# A Top-Down Methodology for Global Urban Air Mobility Demand Estimation


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OASyS: **O**verall **A**ir Transport **Sy**stem Vehicle **S**cenarios

# Research Objective




Urban Air Mobility (UAM): An air transportation system transporting people directly above populated areas


The methodology must be capable of estimating demand at the city level across global markets

Develop a methodology capable of generating demand estimations for urban air mobility operations across global cities

# The Business Case of Urban Air Mobility



| RANK BY FILTER | WORLD RANK | CITY | COUNTRY | CONGESTION LEVEL | |
|---|---|---|---|---|---|
| 1 | 1 | **Bengaluru** | India | **71%** | |
| 2 | 2 | **Manila** | Philippines | **71%** | |
| 3 | 3 | **Bogota** | Colombia | **68%** | ↑ 5% |
| 4 | 4 | **Mumbai** | India | **65%** | 0% |
| 5 | 5 | **Pune** | India | **59%** | |
| 6 | 6 | **Moscow region (oblast)** | Russia | **59%** | ↑ 3% |
| 7 | 7 | **Lima** | Peru | **57%** | ↓ 1% |
| 8 | 8 | **New Delhi** | India | **56%** | ↓ 2% |
| 9 | 9 | **Istanbul** | Turkey | **55%** | ↑ 2% |
| 10 | 10 | **Jakarta** | Indonesia | **53%** | 0% |

Source: TomTom Traffic Index

- High and rising levels of roadway congestion is driving the need for a new, faster mode of transport
- In 2017, roadway congestion cost US commuters and companies an estimated $166B for extra time and wasted fuel

  Source: TAMU Mobility Report

- Congestion level indicates additional time spent per trip, respective to uncongested baseline

# Over 70 Manufacturers Worldwide are Developing Urban Air Mobility Concepts

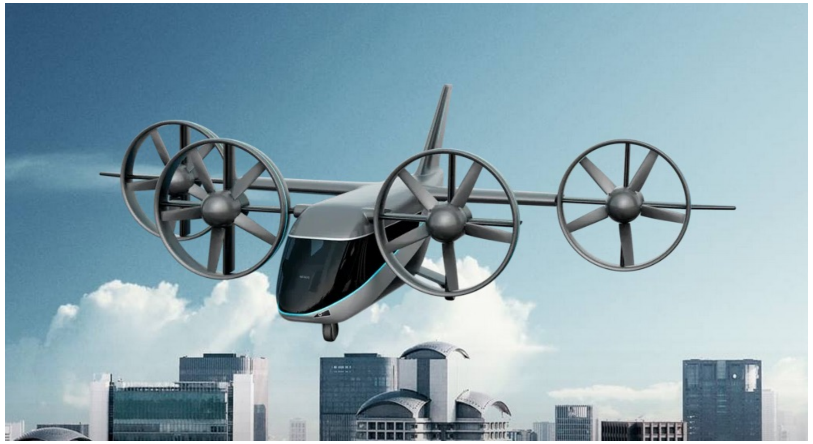


**Joby Aviation**


**Airbus A³ Vahana**


**Boeing PAV**


**Volocopter VoloCity**

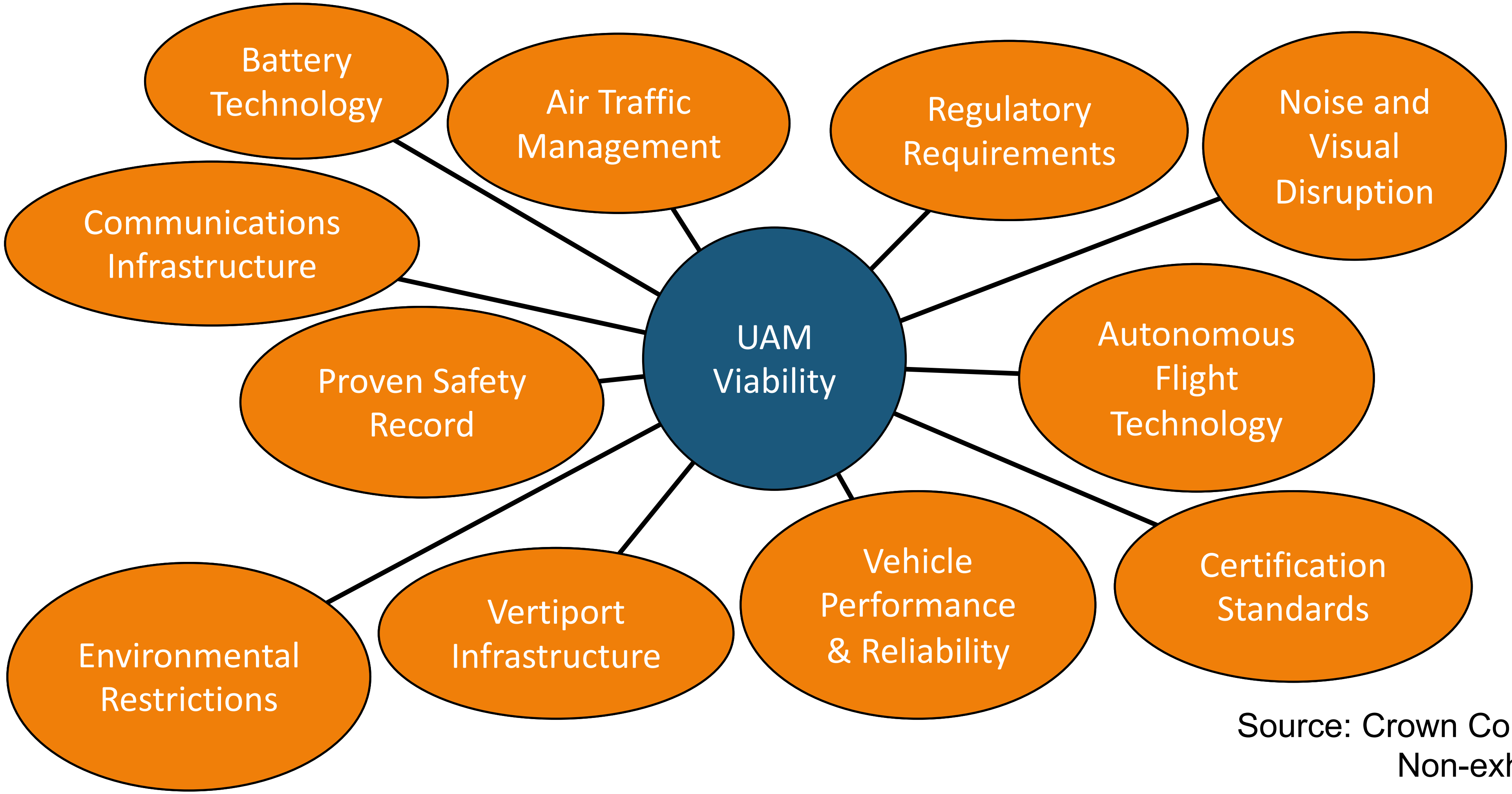


**Bell Nexus**

**Lilium**

# Many Barriers Towards UAM Viability Exist






Source: Crown Consulting Inc
Non-exhaustive list

*Need to understand and estimate the scale of UAM operations to make progress towards each of these barriers*

# Current Demand Estimates



## Market studies by consulting companies:

| Company | Scope | Timeframe | Passenger Trips | Aircraft | Flight Hours |
|---|---|---|---|---|---|
| **Roland Berger** | Global | 2035 | *383 M** | 28 k | *38 M†* |
| **Horvath & Partners** | 125 global cities | 2035 | *150 M†* | *11 k** | 15 M |
| **KPMG** | 31 global cities | 2030 | 12 M | *876** | *1 M†* |
| **Porsche Consulting** | Global | 2035 | *205 M** | 15 k | *21 M†* |

**Assuming an aircraft makes 15 trips per day, with 2.5 passengers per trip, on average*
*†Assuming 15 flight minutes per trip, on average*

## NASA-sponsored market reports:

| Company | Scope | Timeframe | Passenger Trips | Aircraft |
|---|---|---|---|---|
| **Crown Consulting Inc.** | 15 US cities | 2030 | 740 M | 23 k |
| **Booz Allen Hamilton** | All 484 US cities | Near-term | 30 M | 4.1 k |

**Limited available literature regarding global UAM demand estimation methodologies**

# Top Down Methodology



- UAM will likely serve intracity and intercity regions, competing with traditional ground transport modes
- Thus, UAM passenger kilometers traveled (PKM) may be estimated as a portion of the total PKM across all modes of ground transport
- Traffic forecasting typically conducted using four-step transportation model
  - Infeasible to implement due to data availability, effort required, and computational expense

Generic Top-Down Approach:

**Total Addressable Market** → **Market Share** → **Revenue**

Applied for UAM Demand Estimation:

**Total Ground PKM** → **UAM Modal Split** → **UAM Demand**

*An approach considering the inherent benefits of UAM without the need for traveler behavior data is desired*

# Estimating the value of travel time savings is a possible solution



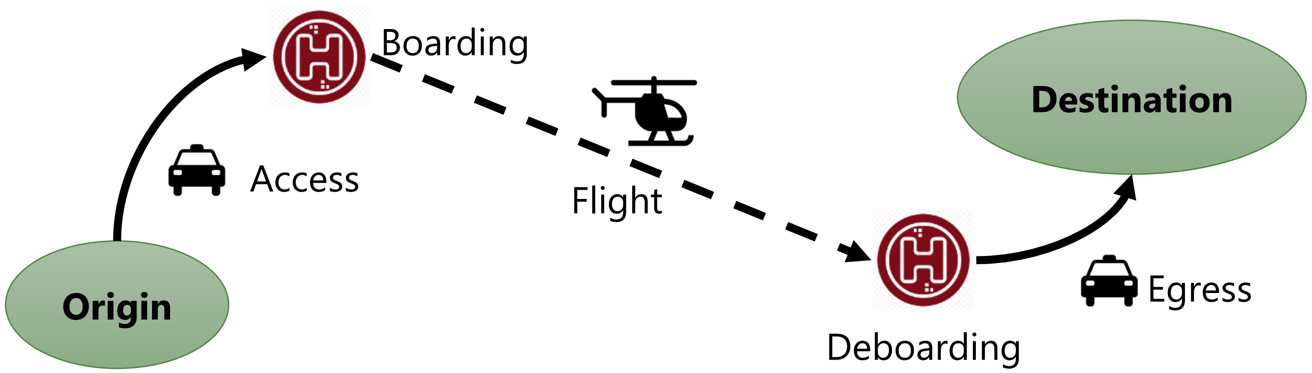
- A binary choice model considering value of travel time savings (VTTS) offers a solution [1]

$$Cost_{UAM} \leq WTP = Cost_m + VTTS * (Time_m - Time_{UAM})$$

  - $Cost_{UAM}$ is the cost of a specific trip using UAM
  - $Cost_m$ is the cost of a specific trip using an alternate mode $m$
  - $VTTS$ is the dollar value an individual places per unit time saved
  - $Time_m$ is the trip time of a specific trip using alternate mode $m$
  - $Time_{UAM}$ is the trip time of a specific trip using UAM
- Has been implemented in past UAM studies for local areas [1, 2]
- Can be expanded to consider global cities without high data requirements

[1] N. Sirirojvisuth, S. Briceno, and C. Justin, "Life-Cycle Economic Analysis and Optimization for Urban Air Mobility (UAM)" (2020)
[2] Booz Allen Hamilton, "UAM Market Study - Technical Out Breif" (2018)

# Concept of Operations (CONOPS)




- Vertiport density, D, fixed:

$$D = vertiport/area$$

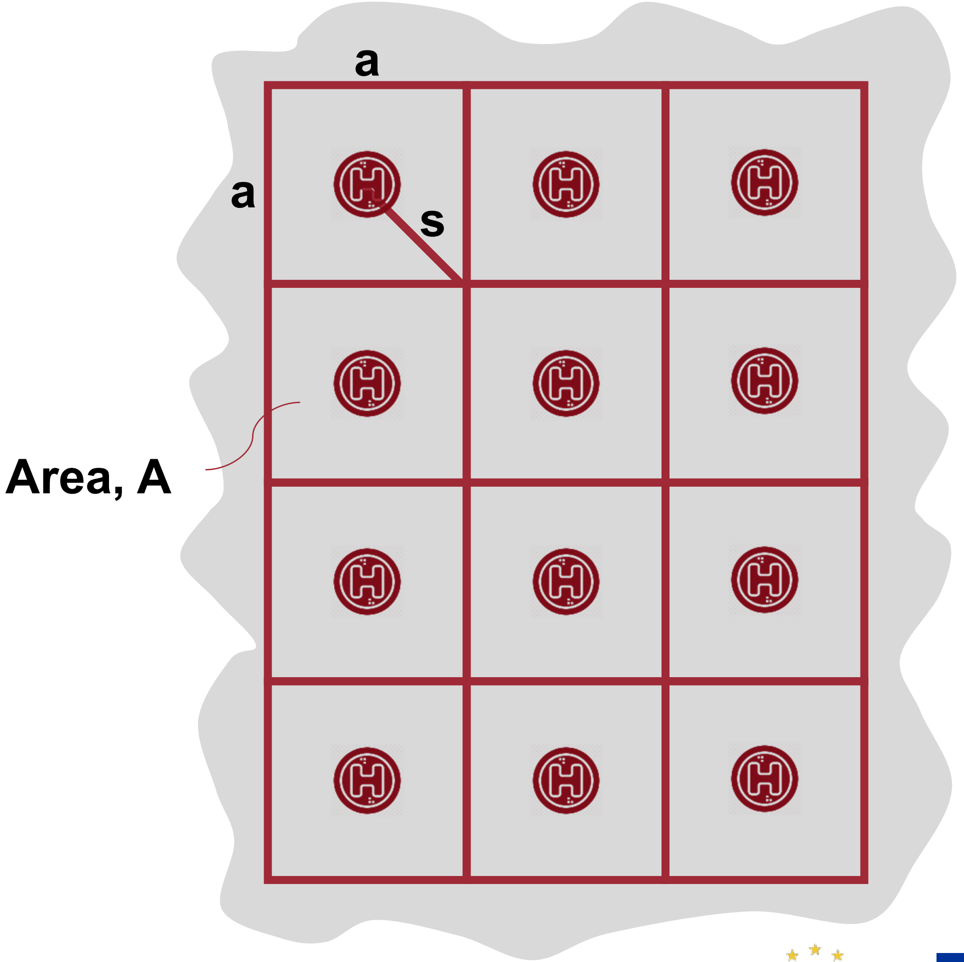
- Average distance to vertiport:

$$d_v = s * 2/3$$

- UAM trip distance (conservative):

$$d_{UAM} = 2 * d_v + d_t,$$
$$d_t = nominal\ trip\ distance$$

Vertiport Density



# Estimating Market Share – UAM Trip Cost



$$\boldsymbol{Cost_{UAM}} \leq WTP = Cost_m + VTTS * (Time_m - Time_{UAM})$$

- UAM is a multi-modal trip option; cost of UAM trip is the sum of costs of all trip segments

$$Cost_{UAM} = Cost_{access}(d_v) + Cost_{flight}(d_t) + Cost_{egress}(d_v)$$

- $Cost_{access}$, $Cost_{egress}$:
  - CONOPS assumes access and egress is completed using a rideshare option across equivalent distances, $d_v$
- $Cost_{flight}$:
  - leverage existing studies to estimate UAM ticket costs, or evaluate a range and identify sensitivity
    - BAH Estimates ~$3.88/km for a 5-seat eVTOL, near term
    - Other studies suggest $0.55/km to $1.65/km by 2030 [1] and ~$0.43/km in the long term [2]

[1] M. Kreimeier, P. Strathoff, D. Gottschalk, and E. Stumpf, “Economic Assessment of Air Mobility On-Demand Concepts” (2018)
[2] Uber Elevate “Fast-Forwarding to a Future of On-Demand Urban Air Transportation” (2016)



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# Estimating Market Share – Alternate Mode Trip Cost



$$Cost_{UAM} \leq WTP = \boldsymbol{Cost_m} + VTTS * (Time_m - Time_{UAM})$$

- Estimating the cost for alternate modes of transport is much simpler
  - Organizations across many areas publish average cost per distance for owning personal vehicles ($0.37/km in the US, according to AAA)
  - Public transit ticket costs can also be identified on the city level


**Personal Vehicle**

PHX Public Transit

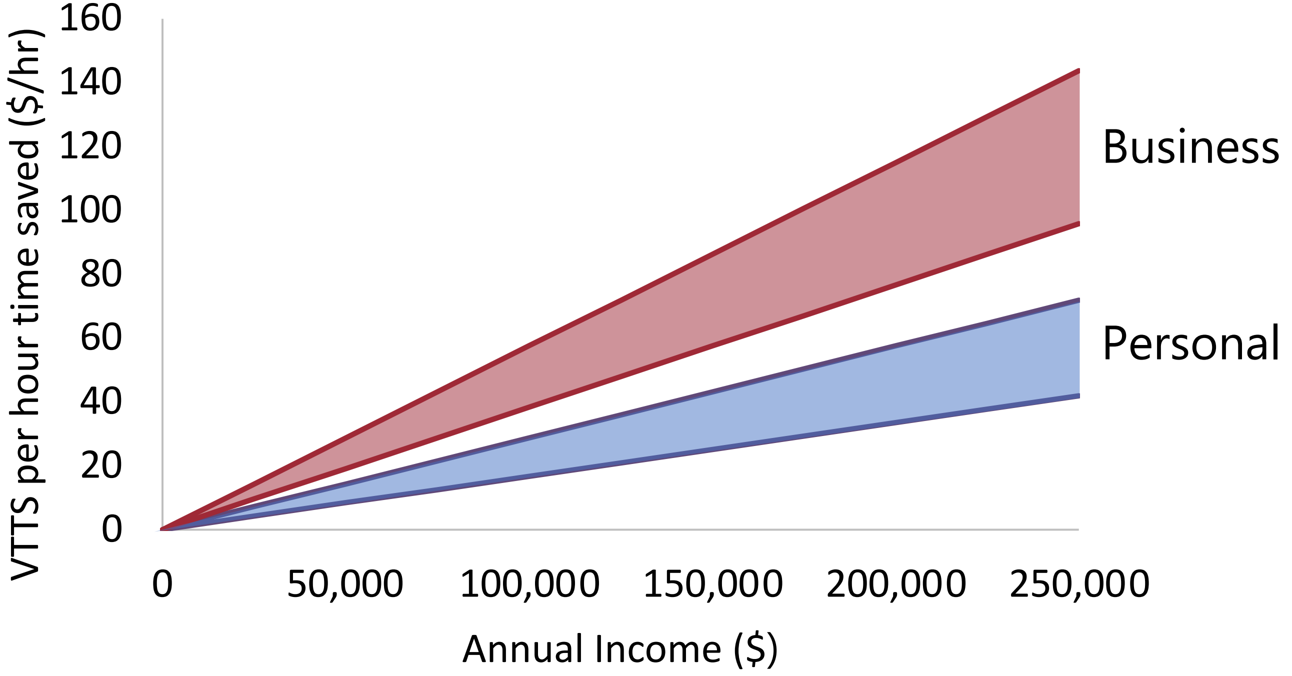

**Public Transit**

# Estimating Market Share - VTTS



$$Cost_{UAM} \leq WTP = Cost_m + \boldsymbol{VTTS} * (Time_m - Time_{UAM})$$

- VTTS is typically a function of income and trip purpose [1]
  - 35% to 60% of hourly rate earnings for personal trips
  - 80% to 120% of hourly rate earnings for business trips




Can be further disaggregated:
- Work
- Education
- Shopping/Leisure
- Vacation
- Other

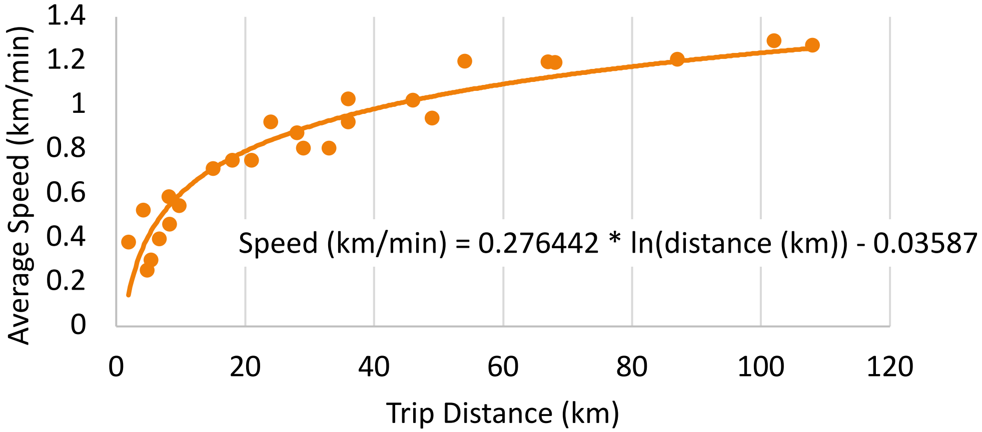
[1] "Revised Departmental Guidance on Valuation of Travel," U.S. Department of Transportation, Washington, DC, 2011.

# Estimating Market Share – Alternate Mode Trip Time

$$Cost_{UAM} \leq WTP = Cost_m + VTTS * (\boldsymbol{Time_m} - Time_{UAM})$$

- Door-to-door travel time for personal vehicles and public transit is heavily route and time of day dependent
- Performing an origin-destination (OD) level evaluation is too computationally expensive; average speeds across all routes and times will be sufficient
  - For higher fidelity, build a regression across average speeds by trip distance

Logarithmic fit to randomly sampled routes in Paris using passenger vehicle



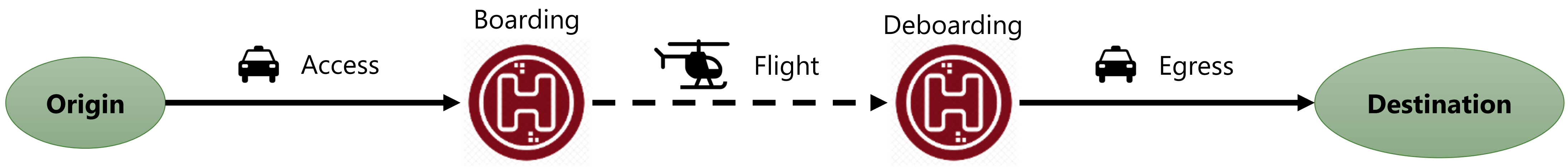
# Estimating Market Share – UAM Trip Time



$$Cost_{UAM} \leq WTP = Cost_m + VTTS * (Time_m - \boldsymbol{Time_{UAM}})$$

- UAM is a multi-modal trip option; UAM trip time can be broken down as:

$$Time_{UAM} = t_{access} + t_{boarding} + t_{flight} + t_{deboarding} + t_{egress}$$




**Rideshare Trip Time (avg vertiport distance)**

**Constant cruise speed**

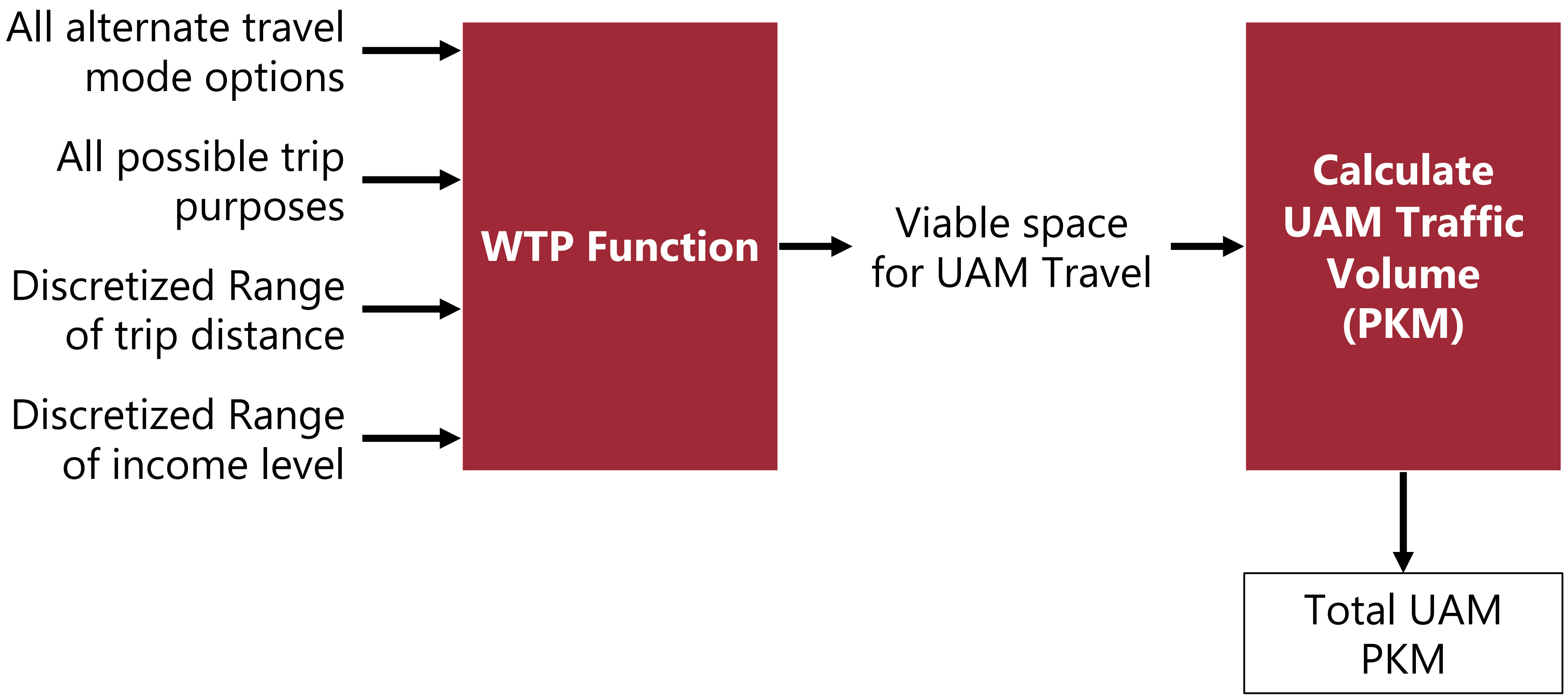
**Rideshare Trip Time (avg vertiport distance)**

**Walking, ticket purchase, wait time, boarding, safety check**

**Deboarding, exiting**

# Final Demand Estimation





# Estimating PKM Across Viable UAM Trips

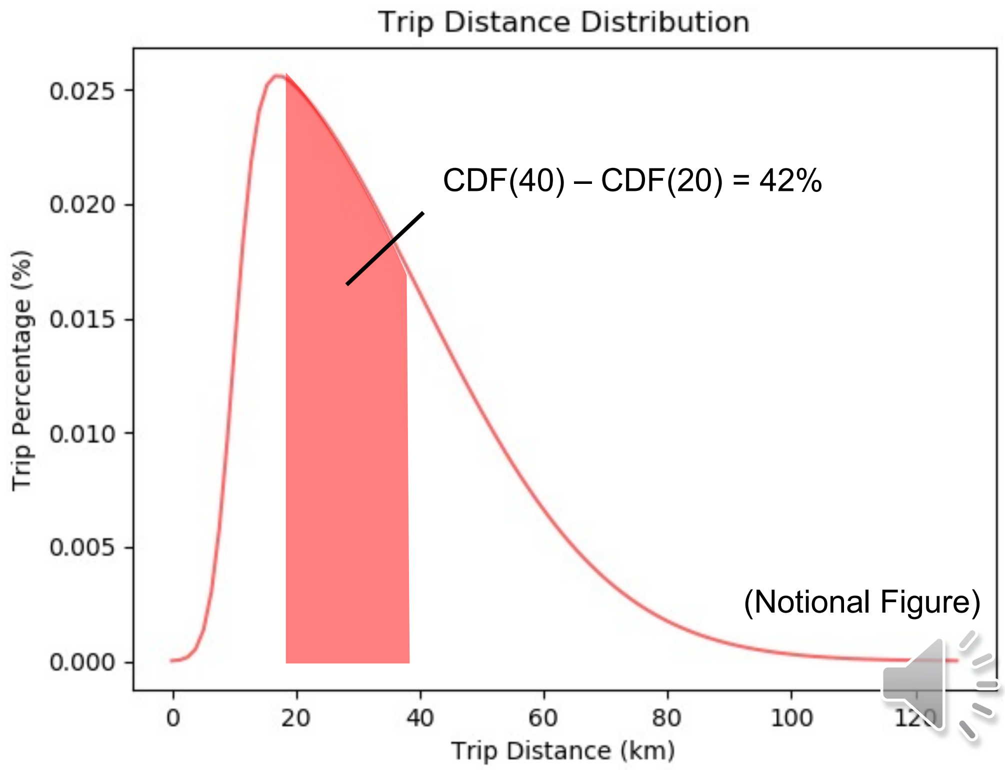


- Assume mode share, trip purpose, trip distance distribution, and traveler income distributions are all independent of each other
  - i.e.: a traveler earning $50k is just as likely to take a 10 km trip as a traveler earning $200k
- Calculate UAM PKM as:

$$PKM_{UAM} = PKM_{tot} * s_m * s_p * \left(CDF_{TD}(d_2) - CDF_{TD}(d_1)\right) * \left(CDF_{inc}(i_2) - CDF_{inc}(i_1)\right)$$

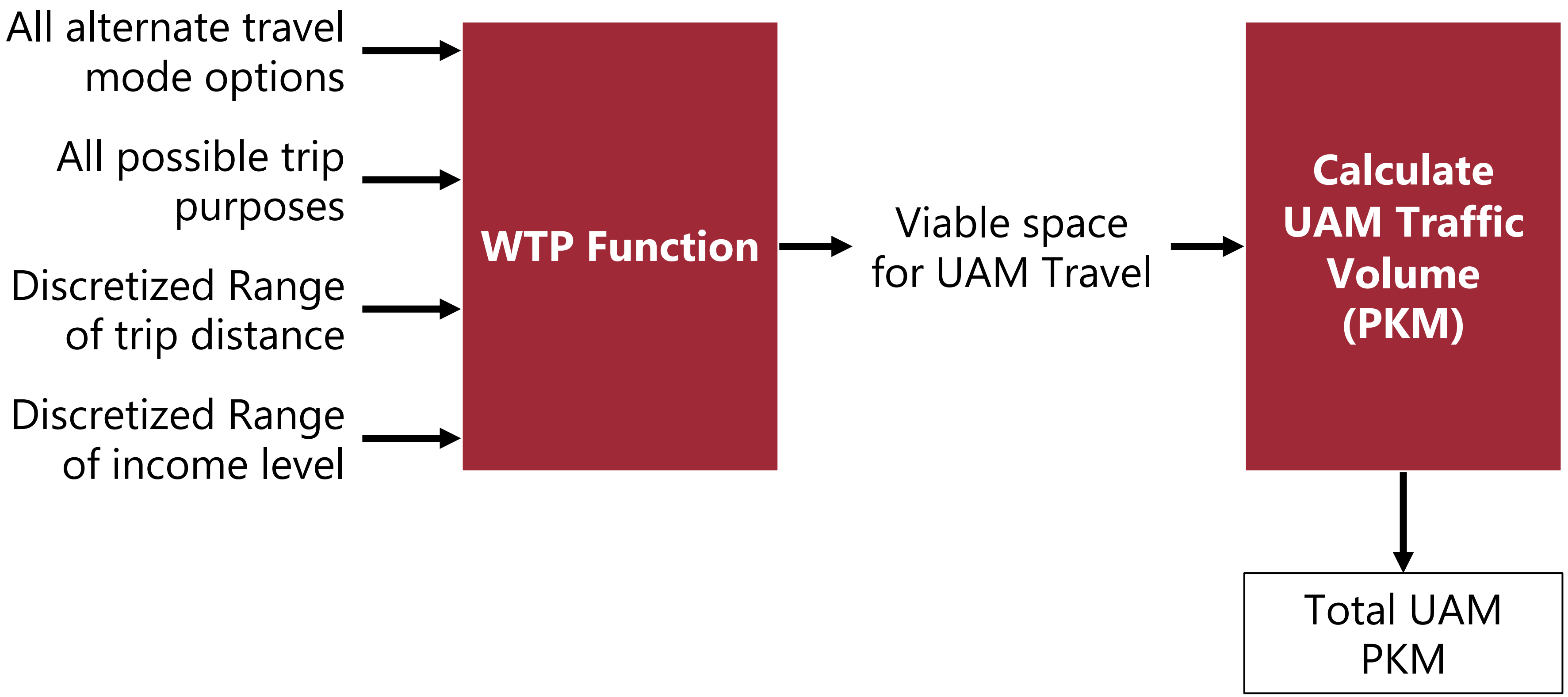
- Example – WTP analysis found that a viable space of UAM travel occurs on trips of:
  - *Mode: personal vehicle – 75% of all trips*
  - *Purpose: business – 17% of all trips*
  - *Trip Distance: 20 to 40 km – 42% of all traffic*
  - *Annual Income: $140k to $150k – 2% of all travelers*
- For a city with 100 billion annual PKM, we identify:

$$100\ billion\ PKM * 0.75 * 0.17 * 0.42 * 0.02 = 107\ million\ PKM$$



# Final Demand Estimation





# Scope of Cities for Implementation



- KPMG suggests UAM will likely target high-density business travel routes used by a relatively price-insensitive customer base, and has identified 31 cities to see initial operations [1]
- This implementation will consider the same set of cities, during year 2035

| | | |
|---|---|---|
| Tokyo | Shanghai | New York |
| Beijing | Seoul | Los Angeles |
| Osaka | Guangzhou | Tianjin |
| Mexico City | Shenzhen | Sao Paulo |
| London | Paris | Chicago |
| Bangkok | Jakarta | Wuhan |
| Kuala | Dallas | Hong Kong |
| Toronto | Madrid | Houston |
| San | Melbourne | Sydney |
| Washington DC | Phoenix | Taipei |
| Dubai | | |

[1] “Getting Mobility Off the Ground,” Tech. rep., KPMG LLP, 2019

# Results



**UAM Share of Total PKM**

| UAM Ticket Cost ($/km) | Vertiport Density (area, $km^2$, per vertiport) 150 | 300 | 450 |
|---|---|---|---|
| $ 0.30 | 8.51% | 4.74% | 3.21% |
| $ 0.60 | 2.62% | 1.54% | 1.06% |
| $ 0.90 | 1.27% | 0.75% | 0.53% |
| $ 1.20 | 0.72% | 0.42% | 0.30% |
| $ 1.50 | 0.43% | 0.25% | 0.18% |
| $ 1.80 | 0.28% | 0.16% | 0.12% |

**Annual UAM Pax Trips (Million)**

| UAM Ticket Cost ($/km) | Vertiport Density (area, $km^2$, per vertiport) 150 | 300 | 450 |
|---|---|---|---|
| $ 0.30 | 6,355 | 2,645 | 1,607 |
| $ 0.60 | 2,313 | 1,065 | 635 |
| $ 0.90 | 1,207 | 541 | 327 |
| $ 1.20 | 708 | 306 | 185 |
| $ 1.50 | 437 | 182 | 112 |
| $ 1.80 | 287 | 119 | 71 |

**Annual UAM Utilization (Million hrs)**

| UAM Ticket Cost ($/km) | Vertiport Density (area, $km^2$, per vertiport) 150 | 300 | 450 |
|---|---|---|---|
| $ 0.30 | 1,505 | 839 | 567 |
| $ 0.60 | 464 | 272 | 188 |
| $ 0.90 | 225 | 133 | 94 |
| $ 1.20 | 128 | 75 | 53 |
| $ 1.50 | 77 | 45 | 32 |
| $ 1.80 | 49 | 29 | 21 |

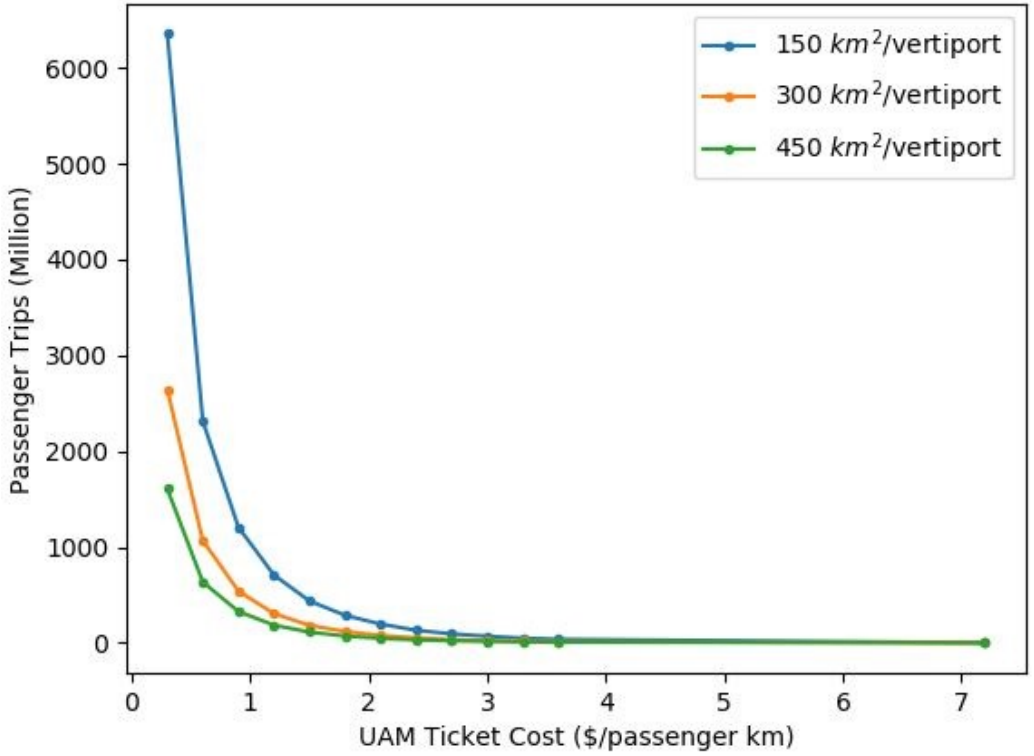
- For reference:
  - UAM Cost: $0.93/km (2030), CCI; $1.30/km (initial) and $0.43/km (near-term), Uber
  - 300 $km^2$/vertiport equates to ~21 vertiports in Los Angeles
  - Range of estimates by consulting companies:
    - Pax Trips: 12 M – 740 M
    - Flight hours: 1 M – 123 M

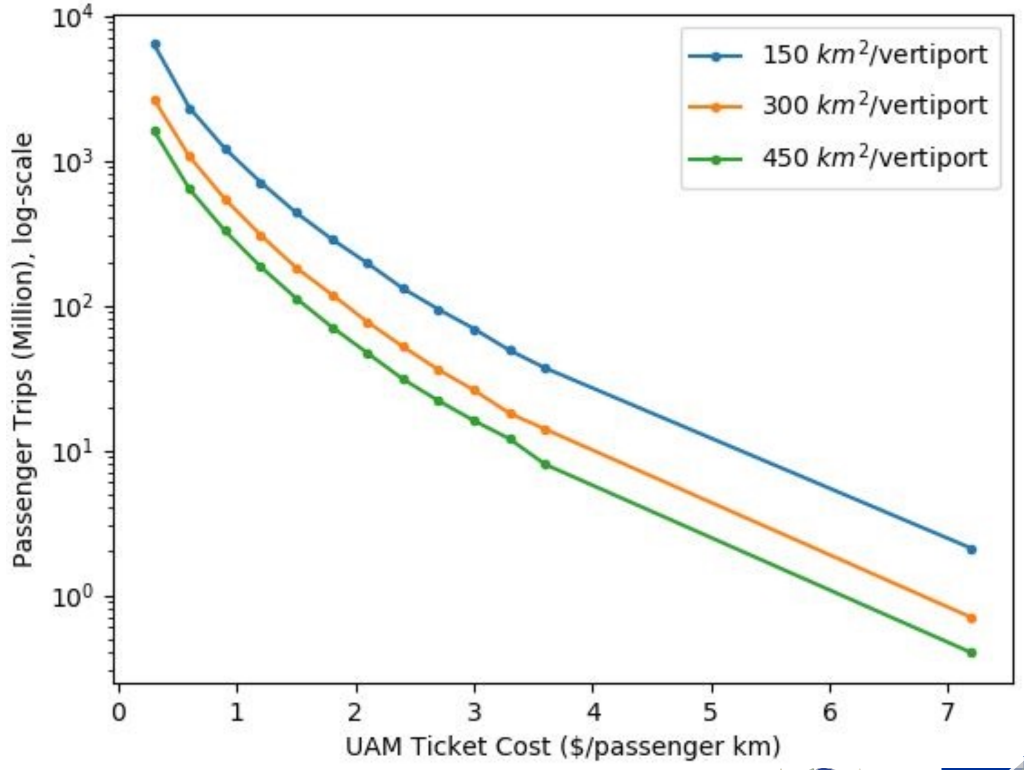
*Strong market demand exists for a range of UAM ticket costs and vertiport densities*

# Results



- Passenger trips increase exponentially with decreasing UAM ticket costs
- Faster than exponential increase at $0.30/km
  - Assumed cost for passenger vehicle is $0.37/km



# Conclusion



- Strong market demand exists for a range of UAM ticket costs and vertiport densities, ranging from 70 million annual pax trips globally up to 6.3 billion pax trips
- Demand expands exponentially with decreases in ticket cost and area/vertiport
- Manufacturers may leverage these results to identify and plan for an optimal production rate
- City planners must focus on developing vertiport infrastructure quickly and efficiently
- By 2035, air traffic management systems should have the capability to handle mature operations
- Regulators must move quickly to outline vehicle certifications and flying regulations

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# Thank you!

# Questions?

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