

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

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OASyS: Overall Air Transport System Vehicle Scenarios



Research Objective

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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











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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%	>

- 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

Source: TomTom Traffic Index

Over 70 Manufacturers Worldwide are Developing Urban Air Mobility Concepts

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Joby Aviation



Airbus A³ Vahana



Boeing PAV



Volocopter VoloCity



Bell Nexus



Lilium

Many Barriers Towards UAM Viability Exist

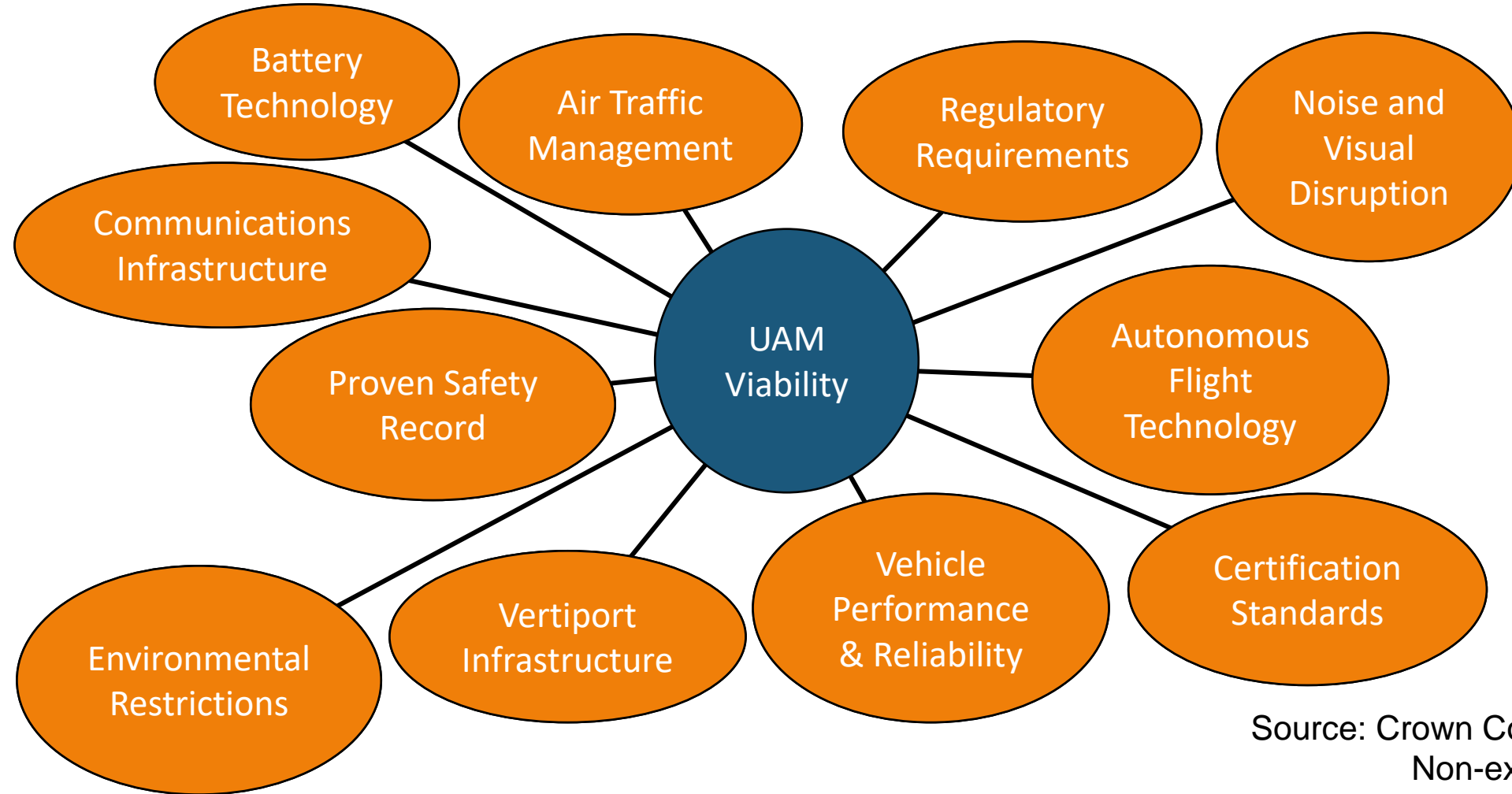
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Source: Crown Consulting Inc
Non-exhaustive list

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



Current Demand Estimates

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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

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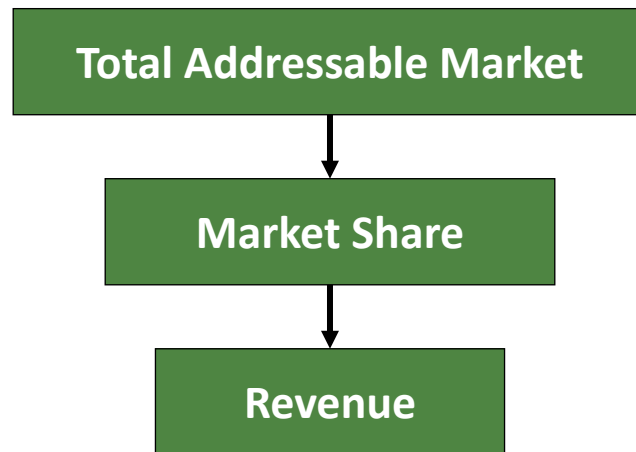
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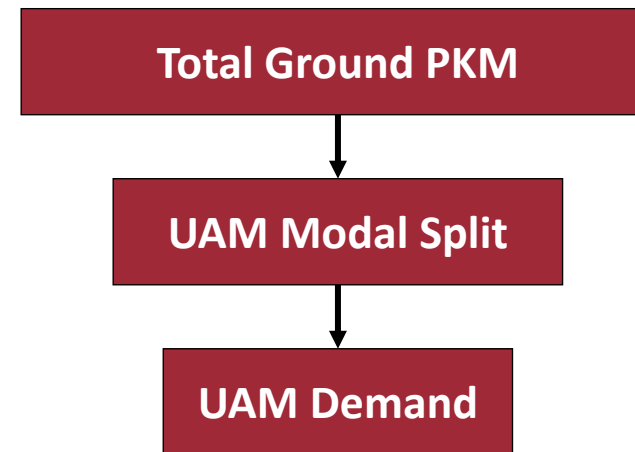
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- UAM will likely serve intracity and intercity regions, competing with traditional ground transport modes
- Thus, UAM passenger kilometers traveled (PKM) may be estimated as a portion of the total PKM across all modes of ground transport
- Traffic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

Generic Top-Down Approach:



Applied for UAM Demand Estimation:



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

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- 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 Brief" (2018)

Concept of Operations (CONOPS)

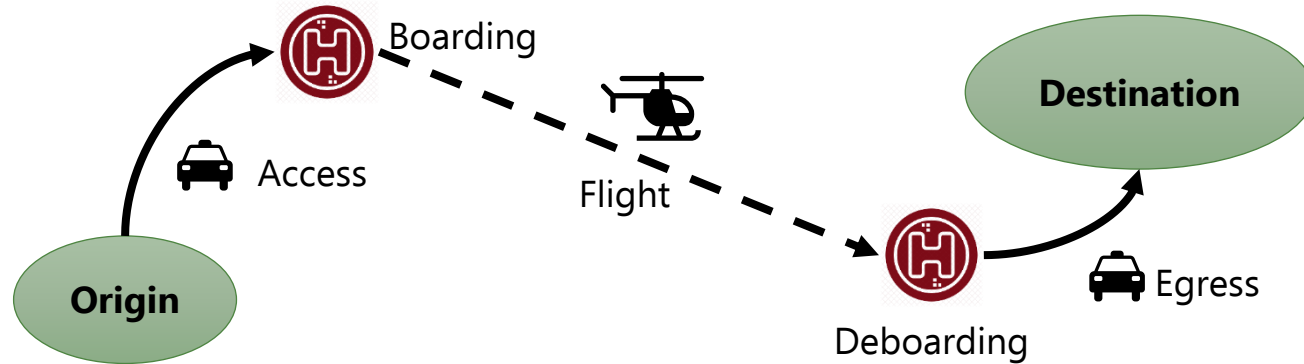
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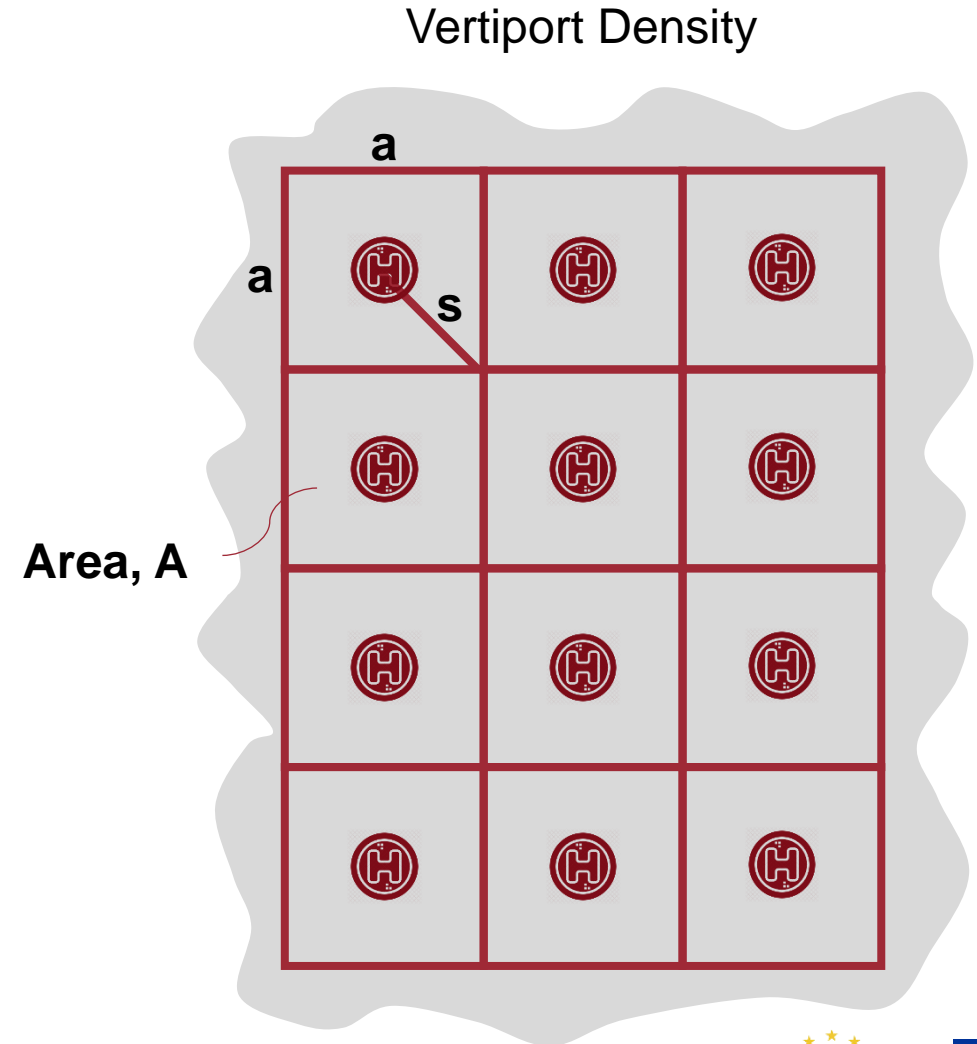
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- Vertiport density, D , fixed:
$$D = \text{vertiport} / \text{area}$$
- Average distance to vertiport:
$$d_v = s * 2/3$$
- UAM trip distance (conservative):
$$d_{UAM} = 2 * d_v + d_t,$$

$$d_t = \text{nominal trip distance}$$



Estimating Market Share – UAM Trip Cost

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$$\text{Cost}_{UAM} \leq WTP = \text{Cost}_m + VTS * (\text{Time}_m - \text{Time}_{UAM})$$

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

$$\text{Cost}_{UAM} = \text{Cost}_{access}(d_v) + \text{Cost}_{flight}(d_t) + \text{Cost}_{egress}(d_v)$$

- 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)

Estimating Market Share – Alternate Mode Trip Cost

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

- 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

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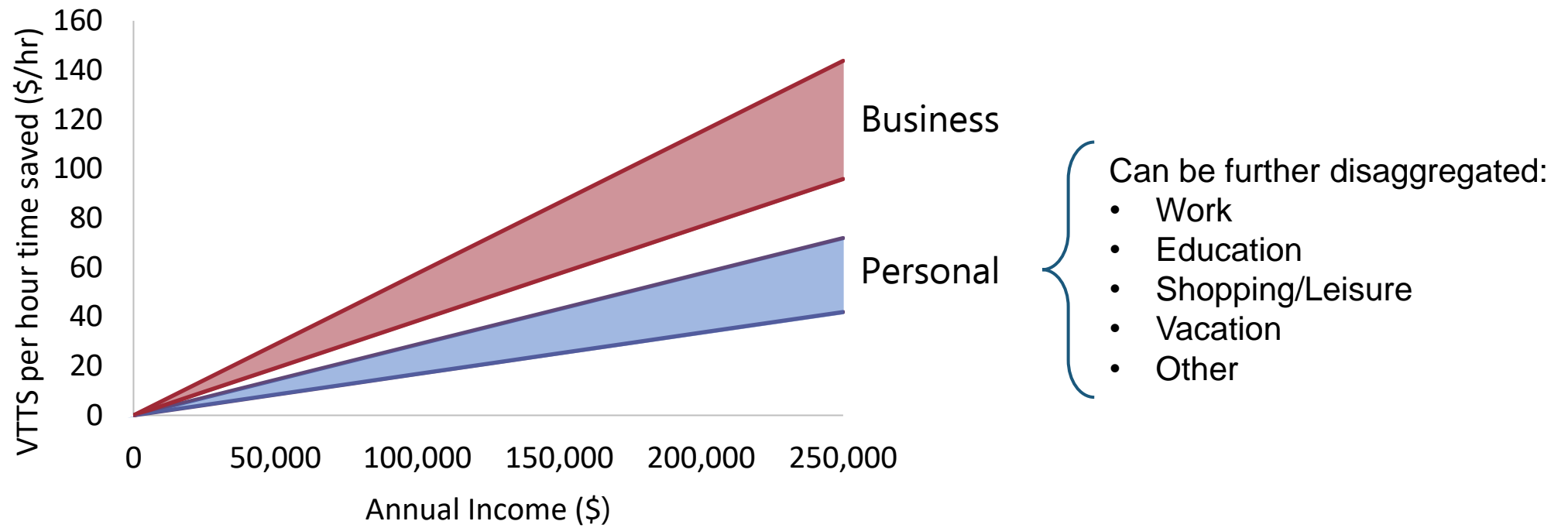
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$$Cost_{UAM} \leq WTP = Cost_m + VTTS * (Time_m - Time_{UAM})$$

- 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



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

Estimating Market Share – Alternate Mode Trip Time

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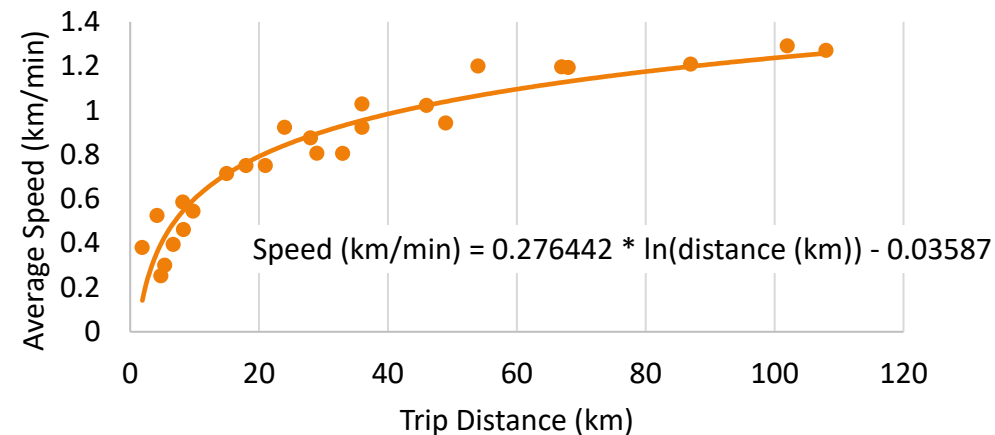
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$$Cost_{UAM} \leq WTP = Cost_m + VTTS * (Time_m - Time_{UAM})$$

- 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



Final Demand Estimation

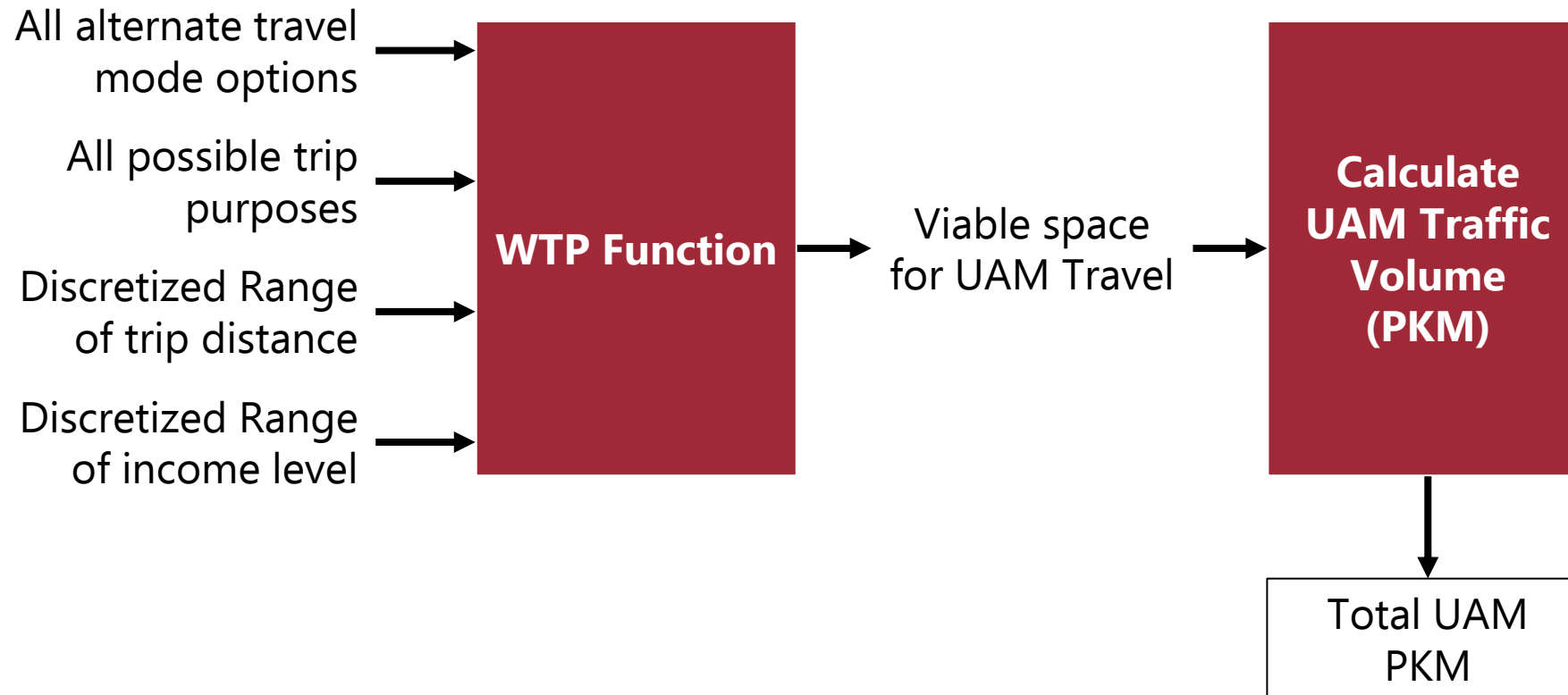
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Estimating PKM Across Viable UAM Trips

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- 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:

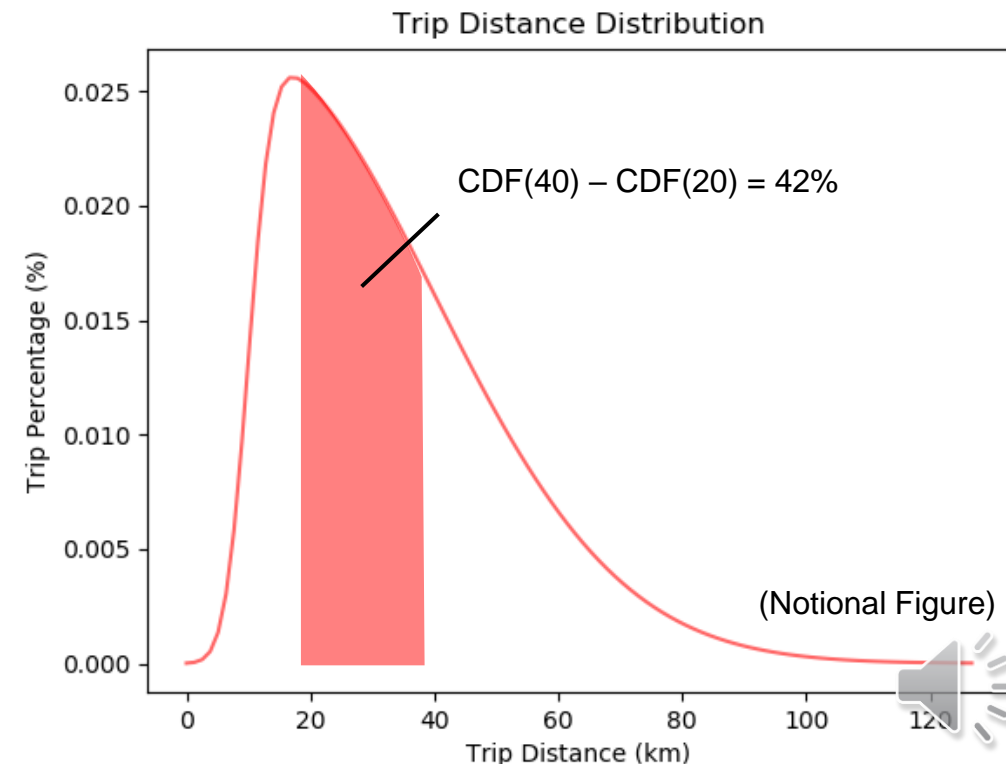
$$PKM_{UAM} = PKM_{tot} * s_m * s_p * (CDF_{TD}(d_2) - CDF_{TD}(d_1)) * (CDF_{inc}(i_2) - CDF_{inc}(i_1))$$

- 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:

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



Final Demand Estimation

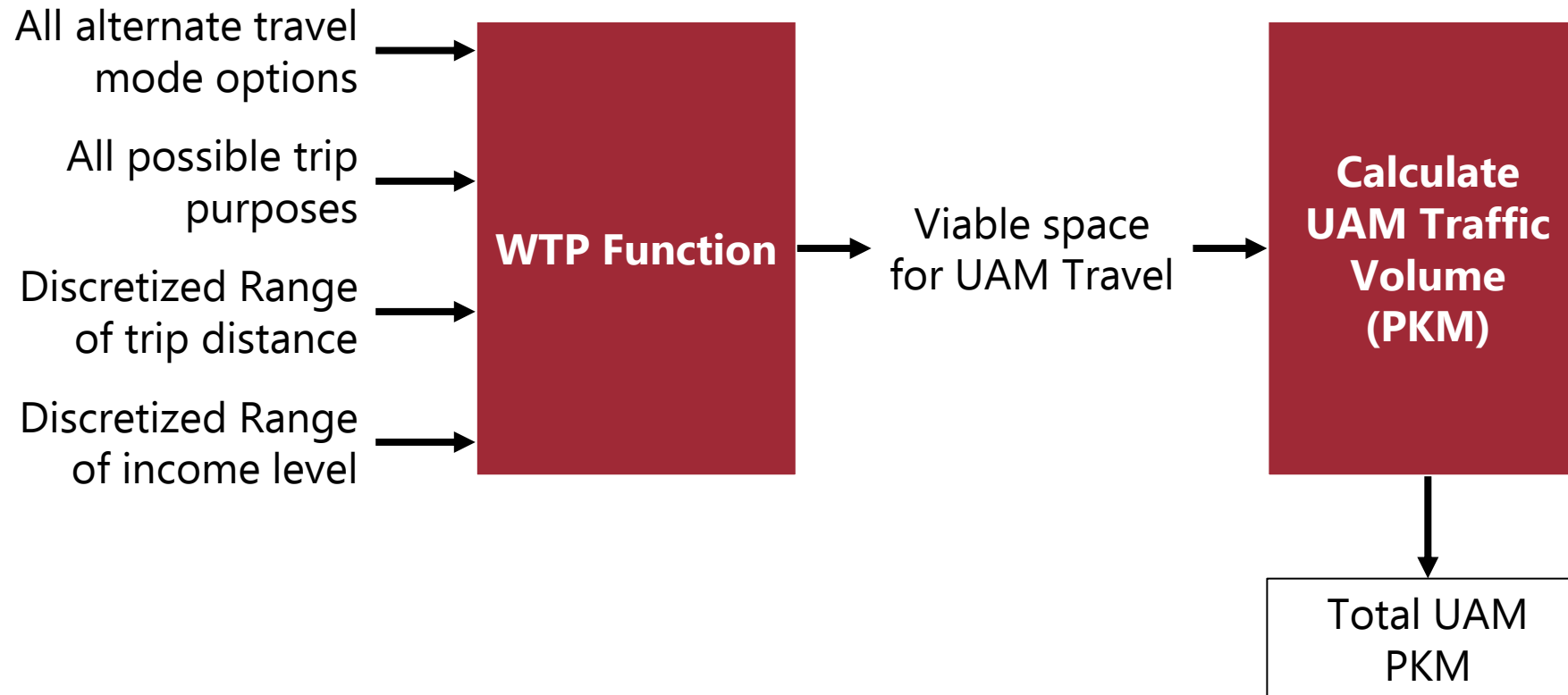
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Scope of Cities for Implementation

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- 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

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UAM Share of Total PKM				
		Vertiport Density (area, km ² , per vertiport)		
		150	300	450
UAM Ticket Cost (\$/km)	\$ 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)				
		Vertiport Density (area, km ² , per vertiport)		
		150	300	450
UAM Ticket Cost (\$/km)	\$ 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

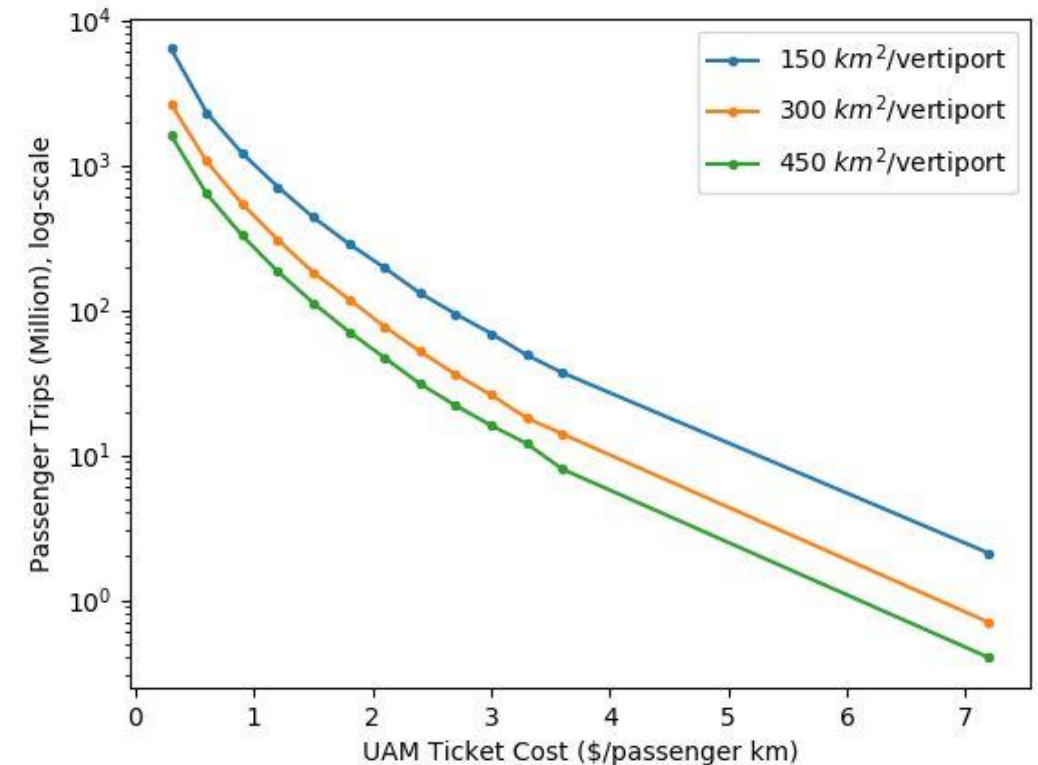
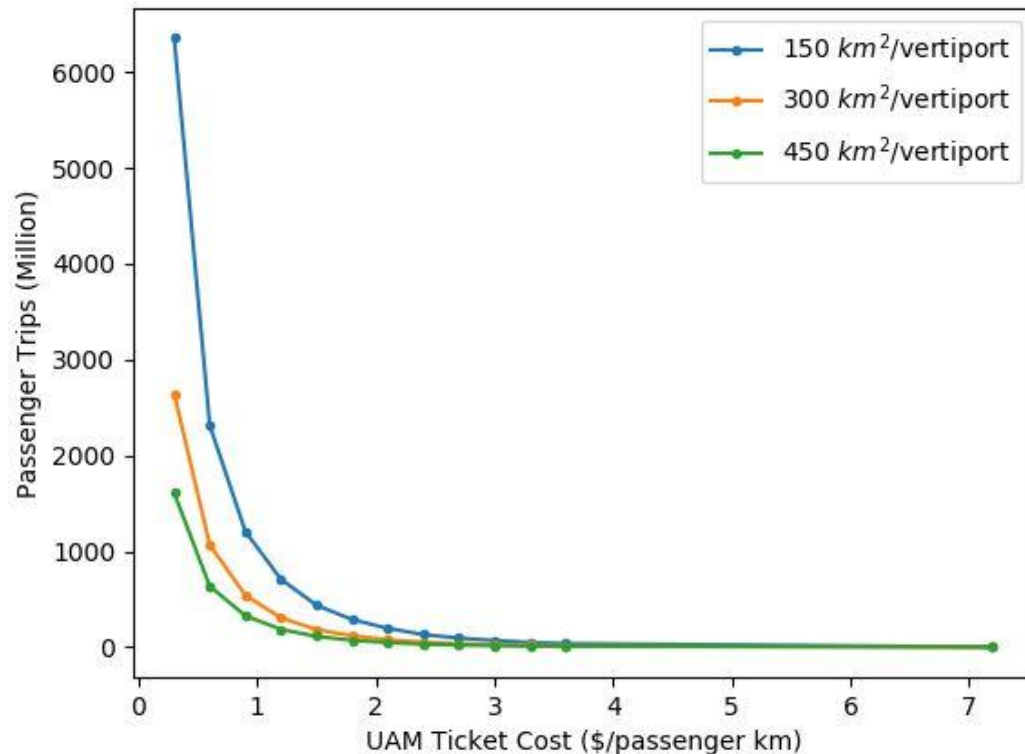
Annual UAM Utilization (Million hrs)				
		Vertiport Density (area, km ² , per vertiport)		
		150	300	450
UAM Ticket Cost (\$/km)	\$ 0.30	1,505	839	567
	\$ 0.60	464	272	188
	\$ 0.90	225	133	94
	\$ 1.20	128	75	53
	\$ 1.50	77	45	32
	\$ 1.80	49	29	21

- For reference:
 - UAM Cost: \$0.93/km (2030), CCI; \$1.30/km (initial) and \$0.43/km (near-term), Uber
 - 300 km²/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



- 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



- 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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