FURTHER EXPLORATION OF OPERATION LIMITS FOR ADVANCED AIR MOBILITY MISSIONS

NASA Systems Analysis Symposium

Presenters: Dr. Dan DeLaurentis, Principal Investigator

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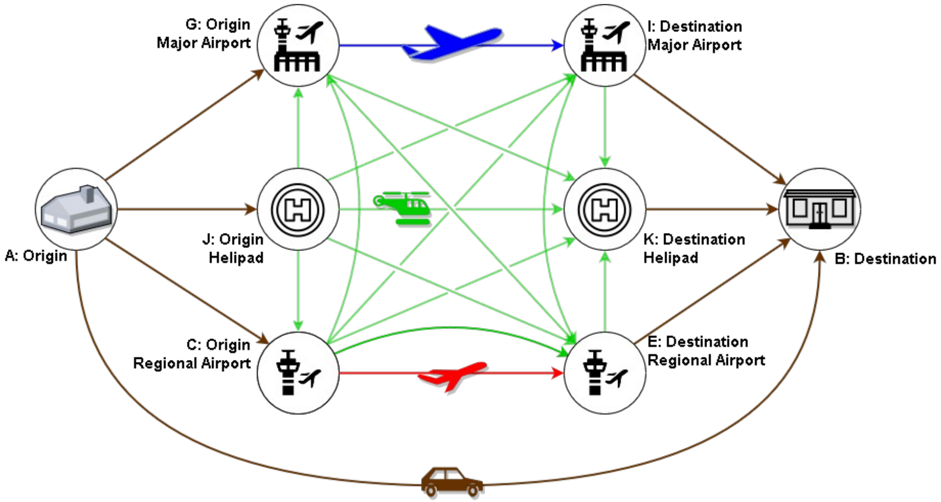
Overview of AAM Operational Limits Study

- *Operational limits are factors that may inhibit large-scale Advanced Air Mobility (AAM) operations*
- *Continuing our prior work, we aim to answer the following research questions:*
  1. *How to identify the potential number of passenger-carrying trips that could make use of passenger UAM/RAM segment(s) in a metropolitan area?*
  2. *How to quantify the impact of operational limits on other AAM mission system-of-systems (e.g. cargo delivery)?*
- *We'll brief today only on the Chicago, Dallas, and New York City Metropolitan Areas (Orlando, Denver, San Francisco assessments on-going)*



Network Model of the
Modular Computational Analysis Framework

A study to investigate total mobility using both CTOL and VTOL-capable aircraft

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Prior work from AVIATION 2019:
https://arc.aiaa.org/doi/10.2514/6.2019-3518

Identifying and Analyzing Operational Limits for Passenger-Carrying Urban Air Mobility Missions

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Prior work from AVIATION 2020:
https://arc.aiaa.org/doi/abs/10.2514/6.2020-2913

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

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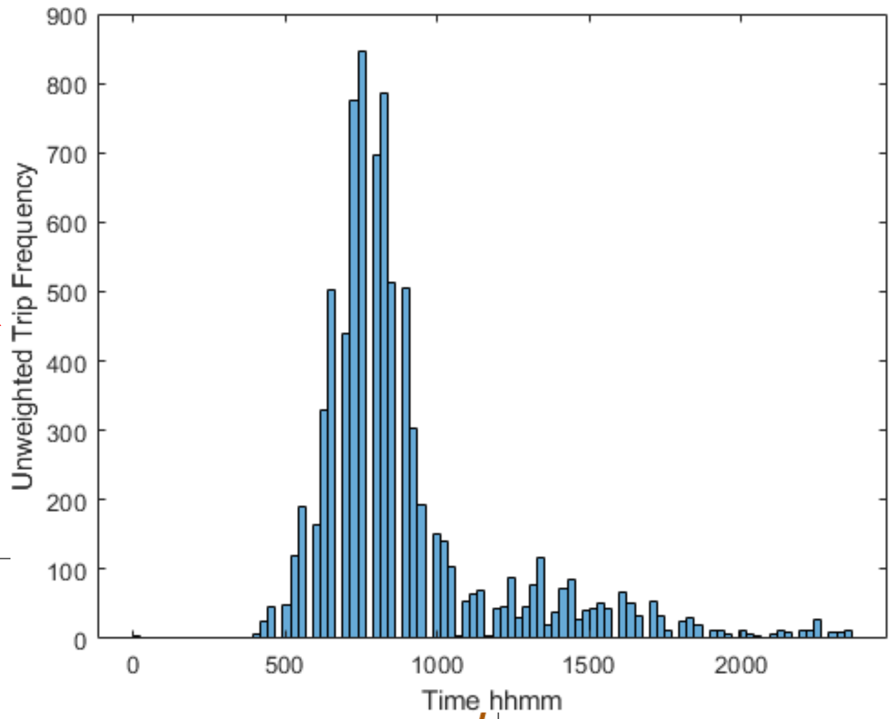
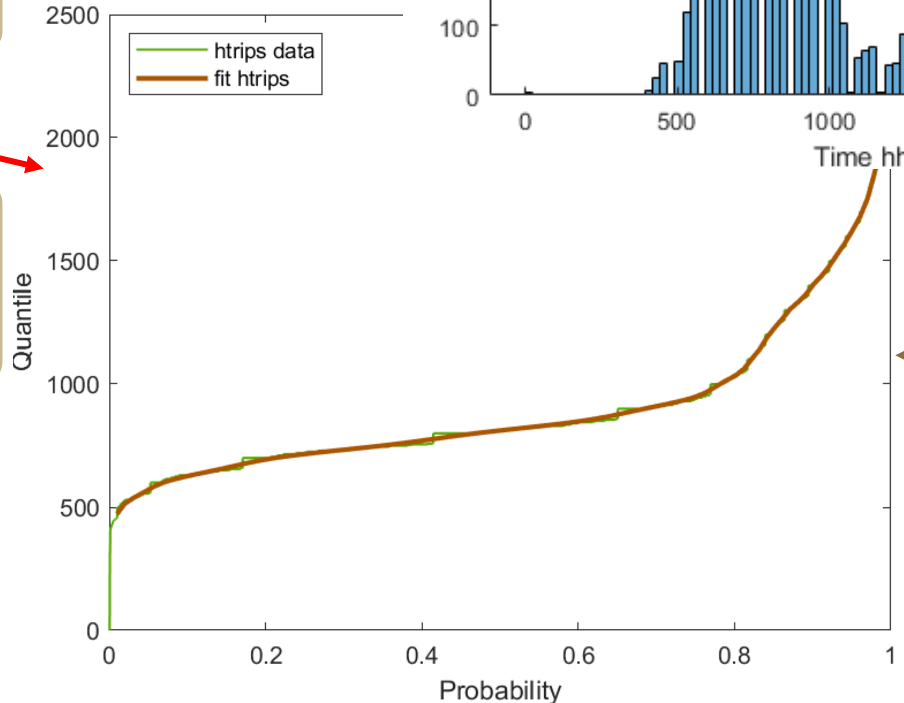
Prior work from AVIATION 2021
https://arc.aiaa.org/doi/10.2514/6.2021-3174

Demographic-Based Commuter Trip Generation Process

1. *Get number of individuals within regional definition via ACS/LODES*
2. *Assume to/from work trip end time distribution for data*
3. *Put distribution data in 15m or 30min bins*
4. *Get tract-level income distribution data from ACS*
5. *Fit distributions to inverse CDF for end time and ACS data*
6. *Generate n samples from U(0,1) based on number of households and ATS Brief*
7. *Select income and trip end time that corresponds to random variable*
8. *Pair sampled trip, end times, and income with origin and destination centroids*
9. *Collate traveler data and trip details for metro area in .csv file*





Key Terms:
ACS: American Commuter Survey (U.S. Census)
ATS: American Transportation Survey (Department of Transportation: National Household Travel Survey)
CDF: Cumulative Distribution Function
htrips data: home-to-work trips data variable name
LODES: Longitudinal employer-household dynamics Origin-Destination Employment Statistics (U.S. Census)

OD Trips as the Unit of the Analysis

Primary output of the computational framework is an effective cost measure designed to effectively capture two elements of a trip: operating cost and travel time

$$Cost_{eff,i} = Cost_{oper,i} + Cost_{time,i}$$
$$Cost_{time,i} = time_{trip,i} * time_{value}$$

where,

$Cost_{eff,i}$: *Effective cost for the mode i*

$Cost_{oper,i}$: *Operating cost of mode i*

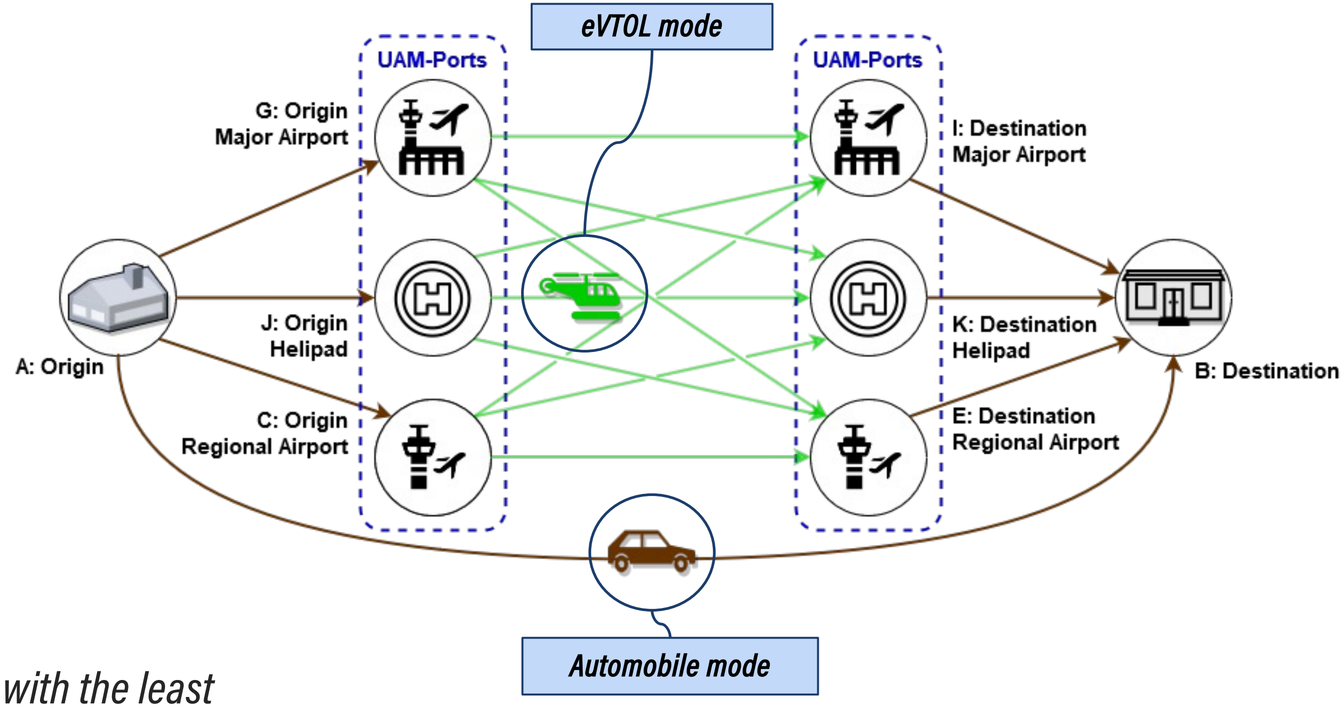
$Cost_{time,i}$: *Cost due to the travel time on mode i*

$time_{trip,i}$: *Total door-to-door trip time for mode i*

$time_{value}$: *Value of time of the passenger*

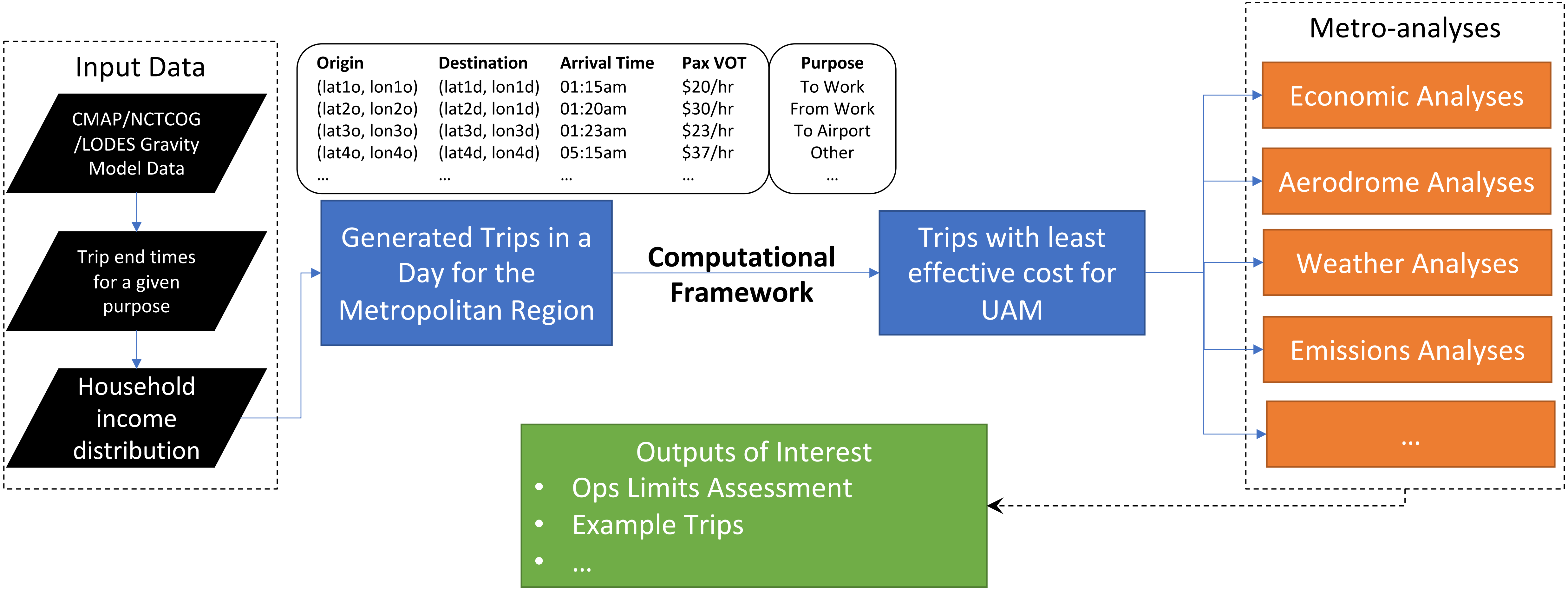
Our framework assumes that the traveler always picks the mode with the least effective cost

Network Model of the Modular Computational Analysis Framework*
Illustrated for UAM but expanded for AAM



*Maheshwari, A., Mudumba, S., Sells, B. E., DeLaurentis, D. A., & Crossley, W. A. (2020). Identifying and Analyzing Operations Limits for Passenger-Carrying Urban Air Mobility Missions. In *AIAA AVIATION 2020 FORUM* (p. 2913). https://doi.org/10.2514/6.2020-2913

Architecture of the Computational Framework



Though analyses are performed in modules, strong complex interdependent dynamics exist between regional factors such as grid index, weather, traffic, infrastructure, etc.

Model Scenario Assumptions

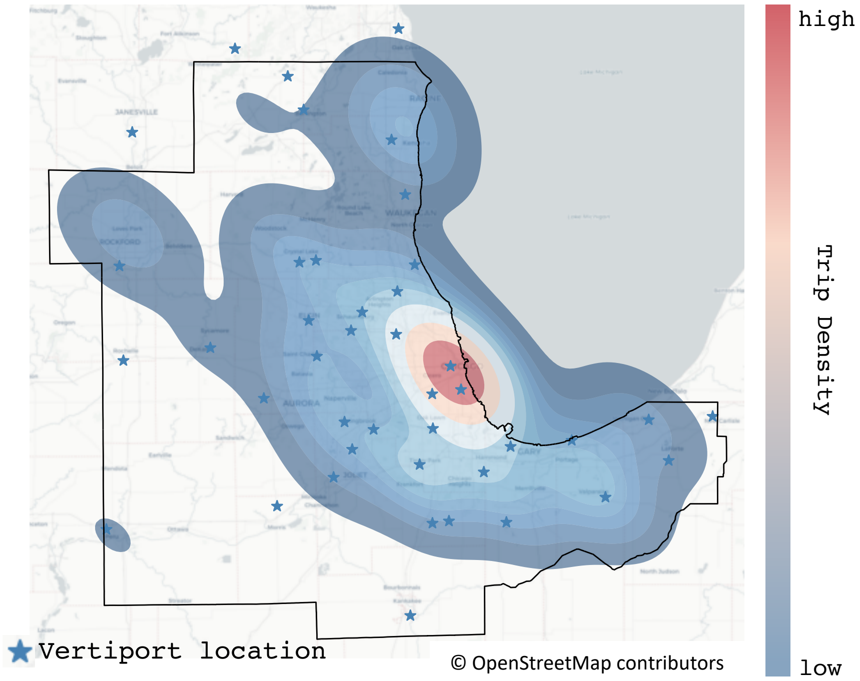
- Evaluating mobility for passenger carrying missions for work commuters
- Metropolitan boundary uses U.S. Census Combined Statistical Area definition
- Applying all-electric Uber-like vehicle in analysis with 1-passenger baseline*†
  - *Payload Capacity: 4-passengers + luggage (~980+ lbs)*
  - *Maximum Range: 70 mile*
  - *Cruise speed: 150 mph*
  - *Direct-operating Cost: $605 per flight hour given one passenger on-board (divided equally when assessing ridesharing)*
- Utilizing existing publicly available infrastructure in each metropolitan
  - *Assume 20 minute recharge for grid-charging or battery-swap in mission profile*
- Ground traffic with real-world road network and traffic congestion
- Network effects are not considered in this scenarios
  - *e.g. vertiport congestion, increased cost due to deadhead flights, etc.*

*Uber Elevate. (2016). "Fast-Forwarding to a Future of On-Demand Urban Air Transportation., *Uber, Tech. Rep.*

†Uber Elevate. (2018). Uber Air Vehicle Requirements and Missions. *Uber, Tech. Rep.*

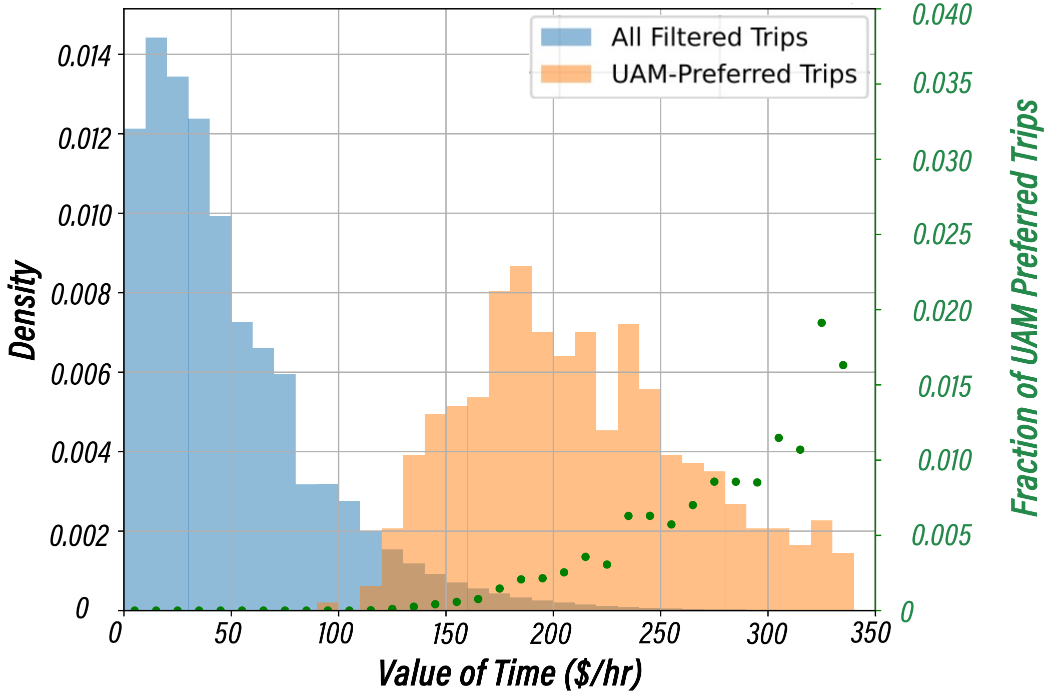
Chicago UAM Economic Sustainability

Heat Map of Expected UAM Demand



- *502 UAM preferred trips among 6.2 million daily commuter trips*
- *Many trip origins and destinations in downtown Chicago*

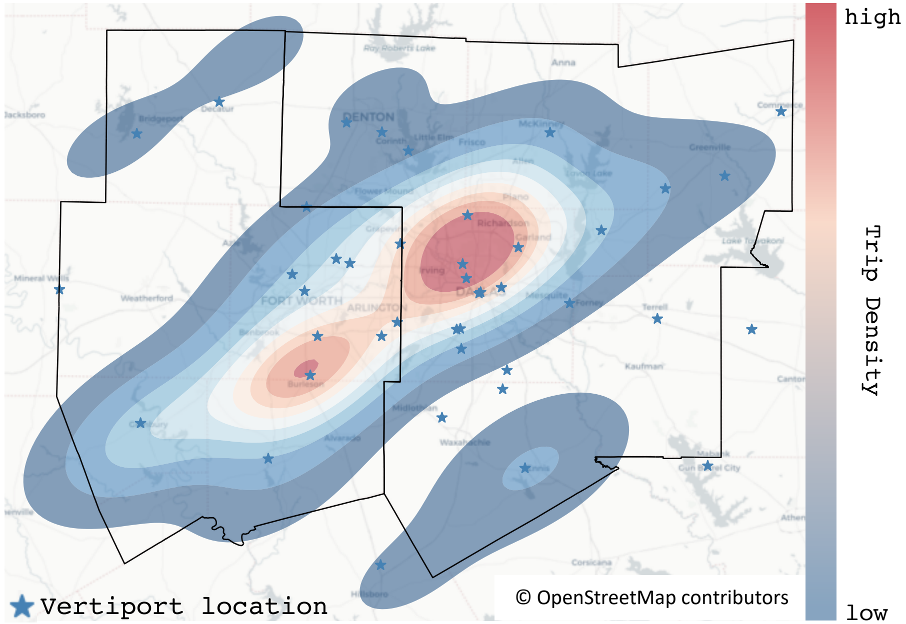
Distribution of Pax Value of Time (VoT) for UAM-Preferred Trips



- *Most of the passengers have value of time more than $100/hour*
- *Highest UAM-preferred trip market share is about 1.5% (~$330/hour VoT Tier)*

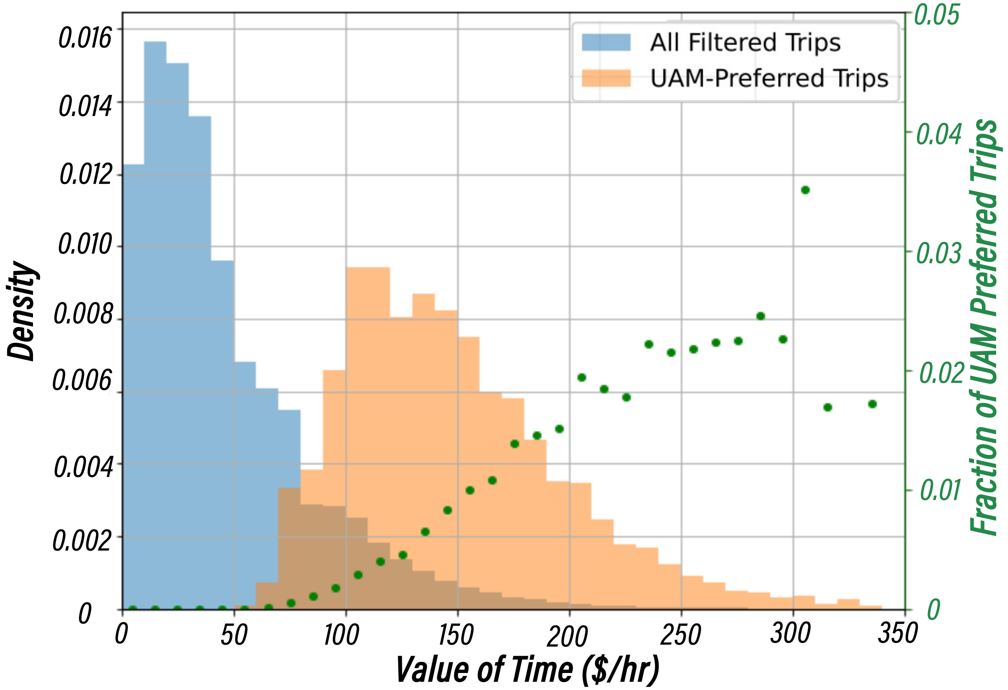
Dallas UAM Economic Sustainability

Heat Map of Expected UAM Demand



- 95 UAM preferred trips among 5.3 million daily commuter trips
- Hot spots around Dallas and south Fort Worth

Distribution of Pax Value of Time (VoT) for UAM-Preferred Trips



- Most passengers have VoT > $150 /hour
- Highest UAM-preferred trip market share is just beyond 0.4% (~$325/hour VoT Tier)

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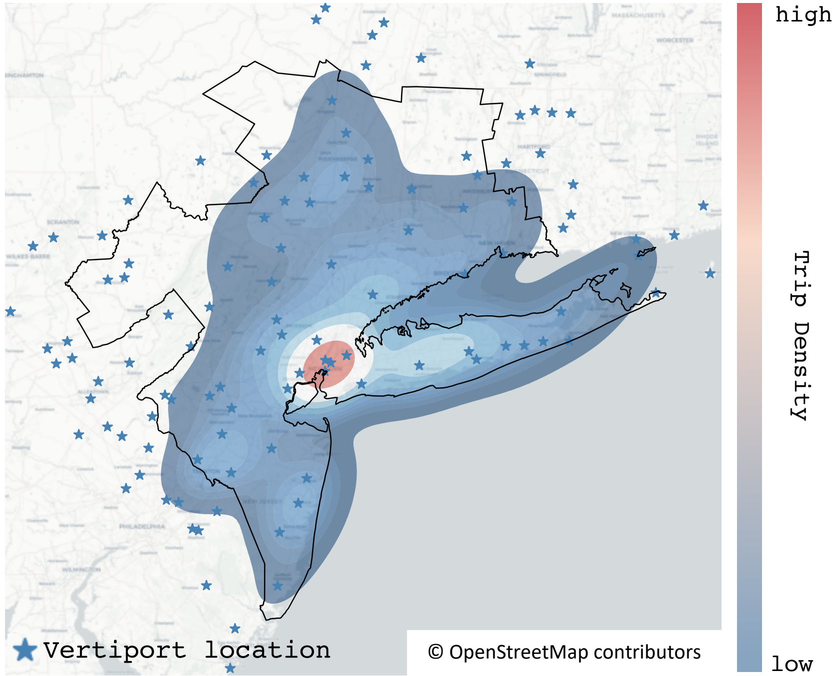
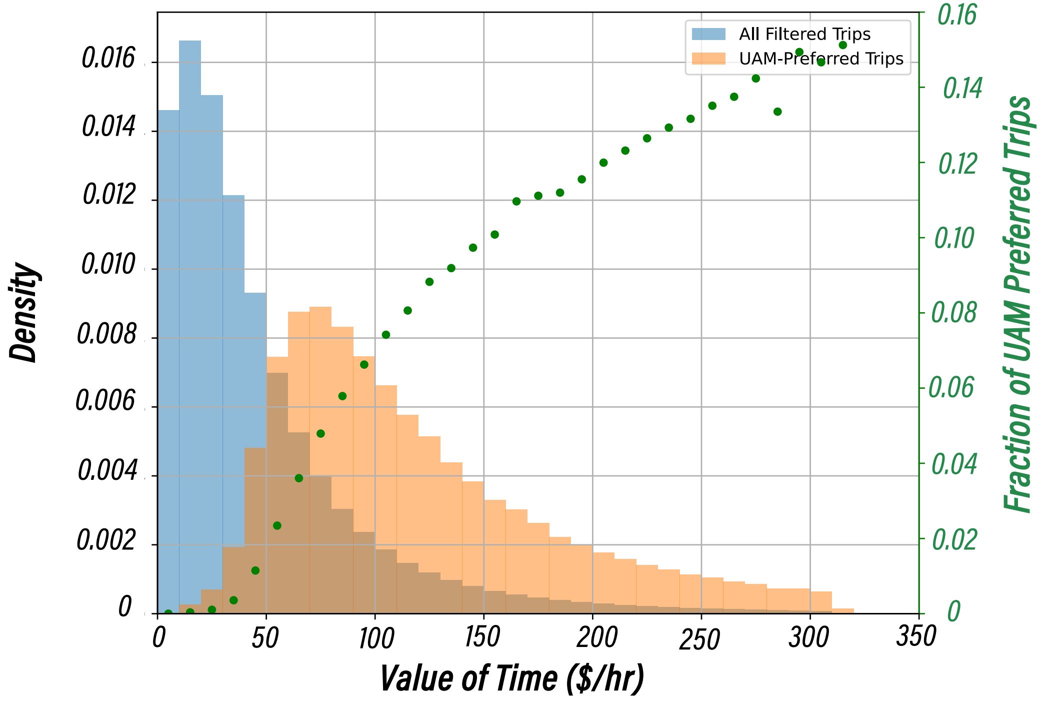
New York City UAM Economic Sustainability

Heat Map of Expected UAM Demand



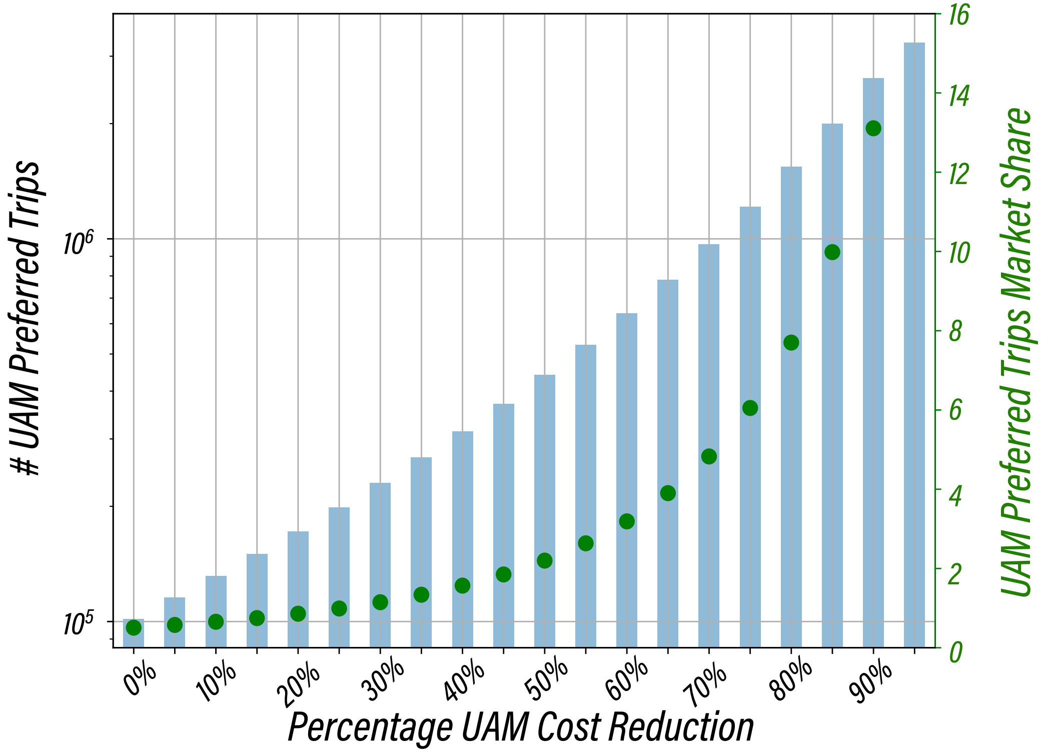
- *101,581 UAM preferred trips among 20 million commuter trips*
- *Concentration of trips to/from Manhattan*

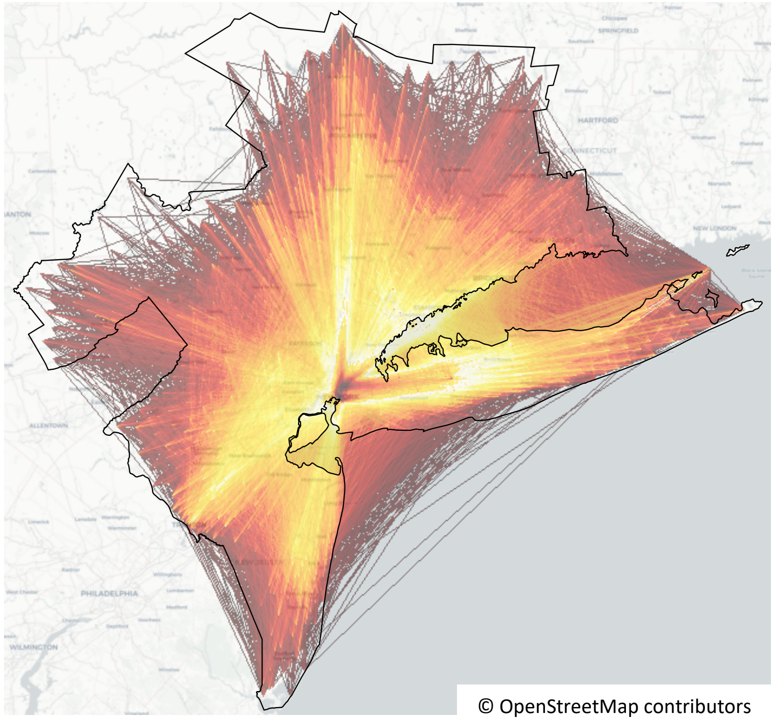
Distribution of Pax Value of Time for UAM-Preferred Trips



- *UAM demand observed as low as $25 VoT*
  - *Likely due to congestion + natural barriers on ground trips*
- *Up to 11% UAM Market Share (VoT: $320/hr)*

Effect of UAM Cost Reduction – NYC Example





links do not represent expected flight paths

- Cost analysis study shows that the market grows exponentially with UAM cost reduction
  - Ride sharing (~50% reduction with 2-pax sharing the vehicle) is one means to reduce cost

- Mapping NYC metro demand highlights possible locations for vertiport network for Entry into Service (EIS)

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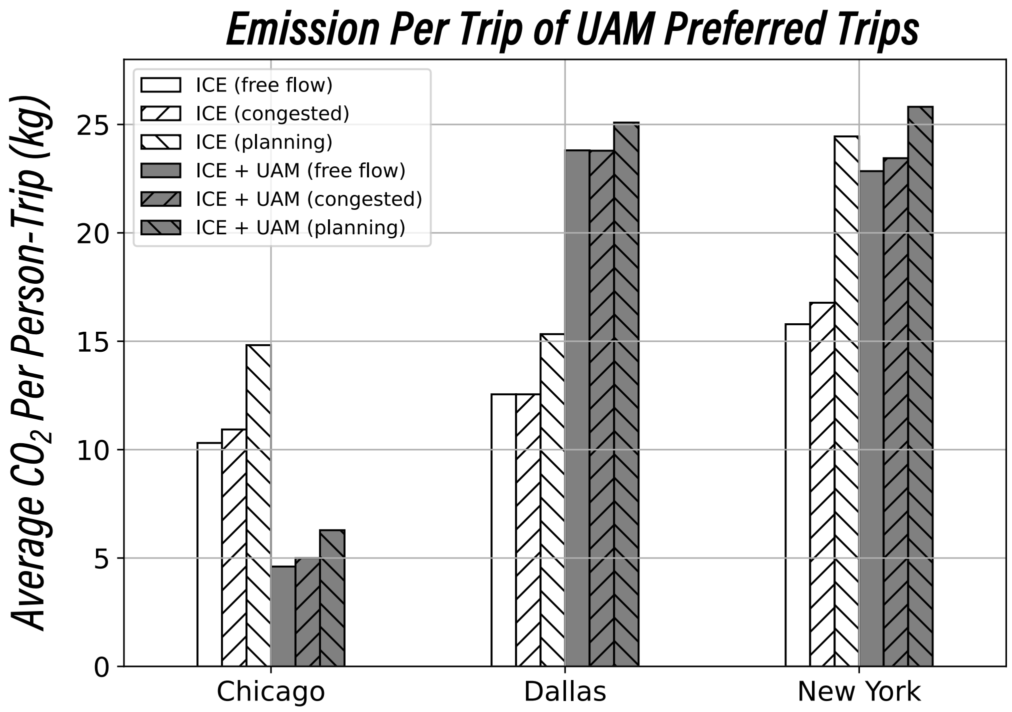
UAM Environmental Sustainability

Comparison of Emissions – Ground Vehicles vs. eVTOL UAM

- *Scenario Assumption*
  - *UAM vehicles charge at destination airports/vertiports*
  - *Auto emissions depend on the average speed of the vehicle (including congestion factor)*
- *Ground congestion model*
  - *Free flow – no congestion*
  - *Congested – observed typical congestion*
  - *Planning – travel time with heavy congestion*
- *Trip emissions are driven by driving conditions & the electric grid*



ICE + UAM: indicates trips utilized ICE to/from UAM airports/vertiports

ICE: Internal Combustion Engine ground vehicles

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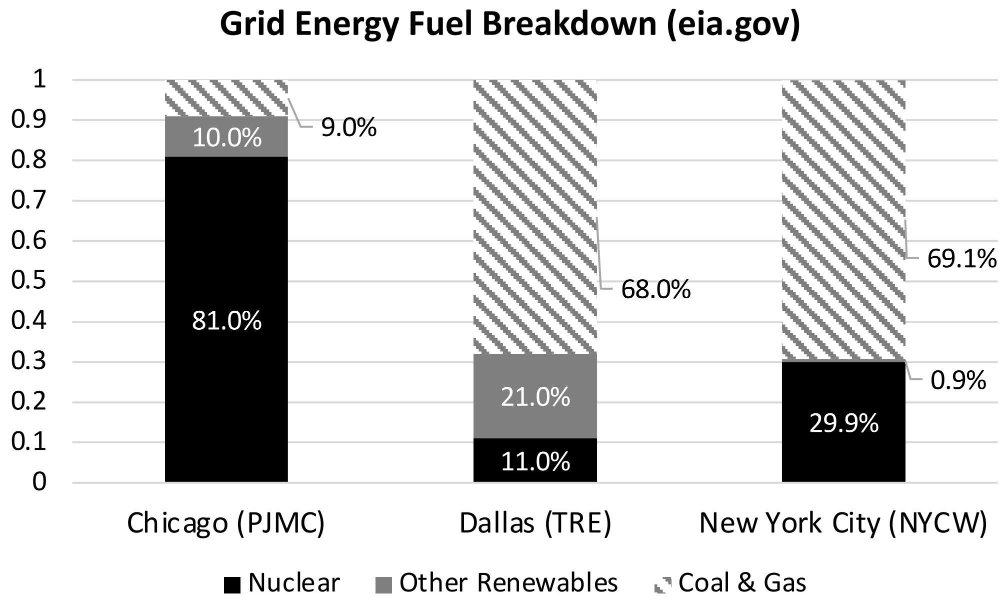
UAM Environmental Sustainability

Grid Emissions Dictate UAM Environmental Sustainability

- *UAM with electric aircraft does not always mean lower emissions compared to ICE automobiles*
  - *Chicago has the lowest UAM emissions (grid - 81% Nuclear Energy)*

Region	*Grid Emission Index (g/kWh)*
Chicago (PJMC)[1]	*47*
Dallas (TRE)[1]	*409*
New York City (NYCW)[2]	*288*



[1] Mudumba, S. V., Chao, H., Maheshwari, A., DeLaurentis, D. A., & Crossley, W. A. (2021). Modeling C02 Emissions from Trips using Urban Air Mobility and Emerging Automobile Technologies. Transportation Research Record, 2675(9), 1224–1237. https://doi.org/10.1177/03611981211006439
[2] Environmental Protection Agency. (n.d.). eGrid Power Profiler. EPA. Retrieved October 28, 2022, from https://www.epa.gov/egrid/power-profiler#/

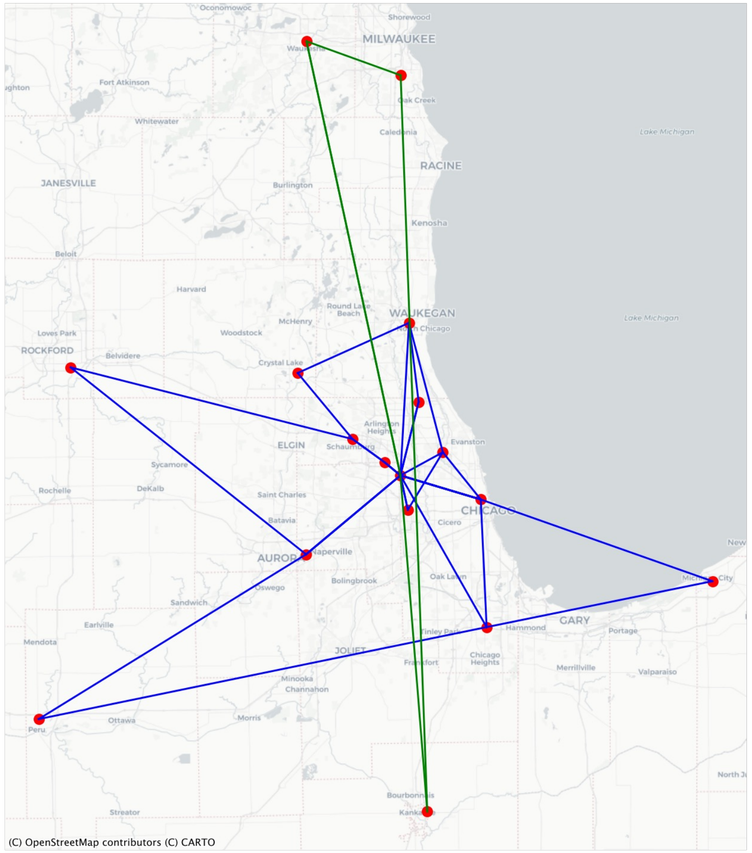
Summary & Ongoing Work

Summary

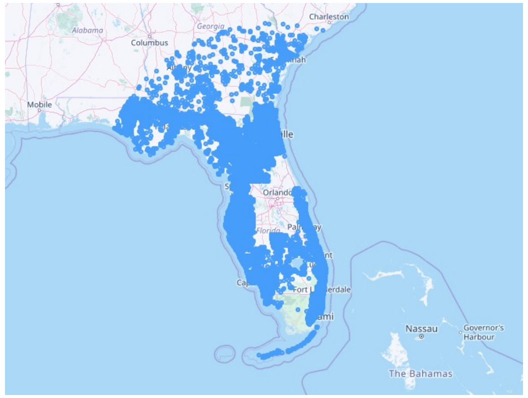
- *Continued assessment of various UAM network configurations to understand UAM operations' limits across 7 metro areas (3 presented here)*
- *Demographics and road network topology are two main driving factors for UAM market size*
- *Ride sharing can lead to reduced costs (greater market share) and environmental footprints*
- *Electric AAM emissions are highly dependent on which fuels are used to power a region's grid*

Ongoing Work:

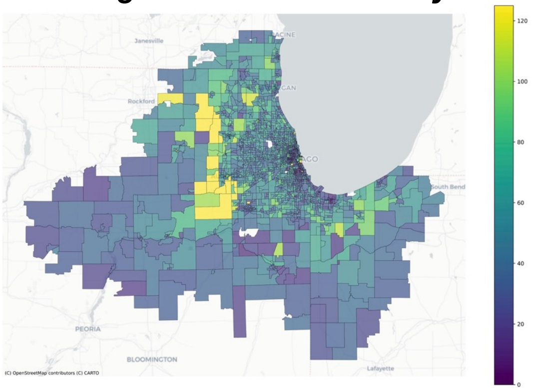
Cargo Middle Mile Delivery



Passenger Regional Air Mobility



Cargo Last Mile Delivery



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Thank You!

We welcome any comments or questions!

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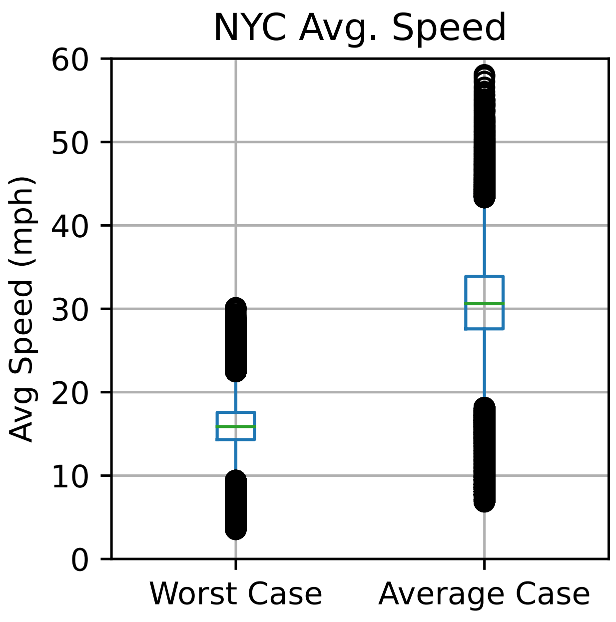
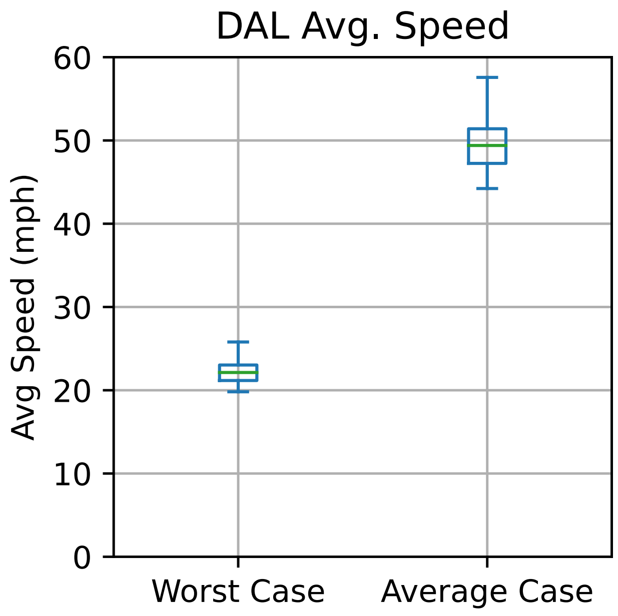
Back-up

Emissions Comparison NYC vs. DAL

Average Ground Vehicle Speed Comparison



Average speed of car trip ~ 30mph

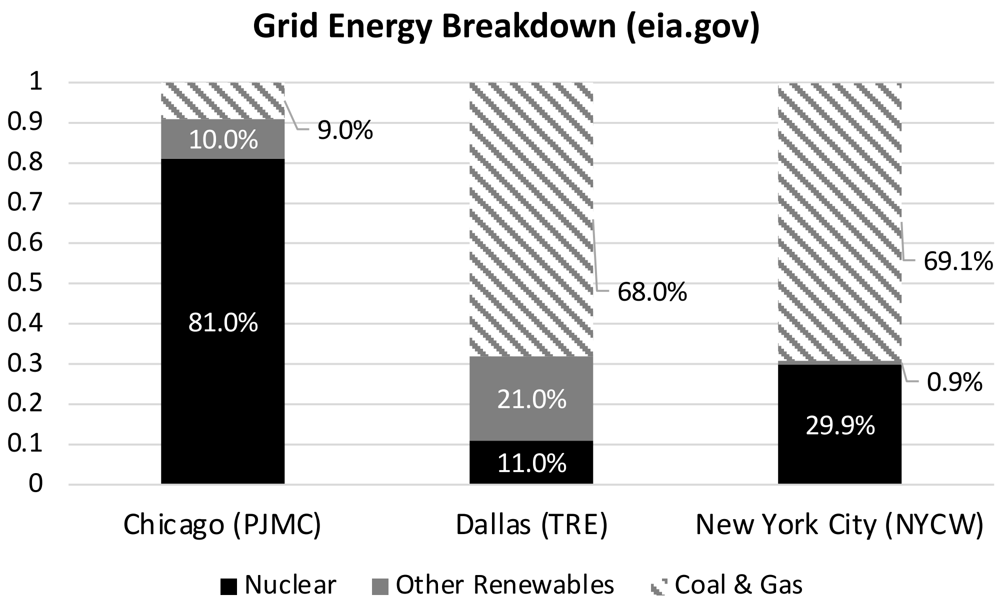


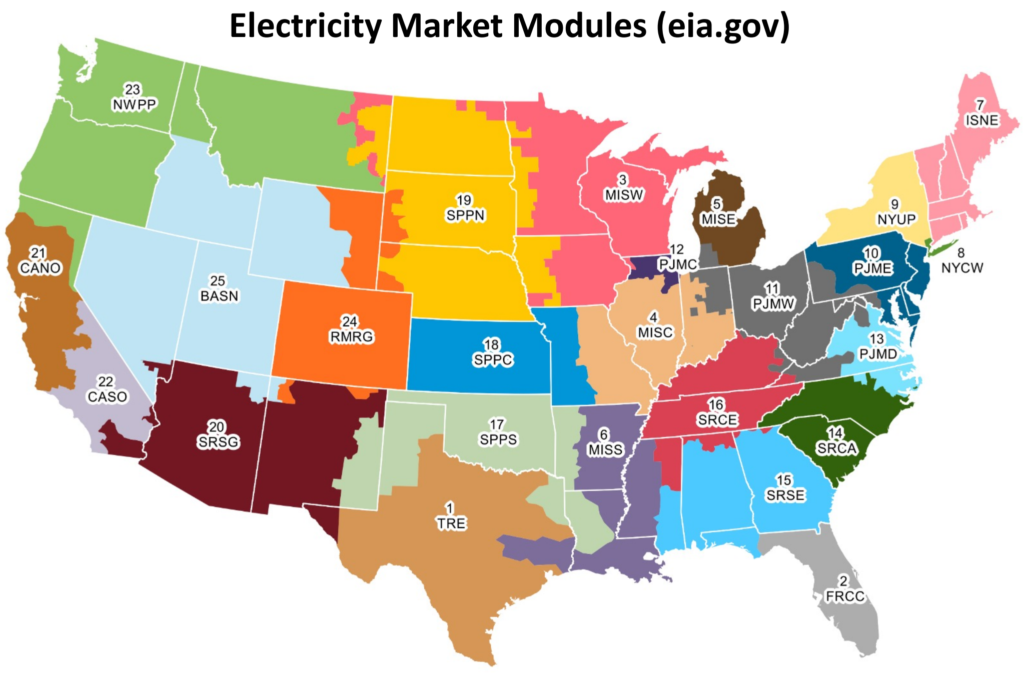
Average speed of car trip ~ 50mph

- *DAL average speed 20mph greater than NYC*
- *Speed discrepancy highlights route conditions between NYC & DAL*
  - *NYC – Predominantly "city" driving (higher emissions)*
  - *DAL – More "highway" driving (lower emissions)*

Grid Makeup NYC, DAL, CHI

Energy breakdown between metros,





Sustainability

Economic Sustainability

- *Continued assessment of various UAM network configurations to maximize UAM market potential*
- *Demographics and road network topology are the two main driving factors for UAM market size*
- *Identifying possible transportation market penetration potential with UAM cost reduction*

Environmental Sustainability

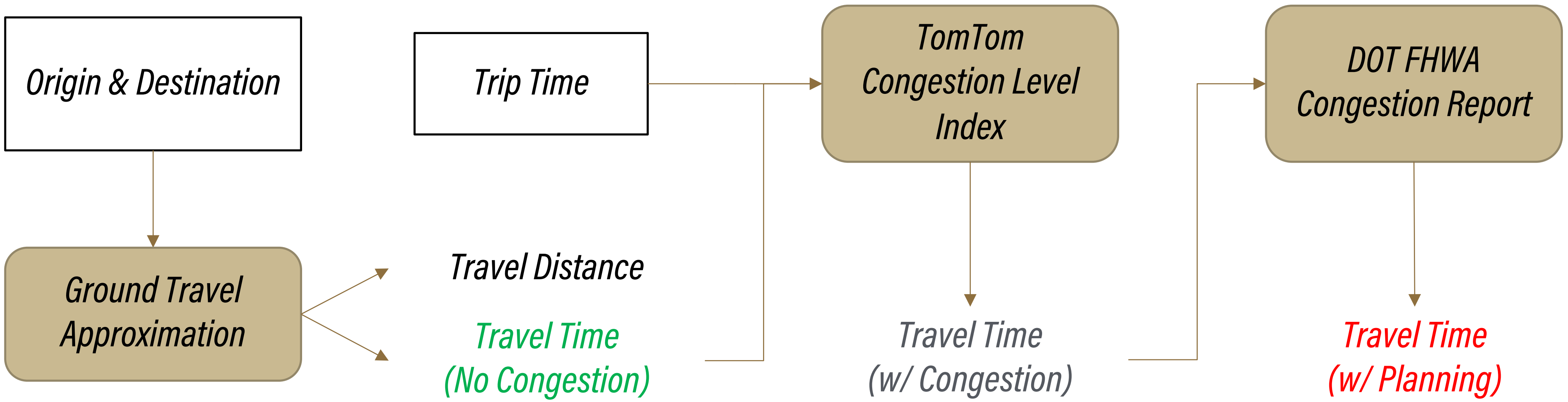
- *Electrification of aerial vehicles highlights the importance of grid sustainability*
- *Reliance on non-renewable energy for the grid negates potential eVTOL emissions reductions*

*Equity-Focused Sustainability**

- *Future work could investigate missions, conops, and use-cases that enable operations for broader communities*

**not in current statement of work*

Methodology to Model Ground Congestion



$$Time_{Congestion} = Time_{Approximation} * (1 + Congestion\ Level_{TomTom})$$

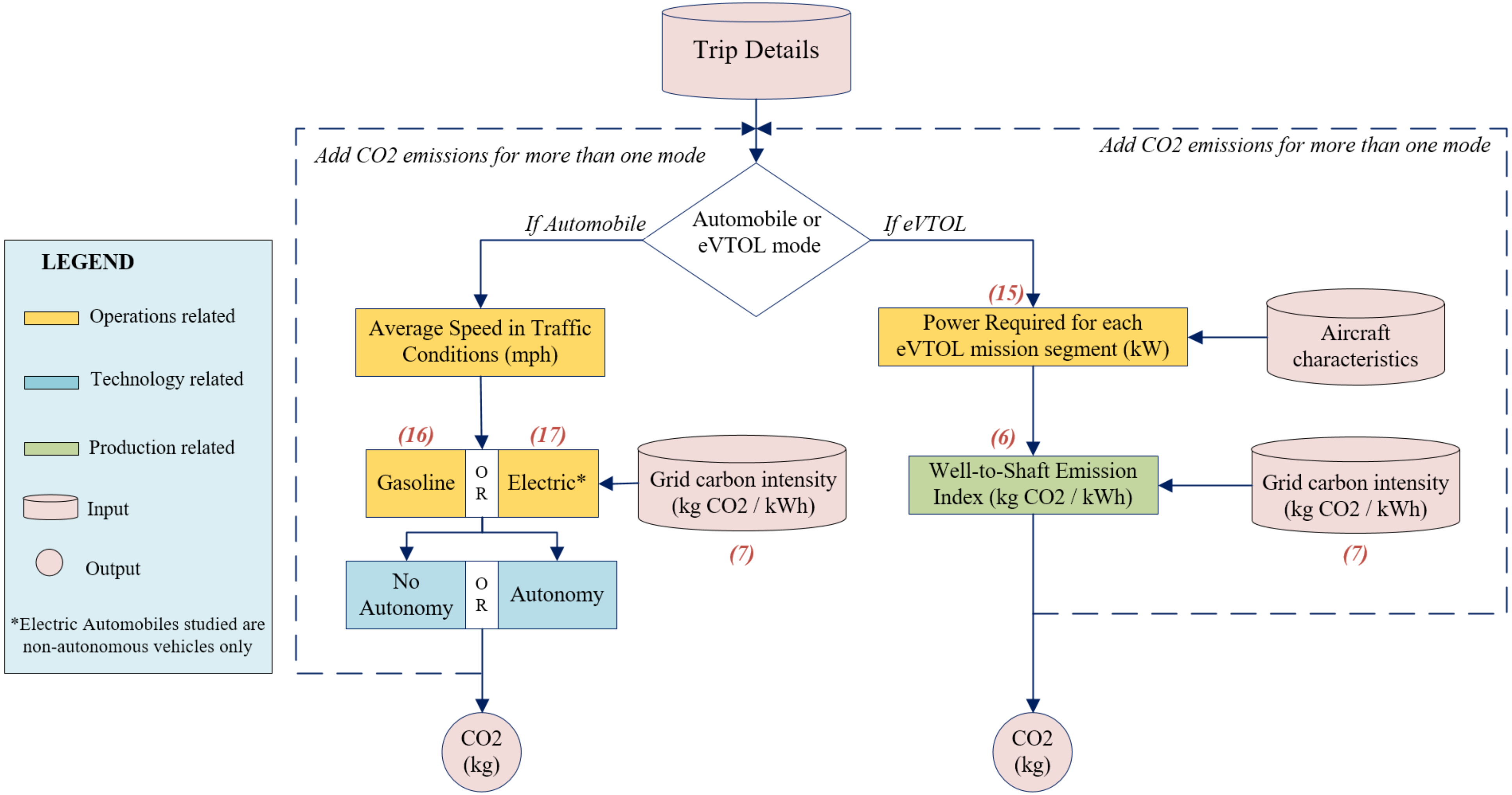
$$Time_{Planning} = Time_{Congestion} * \frac{Planning\ Time\ Index}{Travel\ Time\ Index}$$

Note: Ground Congestion only affects the auto-only trips

Key Assumptions

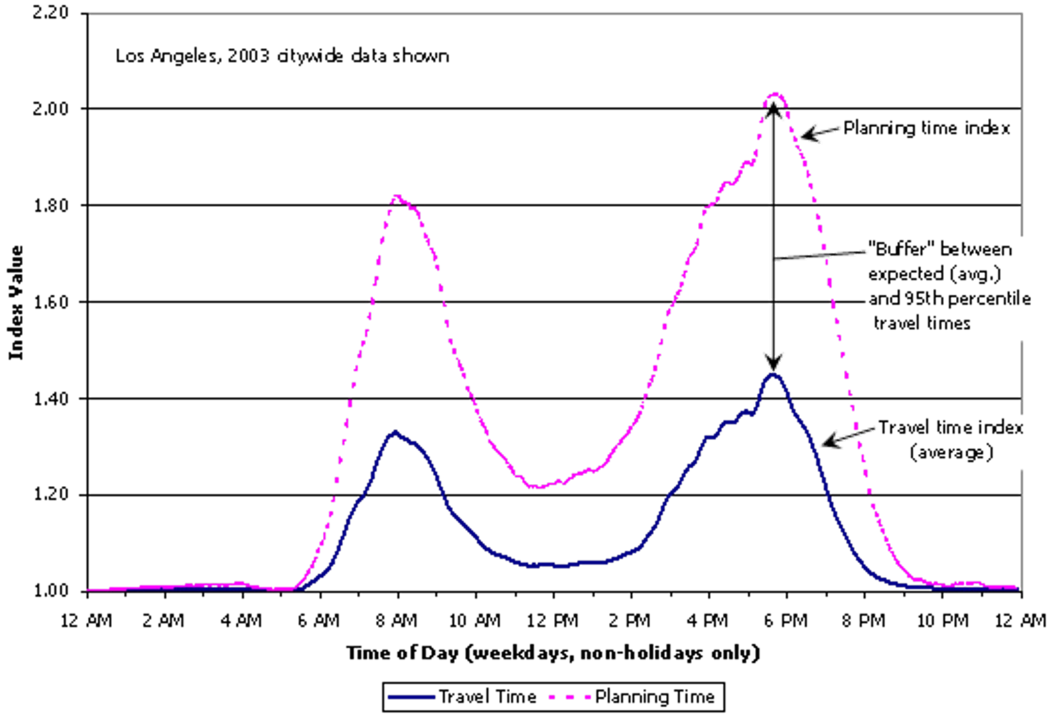
- Evolution of gasoline technology emissions in the future is not analyzed in this study
- For electric vehicles future emissions outlook, only varied the regional grid emission index values from EIA Outlook
- Future automobile emissions vs. traffic congestion levels trends are kept fixed at Year 2020

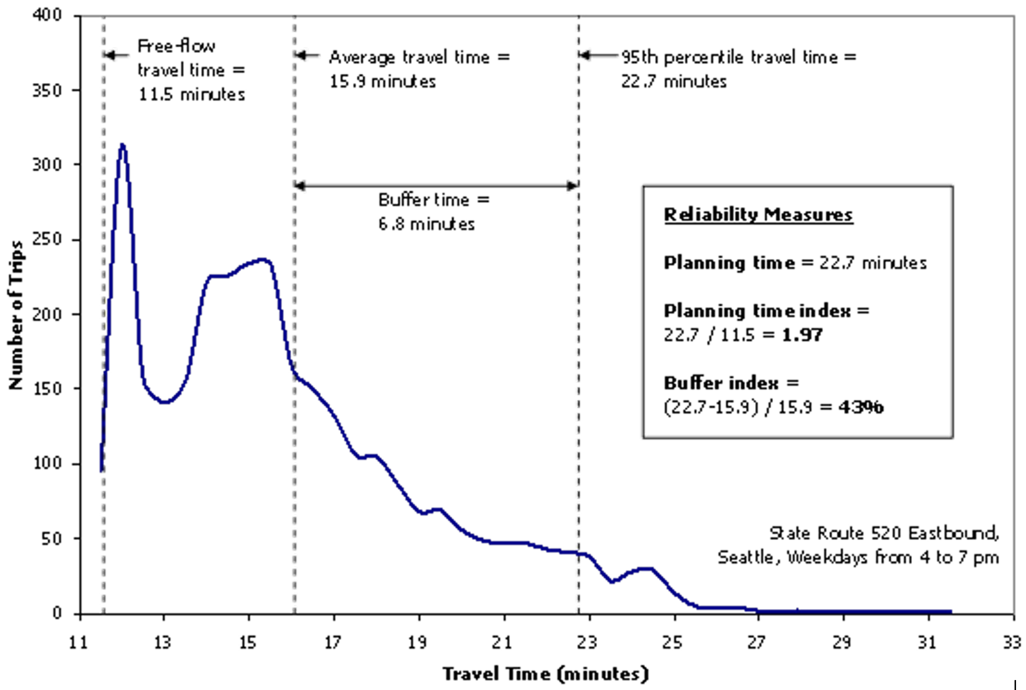
Emissions Module Overview



Intro to Travel Reliability Metrics

- **Travel Time Index: Ratio of the peak-period travel time to the free-flow travel time**
  - *Represents the average travel time during peak traffic condition*
- **Planning Time Index: Ratio of the 95th percentile travel time to the free flow time**
  - *Represents the total time that should be planned when an adequate buffer time is included*

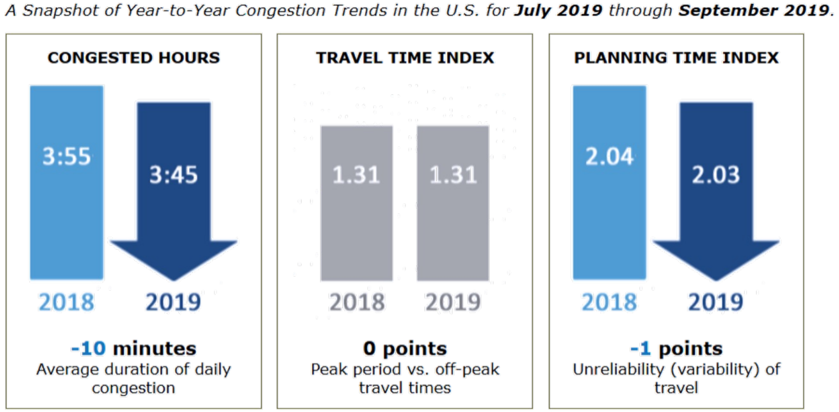


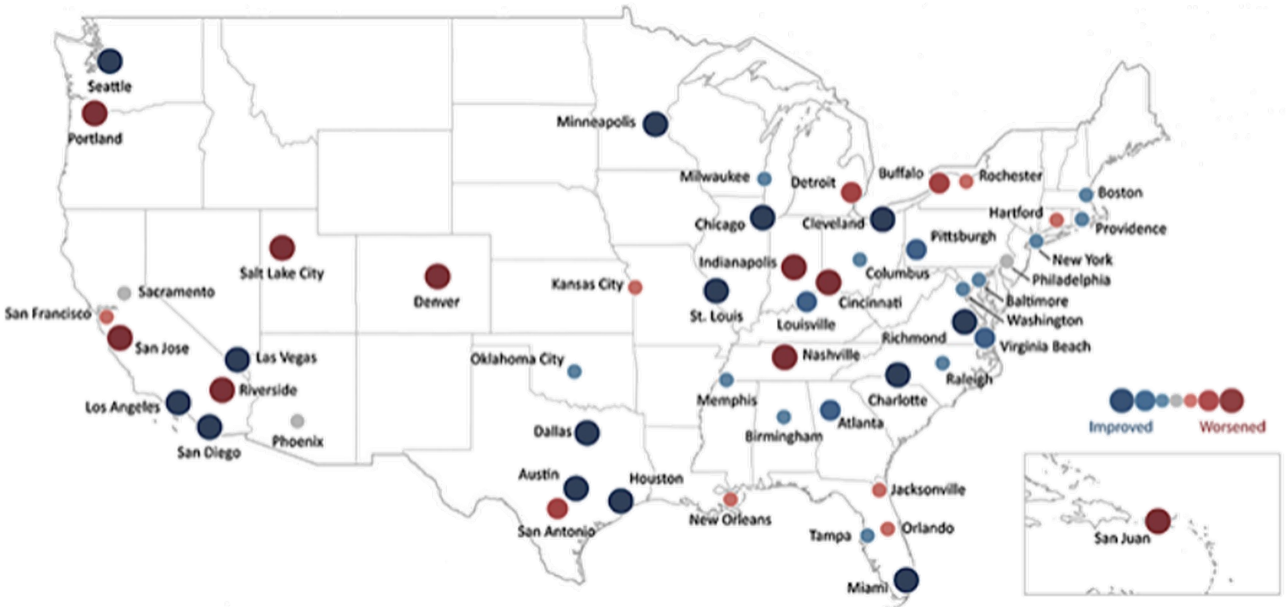


Source: https://ops.fhwa.dot.gov/perf_measurement/ucr/reports/fy2019_q4.htm

Quarterly Urban Congestion Reports

- Provides congestion information for major US metropolitan areas
- Information is unavailable at the time of day resolution





City (MSA)	Congested Hours		Travel Time Index		Planning Time Index		% Complete Data
	2019	Change from 2018	2019	Change from 2018	2019	Change from 2018	
Chicago, IL	5:12	-0:32	1.36	-3	2.14	-7	96%
Dallas-Fort Worth, TX	3:45	-0:28	1.27	-2	2.03	-6	91%
New York, NY	5:46	-0:17	1.33	+1	2.09	-5	92%

Source: US DOT Federal Highway Administration
https://ops.fhwa.dot.gov/perf_measurement/ucr/reports/fy2019_q4.htm