOL aircraft (mph)	150	Coefficient to transfer straight line distance to walking/biking/e-scootering distance	1.1

Optimal Vertiport Locations and Trip Allocations

532
of
266,734
= 0.20%

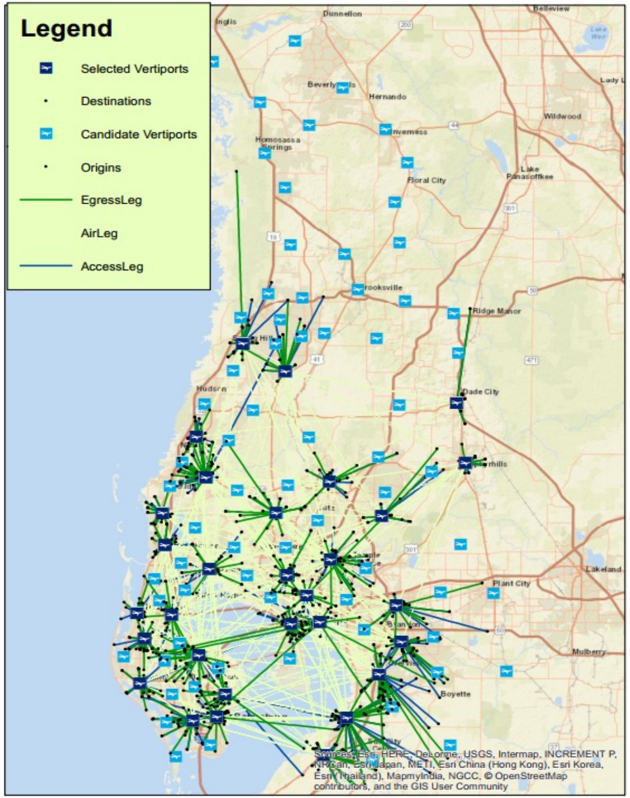
- Vertiport demand unevenly-distributed
- Northern region under-served

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

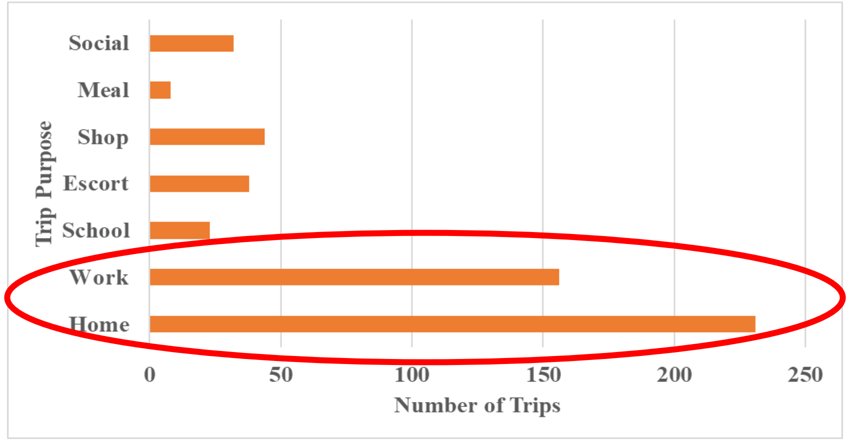
Vertiport Index	11	12	13	14	15	16	17	18	19	20
Demand	31	43	27	30	41	20	34	26	33	42

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



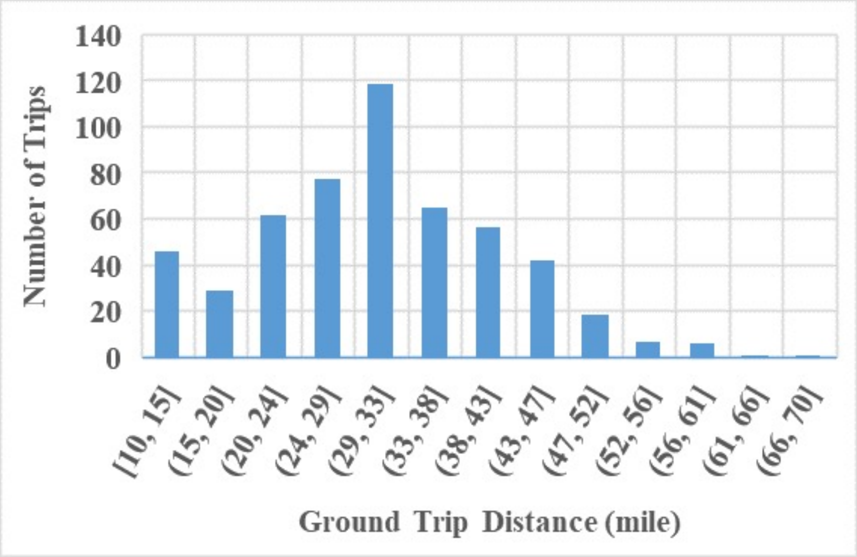
Trip Purposes and Access and Egress Modes of UAM Trips

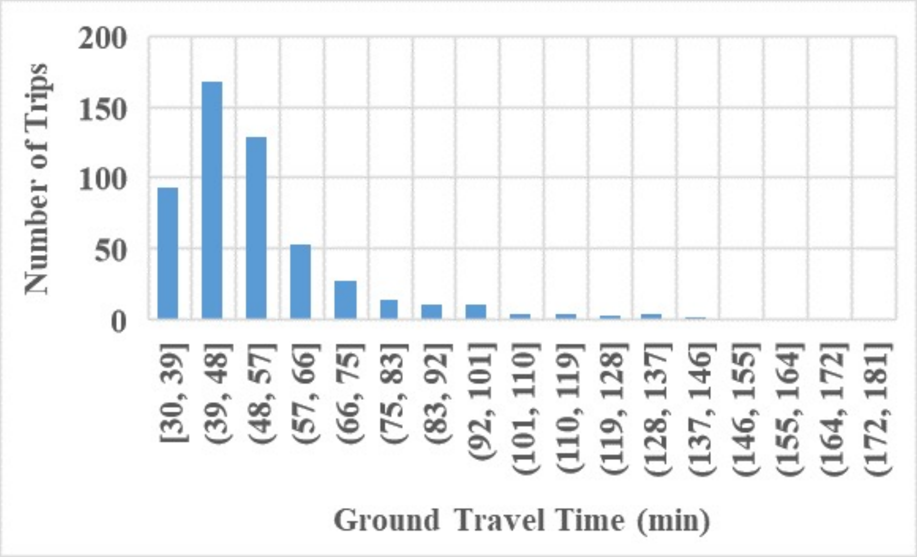
	Transportation Mode	Value
Vertiport Access	Personal vehicle	495
	For-hire service	10
	Bike	1
	E-scooter	10
	Transit	16
Vertiport Egress	Personal vehicle	161
	For hire-service	329
	Transit	42



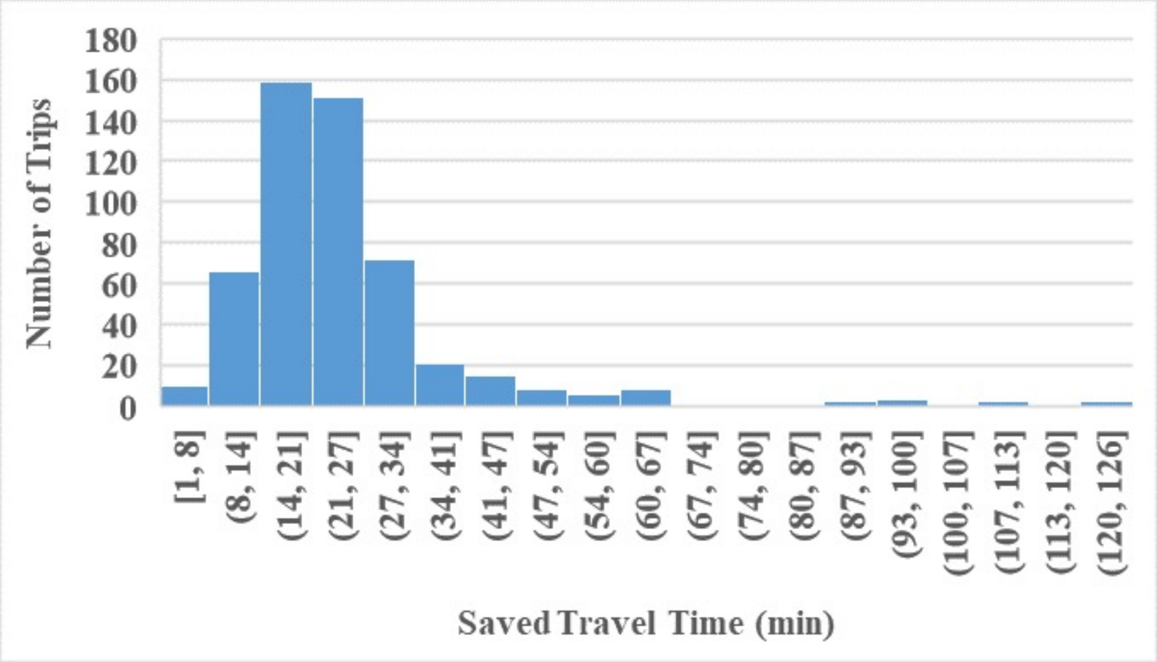
Trip Purposes of UAM Trips

Distribution of Ground Travel Distance and Time of UAM Trips without Diverting to UAM



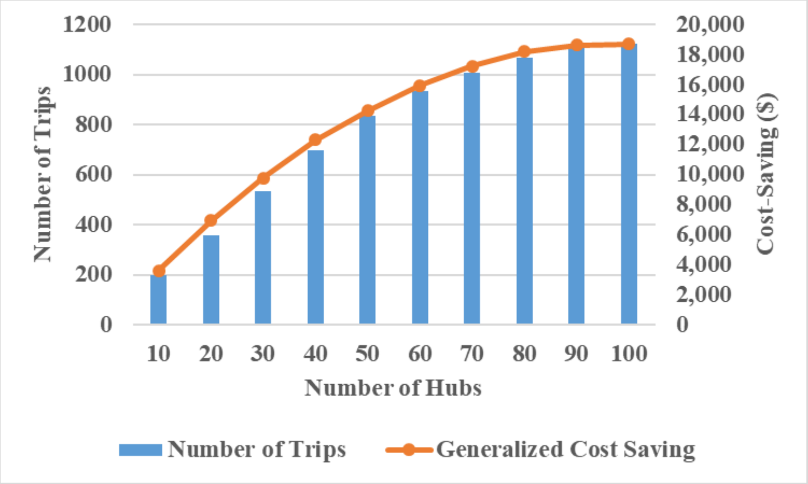


Distribution of Saved Trip Time by Diverting to UAM

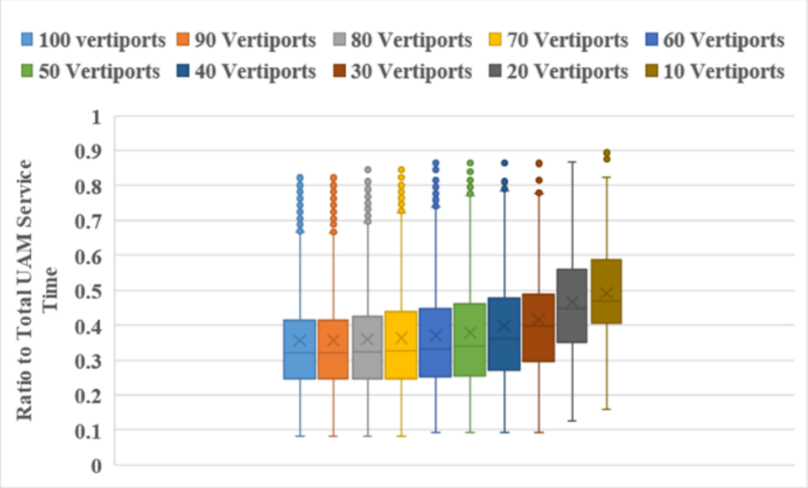


Sensitivity Analysis – Number of Vertiports

Major findings: Marginal effects decrease with increasing number of vertiports.
Market gets saturated after 80 vertiports.
Accessibility to vertiports increases with increasing number of vertiports.



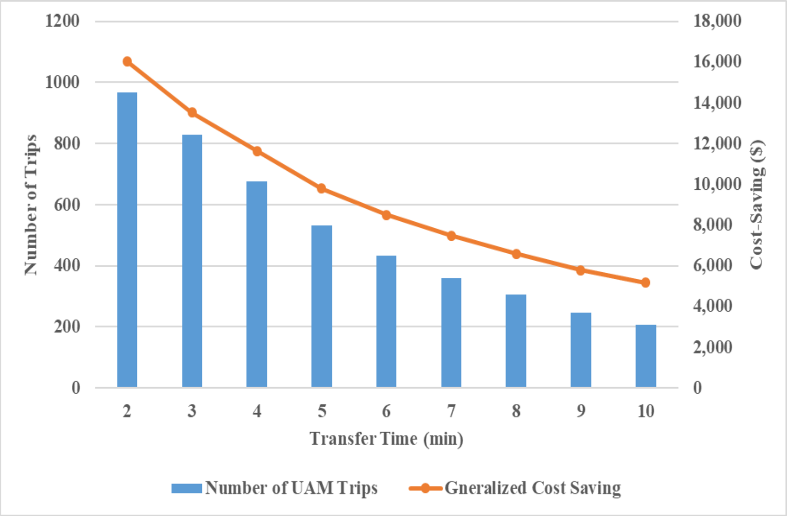
Generalized cost-saving and UAM adoption variation with different number of vertiports



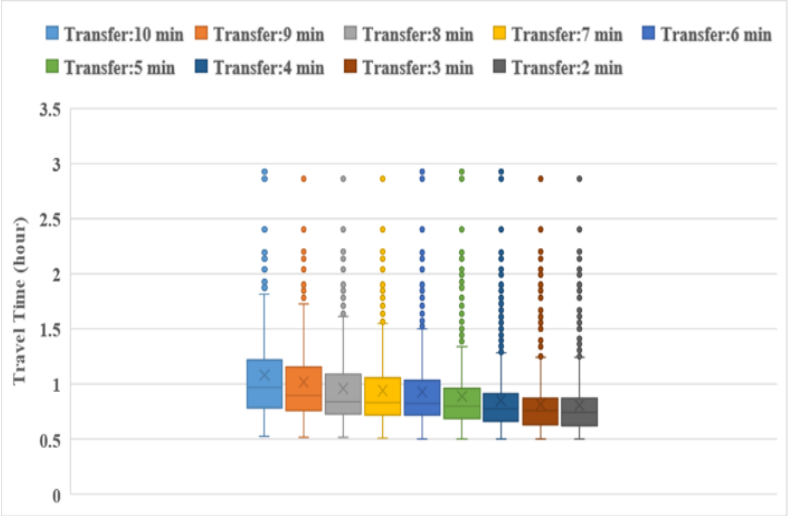
Vertiport access & egress time with different number of vertiports

Sensitivity Analysis – Transfer Time

Major findings: System cost-saving and UAM adoption is negatively correlated with transfer time
Travelers with long travel time is less sensitive to the increase of transfer time



Generalized cost-saving and UAM adoption variation with different transfer time

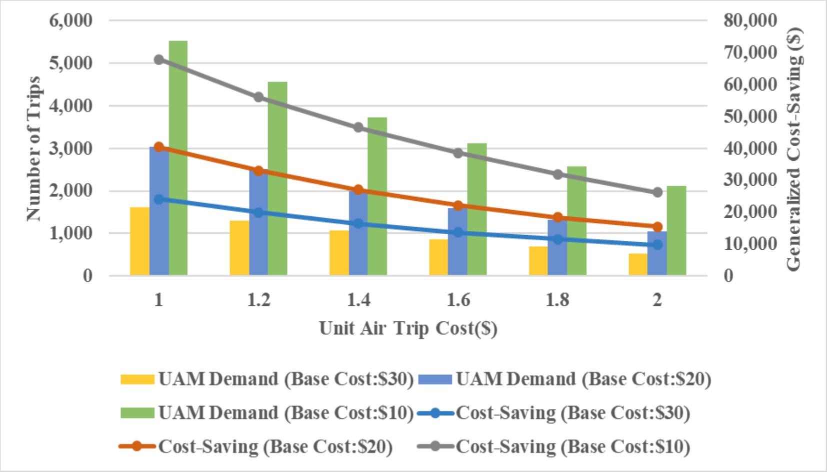


Travel time distribution variation if UAM users stick to ground transportation

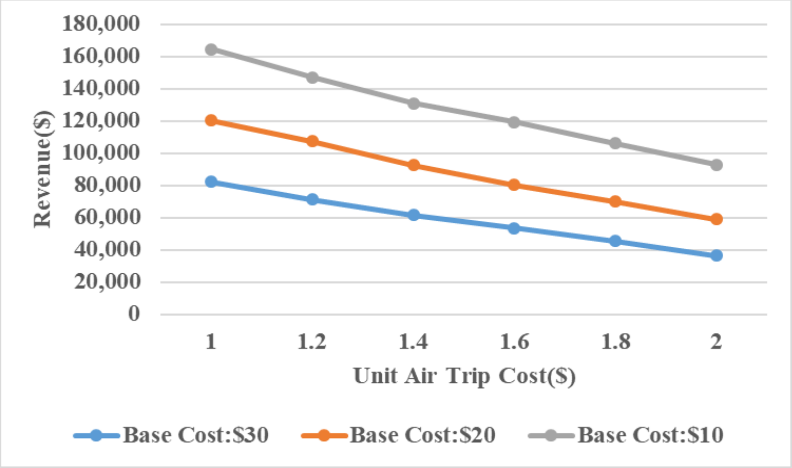
Sensitivity Analysis – Pricing Schemes

Major findings: UAM adoption, generalized cost of the system and revenue generation for service providers are almost linearly correlated with the unit cost of air trip

$$c_{kd} = Base + unit^{a} * d_{kd}$$



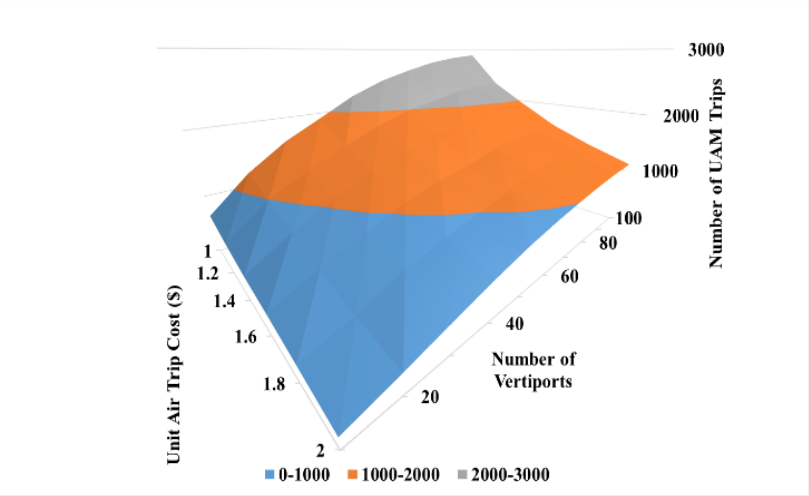
Generalized cost-saving and UAM adoption variation with respect to different pricing schemes



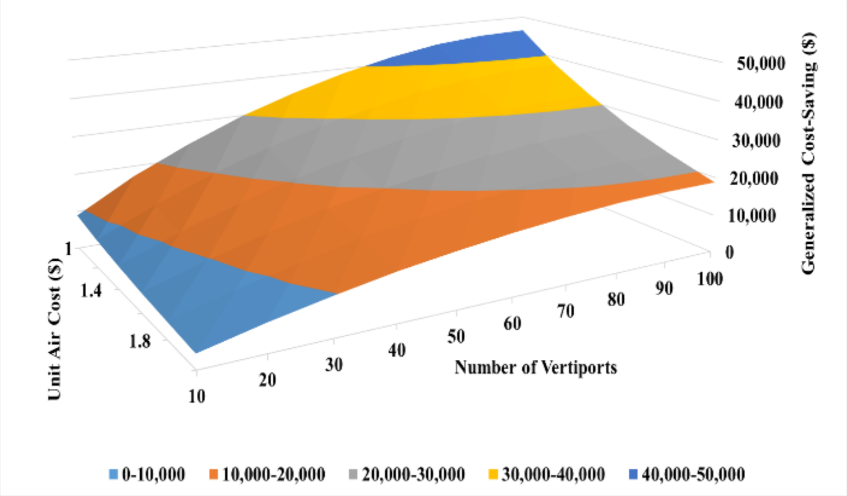
Variation of total revenue generated for service provider with respect to different pricing strategies

Sensitivity Analysis – Number of Vertiports & Unit Air Trip Cost

Major findings: Generalized cost-saving and UAM demand is more sensitive with number of vertiports for lower unit air trip cost
Generalized cost-saving and UAM demand is more sensitive with unit air cost for larger number of vertiports

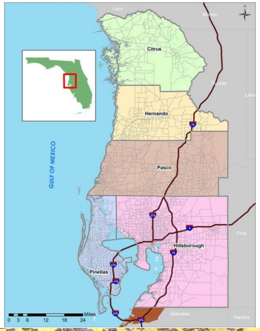


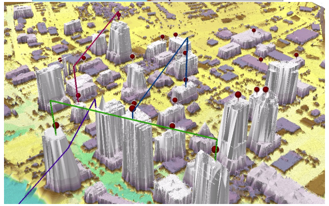
UAM demand variation with different unit air trip cost and number of vertiports

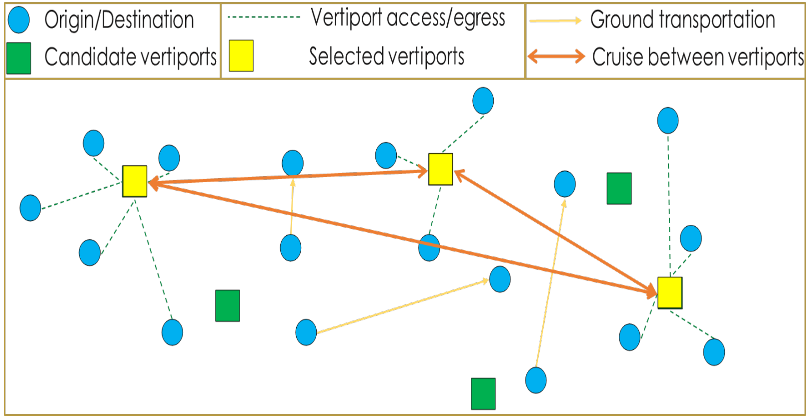


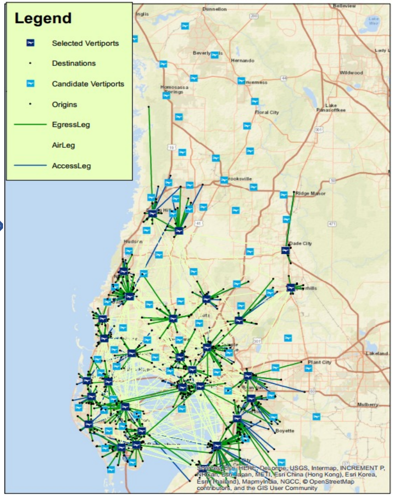
Generalized cost-saving variation with different unit air trip cost and number of vertiports

Vertiport Locations and Demand Estimation of Urban Air Mobility









- Optimal locations of vertiports
- Passenger allocation to vertiports
- Access and egress modes of each passenger

- Diverted demand in the region
- Saved travel time and reduced system generalized cost
- Optimal number of vertiports to serve the region

Summary

- A deterministic IP model was formulated by combining the modeling structure of the traditional hub-and-spoke problem and the mode choice modeling of individual travelers.
- By analyzing the nature of the network design problem and the UAM trip characteristics, an additional constraint was proposed and preprocessed along with other constraints in order to largely reduce the feasible region of the IP problem.
- The optimization results show significant time savings due to the introduction of UAM service and a non-uniform distribution of demand at different vertiports.

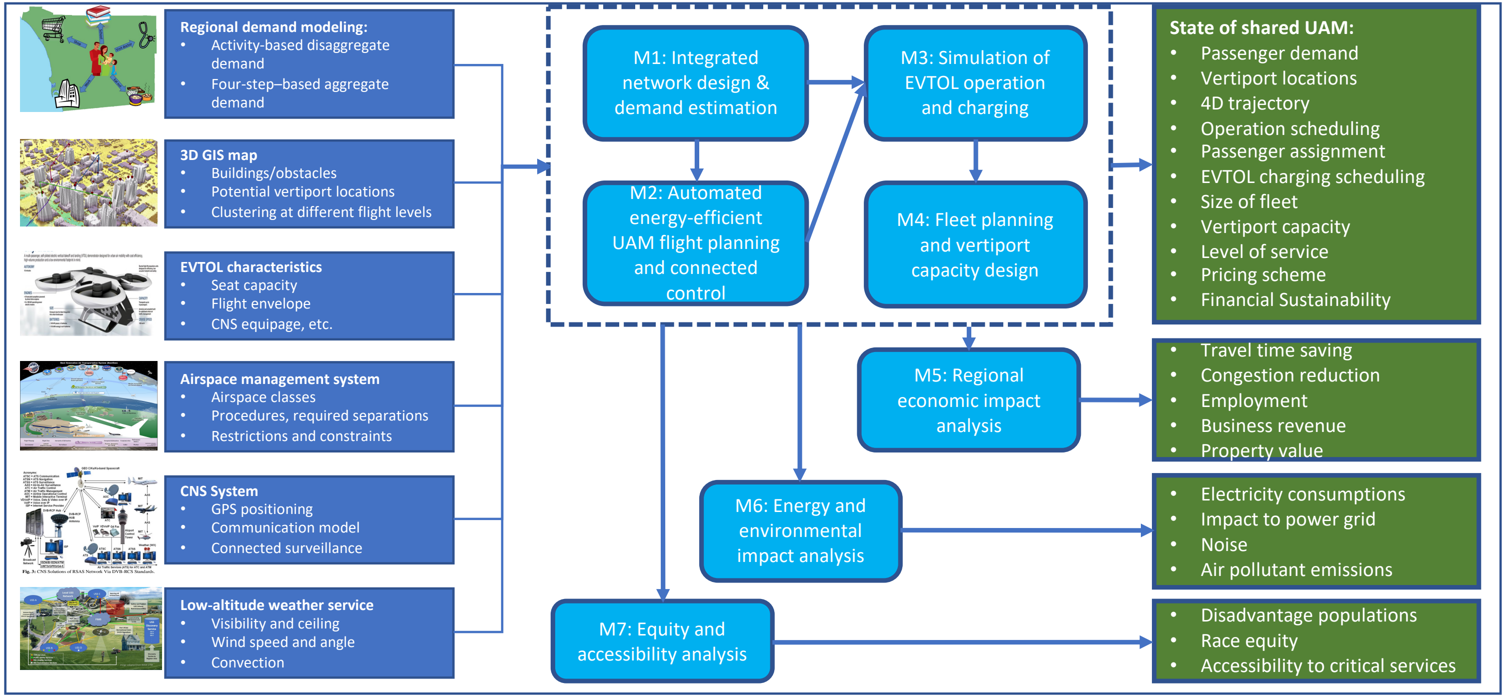
Summary (Cont'd)

- Sensitivity analyses were conducted to explore the effects of critical factors from the supply side of UAM adoption and service performance.
- The proposed modeling framework and sensitivity analysis can provide city managers and UAM operators with a better understanding of emerging on-demand UAM and can provide insights for designing future UAM service in terms of infrastructure requirements and pricing strategies.
- Induced demand was not considered in this study, however, it will not affect the outcomes of the case study.

Future Research

- In future research with a higher market penetration of UAM, induced demand should be considered.
- Taking randomness into the problem formulation and proposing a more reliable UAM network design is a future research interest.
- Capacitated vertiport location problem.

UAM Research at USF



Shared Urban Air Mobility Evaluation Tool (SUAMET)

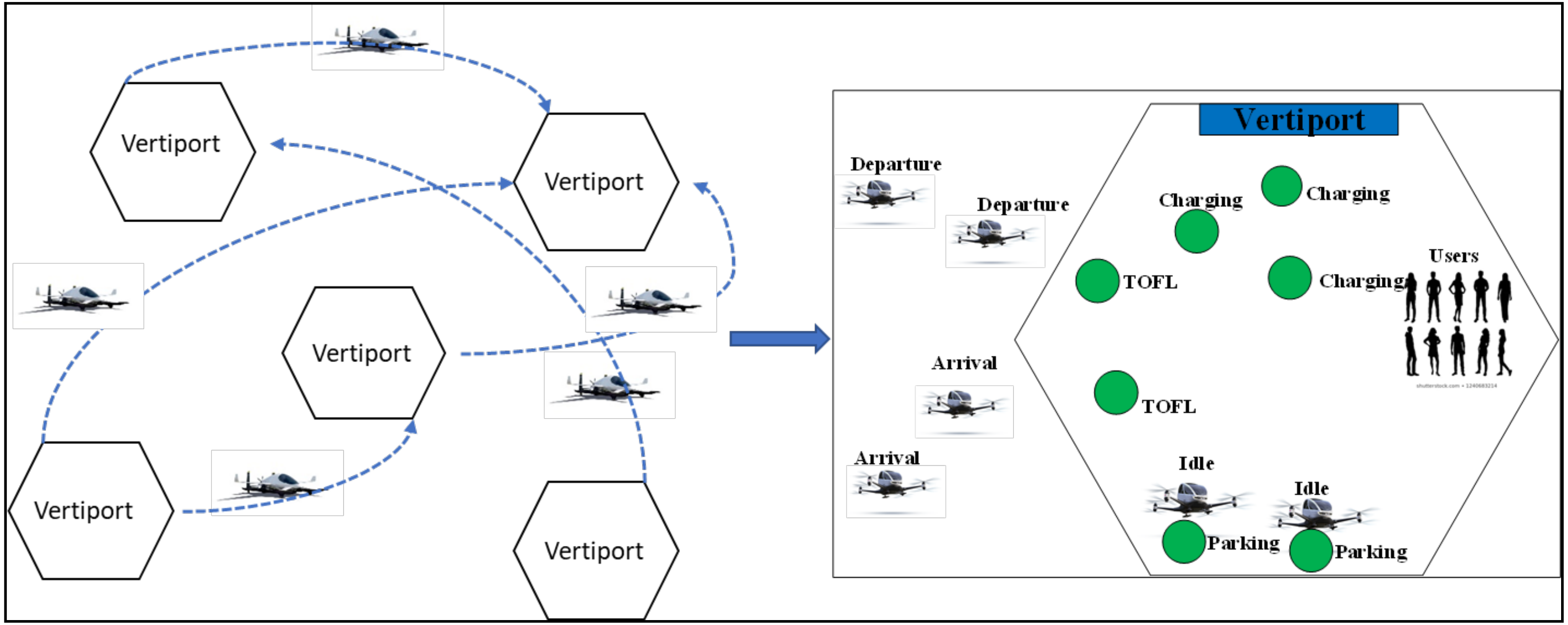
Ongoing Efforts

- (M2) Automated flight planning model
- (M3) UAM operation simulation model
- (M4) Simulation optimization for fleet planning
- (M6) Environmental impact analysis of UAM
- (M1+) Understanding induced demand of emerging UAM

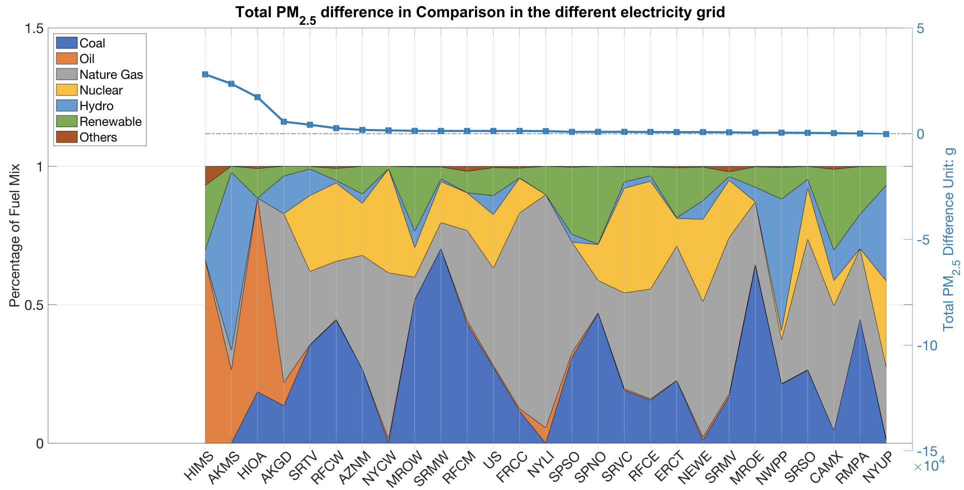
Automated Flight Planning of High-Density Urban Air Mobility Operations

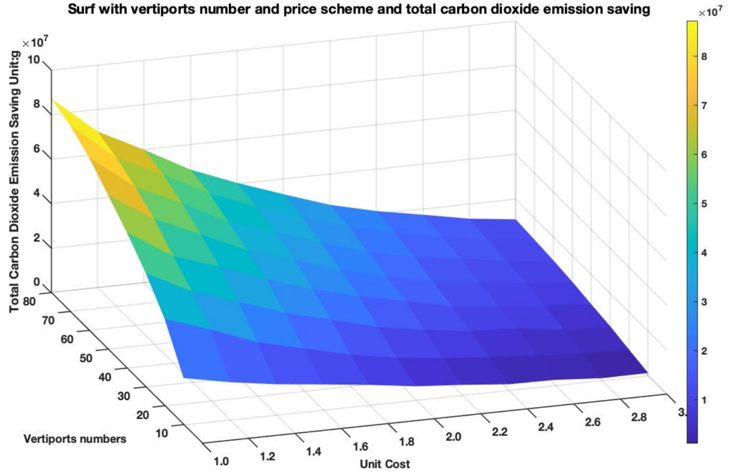
- Hualong Tang, **Yu Zhang^,** Hualong Vahid Mohmoodian, Hadi Charkhgard (2021). Automated Flight Planning of High-Density Urban Air Mobility. Transportation Research Part C: Emerging Technologies, [Volume 131](), October 2021, [https://doi.org/10.1016/j.trc.2021.103324]().
- Amazon Research Award 2021, "Design of an automated advanced air mobility flight planning system (AAFPS)".

Agent-based Simulation of Future On-demand UAM Service with eVTOLs



Environmental Impact Analysis of Future on-Demand UAM





- Pengli Zhao, Joseph Post, Zhiqiang Wu, Yu Zhang^, Environmental Impact Analysis of On-Demand Urban Air Mobility: A Case Study of the Tampa Bay Area, submitted to TRB Annual Meeting 2022

Thank You!

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