NASA Urban Air Mobility

November 2018

URBAN AIR MOBILITY (UAM) MARKET STUDY

CCI Crown Consulting, Inc.
Ascension Global
Georgia Tech Aerospace Systems Design Lab
McKinsey&Company

Disclaimer to the Technical Briefing

- This report incorporates a **consistent set of assumptions of a "living" UAM model**
  - Last-mile delivery, air metro, and air taxi models are all **comprised of over 50 variables each**, all of which can be modified to test certain assumptions or as market conditions change
- **All numbers reported here should be considered in conjunction** with the use case-specific econometric models (also maintained by NASA)

This report assesses UAM viability and potential barriers and solutions

Report Inputs
(Deliverable 1)

- **Interviews with >100 experts** across the Unmanned Aircraft Systems (UAS), eVTOL, regulatory, and relevant technology fields
- **Detailed assumptions and inputs** for >50 variables (such as wind shear and battery storage efficiency) for each use case model
- **Aggregated insights** from large consumer and business-to-business surveys with >2,000 respondents across 5 representative metropolitan areas

Living Econometric Model / User Interface (UI)
(Deliverable 2)

- **Detailed econometric model**
  - Living model that the Aeronautics Research Mission Directorate (ARMD) can update as variables change in the future
  - Complete documentation that the ARMD team can update to align with model changes
- **Executive user interface**
  - Tool that ARMD can use to explore the 10 most significant variables in each use case

UAM Market Study
(Deliverable 3 - Focus of this document)

- **Holistic assessment** of use case profitability by 2030
- **Review of technology, regulatory, and infrastructure** changes likely needed to achieve UAM operations
- **Overview of potential public acceptance landscape** and possible solutions and barriers to widespread UAM adoption

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

Five principles guided the development of this report

1 **Flexible:** Since UAM is quickly evolving, ARMD will likely require a *rigorous and dynamic model* that can evolve as technology changes, not a static report that will quickly become obsolete

2 **Challenging:** The assessment should evaluate the most challenging use cases to *push the boundaries of technology and regulatory constraints*

3 **Unbiased:** To avoid a biased answer, the UAM assessment should draw on a *diverse set of stakeholders* (e.g., original equipment manufacturers [OEMs], component manufacturers, infrastructure providers, operators, regulators, special interest groups)

4 **Exhaustive:** *The full system of costs* (across OEMs, operators, and infrastructure providers) should be included, not just the vehicles and supporting equipment

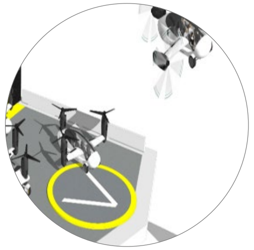
5 **Consumer-backed:** UAM models should incorporate *consumer and business willingness to pay*, since price may be a major barrier to widespread adoption

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

Analysis focused on the three most challenging (and different) UAM use cases

Use case 1 – Last-mile delivery

Rapid delivery of packages (less than 5 lb.) from local distribution hubs to a dedicated receiving vessel. Deliveries are unscheduled and routed as online orders are placed



Use case 2 – Air metro

Resembles current public transit options such as subways and buses, with pre-determined routes, regular schedules, and set stops in high traffic areas throughout each city. Vehicles are autonomously operated and can accommodate 2 to 5 passengers at a time, with an average load of 3 passengers per trip

Use case 3 – Air taxi

The air taxi use case is a near-ubiquitous (or door-to-door) ridesharing operation that allows consumers to call vertical takeoff and landing aircraft (VTOLs) to their desired pickup locations and specify drop-off destinations at rooftops throughout a given city. Rides are unscheduled and on demand like ridesharing applications today. Like the air metro case, vehicles are autonomously operated and can accommodate 2 to 5 passengers at a time, with an average load of 1 passenger per trip

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

Study findings

- **Near-market segments:** A commercially viable market for last-mile parcel delivery and air metro could be in place by 2030
- **Likely market constraint:** There is likely a limited potential market for air taxis in concentrated areas of high net worth individuals and businesses in 2030
- **Key challenges:** For UAM to be viable, it is necessary to address the technical, physical, operational, and integration challenges of a highly interdependent system-of-systems
- **Dependencies for the market to become viable:**
  - Safety and security
  - Economics
  - Transportation demand
  - Regulation
  - Market substitutes (e.g., autonomous delivery and transportation)
  - Public acceptance

Contents

Findings are informed by interviews, surveys and research

Econometric model

- Algorithm to test economic viability of UAM (3 separate use cases), incorporate consumer (and business) demand and willingness to pay; UAM industry costs (including over 50 variables); weather and technical constraints; and evolution of costs over time
- Adaptable and 'living' parametric model that allows ARMD to continually update key data items as the market evolves

Over 200 expert/executive interviews, including with:

Director of Product, Aircraft company	Former General Manager, Aircraft company
Former Sr. Manufacturing Engineer, Automotive company	Former Technical Operations Manager, Retailer
Former Field Operations Manager, UAS company	Current Chairman of UAS association
Former CEO, Global Freight Forwarding, Logistics company	Head of Business Development, Logistics company
Former Sr. Manager, Retail company	Manager, C-UAV company
Former President and CEO, Helipad company	VP of Sales, UAS company
Chief Marketing Officer, UAS company	COO, Aircraft company
Former Group Leader, Aircraft company	Program Manager, Defense company
Founder, Aircraft company	Director of Technology, Logistics company
Former Regional Operations Manager, Logistics company	Former Managing Director, Automotive company
Former VP of Engineering, and Systems, UAS company	Former Head of Operations, Ground robotics company
Former Director of Global Bus. Dev., Logistics company	Former Head of ADAS, Automotive company
Former Executive VP, Automotive company	Former Vice President, Delivery logistics company
Founder/Managing Member, UAS company	Former Autonomous Vehicle Instructor, Automotive company
Former Vice President of Operations, Sensor company	Director, UAS university research program
Former Project Manager, Aircraft company	Director, UAS university program
Former VP of Operations and Strategy, UAS company	Former Vice President, EU delivery logistics company
Founder, UAS company	Executive Director, UAS test site
Co-Founder, Aircraft operations company	Former Chairman, UAS association
Former Civil Certification Manager, Helicopter company	7+ additional topical experts (e.g., warehousing)

Survey with 2,000+ consumer/business respondents

- Current transportation and delivery spend by consumer income and age
- Consumer willingness to pay for increased speed across both transportation and delivery use cases by income, age, and average trip duration
- Public acceptance of UAS technology, broadly, and transportation and delivery UAM options, specifically

---

- Current B2B delivery spend by company size and speed preferences
- Business willingness to pay for increased delivery speed

Data and research

- Frost & Sullivan, "Future of Flying Cars 2017-2035"
- Teal Group, "World Civil Unmanned Aerial Systems: Market Profile and Forecast 2017"
- Frost and Sullivan, "Global Commercial Mapping and Surveying Unmanned Aerial Systems Services Market," 2016
- Uber Elevate White Paper
- Resilient Ops, Inc., "Traffic Flow Management in the Presence of Unmanned Aircraft
- University of Massachusetts Amherst, "Unmanned Aircraft System traffic management: Concept of operation and system architecture"
- US Postal Service (USPS) report, "Public Perception of UAS Delivery in the US"
- US Department of Transportation (DOT) report, "Exploring the Relationship between Travel Demand and Economic Growth," 2012

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

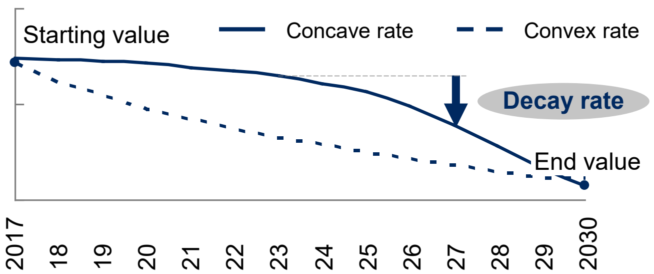
Deep dive: supply and demand equations are built off of cost and production curves

EXAMPLE: LAST-MILE DELIVERY

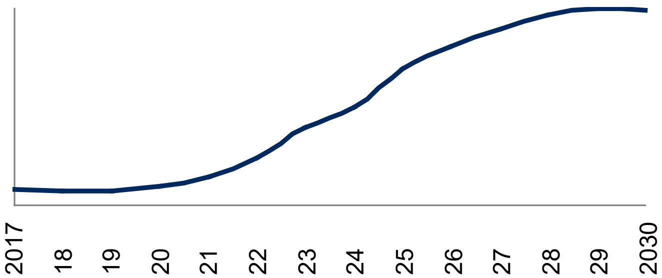
Assum-ptions

2030 component costs are calculated from end value estimates or assumed rates of decay…

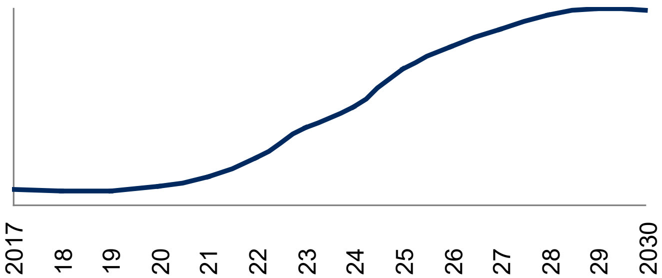
Price of components



of vehicles produced



Total cost of producing vehicles



Forecast

…And forecast costs each year between now and 2030

Year	Airframe	Avionics	Sensing Systems	Other Components	Total Cost	Cost share #1	S #2	S #3	# UAS produced
2017	$3,500	$3,000	$11,500	$3,000	$20,000	0.18	0.15	0.58	2,000
…	…	…	…	…	…	…	…	…	…
2030	$700	$2,700	$5,750	$1,025	$10,175	0.15	0.56	0.07	40,000

Estimation of cost function

Forecasted data are then fed into the translog function…

$$VP = \alpha_0 + \sum_{i=1}^{n} \alpha_i * ln\,(ri)$$

$$ES = \sum_{i=1}^{n} B_{iQ}\, ln\,(r_i) * ln\,(QP)$$

$$TI = \sum_{i=1}^{n} g_{it} * t * ln\,(r_i) + gtQ * t * ln\,(QP)$$

- α_i — Sensitivity to component i
- r_i — Input price of component i
- ES — Impact of scale on cost
- Q_P — Number of UAS produced
- B_{iD} — Sensitivity of component to number of UAS
- TI — Impact of innovation on cost
- t — Time (year)
- Y_{it} — Sensitivity of component to time
- Y_{tQ} — Sensitivity of number of UAS to time
- VP — Total cost of UAS production

Translog estimation algorithm

$\ln(C) = VP + ES + TI$

Using an iteratively seemingly unrelated regression

Cost and production model

…And the parameters from the translog cost function are used to compute the economies of scale and impact of technological change on cost

Taking partial derivatives of the above equations with respect to quantity and time provides the following equations to observe how changes in quantity and time impact the price.

$$Economies\ of\ scale = \beta_Q + \beta_{QQ} * \ln(Q_P) + \sum \alpha_i \ln(r_i) + g_{tQ} * t$$

$$Rate\ of\ technological\ change = -(gt + gtq * t + gtt * t + a_{r11} * \ln(r_1) + a_{r12} * \ln(r_2) + a_{r13} * \ln(r_3))$$

Econometric models made several critical assumptions

Use case-specific assumptions

- Receiving vessels for last-mile delivery are positioned to allow for (average) door-to-door 20-minute delivery
- Vertiports for the air metro case are positioned to enable 20 minute door-to-door trips[1]
- Vertiports and vertistops in the air taxi case are positioned to enable 10-minute door-to-door trips[2]
- Air metro assumes 3 passengers per ride while air taxi assumes 1 passenger per ride

Vehicle assumptions

- Delivery UAS are highly modular, which increases useful life and the number of purchased components
- Transportation UAS have modular batteries; other components are replaced with the vehicle
- Delivery UAS are assumed to have 0.5 days per week of potential maintenance time and operational downtime while transportation vehicles have 1.5 days per week. Additional haircuts on operational time are incorporated for loading, unloading, battery swapping, and weather

Technology, infrastructure, and regulatory assumptions

- Technology in key areas, such as Unmanned Traffic Management (UTM), detect-and-avoid, noise management, operations in GPS-denied environments, and automation, will have step-change advances
- Costs of key technologies currently on the market (e.g., LiDAR, battery storage, sensing and navigation systems) will decline significantly
- Private and public entities will be willing to invest in and build key infrastructure requirements (e.g., receiving vessels, vertiports) to provide the necessary coverage for UAM operations
- Regulations will be in place that allow UAM operations to occur (such as airworthiness standards for vehicles to be created), and regulations and local ordinances will not block UAM, including no local ordinances that limit the construction or placement of key enabling infrastructure elements (i.e., receiving vessels, distribution hubs, vertiports, or other infrastructure)
- Certification processes will take into account the rapidly changing technology in the space and the models will incorporate year-by-year cost curves for each of the components (e.g., battery cost, airframe costs); it is also assumed that regulation will allow manufacturers to rapidly move down cost curves

1 Commute times are an average and will vary by location and distance traveled.

2 To enable 10-minute door-to-door commute times (on average), vertiport and vertistop infrastructure must be ubiquitous.

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

1 | Last-mile delivery

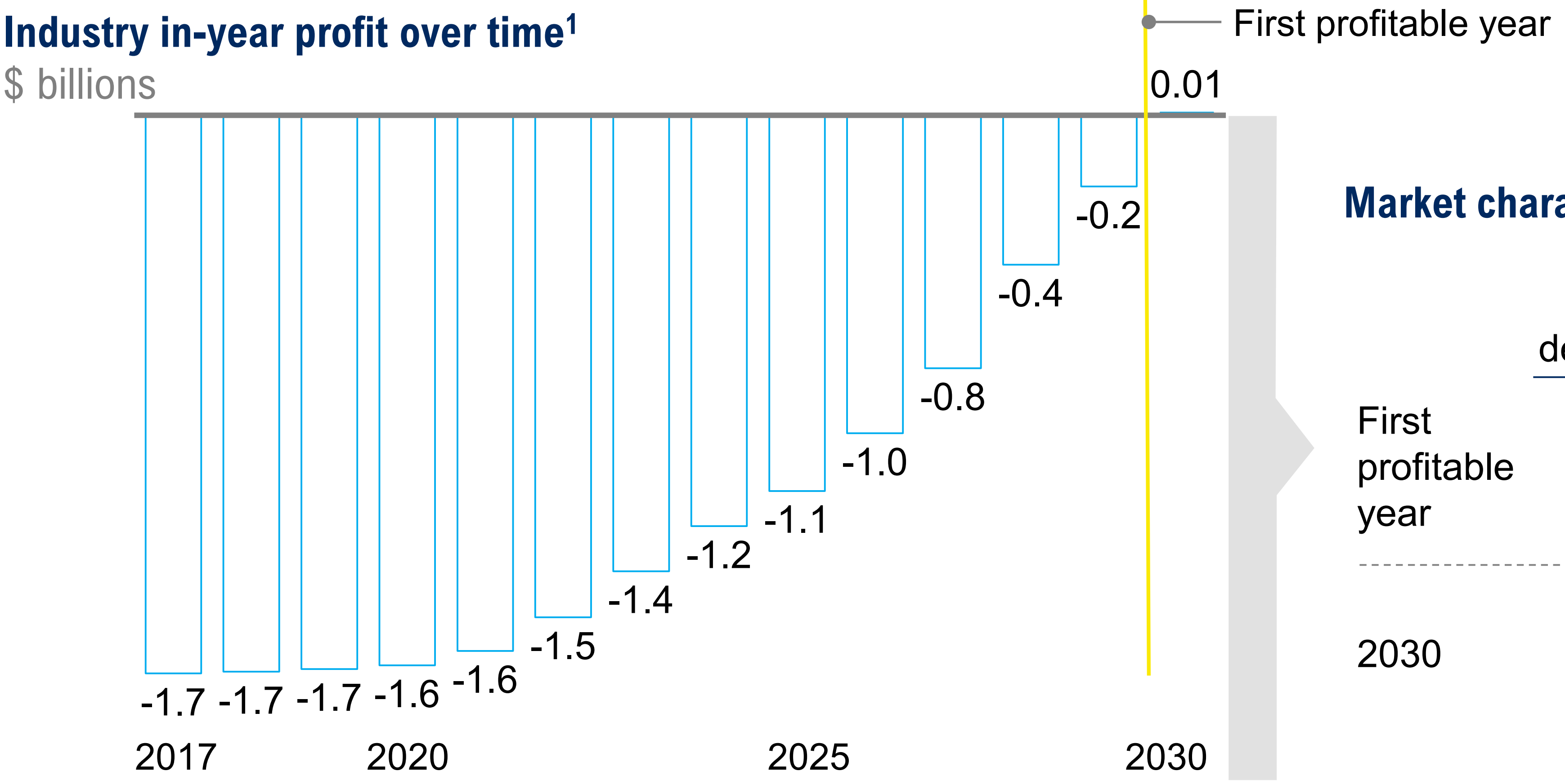
Last-mile delivery is rapid package delivery from local distribution hubs to a receiving vessel. Deliveries are unscheduled and flight times are determined as orders are placed

Use case attribute	Characteristics
Vehicle	Small UAS
Payload	5 pounds
Distance	Within ~10 miles roundtrip
Scheduling and routes	Deliveries are unscheduled and routes are determined as orders are received
Infrastructure	Receiving vessels, distribution hubs, docking/charging stations, UTM
Technology	Improvements in battery technology, autonomous flight technology, detect-and-avoid (e.g., LiDAR, camera vision), electric propulsion, GPS-denied technology
Potential regulatory requirements[1]	BVLOS (Beyond Visual Line of Sight), air worthiness, UTM, flight above people, altitude restrictions, operator certification, identification, environmental restrictions
Competing technology	Autonomous and human driven ground delivery services (e.g., FedEx, UPS, Amazon Prime), courier services, AGV lockers, droids

1 Regulatory requirements are likely to range across use cases depending on risks (for example, delivery case may have less stringent airworthiness requirements than air taxis).

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

UAS last-mile delivery may have a viable market in 2030



Market characteristics

	No. deliveries	No. vehicles	Price ($/delivery)
First profitable year	0.5B	40k	$4.20
2030	0.5B	40k	$4.20

Last-mile delivery may become more profitable post-2030 as the number of deliveries increases

1 Industry in-year profit implies net in-year profitability across the entire value chain if the market existed (including OEMs, operators, and infrastructure providers), not projected investment losses. It assumes that all regulatory challenges are overcome.

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

There are more than 50 variables in the last mile delivery model, but there are five that likely have a large impact on the overall delivery cost

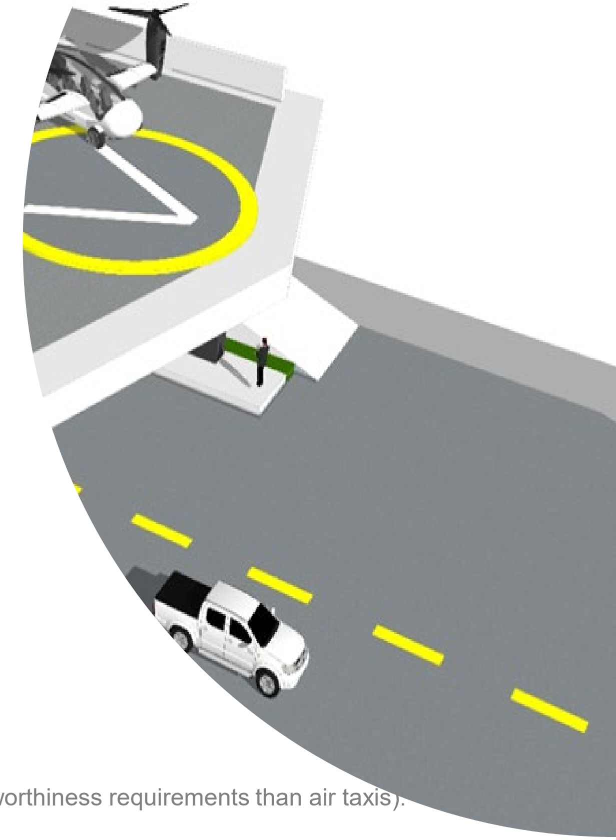
	Variables with high cost shares	Units	Description	Current 2030 assumption	Dependencies
Cert-ification variables	1 **Certification cost per type certificate**	$/type certificate	▪ Cost of certifying the overall vehicle to airworthiness standards (not including the per tail certification cost of ~$500-1500) ▪ Assuming two type certificates per OEM, five OEMs, and a renewal every three years	$5-10mm	▪ Strictness of airworthiness standards ▪ Frequency of certification renewal
Infra-structure variables	2 **Distribution hubs**	$/hub (per year)	▪ Annual depreciation cost of retrofitting current distribution hubs to allow for drones to fit into the logistics plan (i.e., conveyer belts, bay doors that are automatic, roof beacons) plus labor cost ▪ Assumes ~1 hub for every ~200-300k people	$370-390k	▪ Assumption of number of distribution hubs retrofitted
	3 **Receiving vessel density**	# of people per vessel	▪ Vessels for receiving deliveries are required at close geographic proximity to consumers to meet demand effectively, but unlikely to be at every residence ▪ Assumes one vessel serves ~400-500 people in urban areas and ~800-900 in suburban areas, resulting in ~150-200k vessels across all 15 cities	400-900	▪ Assumption of required proximity by consumers
Vehicle variables	4 **Avionics**	$/vehicle	▪ Highly similar systems are widely used and today, have significant OEM costs, require significant R&D expense, and are subject to frequent upgrades with high airworthiness (re-) certification costs ▪ Avionics are critical to flight and will likely include redundancy	$2600-2800	▪ Avionics technology will likely decay at a slower pace than other UAS components
	5 **Sensing systems**	$/vehicle	▪ Cost of systems on UAS that help the vehicle maneuver, including detect-and-avoid technology and GPS-denied environment technology ▪ This cost is ~$10-13k today, and could decrease ~50% by 2030	$5500-6000	▪ Significant cost decline due to tech advances, tempered by high re-certification costs

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

2 | Air metro

The air metro use case resembles current public transit options such as subways and buses, with pre-determined routes, regular schedules, and set stops in high-traffic areas throughout each city

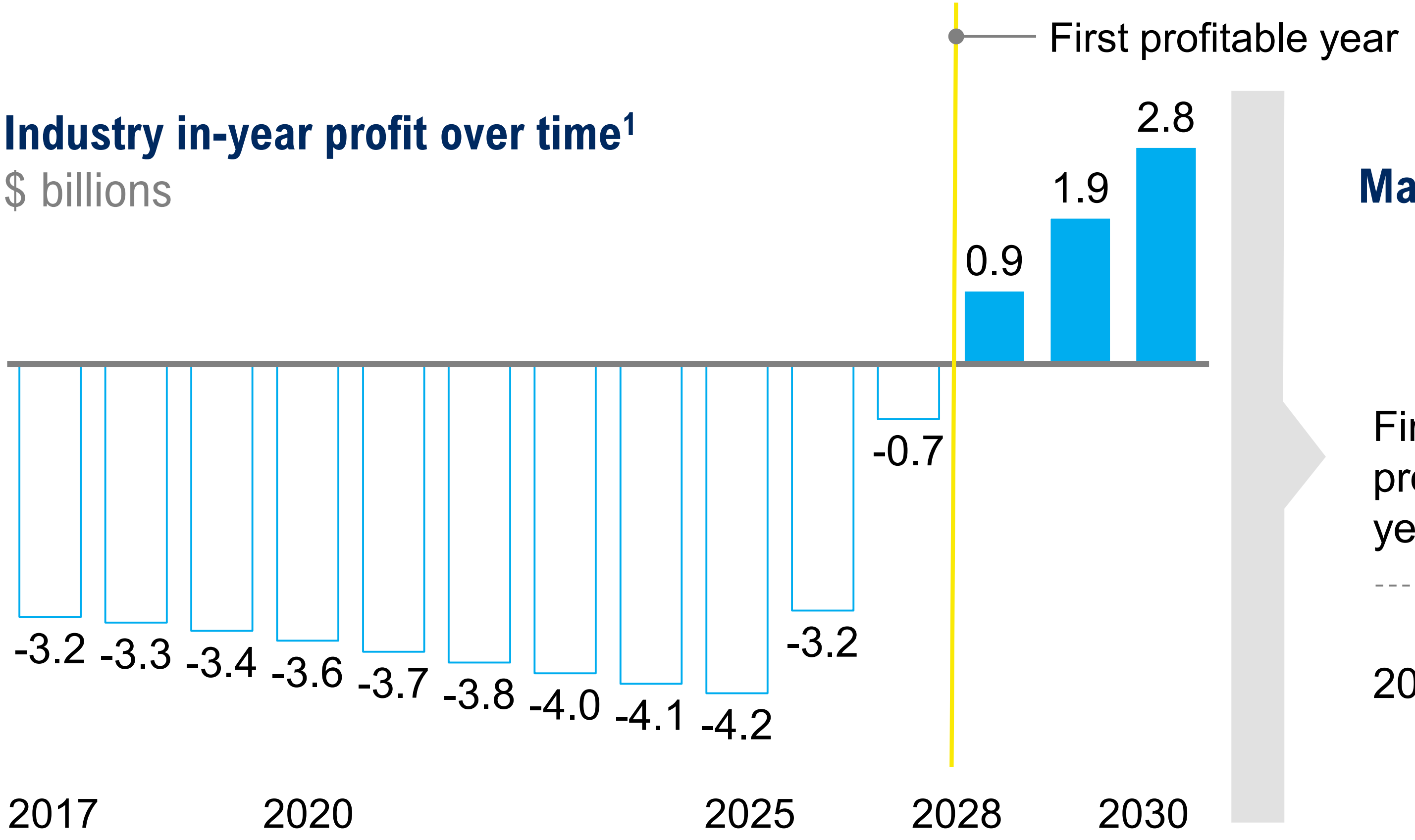
Use case attribute	Description at end state
Vehicle	2-5-passenger autonomous (unpiloted) VTOLs[1]
Payload	~1,000 pounds
Distance	~10-70 miles per trip
Scheduling and routes	Routes are predetermined and scheduled well in advance of flight time
Infrastructure	~100-300 vertiports per MSA located in high-traffic areas capable and of handling ~3-6 VTOLs at once (on average); charging stations; service stations; UTM
Technology	Improvements in battery technology, autonomous flight technology, detect-and-avoid (e.g., LiDAR, camera vision), electric propulsion, GPS-denied technology
Potential regulatory requirements[2]	Development of air worthiness standards, UTM, flight above people, weight and altitude restrictions, BVLOS, operator certification, identification, environmental restrictions
Competing technology	Subway, bus, bike, rideshare, driverless cars (personal vehicle, ride-hail, or rideshare)



1 Vertical Takeoff and Landing 2 Regulatory requirements are likely to range across use cases depending on risks (for example, delivery case may have less-stringent air worthiness requirements than air taxis).

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

Air metro may have a viable market in 2028



Market characteristics

	No. passenger trips	No. vehicles	Price ($/trip)
First profitable year	130M	4.1k	$50
2030	740M	23k	$30

1 Industry in-year profit implies net in-year profitability across the entire value chain if the market existed (including OEMs, operators, and infrastructure providers), not projected investment losses. It assumes that all regulatory challenges are overcome.

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

Vertiport operations in 2030 could follow a distributed hub and spoke model

Suburban areas may be serviced by 1 to 2 vertiports – “the spokes”

Distributed hubs would likely be located in heavily trafficked areas. To accommodate high volumes, a cluster of rooftops in the area may have vertiports and could together serve as the “hub”

Each vertiport may service a limited number of routes. Routes will be demand-driven and may be modified or updated as demand shifts. Passengers may reserve seats in advance to allow for route optimization

As the business case for air metro services becomes firmly established, structures specifically built to accommodate VTOLs may emerge

There are more than 50 variables in the air metro model, but there are seven that likely have a large impact on the overall trip cost

	Variables with high cost shares	Units	Description	Current 2030 assumption	Dependencies
Certification variables	1 Per tail certification cost	$/tail certification	▪ Cost of certifying the each individual vehicle for airworthiness standards as it is produced for operators	$0.5-1.5M	▪ Strictness of airworthiness standards
Infra-structure variables	2 Number of vertiports	No. of vertiports	▪ Vertiports have been created to approximately double the current metro network of the 15 select cities	2500-3500	▪ Assumption of required minimum distribution changes
Operator variables	3 Maintenance cost	$ per vehicle per year	▪ Maintenance costs have been calculated through proxies including lightweight aircrafts (i.e., Cessna), helicopters (i.e., Bell), and some larger aircraft producers (i.e., Boeing)	$70-90K	▪ Potential for high utilization to change the per hour of utilization costs up
	4 Energy cost	$ per year per vehicle	▪ Cost associated with charging each battery, based on both battery and vehicle efficiency as well as electricity costs	$40-45K	▪ US electricity prices ▪ Efficiency of batteries
Technical limitation variables	5 No. passengers per trip	No. of passengers	▪ It is assumed that 3 new passengers get on to the vTOL at each stop for the next 'new trip'	3	▪ Assumptions surrounding adoption of air metro use case
	6 No. passenger rides per hour	No. of rides	▪ Assuming roughly 10 minutes of flight time per trip of 25 miles, at 150mph on average	14	▪ Speed of vehicles and distance between vertiports
OEM variables	7 Factory worker productivity	No vehicles per worker per day	▪ Number of vehicles a single worker can produce in a factory each day. Value is linked to OEM investment in automation in manufacturing production lines	0.02	▪ Level of automation in factories

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

3 | Air taxis

The air taxi use case is a door-to-door ride-sharing or ride-hailing operation that allows consumers to call VTOLs to their desired pick-up locations and specify drop-off destinations at rooftops throughout a given city. With air taxis, the destinations are chosen by the passengers

Use case attribute	Characteristics
Vehicle	2- to -5-passenger autonomous (unpiloted) VTOLs[1]
Payload	~1,000 pounds
Distance	~10-70 miles per trip
Scheduling and routes	Routes are unscheduled and unplanned and are likely different each time
Infrastructure	Very large density of vertistops on or near buildings to create a "door-to-door" service; charging stations; service stations; UTM (unmanned traffic management)
Technology	Requires improved battery technology, autonomous flight, detect-and-avoid (e.g., LiDAR, camera vision), electric propulsion, and GPS-denied technology
Potential regulatory requirements[2]	Significant OEM requirements for air worthiness, BVLOS, UTM, flight above people, weight and altitude restrictions, operator certification, identification, environmental restrictions
Competing technology	Human-driven cars (personal vehicle, ride-hail/taxi, rideshare), driverless cars (personal vehicle, ride-hail, rideshare), commuter rail, subway, bus

1 Vertical takeoff and landing 2 Regulatory requirements are likely to range across use cases depending on risks (i.e., delivery case may have less-stringent air worthiness requirements than air taxis).
All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

The cost of ubiquitous vertistops may make the air taxi model prohibitive in 2030

Annual cost per vertistop ($ k)	Max walk time to vertistop (min)[1], based on distance between vertistops (miles) — Air taxi cost per trip ($/trip): 2.5 min (0.3 mi)	6 mins (0.7 mi)	8.5 mins (1 mi)	13 mins (1.5 mi)	17 mins (2 mi)	
10k	$150	$101	$95	$92	$91	
50k	$393	$145	$117	$102	$96	
100k	$697	$201	$144	$114	$103	
300k	**$1,912**	$424	$254	$162	$131	Best cost estimate
500k	$3,126	$647	$363	$211	$158	
	"Ubiquitous" vertiport assumption					

The primary barriers to the air taxi model with ubiquitous vertistops:

- Infrastructure required is dense to accommodate truly "door-to-door" on-demand service
- The model assumes one passenger per trip, whereas there are three passengers per trip in the air metro case

1 Based on an average walking time of 17 minutes/mile.

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

While air taxis are unlikely to be ubiquitous and profitable in 2030, some localized or niche market scenarios could run profitably

- Although under current constraints the model suggests that air taxis are unprofitable for widespread consumption, there are a few possible scenarios wherein an air taxi business may be viable that could be considered
- Additionally, although it may be unprofitable in 2030, the synergies between delivery and air metro infrastructure investments (i.e., UTM, vertiports), as well as investment in technologies leading to cost declines (i.e., batteries, sensing systems) may lead to a post-2030 follow-on market

The air taxi vision proposed in this model requires nearly ubiquitous infrastructure that is unlikely to be achieved in 2030

- To satisfy the vision of creating a taxi system (i.e., door to door, unscheduled) the model assumes there is a walking time of less than 3 minutes to a stop at any time, which makes widespread infrastructure costs across all MSAs unlikely by 2030
- Technology and infrastructure required is nearly identical to the air metro use case, though the air taxi model requires a greater density of vertistops to satisfy people’s need for nearly door-to-door service

Although this market may not be ubiquitous in 2030 there is the possibility for localized profitability:

- In some highly-dense areas (i.e., Manhattan, Boston, SF, Miami, Philadelphia) there may be an opportunity for profitability where a limited number of vertistops would be able to effectively serve certain populations
- There may also be an initial market that primarily serves businesses and wealthy individuals (similar to today’s helicopter services between NYC and the Hamptons), that may act as a catalyst for a future market that can serve the broader population

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

Contents

Public acceptance

- Overall, **25% of the >2,500 consumers surveyed** report they are comfortable with unmanned aerial technology; approximately 25% of consumers report they will not use UAS or eVTOLs when services become widely available. This means that nearly half of all consumers surveyed are potentially comfortable with delivery and UAM use cases

- Across all unmanned aerial use cases, concerns from consumers fall into 5 major categories: safety, privacy, job security, environmental threats, and noise and visual disruption
  - When it comes to UAS last-mile delivery, consumers are specifically concerned about safety (e.g., vehicles malfunctioning and damaging people and property), theft of packages, and invasion of privacy from vehicle camera systems
  - In UAM transport cases, consumers are most concerned about the safety of both passengers and bystanders and prohibitively high costs associated with operations

- Consumers cite proven safety records and demonstrations as factors that would most increase their level of comfort with UAM

- A comprehensive strategy to address public concerns may include targeted technology R&D, unified messaging to counteract misinformation, proactive engagement with interest groups, and large-scale demonstrations of use case capabilities

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

Public concerns generally fall into five categories

Safety

Consumers distrust autonomous technology and are not aware of safety systems in place

Privacy

Civil liberties groups have privacy concerns with widespread UAM adoption but may misunderstand how camera equipment is used in sensing system technology

Jobs

There is concern that autonomous technology will render jobs obsolete across multiple industries

Environment

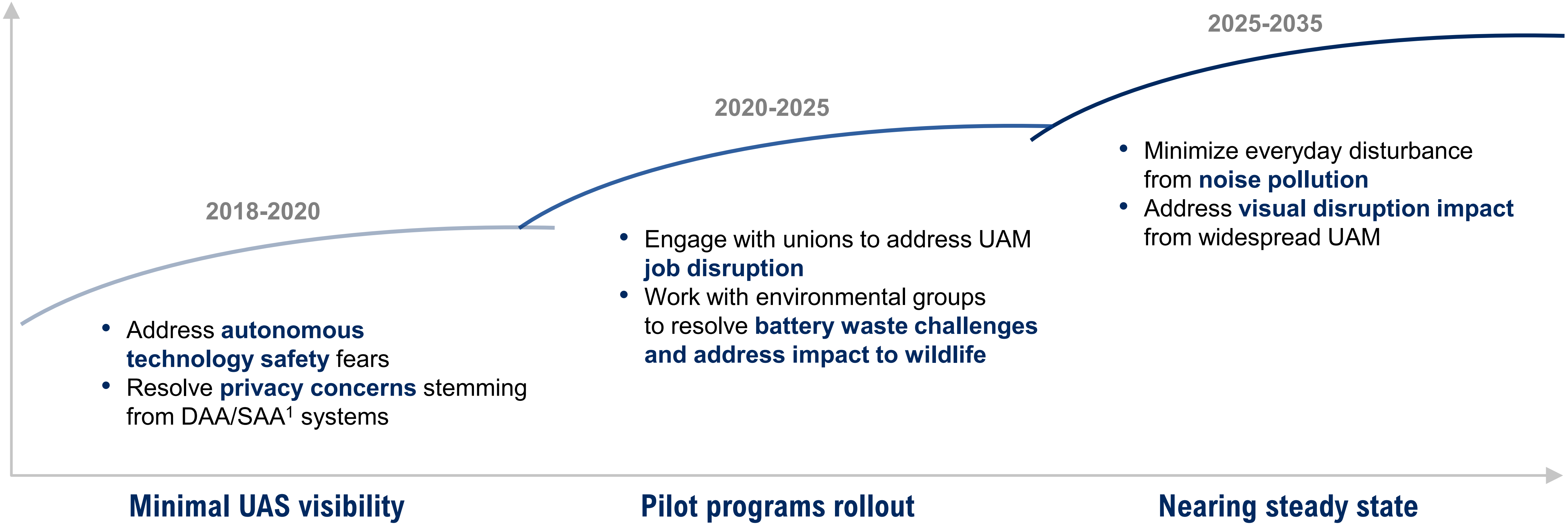
Waste buildup from batteries, impact on wildlife, and energy usage concern younger consumers

Noise and visual disruption

Auditory and visual disturbances in residential neighborhoods are likely to create strong, localized pushback as the market expands

Concerns may evolve as UAS become more prevalent

In addressing public concerns with UAM, early efforts could consider utilizing a phased approach



1 Detect-and-avoid (DAA) or sense-and-avoid (SAA) systems..

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

Three strategies could help address public acceptance concerns

Mitigation strategy	Description
1 Technology R&D	• Invest in key technologies to improve UAM adoption • Focus on noise abatement and safety systems • Establish safety standards (for instance, through FAA coordination)
2 Unified messaging campaign	• Leverage UAM partnerships to coordinate messaging campaign between UAM stakeholders • Address public concerns and emphasize benefits
3 Proactive engagement with concerned groups	• Identify groups that may organize resistance to UAM • Hold forums and co-create solutions to address these concerns

Effective large UAM demonstrations could draw on these three strategies

- Pilot programs may provide a demonstrated safety case to alleviate consumer concerns
- Large-scale demonstrations could provide an avenue for both government and industry to test use case visions and new technologies
- Prior to piloting, stakeholders should consider working to create a unified messaging campaign that preemptively addresses public acceptance challenges
- By engaging activist and interest groups early, pilot programs could test methods for addressing feedback

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

Contents

Overview of the regulatory environment

Today, the regulatory environment does not permit the types of operations that scalable UAM would entail:

- Last-mile delivery is heavily restricted and permitted only through the use of waivers and pilot programs
- Air metro and air taxi regimes are permitted only as traditional manned helicopter services, which leave out critical components of their business cases (e.g., autonomy, eVTOL design)

However, the **DOT Integration Pilot Program (IPP)** is opening up opportunities for expanding last-mile delivery pilots. Enabling last-mile delivery, air metros, and air taxis requires addressing five major categories of regulation:

- Air traffic & fleet operations management
- Vehicle development & production
- Airspace design & implementation
- Individual vehicle management & operations
- Community integration

The majority of regulatory requirements reside at the Federal level under the jurisdiction of the FAA, DOT, and DHS; however, there is likely to be significant state and local involvement in certain areas in the form of registration requirements for operators and vehicles, zoning and infrastructure requirements, and local ordinances. Absent significant changes, the timeline for the regulatory climate to be in place for scalable operations is in the near-term (~2 to 5 years) for last-mile delivery and mid- to long-term (~ 10 or more years) for air metro and air taxi. Leveraging innovative risk management approaches, such as safety management systems (SMS) and selected industry self-regulation, can help accelerate these timelines, but the rulemaking process itself remains the long pole in the tent for getting the required regulation in place

As NASA considers structuring a Public-Private Partnership (PPP) and launching the Grand Challenge, it can evaluate several opportunities to help facilitate the regulatory process:

- Help foster cooperation between agencies by leveraging the PPP to convene the right agencies and focus on critical path issues
- Lead the way on innovative PPPs by facilitating key PPPs on technology, regulatory collaboration, and investment through the alliance
- Help government and industry develop and execute effective and coordinated public engagement campaigns
- Partner with industry on key technologies required to enable UAM operations

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

Last-mile delivery operations are limited and governed primarily by Part 107 and supporting waivers and COAs

Current commercial small UAS (sUAS) operations are governed under Part 107[1]

- **Vehicles:** Aircraft <55 lbs.
- **Operators:** require Part 107 certification for commercial applications; must be 16 years old and pass an in-person knowledge exam and TSA screening
- **Operations:**
  - Aircraft must remain within visual line of sight
  - Fly at or below 400 feet
  - No flights over people
  - Flights only permitted during daylight or civil twilight
  - Must yield right of way to manned aircraft
  - Fly at or below 100 mph
  - Fly only in Class G airspace[2]
  - Cannot operate from a moving aircraft
  - Cannot operate from a moving ground vehicle, unless in sparsely populated areas
- Last-mile delivery **operations may soon be governed by an exemption to Part 135** through the IPP[3]

Expanded operations are permitted on a case-by-case basis with waivers and COAs

- **Part 107 waivers** are available to organizations for expanded operations (e.g., Enhanced Visual Line of Sight (EVLOS), nighttime operations, etc.)
  - In order to get a waiver, organizations must develop a credible safety case that is reviewed and accepted by the FAA
  - To date, there have been over 1,815 waivers granted to organizations around the U.S. for expanded operations[4]
- Public **Certificates or Waivers of Authorization (COA)s** are another avenue for expanded operations available to public sector entities
  - To date, over 70 COAs have been issued to public entities around the U.S.[4]
  - Public agencies are allowed to operate either under blanket COAs or under Part 107 depending on their operations and preference

1 Section 336 is an alternative means of compliance for recreational users operating as hobbyist / aircraft modelers. Operating under this regime significantly lessens the regulatory requirements (e.g., no Part 107 license required), but cannot be used by commercial entities or commercial operations. However, proposed legislation to amend section 336 is currently in the senate as part of the FAA re-authorization bill, which may change the regulatory authority of the FAA over these groups.
2 The Low Altitude Authorization and Notification Capability (LAANC) program is starting to facilitate operations in controlled airspace (Airspace B, C, D, and E).
3 Integration Pilot Program. 4 As of May 22, 2018.

Given restrictive regulatory environment, many companies are looking abroad to conduct their last-mile delivery pilots

Pilot project examples:

- **X – Project Wing** piloting food delivery in Canberra, Australia (Alphabet)
- **Amazon** piloting package delivery in the United Kingdom (amazon)
- **Zipline** piloting medical supply delivery in Rwanda (zipline)
- **Domino's** piloting pizza delivery in New Zealand (Domino's)
- **DHL** piloting package delivery in Germany (DHL)
- **UNICEF** piloting humanitarian UAS corridor in Malawi (unicef)

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

The DOT Integration Pilot Program (IPP) has opened more opportunities for last-mile delivery operations and testing in US

DOT IPP at a glance

- Program developed by DOT and FAA to partner with local communities and businesses to pilot UAS technologies and operations
- Set to run for 3 years
- 10 awards were granted to pilot programs around the US covering a range of communities and use cases
- Last-mile delivery is seen as one of the big winners, being the focus of half of the pilots

Examples of last-mile delivery applications from the IPP

Flirtey

The city of Reno is teamed up with Flirtey to expand its **medical supply delivery program**

Memphis-Shelby airport is teamed up with FedEx to pilot **last-mile parcel delivery, beginning with aircraft parts delivery in airports**, with the potential to expand to other delivery applications

FedEx

flytrex

North Carolina DOT is partnered with Flytrex to pilot **food delivery applications**

The City of San Diego and North Carolina DOT are partnered with Matternet to pilot **food delivery and medical delivery applications** in both urban and rural environments

MATTERNET

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

Going forward, last-mile delivery operations will require evolutions across five key categories of regulation

Air Traffic & Fleet Operations Management
- Operator certification
- Operator licensing
- UTM requirements

Vehicle Development and Production
- sUAS vehicle certification
- Continuing airworthiness

Airspace System Design & Implementation
- Airspace integration
- Zoning restrictions
- Altitude restriction
- Cybersecurity
- Infrastructure requirements

Individual Vehicle Management and Operations
- Registration
- Identification
- Weight restriction
- Pilot certification
- Flight above people
- BVLOS operation
- Autonomous flight

Community integration
- Noise requirements

- Today, last-mile delivery is operating on an exception basis through waivers and pilot programs
- These early operations are charting pathways through Part 107 and Part 135 for future operations
- However, scalable last-mile delivery will require further clarity and standards across these five categories

Air Traffic & Fleet Operations Management and Vehicle Development & Production

	Regulatory need	Why it is required for air metro & air taxi	Where the regulation stands today	Jurisdiction
Air Traffic & Fleet Operations Management	**Operator certification**	Although there currently is no requirement for operator certification for last-mile delivery, it is possible that operator requirements will be placed on organizations that conduct high frequency/volume operations	There is no operator certification required today; individual pilots must be certified Part 107 pilots, but last-mile delivery operators flying under Part 107 have no certification requirement at this time	Federal (FAA)
Air Traffic & Fleet Operations Management	**Operator licensing**	State and local authorities will likely put up operator/business licensing requirements for last-mile delivery operators	There is currently no operator licensing required today	State & Local
Air Traffic & Fleet Operations Management	**UTM requirements**	UTM technical requirements and operating protocols, authority for system-level control, and potential delegation for operations of UTM system(s) are all required for an effective system of traffic management to be in place to deconflict autonomous operations below 400 ft AGL	UTM technology is being developed and tested in test sites around the country; major jurisdictional, regulatory, and CONOPS questions on UTM remain unanswered	Federal (FAA, DOT, Congress)
Vehicle Development and Production	**sUAS vehicle certification**	It is still not determined whether vehicle airworthiness standards will be required for sUAS undertaking last-mile delivery operations	There is currently no specific Airworthiness Certification standard for sUAS, but aircraft could potentially be certified under existing standards for airplanes or rotorcraft	Federal (FAA)
Vehicle Development and Production	**Continuing Airworthiness**	Similar to sUAS vehicle certification, it is unclear what will be required in terms of continuing airworthiness requirements	There are currently no specific continuing airworthiness standards for sUAS	Federal (FAA)

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

Airspace System Design & Implementation and Community Integration

	Regulatory need	Why it is required for air metro & air taxi	Where the regulation stands today	Jurisdiction
Airspace Design & Implementation	**Airspace integration**	Enables sUAS operations in the NAS and ensures separation and obstacle avoidance; may be required in some urban environments where operations will need to extend above 400 ft AGL or into airspaces other than Class G	Additional rules and systems to govern how UAS are integrated into the NAS are required before scalable operations above 400 ft AGL can be enabled. The FAA has convened an Access to Airspace ARC to make recommendations on this issue	Federal (FAA)
Airspace Design & Implementation	**Zoning restrictions**	Existing access and operational regulations may need to be adapted; many state and local entities may use their zoning authority over take-off and landing to restrict operations	De facto applicable protocols are those governing manned aircraft operations and other time, place and manner restrictions	State & Local
Airspace Design & Implementation	**Altitude restriction**	A lot can be accomplished below 400 ft AGL, but many operations will require access to higher altitudes	Commercial UAS operations above 400 ft AGL currently prohibited without a Part 107 waiver or COA, Part 107 operations in controlled airspace require authorization	Federal (FAA)
Airspace Design & Implementation	**Cybersecurity**	Cybersecurity standards for the vehicles and the overall system to protect against jamming, spoofing, and other forms of interference is necessary for safe and reliable operations	Currently, there are no comprehensive cybersecurity standards for UAS and their supporting systems; more attention will need to be paid to this issue going forward to develop the appropriate standards and technologies	Federal (FAA, DOT, DHS, DOD)
Airspace Design & Implementation	**Infrastructure requirements**	Needed to create sUAS infrastructure standards for key last-mile delivery operations (e.g., receiving vessels)	There are currently no standards for key last-mile delivery infrastructure; industry remains unaligned on the technical visions and needs for receiving vessels	Federal (FAA)
Community	**Noise requirements**	Acceptable noise levels, and resulting vehicle, abatement and operations requirements will be developed by the FAA and local communities	De facto applicable protocols are those governing manned aircraft noise requirements	Federal (FAA), State & Local

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

Individual Vehicle Management & Operations

Individual Vehicle Management & Operations

Registration	Aircraft registration is required for all sUAS over 0.55 lbs.; it is likely that State and Local authorities will create additional registration requirements in certain jurisdictions as well	There is a Federal registry for both sUAS and an aircraft registry for traditional manned aircraft	Federal (FAA), State & Local
Identification	Required for law enforcement and Air Traffic Control (ATC) to remotely track and identify aircraft in order to ensure accountability and enable enforcement where required	Unmanned Aircraft Systems (UAS) Identification and Tracking Aviation Rulemaking Committee (ARC) released their guidance in December 2017; the FAA will consider their recommendations in promulgating a rule	Federal (FAA)
Weight restriction	In order to operate under Part 107 the total aircraft weight, including payload, must be less than 55 lbs.; this is likely sufficient for most last-mile delivery operations, but there may be some instances where a larger aircraft and payload may be desired	sUAS must be under 55 lbs. to operate under Part 107; operations requiring greater payload capacity must pursue certification	Federal (FAA)
Pilot certification	Pilot certification is likely to continue to be required for sUAS operations	Pilot must have a remote pilot airman certificate for commercial operations; cert is currently a written test	Federal (FAA)
Autonomous flight	Required to reduce operator to aircraft ratio, and full integration into automated UTM system	Under Part 107, all operations must be within visual line of sight and under the control of a remote pilot[1]	Federal (FAA)
BVLOS[1] operation	Delivery operations will require BVLOS operations in all scalable last-mile delivery models	BVLOS operations currently prohibited without a Part 107 waiver or COA; some EVLOS[2] waivers have been granted to certain organizations (e.g., PrecisionHawk, BNSF, and GE) but true BVLOS flights are heavily restricted	Federal (FAA)
Flight above people	Enables operations in urban and suburban areas where demand is likely to be significant and flight routes will require operations above people	UAS operations over people are currently prohibited without a Part 107 waiver or COA; some flight above people testing has been done (e.g., CNN operations), and is expected to be further tested in the IPP	Federal (FAA)

1 Beyond Visual Line of Sight (BVLOS); 2 Enhanced Visual Line of Sight (EVLOS).

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

Today, the closest parallel to the air metro and air taxi markets are manned helicopter services

Helicopter service market in the US

- There are currently 5,660 heliports in the US (most are not public use) and 9,750 civil helicopters in the fleet
- The civil helicopter transport market is growing but remains relatively limited and expensive, and local communities often view it as disruptive; many communities have issued local ordinances to restrict these routes in their jurisdiction to address community concerns
- The global commercial helicopter market is expected to continue to grow steadily over the next 10 years, from $8.2 billion in 2017 to $11.6 billion by 2027
- The US is expected to lead this market with ~$38 billion in spending over the 10-year period; this growth is driven by increasing adoption of helicopters for public and para-public missions, like the Helicopter Emergency Medical Services (HEMS), law enforcement, and search & rescue
- Many current helicopter services are planning to transition their operations to eVTOLs (e.g., Airbus VOOM) in the future

US regulatory climate for helicopter services

- Today, these helicopter services are primarily governed by Part 135
- To achieve a more scalable and accessible air metro UAM market, current operations will need to undergo several major innovations, including:
  - Automation and development of associated safety systems
  - Distributed electric propulsion systems
  - Commercialization of tilt-rotor designs
  - Battery power improvements
  - New infrastructure designs and standards
- These evolutions will require significant changes to the existing regulatory regime, spanning everything from airworthiness to operator certification to infrastructure standards

Source: Global Commercial Helicopter Market Report, Strategic Defense Intelligence; Expert interviews

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

Going forward, air metro and air taxi operations will require evolutions across five key categories of regulation

Air Traffic & Fleet Operations Management	Vehicle Development & Production	Airspace System Design & Implementation	Individual Vehicle Management & Operations	Community integration
Operator certification	Vehicle certification	Zoning restrictions	Registration	Noise requirements
Operator licensing	Continuing airworthiness	Cybersecurity	Surveillance	
Fleet management		Infrastructure requirements	Pilot certification	
UAM TM & airspace integration			Autonomous operations	

- Today, air metro and air taxi operations are most closely paralleled by rules governing rotorcraft
- Adding electrification and autonomy to the mix will require a significant degree of maturation in the existing regulations and/or the introduction of new regulation to govern these aircraft and operations
- Integrated and autonomous UAM traffic management systems and associated protocols are in a nascent state, and pathways to vehicle certification remain to be charted

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

Air Traffic & Fleet Operations Management and Community Integration

	Regulatory need	Why it is required for air metro and air taxi	Where the regulation stands today	Jurisdiction
Air Traffic & Fleet Operations Management	**Operator certification**	AOC/Operator certification will be required for Air Metro and Air Taxi operators; these requirements will likely be an evolution of existing manned operator certifications	Under the current regulatory structure, there is only a standard for piloted operations, which operate under Part 135 in most cases; alterations and additional regulation may be needed for autonomous operations	Federal (FAA)
	Operator licensing	State and local authorities will likely implement operator/business licensing requirements for air metro & air taxi operations	Depending on the jurisdiction and operation type, additional licensing requirements exist for manned equivalents (e.g., medical operations licensing)	State & Local
	Fleet management	eVTOLs will require automated fleet management software and associated protocols to enable scalable autonomous use cases	There is no current regulatory baseline governing technical or protocol standards for autonomous fleet management	Federal (FAA)
	UAM traffic management & airspace integration	UAM Traffic Management (UTM) technical requirements, operating protocols, and supporting infrastructure and technologies are required for an effective system of traffic management to be in place to allow for autonomous eVTOL operations; eVTOLs will operate in airspace with a range of cooperative, noncooperative, and autonomous traffic, and an integrated, automated system for UAM traffic management will be needed to manage and deconflict this traffic	Additional rules and systems to govern how autonomous eVTOLs are integrated into the NAS are required before scalable operations can be enabled	Federal (FAA, DOT, Congress)
Community	**Noise requirements**	Acceptable noise levels, and resulting vehicle, abatement and operations requirements will be developed by the FAA and local communities	De facto applicable protocols are those governing manned aircraft noise restrictions	Federal (FAA), State & Local

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

Vehicle Development and Production and Airspace System Design and Implementation

	Regulatory need	Why it is required for air metro & air taxi	Where the regulation stands today	Jurisdiction
Vehicle Development and Production	**Vehicle certification**	Vehicle airworthiness certification standards will need to be evolved to encompass electric propulsion, autonomy, and its related technologies and subsystems	There is currently no clear certification path for an autonomous eVTOL; Part 23 and Part 21 are often seen as a starting point for the evolutions that will need to occur to enable vehicle certification, but a proven, viable path has yet to be established	Federal (FAA)
	Continuing Airworthiness	Continuing airworthiness standards will need to be developed to govern autonomous eVTOLs	There are currently no continuing airworthiness standards for autonomous eVTOLs; rotorcraft continuing airworthiness standards are the most likely future baseline	Federal (FAA)
Airspace Design and Implementation	**Zoning restrictions**	Existing access and operational regulations may need to be adapted to accommodate LMD	De facto applicable protocols are those governing manned aircraft operations and other time, place and manner restrictions	State & Local
	Cybersecurity	Cybersecurity standards for the vehicles and the overall system to protect against jamming, spoofing, and other forms of interference are necessary for safe and reliable operations	Currently, there are no comprehensive cybersecurity standards for autonomous vehicles and their supporting systems (e.g., UTM); more attention will need to be paid to this issue going forward to develop the appropriate standards and technologies	Federal (FAA, DOT, DHS, DOD)
	Infrastructure requirements	Needed to create UAM infrastructure standards for key air metro and air taxi operations (e.g., vertiports)	There are currently no vertiport-specific standards and industry remains unaligned on the technical visions and needs for vertiports; currently all “vertiports” would need to comply with airport and/or heliport standards	Federal (FAA)

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

Individual Vehicle Management & Operations

Individual Vehicle Management & Operations

Regulatory need	Why it is required for air metro & air taxi	Where the regulation stands today	Jurisdiction
Registration	Aircraft registration is required for the majority of aircraft; it is likely that State and Local authorities will create additional registration requirements in certain jurisdictions as well	There is a Federal registry for traditional manned aircraft	Federal (FAA), State & Local
Surveillance	Required for Air Traffic Control (ATC) and public safety officials to remotely track and identify aircraft in order to ensure separation standards, accountability and enable enforcement where required	There are currently no specific rules or requirements for autonomous eVTOLs, the closest parallel is equipage requirements for aircraft operating within the Mode C Veil	Federal (FAA)
Pilot certification	Pilot certification will likely be required for potential interim use cases involving remote pilots for eVTOLs; these requirements will change as the platforms transition to full autonomy	Currently, there is no way to certify as a remote pilot of a remotely piloted eVTOL	Federal (FAA)
Autonomous operations	Required for full-scale use case operations, which will entail repeated autonomous operations; regulation will need to be put in place to govern technical standards for autonomous mission management systems, and standards and protocols for autonomous operations	Currently, regulation is in place to allow for piloted helicopter operation and VLOS operations for sUAS; there is no clear regulation in place to govern autonomous passenger-carrying operations or the systems that support them	Federal (FAA)

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

Future regulation will likely marry sUAS and manned commercial rules

This process is likely to be time consuming and labor intensive, and completed in a series of incremental steps.
Both legs of this evolution will require significant updates to many existing Parts that interact with different components of UAM operations

	Part 107 (sUAS) evolution	Manned commercial evolution
Last-mile delivery	Last-mile delivery applications will likely be primarily an evolution of Part 107 (sUAS) regulations The vehicles, operations, and airspace concerns that regulators are currently tackling for sUAS more broadly are directly applicable to last-mile delivery, and therefore, will likely be addressed in large part by evolutions of Part 107	Last-mile delivery will likely entail revisions to Part 135 Currently, last-mile delivery operations for the IPP are expected to operate under Part 135 Many components of last-mile delivery will borrow from evolutions of manned standards (for example, operator certification, should it be adopted, is likely to borrow from existing operator certification standards for commercial operations)
Air metro and air taxi	Some of the standards and regulatory precedent will likely be borrowed from or based on evolutions of Part 107 for key technologies, systems, and operations that are shared between sUAS and Air Taxi or Air Metro regimes (e.g., UTM designs and standards, battery safety standards, Designated Approving Authority [DAA] technology standards)	Air Metro and Air Taxi use cases will likely borrow part of their regulatory frameworks from existing manned commercial operations (e.g., Parts 135, 91) Many of these Parts already tackle the beginnings of automation, but none of them are a perfect fit for UAM operations. For example, even manned rotorcraft operations fail to address scalable UAM because they rely primarily on VFR[1]

1 Visual Flight Rules

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

Regulatory progress faces challenges

- **Time-consuming regulatory processes.** The regulatory process struggles to keep pace with the speed of innovation and demands from industry, many of whom are unfamiliar with aviation and the regulatory process associated with it. The rulemaking process is inherently collaborative, and requires community engagement and review as well as compliance with the Administrative Procedures Act. This creates a lengthy process for something like UAM, which is a complex and multifaceted issue requiring multiple rulemakings and Part updates

- **Resource constraints for the regulators.** The regulatory process is labor intensive, and regulators face tight resource constraints, large workloads, and multiple demands on their time

- **Pressure to move more quickly.** Regulators are under significant pressure to move more quickly, but not at the cost of safety, given perceptions that the US is being “outpaced” in this arena, and industry concerns around enabling commercial markets

- **Open development needs for key technologies.** Many technologies are simply not there yet in terms of capabilities and performance to fill certain functions that are required for safe and reliable operations (e.g., DAA, GPS-denied environment navigation, etc.). Absent reliable technologies for these functions, regulators cannot set reasonable or reliable safety standards for key UAM operations

- **State and local pre-emption.** In lieu of clear Federal rules and guidance, there is likely to be more unilateral action taken by State and Local authorities. This risks causing a more complex and fragmented regulatory landscape to manage and navigate in the future

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

Full-scale last-mile delivery is currently near-term timeframe

<table>
<tr><th></th><th>Immediate (~0-24 months)</th><th>Near-term (~2-5 years)</th><th>Mid-term (~5-10 years)</th><th>Long-term (~10+ years)</th></tr>
<tr><td rowspan="3">Air Traffic & Fleet Operations</td><td></td><td>Operator certification</td><td></td><td></td></tr>
<tr><td></td><td>Operator licensing</td><td></td><td></td></tr>
<tr><td></td><td>UTM requirements</td><td></td><td></td></tr>
<tr><td rowspan="2">Vehicle</td><td></td><td colspan="2">sUAS vehicle certification</td><td></td></tr>
<tr><td></td><td colspan="2">Continuing airworthiness</td><td></td></tr>
<tr><td rowspan="5">Airspace System Design & Implementation</td><td></td><td></td><td>Airspace integration</td><td></td></tr>
<tr><td colspan="3">Zoning restrictions</td><td></td></tr>
<tr><td></td><td></td><td>Altitude restriction</td><td></td></tr>
<tr><td></td><td></td><td colspan="2">Cybersecurity</td></tr>
<tr><td colspan="2">Infrastructure requirements</td><td></td><td></td></tr>
<tr><td rowspan="7">Individual Vehicle Management & Operations</td><td>Registration</td><td></td><td></td><td></td></tr>
<tr><td></td><td colspan="2">Weight restriction</td><td></td></tr>
<tr><td>Identification</td><td></td><td></td><td></td></tr>
<tr><td>Pilot certification</td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td>Autonomous flight</td><td></td></tr>
<tr><td></td><td>BVLOS</td><td></td><td></td></tr>
<tr><td>Flight above people</td><td></td><td></td><td></td></tr>
<tr><td>Community</td><td colspan="3">Noise requirements</td><td></td></tr>
</table>

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

Likely timeframe for starting scalable operations

Full-scale air metro and air taxi are currently mid- to long-term

Immediate (~0-24 months) | **Near-term** (~2-5 years) | **Mid-term** (~5-10 years) | **Long-term** (~10+ years)

Air Traffic & Fleet Operations

- Operator certification[1]
- Operator licensing[1]
- UAM TM & airspace integration
- Fleet management

Vehicle

- eVTOL vehicle certification
- Continuing airworthiness

Airspace System Design & Implementation

- Zoning restrictions
- Cybersecurity
- Infrastructure requirements

Individual Vehicle Management & Operations

- Registration
- Surveillance
- Pilot certification[2]
- Autonomous flight

Community

- Noise requirements

1 Currently possible for manned operations under Parts 135 and 121; adaptions will likely occur for unmanned operations as needs arise.
2 Currently possible to get pilot certification for manned operations, unmanned "pilot" certification will develop in the long to extended term.

Likely timeframe for starting scalable operations

Forward-leaning risk management will be critical in driving efficiency in the UAM regulatory process

Enabling Safety Management Systems (SMS)

- Many of these technologies are not currently up and running ultimately because of risk and how risk is mitigated
- The FAA is able to operate most efficiently when it can delegate the details of safety and risk mitigation to operators who have approved Safety Management Systems (SMS); building these protocols for UAS operators allows for faster approvals for operations and can accelerate expansion and scaling of UAM operations in the NAS

Facilitating selected industry self-regulation

- Regulators may be able to leverage industry self-regulation in certain areas to help accelerate the pace of adoption and implementation of UAM technologies and operations
- Industry is often able to move more quickly than regulators in adopting consensus standards as opposed to putting standards through the rulemaking process; as a result, there are certain areas where industry consensus standards or industry-driven self-regulation could help alleviate some of the burden of the regulatory process, and accelerate adoption and implementation while maintaining the highest safety standard
- Insurance requirements may provide an effective avenue for industry self-regulation; should the FAA require operators to carry certain insurance limits, insurance companies will help the industry self-regulate as they will be unwilling to insure unsafe operators[1]

1 This avenue would require significant confidence in insurers' ability to accurately assess and quantify risk in UAM operations.

The UAM regulatory process remains time-consuming

The rulemaking process itself moves very slowly

- The process is governed by the Administrative Procedures Act (APA) and three associated executive orders (12866, 13563, and 13579)
- Aviation rulemaking normally will take 38 to 42 months or more for a significant rule, and 30 months for a less significant rule.
- There are 3 formal stages to rulemaking (pre-rule, proposed rule, and final rule), but there are 9 distinct steps to the end-to-end process
- This process is very detailed and requires strict compliance with the requirements and analyses under each stage, and is very time and labor intensive as a result; there are some steps that have historically acted as chokepoints for rulemaking (e.g., time intensity for adjudicating comments, OST approval, OMB approval)
- The rulemaking timelines for something as robust as UAM tend to be extended due to the requirements for compliance with each stage of this process for each individual rule and rule update that is undertaken
- Rulemaking can take longer at FAA compared to other agencies or departments because coordination is required with both DOT and the Office of Information and Regulatory Affairs (OIRA)
- Some agencies tend to operate under de-facto numerical limits on how many rules it can send each year to OIRA
- Even “good” rules (e.g., Part 23 re-write) suffer from the perception that rules are bad and fewer new regulations is better; “good” rules often get held because other rules, especially if mandated by Congress, take priority

Accelerating the regulatory timeline

- Given the APA’s requirements, going through the traditional process will lead to long timelines for UAM regulation to be in place
- Within APA, a potentially significant reduction in the time needed for rulemakings may be possible by more closely involving DOT, OIRA, and other relevant government agencies in the development and drafting of rules
  - Once the draft rules are complete, there could be concurrent agency review with an abbreviated period for comments
- Some other potential avenues for acceleration, should legislators or regulators choose to pursue them:
  - Congressional delegation of some airspace regulatory jurisdiction to state and local governing authorities
  - Regulator delegation of specific issues to industry consensus standards bodies or to state and local governing authorities

Principles for a progressive and effective UAM regulatory regime

Fostering cooperation among agencies. Many of these issues are inter-agency challenges (e.g., cybersecurity will require FAA, DHS, DOJ, and DOD cooperation at a minimum) and will require effective coordination and governance in order to be successful

Developing innovative Public Private Partnerships. USDOT have already started this process by setting up a FACA in the form of the DAC and launching initiatives like Pathfinder, IPP, and LAANC. However, true success in this arena is going to require more innovative P3 structures like these that allow for more agile co-development, testing, and standard-setting opportunities

Adopting performance-based regulations. Given the pace of technological change likely to be seen in the UAM industry, building performance-based regulations are going to be critical to enabling innovation. The FAA has already begun the transition to this form of regulation with the 14 CFR Part 23 rewrite; this kind of approach will be critical to UAM

Implementing forward-leaning risk management approaches. Regulators can operate more efficiently by delegating details of safety and risk mitigation to operators who have approved Safety Management Systems (SMS). SMS in conjunction with facilitating selected industry self-regulation can help improve efficiency of the regulatory process across the UAM ecosystem

Acknowledging that politics are local. Although the regulatory authority is primarily Federal, local communities are going to be a major factor in the integration and adoption of UAM technologies and operations. Local sentiments will dictate both the market adoption rates and what ordinances are created, as well as the resulting ease of integration

Developing new methods that match the new face of aviation. The UAM and UAS industries are much more vast and fragmented than the traditional manned aviation landscape. The ecosystem is larger and contains a much wider range of corporate sophistication and background than ever before. This means that some of the old ways of doing business may no longer be sustainable and new solutions will need to be developed to help the full ecosystem develop and operate unmanned aircraft safely in an urban environment

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

Contents

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

Use cases are grouped according to conditions for a viable market

Conditions for a Viable Market	Last-mile parcel delivery Commercially viable market profitable around 2030	Air Metro Commercially viable market with in-year profitability in 2028	Air Taxi Possible market in 2030 in concentrated areas of high net-worth individuals and businesses
Safety and Security	Detect-and-avoid, GPS-denied technology, weather mitigation, UTM technology Regulatory requirements for BVLOS, airworthiness, UTM certification, flight above people, altitude restrictions, operator certification, identification, environmental restrictions (e.g., noise, visual noise), emergency procedures, data security	Detect-and-avoid, GPS-denied technology, weather mitigation, UTM technology Regulatory requirements for airworthiness standards, UTM certification, flight above people, weight and altitude restrictions, BVLOS, operator certification, identification, environmental restrictions (e.g., noise, visual noise), emergency procedures, data security	Detect-and-avoid, GPS-denied technology, weather mitigation, UTM technology Regulatory requirements for airworthiness standards, BVLOS, UTM certification, flight above people, weight and altitude restrictions, operator certification, identification, environmental restrictions (e.g., noise, visual noise), emergency procedures, data security
Economics	Battery technology, autonomous flight technology, infrastructure (receiving vessels, distribution hubs, docking/charging stations, UTM)	Battery technology, autonomous flight technology, electric propulsion, infrastructure (~200 vertiports per MSA located in high-traffic areas capable and of handling ~3-6 VTOLs at once; charging stations; service stations; UTM)	Battery technology, autonomous flight technology, electric propulsion, infrastructure (very large density of vertistops on or near buildings to create a "door-to-door" service; charging stations; service stations; UTM)
Demand for Transportation	Competing modes (autonomous and human-driven ground delivery services (e.g., FedEx, UPS, Amazon Prime), courier services, autonomous ground vehicle (AGV) lockers, droids)	Competing modes (subway, bus, bike, ride-hail/taxi, or rideshare)	Competing modes (subway, bus, bike, ride-hail/taxi, or rideshare)
Public acceptance	Proven safety record, privacy, job security, environmental threats, and noise and visual disruption	Proven safety record, privacy, job security, environmental threats, and noise and visual disruption	Proven safety record, privacy, job security, environmental threats, and noise and visual disruption

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

Barriers for a viable market vary in degree and detail by use case, but broadly sit under four categories

Barriers to a Viable UAM Market
Safety and Security ▪ Regulation and certification of vehicles and operations ▪ Cybersecurity ▪ Robust air traffic management and collision avoidance
Economics ▪ Infrastructure investment - Last-mile parcel delivery: package handling - Air metro: charging stations and vertiports - Air taxi: charging stations and very large density of vertistops ▪ Operating cost reduction (electric propulsion, autonomous flight)
Demand for Transportation ▪ Competitive modes (autonomous and human-driven ground services) ▪ Willingness to pay for speed (instant delivery, trip time)
Public Acceptance ▪ Perceived safety (proven safety record) ▪ Environmental and societal concerns (noise, emissions, privacy, visual disruption), including land use and local regulatory issues

Indicators of Viability for UAM Markets
Critical events or tipping points may be used to project viability of UAM markets

Conditions for a viable market	Barriers	Last-mile parcel delivery indicators	Air metro indicators (Indicators for air taxi will be similar)
Safety and security	Regulation and certification of vehicles and operations	• Regulatory climate for vehicles, operators, and UTM in place • Initial commercial operations	• Regulatory climate in place for vehicles, operators, and UTM for commercial passenger operations in urban areas • Initial commercial operations
	Cybersecurity	• Cybersecurity standards and requirements in place	• Cybersecurity standards and requirements in place
	Robust air traffic management and collision avoidance	• UTM for BVLOS operations in place	• UTM for passenger operations in urban areas in place • UTM for autonomous passenger operations in place
Economics	Infrastructure investment	• Initial investments for UAS package handling and distribution • Annual growth in number of distribution hubs	• Initial investments in charging stations and vertiports • Annual growth in number of vertiports
	Operating cost reduction	• Annual reduction in cost per parcel delivered • Introduction of autonomous operations	• Annual reduction in cost per passenger trip • Introduction of autonomous passenger operations
Demand for transportation	Competitive modes	• Annual growth in number of same-day deliveries (all modes)	• Annual growth in number of urban passenger trips (all modes)
	Willingness to pay for speed (instant delivery, trip time)	• Annual growth in number of parcels delivered by air mode • Projected year for 25% air share of same-day deliveries	• Annual growth in air market share as percent of all urban passenger trips
Public acceptance	Perceived safety	• Proven safety record equivalent to ground mode deliveries	• Proven safety record better than ground mode travel
	Environmental and societal concerns	• Number and severity of local operational restrictions	• Number and severity of local operational restrictions

Suggested Framework for Assessing Technology Contributions to UAM Viability
Barriers link technologies to conditions for a viable market

Technologies	Barriers	Conditions
Autonomy Sensing Cybersecurity Propulsion Energy storage Emissions Structures Safety Pilot training Certification Communications Controls Operations Traffic management Infrastructure	Regulation & certification Cybersecurity Air traffic management Infrastructure investment Affordability Competitive modes Willingness to pay Perceived safety Environment	Safety & security Economics Demand for transportation Public acceptance

Viable Market

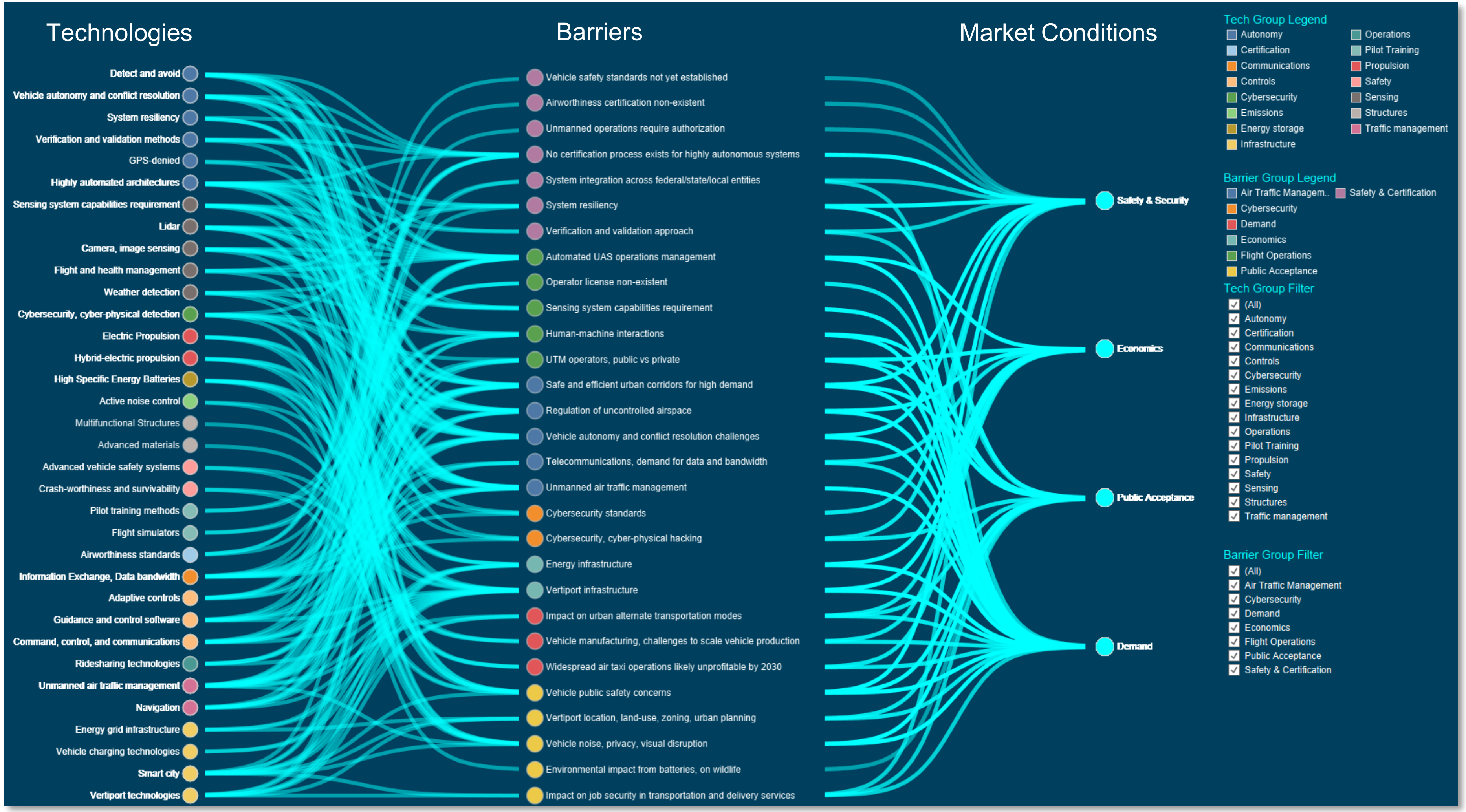
All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

Rationale for a UAM Technology Assessment Framework

- UAM **differs from traditional aeronautical concepts** in several ways:
  - UAM is a **highly integrated and interdependent** system-of-systems
  - Some of the **key technologies are outside the traditional aeronautics areas**
  - **Public acceptance and infrastructure investment** pose major barriers
- ARMD will need to **assess the viability of UAM markets and concepts** and determine how existing and proposed technologies can help to overcome the associated barriers
- A **consistent and comprehensive framework** can support NASA portfolio decisions as markets and technologies evolve
- The framework can **help to identify where additional data or analysis is needed** to improve the quality of assessments

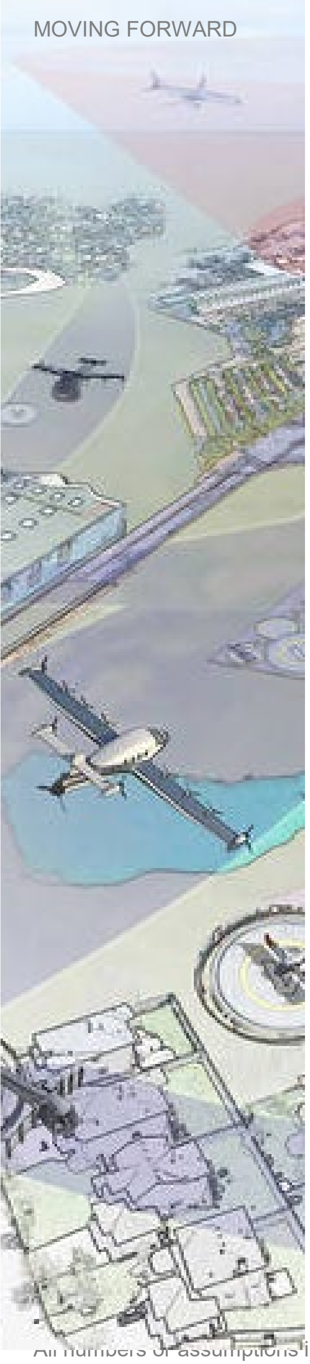
Detailed UAM Technology Assessment Framework

- Tableau or similar software can be used to trace connections or impacts across the framework
- The framework can be portrayed at multiple levels of detail



Contents

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models



Moving forward

- It is critical to evaluate UAM in terms of specific use cases (e.g., air metro) to produce meaningful results
- Determining the viability of specific UAM use cases likely requires a holistic approach that considers UAM's complex ecosystem
  - This study used over 100 discrete assumptions for the use cases (from the cost of sensing systems, to battery efficiency, to weather estimates in the 15 US cities studied)
  - Many of the most significant challenges to UAM are regulatory or policy-related across multiple governmental entities and would likely need to address evolving technologies
- There is an opportunity to coordinate planning for UAM research with industry needs
  - No single actor (public or private) has emerged yet as the UAM industry convener
  - Market participants do not yet agree on the vision for each UAM use case
- Public acceptance of UAM is likely to be more complicated than asking popular opinion; local policy, interest groups and research (for example, on noise) each play a major role

Last-mile Parcel Delivery and Air Metro Markets

There could be a commercially viable market for last-mile parcel delivery and air metro service

- Last-mile parcel delivery may be a **profitable market with ~500M UAS deliveries at a price point near ~$4.20 per delivery by 2030**, economic break-even point around 2030
- **Air metro may be profitable in 2028**, with **~750M passenger trips by 2030 at a price of ~$30 per trip** across the 15 major metro areas

Viability of these markets will likely require:

- **Step-change technology advances** in key areas, (e.g., UTM, detect-and-avoid, noise management, operations in GPS-denied environments, automation, and autonomous flight controls)
- Development and implementation of a functional **robust UTM system**
- **Cost declines of key technologies** (e.g., LiDAR, battery storage, sensing, and navigation systems)
- **Regulations** that allow these operations and associated progress (e.g., airworthiness standards for vehicles; lack of local ordinances blocking UAM)
- **Infrastructure investment** (e.g., receiving vessels and vertiports) to provide the necessary coverage for UAS delivery and air metro transportation of people

Air Taxi Market

- There may be a **limited potential market for air taxis** in concentrated areas of high net-worth individuals and businesses
- **Cost of ubiquitous vertistops** may make the air taxi model prohibitive in 2030
- There may be **concentrated areas of high-net worth individuals and businesses served by an air taxi solution** (e.g., Manhattan to suburbs)

Regulation and Certification

- **Five major categories of regulation** need to be addressed: air traffic & fleet operations management, vehicle development & production, airspace design & implementation, individual vehicle management & operations, and community integration
- Most **requirements reside at the Federal level** (FAA, DOT, and DHS), but there is **state and local involvement** in the form of registration requirements for operators and vehicles, zoning and other infrastructure requirements, and local ordinances
- Leveraging **innovative risk management approaches**, such as SMS and **selected industry self-regulation**, can help accelerate these timelines
- Major challenges include **time-consuming regulatory processes, regulators' resource constraints, pressure to move more quickly, development needs for key technologies, and state and local pre-emption**

Public Acceptance

- Public acceptance concerns likely focus on **safety, privacy, job security, environmental threats, and noise & visual disruption**
- Consumer and community concerns **involve a variety of stakeholders** with a variety or views, roles, and degrees of influence
- For UAS last-mile delivery, consumers are likely most concerned about **safety, theft of packages, and invasion of privacy**
- In UAM transport cases, consumers are likely most concerned about **safety of passengers and bystanders and prohibitively high costs**
- Consumers cite **proven safety records and demonstrations as factors that would most increase their level of comfort**

Lessons Learned

- Analysis of UAM markets requires a **holistic approach that considers interconnected conditions for viability**
  - For example, many of the most significant challenges to UAM are regulatory- or policy-related **across multiple governmental entities and may address evolving technologies**
- **Use cases are a vital tool** to produce meaningful results
  - The use cases highlighted both common threads across the three markets and differing levels of conditions for viable markets, and they produced specific issues for NASA consideration
- Planning for UAM research **may consider assumptions and inputs from a wide range of sources**
  - **No single actor (public or private) has emerged as the convener for UAM**, and there is may not be agreement among market participants about viability and timing of UAM use cases
- Similarly, UAM studies may recognize that **public acceptance is a complex issue encompassing multiple perspectives** from a variety of sources

Appendix

- **Econometric and public acceptance analysis**
  - Enabler Analysis
  - Public acceptance deep-dive
  - Model equations
  - Demand deep-dive
  - Supply deep-dive

Appendix

- **Econometric and public acceptance analysis**
  - **Enabler Analysis**
  - Public acceptance deep-dive
  - Model equations
  - Demand deep-dive
  - Supply deep-dive

There are likely three significant infrastructure requirements for last-mile delivery and air metro UAM use cases

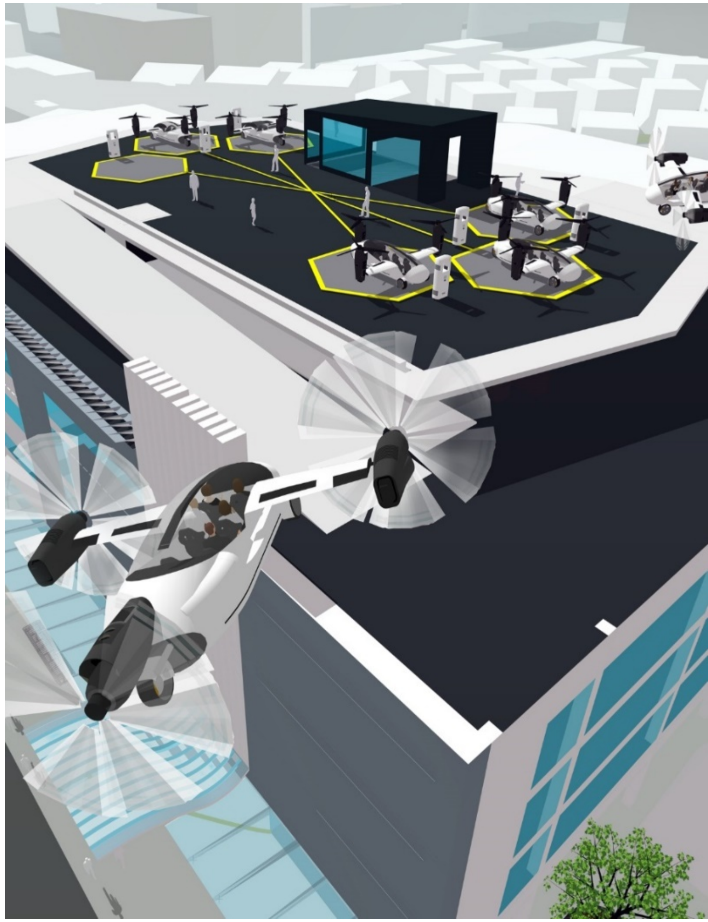
	Description
1 Vertiports	▪ Locations for embarking, disembarking, and charging passenger eVTOLs in the air metro use case ▪ Capable of accommodating several stationary eVTOLs simultaneously
2 Receiving vessels	▪ Infrastructure for receiving package deliveries in urban or suburban areas ▪ Vessels are in lieu of backyard, personal landing locations, which are limited in metropolitan areas due to space constraints, theft concerns, and flight restrictions
3 Distribution hubs	▪ Locations for distributing packages (analogous to modern Amazon or USPS distribution centers) ▪ Likely to be current infrastructure that is retrofitted for UAM needs

Significant cost reduction for any of these vital pieces of infrastructure could have a major impact on UAM markets

1 Basic requirements for average vertiports in 2030

~2,500-3,500 vertiports could be distributed across MSAs to meet projected air metro demand. The average vertiport may be capable of accommodating **between 3 and 6 grounded vehicles at one time** (though some vertiports may be larger or smaller depending on space, demand, and location) to allow passengers to embark and disembark and to accommodate rapid battery swap within the roughly **2-4-minute landing time**. The specific number of vehicles that each vertiport can accommodate will likely vary depending on location. In urban areas, vertiports are likely to be located on the rooftops of buildings, and large urban hubs may be constructed by having several rooftops serve as vertiports in the same area

	Requirement type	Description of average vertiport
Physical requirements	Number of vehicles accommodated	3-6 vehicles on average, but the number of vehicles will vary based on location, space available, and demand
	Total vertiport size[1]	~24-50K sq feet per vertiport on average, including landing areas and additional space for loading/unloading, etc., but will vary based on location and number of landing areas
	Density in MSA	~100-300 vertiports per MSA (twice as dense as metro/subway systems in MSAs), potentially in a hub and spoke model
	Useful life	~10-20 years – given high volume of vehicle landings per structure per day, structure may require significant updating after this time period
	Location placement	Stops placed at strategic high-demand areas with requisite space (e.g., airports, large train stations); hubs may be created by having several vertiports in the same area
Cost requirements	Land cost	~$16-$26 per square foot, based on average cost of underutilized space, may increase as UAM market grows
	Labor	1-5 workers at $15-20/hour, including security guard, maintenance worker(s), and passenger support staff (though will vary based on location needs)
	Building costs	$1-4M, depreciated over the useful life of the vertiport (structure costs include fire suppression system, building materials)
	Maintenance	Maintenance worker(s) fully staffed at the vertiport in case of vehicle or charger defect (~$15-20/hour)
	Cost to retrofit existing structure(s)	NA – few existing buildings have helipads on their rooftops



- **Vertiports may increase utilization with dedicated takeoff and landing locations and then having vehicles taxi to a passenger loading and unloading location**
- **In the long-term there may be investment in dedicated buildings for eVTOL transportation**

1 Assumes vertiports will not be regulated by current FAA heliport guidelines and assumes a decrease in separation for simultaneous operations with the improved precision of autonomous vehicles.
All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

1 Vertiport operations in 2030 could follow a distributed hub and spoke model

Distributed hubs would likely be located in heavily trafficked areas. To accommodate high volumes, a cluster of rooftops in the area may have vertiports and could together serve as the "hub"

Suburban areas may be serviced by 1-2 vertiports – "the spokes"

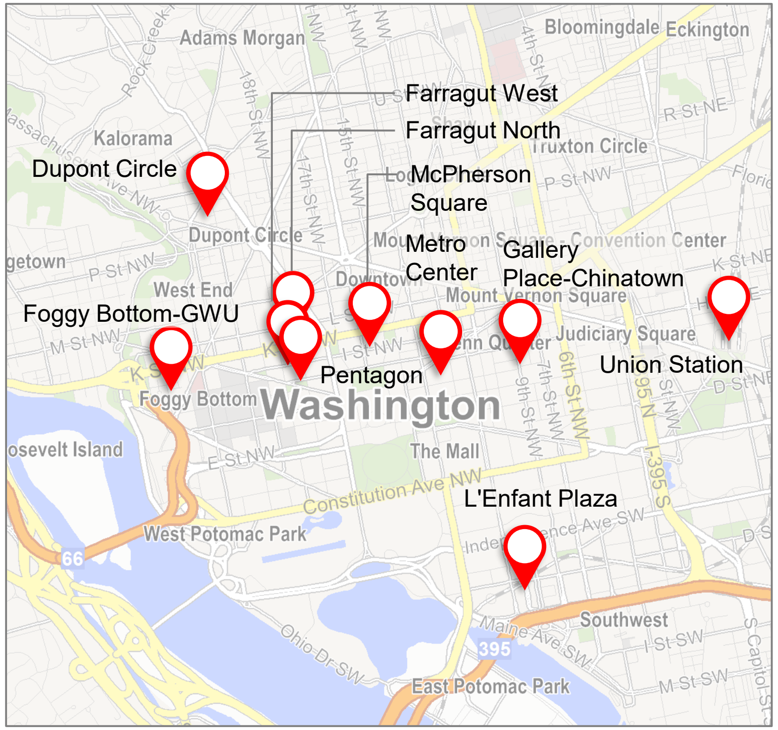
Each vertiport may service a limited number of routes. Routes will be demand-driven and may be modified or updated as demand shifts. Passengers may reserve seats in advance to allow for route optimization

As the business case for air metro services becomes firmly established, structures specifically built to accommodate eVTOLs may emerge

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models.

1 Distributed hub example: In Washington D.C., 10 distributed hubs with 33 vertiports at current metro locations may be needed to accommodate >30% of peak hour demand

Station equivalent	Percent demand[1]	Number of landing areas required[2]	Number of vertiports required[3]
Union Station	4.77%	18	5
Metro Center	3.93%	15	4
Gallery Place-Chinatown	3.66%	14	4
Farragut North	3.59%	13	4
L'Enfant Plaza	3.30%	12	3
Farragut West	3.06%	11	3
Foggy Bottom-GWU	2.88%	11	3
Dupont Circle	2.77%	10	3
McPherson Square	2.16%	8	2
Pentagon	2.13%	8	2
Total	**32.25%**	**120**	**33**



1 Assumes same percent distribution of weekday commutes as the listed DC metro stations 2 Assumes average number of vehicle trips per hour of 3,004 (740M passenger trips divided by 15 MSAs, divided by 365 days per year and 15 hours of air metro service time) and that peak hour (e.g., rush hour) vehicle trips per hour are 3,905 (30% higher than average). Also assumes that every landing area can accommodate 10.91 vehicles per hour 3 Assumes all vertiports have four landing areas
SOURCE: Metrorail average weekday passenger boardings 2017, WMATA

2 Basic requirement for receiving vessels

Packages delivered via UAS may be dropped off in receiving vessels in urban and suburban areas where backyard drop-off may not be a viable delivery method. **Customers or intermediary runners could walk to the receiving vessel to** retrieve the package for pick-up. Receiving vessels may need to be placed at a high enough density within the MSAs to ensure that **round-trip walking time to pick up a package is no longer than 5-10 minutes**

	Requirement type	Description
Physical requirements	Structure size	Size of individual structures not limited by cost or anticipated regulations – only by available rooftop space and demand
	Density in MSA	~4-8 vessels per sq. mi. depending on population density; serves ~400-900 people per vessel
	Number of packages accommodated	Limited only by rooftop space available; each serves ~400 people in urban locations, ~900 in suburban locations
	Useful life	~5-15 years – vessels likely to require updating of electronic equipment and landing systems
	Location placement	Rooftops of gas stations and structures of similar size; may become amenity offered by apartment developers
Cost requirements	Land cost	~$10-20 per square foot, based on average cost of underutilized space, may increase as UAM market grows
	Labor	Cost for intermediary runner estimated at close to minimum wage (~$15/hour); 10% of 40-hour workweek per vessel
	Building costs	~$10-15K per vessel – includes landing zone, beacon, and guiding equipment/lights to help facilitate UAS landing
	Maintenance	~$110-$140 annually for basic maintenance (assumed 1 visit needed per locker per year)
	Cost to retrofit existing structure(s)	NA – no such vessels currently exist, and existing rooftop infrastructure alone cannot support secure UAS delivery

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

3 Basic requirements for distribution hubs

Distribution hubs may either be centralized or decentralized (e.g., retail stores with individual hubs to send orders directly to consumers). Existing centralized distribution hubs – **specialized warehouses stocked with packages to be delivered to their final destinations** - may be retrofitted to accommodate UAS activity, and the model assumes **roughly 100-300 hubs per city (or 1 for every ~200,000-300,000 people)**. Development costs may range depending on strategy: 1) **repurposing** of available infrastructure, 2) **renovation** of facilities with similar layout and physical structure, 3) **development of new facilities** and infrastructure

	Requirement type	Description
Physical requirements	Structure size	~600-800K sq. feet for existing fulfillment centers operations, ~30-40K sq feet for existing instant delivery hubs
	Density in MSA	~1 per 200-300k people (more for mega-hubs in suburban areas, fewer for smaller urban fulfillment centers)
	Number of vehicles accommodated	~80-120 UAS per distribution hub, though facilities may be easily retrofitted to accommodate larger numbers
	Useful life	~4-7 years – estimated as number of years before retrofitting requires updating due to increased automation
	Location placement	Centralized hubs already placed; decentralized hubs to be placed at or near retail stores with necessary demand
Cost requirements	Land cost	No distinct land cost baked into total cost of UAS delivery since centralized hubs already exist for non-UAS delivery
	Labor	~$10-20/hour, but annual costs will decrease as automation within facilities increases
	Building costs	NA – assume that UAS operations will be incorporated into existing hubs and fulfillment centers
	Maintenance	Maintenance needs may increase as automation within facilities increases, but will be borne across delivery modes
	Cost to retrofit existing structure(s)	~$50-150K/hub to create docking racks for unused vehicles, automatic bay doors, automated payload conveyor belts

For UAM to be viable, it is necessary to address the technical, physical, operational, and integration challenges of UTM

	Description
1 **Technical capabilities**	▪ Operational tasks that a UTM system must be able to execute in order to create safe flight patterns (e.g., route deconflicting, severe weather avoidance, flight sequencing and spacing)
2 **Physical infrastructure**	▪ Physical requirements for a UTM system (e.g., beacons to create corridors, servers to run system, buildings to host flight exception management operators)
3 **Operational barriers**	▪ Operational improvements required to allow large-scale deployment of UAM (e.g., manual sector handoffs, low operator-vehicle ratio)
4 **Airspace integration**	▪ Integration between programs governing UAM operations in class G airspace and the National Airspace System (NAS) ▪ Solutions to preemption by state and local authorities ▪ Coordination across private operators

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

1 An adequate UTM system will likely need to be capable of solving a number of complex technical tasks

ATM requirement	Description
Airspace design	Rules for operating within specific geographic locations based on altitude or proximity to people / places or objects of interest
Corridors	A system of air routes into and out of high traffic areas (e.g., VTOL “highways”)
Dynamic geo-fencing	The ability to push information to a UAS in or near areas with prohibitions on UAS operations based on current events (e.g., concert)
Severe weather avoidance	A way to monitor developing weather situations on the ground and push this information to UAS in order to prevent flight into dangerous weather
Congestion management	System is able to provide data to UAS about congestion and guidance to avoid or operate safely within these areas
Terrain avoidance	Direction to the UAS that will allow it to avoid contact with the earth’s surface and built up structures (e.g., buildings, etc.)
Route planning and re-routing	Service that plans an optimal route from takeoff to landing taking into account the vehicle characteristics, weather, payload, and other traffic
Separation management	Ensures a safe distance between UAS vehicles within and between aerodomes
Sequencing and spacing	Ensures that UAS vehicles are properly separated during takeoff and landing for safe operations, taking into account weather and vehicle characteristics
Contingency management	Emergency landing site guidance for UAS and geo-fencing segments of airspace

2 Executing those technical tasks likely necessitates a robust physical UTM infrastructure

	Potential 2030 cost	Description/assumptions involved
Beacons	**$40-60M**	▪ ~$80-120 per beacon ▪ Assuming 3-6 beacons per square mile to create corridors to help provide guidance for the vehicles and effective UAS 'travel lanes' ▪ Useful life of 40-60 years
Flight exception management locations	**$10-20M**	▪ ~$1-2M per building ▪ Assumes 1 location per MSA (15 total) ▪ Building useful life of 40-60 years ▪ Building location needs to include computers, desks, chairs for remote operators
Telecom system upgrades	**$20-40M annually**	▪ Assumption is that 5G infrastructure investments are exogenous to the UTM system ▪ Upgrade costs will be~ $20-40M annually in the US alone
Autonomous functionality servers	**$0.3-7M**	▪ ~2% of revenues for all operational costs ▪ Assumes server costs are ~$0.3-0.6M for delivery use case, which has lower vehicle costs, and ~$4-7M for air metro use case ▪ Assumes server costs are only costs associated with full UTM integration

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

3 Operational barriers that may need to be solved to unlock UTM in urban environments

What exists now	What may be required for fully-scaled UAM operations	
Manual sector hand-offs	**Automated sector hand-offs**	▪ Requires creation of dynamic sectorization model to accommodate high traffic volume (current system handles low-volume commercial airline traffic) ▪ Automated management of sector handoffs ▪ Necessitates processes to identify, highlight and alert when conflicts require human intervention (e.g., FAA's LAANCE low-altitude notification system)
1:10 operator to aircraft ratio	**1:100 operator to aircraft ratio (for delivery)**	▪ Requires substantial technological increases in sensing system capabilities (e.g., automation, GPS-denied environments, LiDAR) ▪ Needs verified processes to identify conflicts that cannot be resolved by automated systems and processes to facilitate emergency rapid hand-off to human operators on standby
Strict airspace restrictions in urban environments	**Urban corridors to accommodate high demand**	▪ Requires management of operational traffic by creating safe and efficient corridors volume to maneuver in low altitude ▪ Creates determination of safe distances between vehicles based on weather contingencies
Airspace division above / below 400 feet	**Modified regulation of Class G airspace**	▪ Requires clear rules to be set up that will cover traffic between individual vehicles and cross operators, as most UAM operations will occur in currently unregulated class G airspace ▪ Necessitates solving jurisdictional questions over class G airspace to anticipate widespread attempt at preemption by state/local authorities

3 UAS operations may take 5 forms that each present unique challenges to integration with the NAS

Operations relevant for UAM

	Description	Potential challenges to NAS integration
1 Visual line of sight operations	▪ Operations within the visual line of sight of the operator ▪ Only occurring within class G airspace	▪ No challenges as no need to integrate – no VLOS operations occur above class G airspace ▪ VLOS operations do not require a robust UTM system for management as aircraft remains in operator VLOS
2 Low-altitude rural operations	▪ BVLOS operations within class G airspace in rural areas ▪ Lower risk of flight over people or close to stationary objects (e.g., buildings)	▪ Will likely require some degree of UTM capabilities in order to ensure against conflicts with other aviation operations (e.g., precision agriculture operations)
3 Low-altitude urban operations	▪ BVLOS operations in class G airspace in urban areas ▪ Flight over people and proximity to stationary objects (e.g., buildings)	▪ Will likely require a robust UTM system that can interface with dense, controlled air traffic environments and operate safely in uncontrolled airspace (e.g., traffic monitoring / package delivery)
4 Visual Flight Rules (VFR)-like operations	▪ Operations below critical NAS infrastructure (between class G and 10K' MSL)	▪ Will likely need to routinely integrate with both cooperative and non-cooperative aircraft (e.g., infrastructure surveillance, passenger transport)
5 Instrument Flight Rules (IFR)-like operations	▪ Flight above 10K' MSL ▪ Example use cases of cargo transport and communication relay	▪ UAS will likely be expected to meet certifications standards and operate safely with traditional air traffic and ATM services (e.g., communication relay and cargo transport)

Creating an effective UTM system not only requires technical solutions but also a process to seamlessly address needs spanning all classes of airspace

4 Second-order challenges beyond NAS integration may present themselves as the industry grows

A. Solving preemption from state/local authorities

System integration across state lines may become increasingly complex as state and local governing bodies begin to enact widely varying rules and regulations over airspace critical to UAM operations

- Both state and local authorities have begun to make efforts to **preemptively claim control over class G airspace** in order to set individual rules and regulations on UAS flight
- In some cases, preemption by state and local authorities has resulted in **less restrictive regulations enacted to encourage innovation**
- However, other governing authorities have created strict rules within their own class G airspace in order to **severely limit or ban flights entirely**
- The industry may need to **solve the question of jurisdiction and deconflict claims** in order to have effective air traffic movement between regions/states
- The FAA Drone Advisory Committee (DAC) created a subcommittee to address this question
- Thus far **no other public entity is addressing these questions**

B. Solving coordination across private operators

Forgoing a standardized, publicly-run UTM system in favor of a system that is privately run by one or more operators may have significant implications for the types of challenges that need to be addressed

Will there be multiple operators?

- Having 2 or more operators controlling separate systems in a given region

Which operator is controlling which airspace?

- Clear delineations between companies' different "airspace turf" are required to ensure safe operations

How will gaps in UTM coverage be filled?

- Rural areas will likely be more costly to cover, incentivizing fragmented and incomplete UTM coverage

How to integrate disparate systems to provide complete coverage?

- These separate systems must be able to communicate easily to de-conflict and reroute vehicles
- UTM systems must also integrate handoffs from automated to manual control in case of emergency

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

Aircraft design typically spans at least 8 major systems, many of which will likely have specialized requirements for UAS deliveries and VTOL transportation

NON-EXHAUSTIVE

System	Description	Likely delivery use case requirements	Likely air metro use case requirements
1 Aerostructures	▪ Airframe including fuselage, wings (if applicable), empennage; nacelles	▪ Airframe must incorporate package drop-off/pick-up mechanism ▪ Should be able to withstand stress from frequent landing	▪ Must be able to withstand and correct for weather interference, including in urban canyons ▪ Should be able to withstand stress from frequent landing
2 Engines and APUs	▪ Rotors, housing, engine controls ▪ APU incl. accessories and control electronics	▪ Rotor redundancy in case of primary system failure	▪ Rotor redundancy in case of primary system failure
3 Avionics, flight control	▪ Flight management, navigation ▪ Flight control computer and software, actuators	▪ Autonomous route development and navigation despite loss of signal or poor conditions ▪ Ability to integrate with UTM system and update unscheduled flight paths in real-time	▪ Autonomous route development and navigation despite loss of signal or poor conditions ▪ Able to integrate with UTM system and modified scheduled flight paths in real-time ▪ Emergency systems and protocols must be developed to minimize risk in situations of crisis or vehicle failures
4 Electrical systems	▪ Power generation, management, and distribution, excluding actuation	▪ High-precision electric propulsion to allow for precise navigation and package drop-off at receiving vessels ▪ Sufficient range to service 10 mile maximum distance, with some reserve battery ▪ Safe guards must be in place for heat and fire concerns	▪ Electric propulsion system capable of maintaining safe operations in urban corridors ▪ Sufficient range to service 75 mile maximum distance, with some reserve battery ▪ Safe guards must be in place for heat and fire concerns
5 Hydraulic systems	▪ Hydraulic power generation and distribution excluding actuation	▪ Not applicable to UAS delivery	▪ Not applicable to eVTOLs
6 Interiors	▪ Seating, controls/displays, air conditioning, heating, pressurization, cargo handling system	▪ Not applicable to UAS delivery use case	▪ Must be able to accommodate 4 passengers, with some incremental payload (e.g., suitcases)
7 Landing gear	▪ Includes electronic controls, steering, wheels, and brakes	▪ Must be capable of vertical takeoff and landing (VTOL), requiring landing skids	▪ Must be capable of vertical takeoff and landing (VTOL), requiring landing skids
8 Other systems	▪ Diverse selection of subsegments including noise and inclement weather mitigation technologies	▪ Must not create unsustainable noise levels for affected communities ▪ Weather mitigation system	▪ Must not create unsustainable noise levels for affected communities ▪ Weather mitigation system

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

Appendix

- **Econometric and public acceptance analysis**
  - Enabler Analysis
  - **Public acceptance deep-dive**
    - Transportation
    - Delivery
    - Noise and visual impacts
  - Model equations
  - Demand deep-dive
  - Supply deep-dive

The approach to assessing public acceptance

	Stakeholders involved	Description	Key output
A Survey	Consumers	▪ **Survey distributed to ~2500 individuals** living in 5 representative US cities[1] based on size, density, public transportation use, and congestion ▪ Asks wide variety of **questions across broad UAS and VTOL acceptance and specific use cases for UAM**	▪ Data addressing **overall consumer comfort with UAS technology** ▪ **Highest priority reported concerns** for future use of transporttation and delivery UAM (e.g., safety, cost, noise, etc.) ▪ **Comfort with competing technologies** (e.g., driverless cars)
B Interviews	Local governments	▪ **Local and state government representatives** and legislators in key urban environments ▪ Representatives of special districts **drafting regional UAS legislation**	▪ Current and planned **local and state mitigation strategies for addressing public concerns** ▪ **Perspectives on upcoming legislation** impacting UAM use case adoption
	Anti-UAS organizations	▪ **Lobbying groups** formally organizing against UAS adoption and UAM markets ▪ **Grassroots organizations and activists** attracting public support	▪ Detailed **UAM concerns from public and private actors** ▪ Assessment of potential **current and future barriers to UAM adoption**
	UAS and UAM unions and advocacy groups	▪ **Lobbying groups (both UAM industry and other impacted sectors)** organizing to support broader UAM adoption ▪ **Non-profit groups** (e.g., AUVSI, Small UAV coalition) dedicated to accelerating UAS and UAM rollout	▪ **Potential strategies** for addressing public concerns ▪ Understanding of **active and planned public acceptance initiatives**
C Literature review	Public reports and press search	▪ **Press search** of relevant articles published in newspapers, blogs, and other forums ▪ **Review of external reports** focused on UAM adoption and public acceptance	▪ Understanding of **public discourse concerning impacts of UAM rollout and adoption** ▪ **Review of previous efforts to understand public acceptance** and implications for UAM adoption

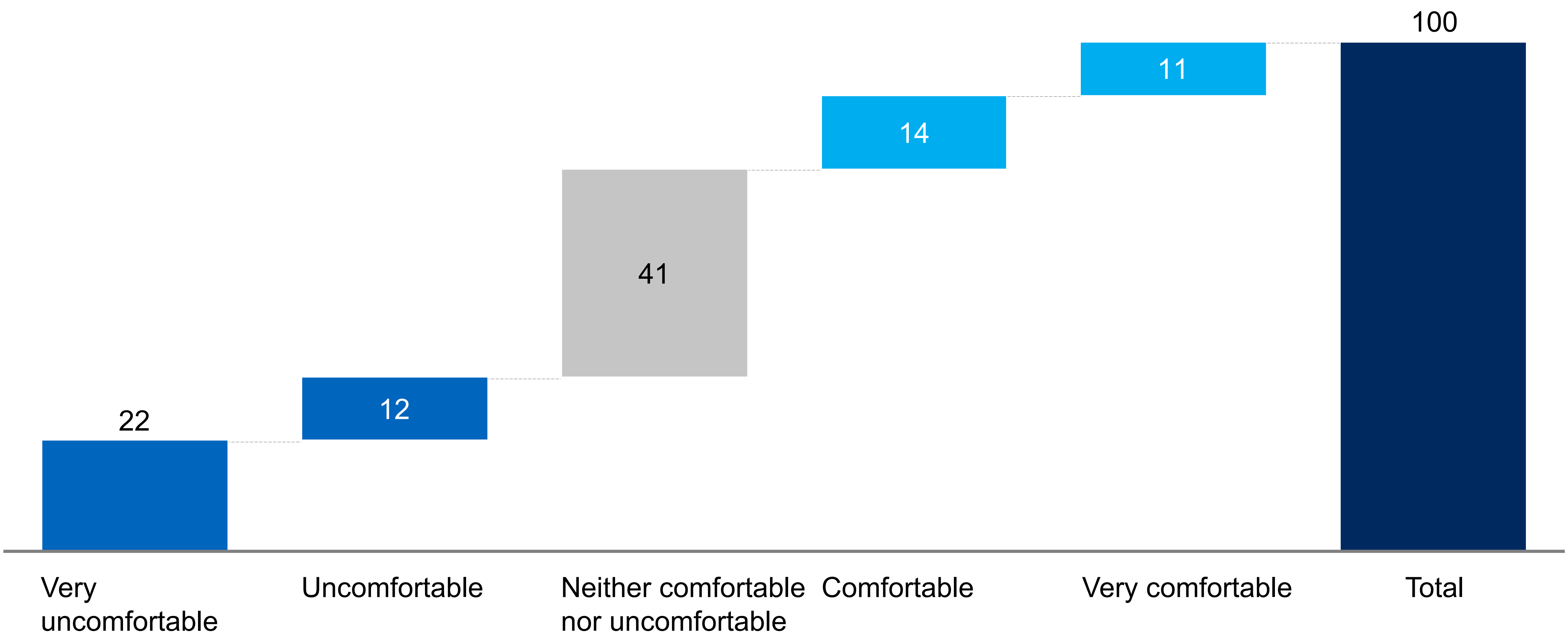
1 New York City, Dallas, Washington DC, San Francisco, Detroit

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

A 34% of target market consumers report they are not comfortable with UAS technology today

Public comfort with UAS technology[1]

% of total respondents



1 Based on survey question, “How comfortable are you with the idea of UAVs (unmanned aerial vehicles) generally?” where survey answers ranged from 1 (very comfortable) to 5 (very uncomfortable)

SOURCE: Survey of n = 2500 respondents across five representative US metropolitan areas: New York City, Washington, D.C., Dallas, Detroit, and San Francisco

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

Appendix

- **Econometric and public acceptance analysis**
  - Enabler Analysis
  - **Public acceptance deep-dive**
    - **Transportation**
    - Delivery
    - Noise and visual impacts
  - Model equations
  - Demand deep-dive
  - Supply deep-dive

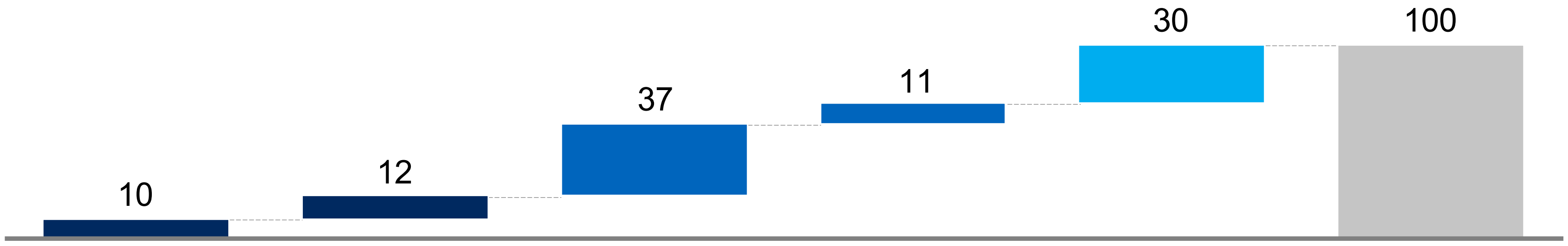
All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

A 27% of consumers report they are unlikely to use autonomous air taxi services in the future

Public acceptance of air taxis[1]

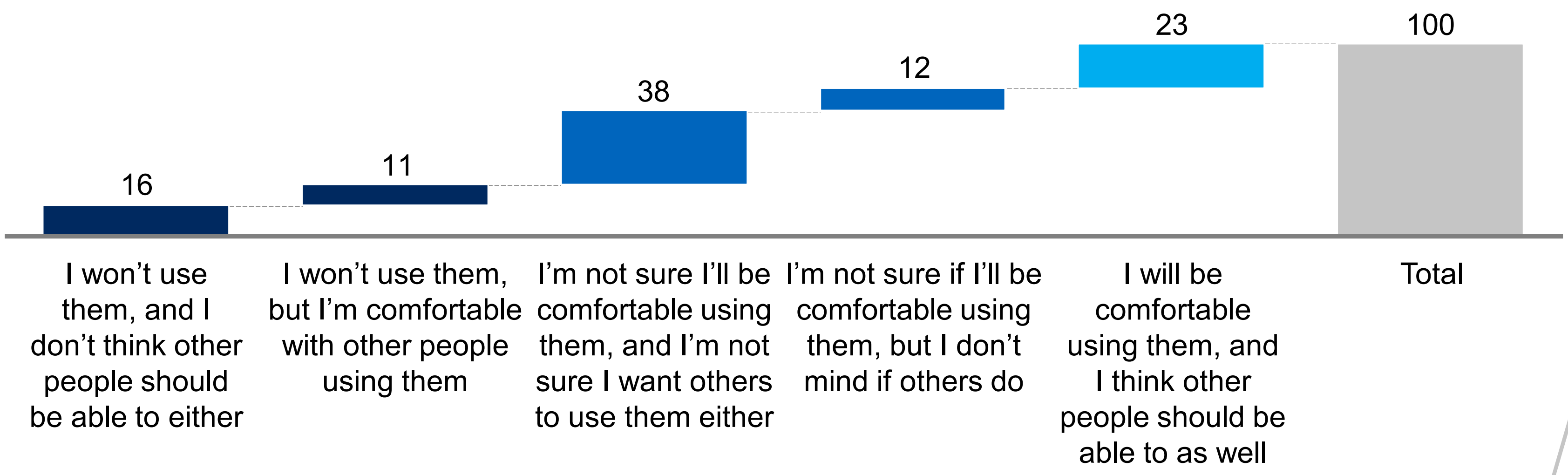
Public acceptance of *piloted* air taxis

% of total respondents



Public acceptance of *autonomous* air taxis

% of total respondents



Key takeaways

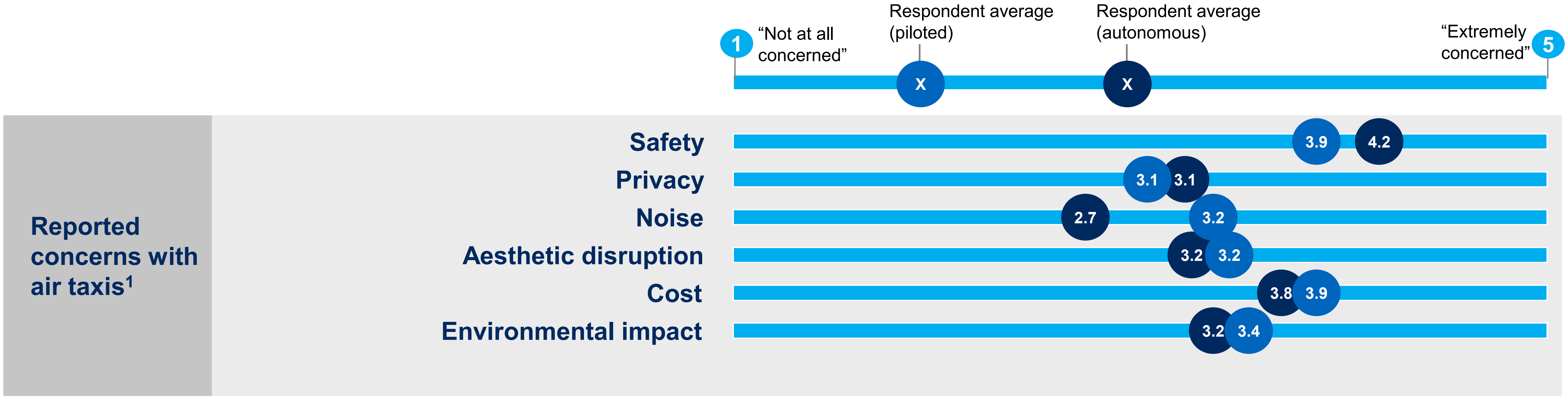
- **Only 5% more consumers are uncomfortable** with anyone using autonomous air taxis as they are with anyone using piloted air taxis
- The majority of respondents **(>70%)** report that they would be comfortable with other people using air taxis services
- 16% of respondents are **not comfortable** with anyone using autonomous air taxis
- Acceptance of autonomous vehicles may change as autonomous ground vehicles become more common

1 Based on 2 survey questions for piloted and autonomous air taxis: "Which one of the following best describes your level of comfort with future piloted / autonomous air taxi services?"

SOURCE: Survey of n = 2500 respondents across five representative US metropolitan areas: New York City, Washington, D.C., Dallas, Detroit, and San Francisco

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

A When it comes to autonomous air taxis, the survey suggests consumers are most concerned with safety and cost



"I worry about the safety factor of both someone in the air and on ground with them."
– Washington DC, age 32

"I'm worried about the possibility of them being hijacked and used against innocent civilians."
– Dallas, age 25

"Safety... technology fails at times just like humans do. I have yet to own technology that has not failed me at all at some point in time or another."
– San Francisco, age 28

1 Based on survey questions, "How concerned are you with the following when it comes to autonomous/piloted air taxis: privacy, noise, safety, environmental impact, cost, aesthetics from 1 (not concerned) to 5 (very concerned)

SOURCE: Survey of n = 2500 respondents across five representative US metropolitan areas: New York City, Washington, D.C., Dallas, Detroit, and San Francisco
All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

A Safety is a particularly high concern for consumers who are the most skeptical of autonomous transportation services

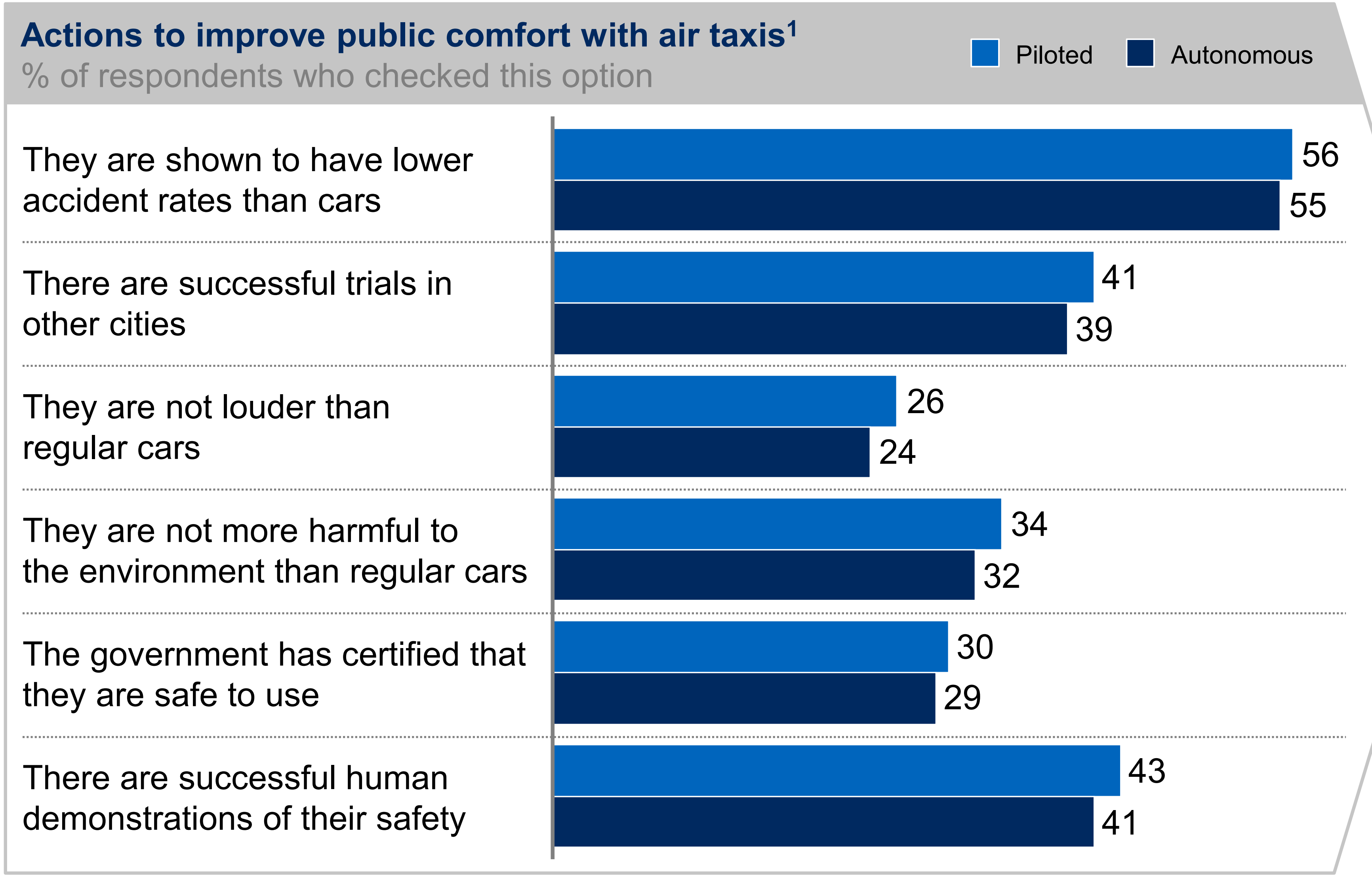
Low concern[1] | Mid concern[1] | High concern[1]

	"I won't use them, and I don't think other people should be able to either."	"I won't use them, but I'm comfortable with other people using them."	"I'm not sure I'll be comfortable using them, and I'm not sure I want others to use them either."	"I'm not sure I'll be comfortable using them, but I don't mind if others do."	"I will be comfortable using them, and I think other people should be able to as well."
Number of respondents	404	266	922	300	571
Privacy	60%	42%	47%	39%	32%
Noise	50%	32%	36%	39%	28%
Safety	90%	79%	85%	82%	60%
Environmental impact	55%	50%	49%	47%	40%
Cost	69%	66%	69%	69%	62%
Aesthetics (disruption to view of sky)	48%	42%	31%	51%	75%

1 "Low concern = 0-49%; "Mid concern" = 50-74%; "High concern" = 75-100% 2 Based on survey questions "Which one of the following best describes your level of comfort with future autonomous air taxi services?" and "How concerned are you about the following factors when it comes to autonomous air taxis?"

SOURCE: Survey of n = 2500 respondents across five representative US metropolitan areas: New York City, Washington, D.C., Dallas, Detroit, and San Francisco

A Customers report that safety demonstrations and proof of low accident rates could make them more comfortable with the idea of UAM transport services



Key takeaways

- Consumers have almost **identical reactions** to the mitigation strategies **across piloted and autonomous UAM**
- What makes most consumers more comfortable with UAM is **proof of lower accident rates compared to human-driven cars**
- Consumers show relative **lack of concern for UAM noise**

1 Based on survey questions, “Would learning any of the following make you more comfortable with accepting autonomous air taxis?” and “Would learning any of the following make you more comfortable with accepting piloted air taxis?”

SOURCE: Survey of n = 2500 respondents across five representative US metropolitan areas: New York City, Washington, D.C., Dallas, Detroit, and San Francisco

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

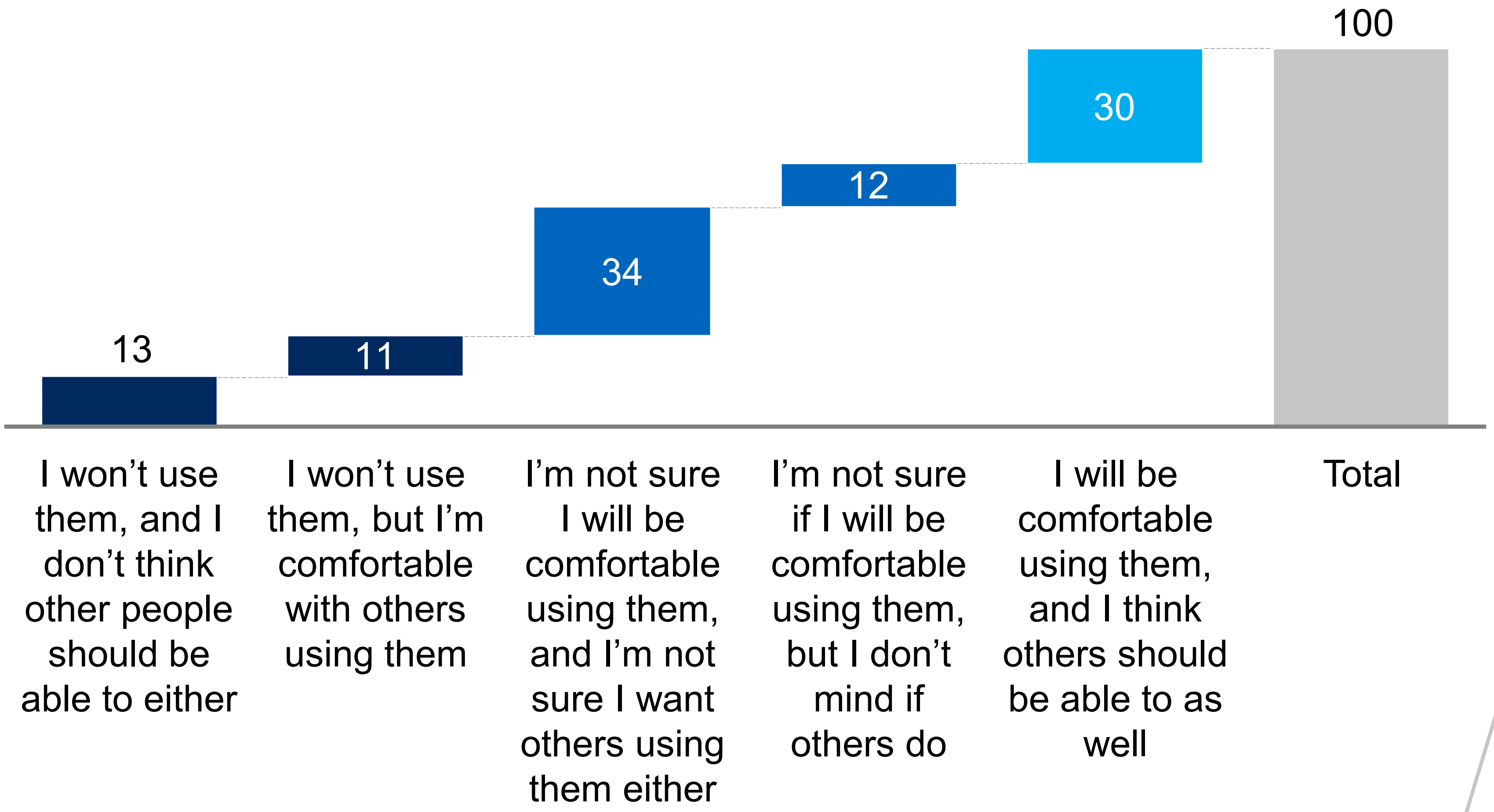
Appendix

- **Econometric and public acceptance analysis**
  - Enabler Analysis
  - **Public acceptance deep-dive**
    - Transportation
    - **Delivery**
    - Noise and visual impacts
  - Model equations
  - Demand deep-dive
  - Supply deep-dive

A 24% of consumers report they are unlikely to use unmanned aerial delivery services in the future

Public acceptance of unmanned aerial delivery vehicles[1]

% of total respondents



Key takeaways

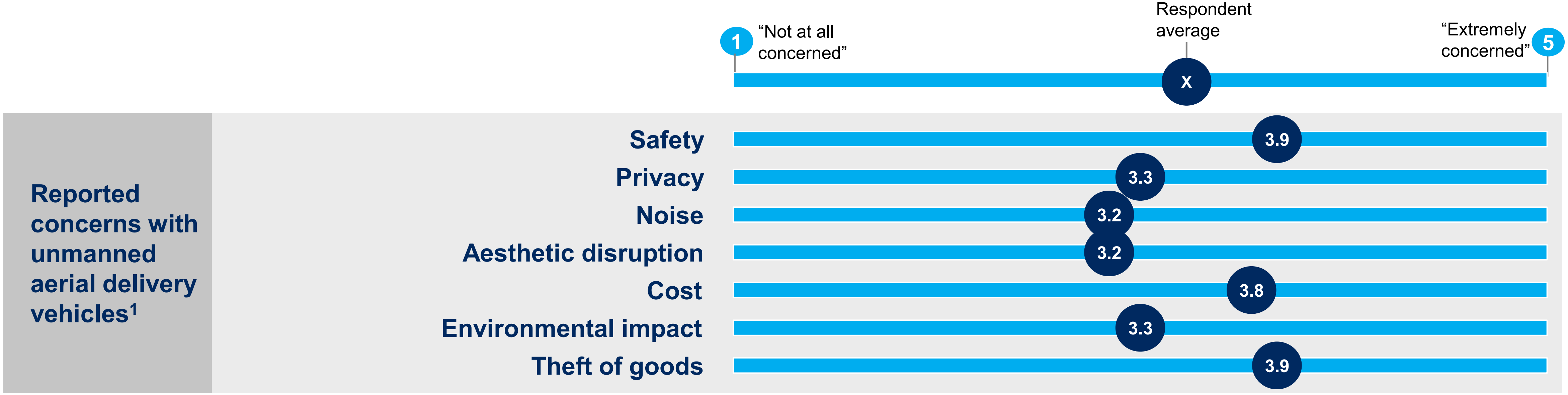
- About the **same number of people report they are uncomfortable** with using UAS for delivery as they are with using UAS for transport use cases
- **30% of consumers report they are already comfortable** with the idea of UAS deliveries

1 Based on survey question "Which one of the following best describes your level of comfort with future autonomous aerial delivery services?

SOURCE: Survey of n = 2500 respondents across five representative US metropolitan areas: New York City, Washington, D.C., Dallas, Detroit, and San Francisco

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

A When it comes to unmanned aerial delivery vehicles, consumers report they are most concerned about safety and theft of goods



I'm worried about "privacy, and that the packages they are delivering will be stolen."

– Dallas, age 63

I'm worried about "theft of goods and personal information."

– New York City, age 46

"Delivery drivers will lose their jobs when aerial delivery options take over."

– Detroit, age 24

1 Based on survey question, "How concerned are you with the following when it comes to unmanned aerial delivery vehicles: privacy, noise, safety, environmental impact, cost, aesthetics, theft of goods from 1 (not concerned) to 5 (very concerned)

SOURCE: Survey of n = 2500 respondents across five representative US metropolitan areas: New York City, Washington, D.C., Dallas, Detroit, and San Francisco
All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

A These concerns are strongest amongst consumers who are least comfortable with UAS delivery technology

Low concern[1] | Mid concern[1] | High concern[1]

	"I won't use them, and I don't think other people should be able to either."	"I won't use them, but I'm comfortable with other people using them."	"I'm not sure I'll be comfortable using them, and I'm not sure I want others to use them either."	"I'm not sure I'll be comfortable using them, but I don't mind if others do."	"I will be comfortable using them, and I think other people should be able to as well."
Number of respondents	325	263	838	285	748
Privacy	69%	47%	56%	46%	34%
Noise	61%	42%	53%	41%	32%
Safety	88%	70%	79%	72%	52%
Environmental impact	64%	46%	54%	45%	37%
Cost	79%	70%	73%	69%	66%
Aesthetics (disruption to view of sky)	66%	47%	55%	43%	30%
Theft of goods being delivered	77%	70%	78%	67%	60%

1 "Low concern" = 0-49%; "Mid concern" = 50-69%; "High concern" = 70-100% 2 Based on survey questions "Which one of the following statements best describes your level of comfort with future **autonomous** (pilotless) aerial delivery services?" and "" How concerned are you about the following factors when it comes to **autonomous** aerial delivery vehicles?"

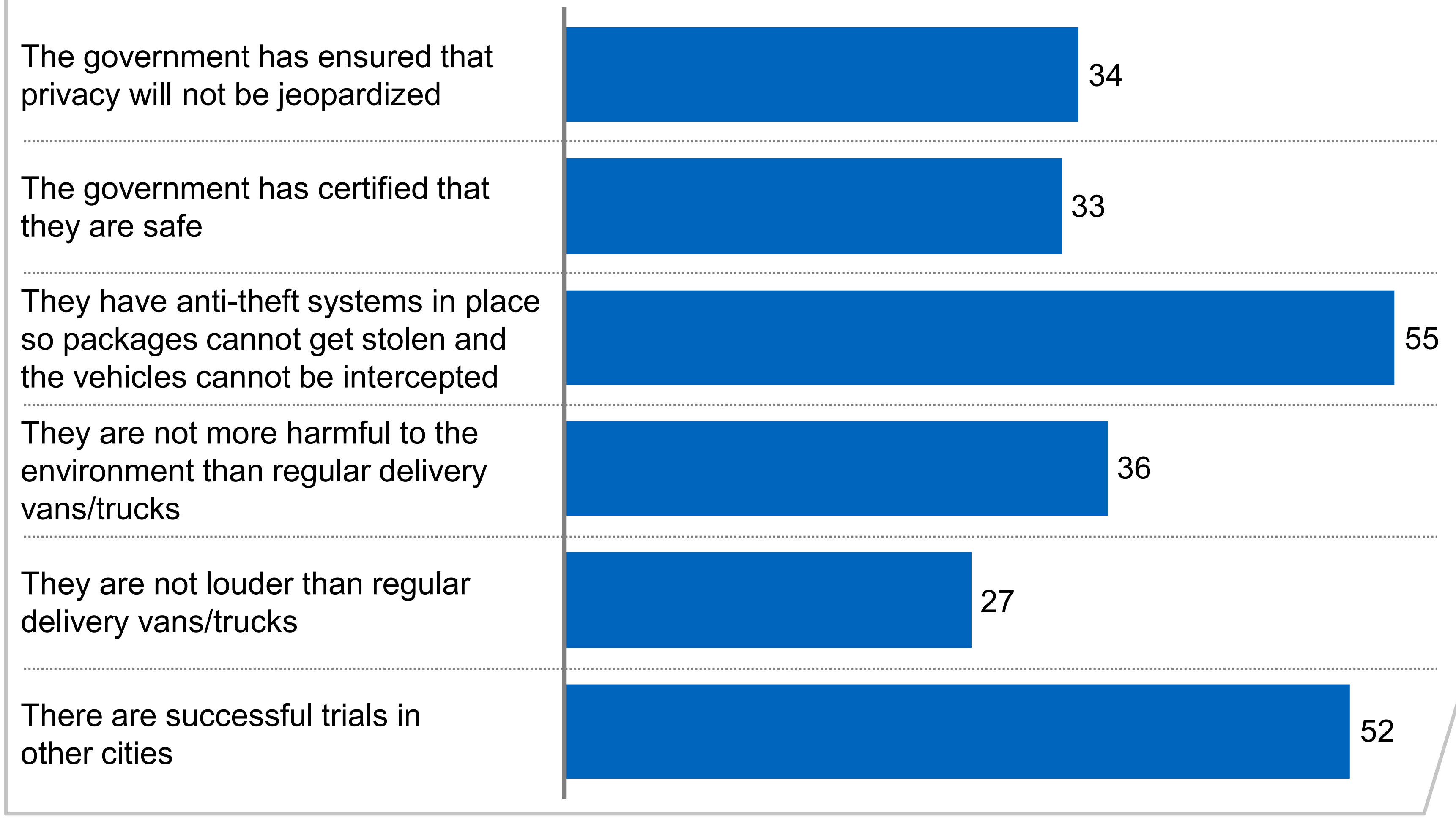
SOURCE: Survey of n = 2500 respondents across five representative US metropolitan areas: New York City, Washington, D.C., Dallas, Detroit, and San Francisco.

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

A Customers report that anti-theft devices and successful trials could make them more comfortable with the idea of unmanned aerial delivery vehicles

Actions to improve public comfort with autonomous delivery vehicles[1]

% of respondents who checked each option



Key takeaways

- **Consumers are looking for proof that their packages will not be stolen** if they are delivered via UAS
- Consumers place high value on **successful trials of UAS for delivery**
- Showing consumers that **UAS are not louder** than alternative delivery methods **least impacts their level of acceptance** of unmanned aerial delivery vehicles

1 Based on survey question, “Would learning any of the following make you more comfortable with accepting unmanned aerial delivery vehicles?”

SOURCE: Survey of n = 2500 respondents across five representative US metropolitan areas: New York City, Washington, D.C., Dallas, Detroit, and San Francisco
All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

B In interviews and press searches, consumers also express concerns with safety, environmental impact, and automation

Takeaway	Quote
Ensuring adequate safety systems is a priority	"I'm worried about **a simple glitch in the system** that could potentially shut it down. **I've never even heard of a safety system in place** on a UAV in case of failure – are there parachutes? Airbags? **These are the things I need to see and hear and know about**."
	"Computers fail all the time. Systems go down. **I want to know that if this were to occur, that there would be a back-up system in place** to manually control the aircraft."
There is fear over hacking and terrorist hijacking	"I worry that given how little we really understand about cybersecurity, **autonomous vehicles could be hijacked by hacking the flight systems**. I know regular cars have computer systems that can be hacked, but I do have a strong lingering apprehension about it."
	"Hackers could **hijack the system and either kill people or steal the goods**…they could also be used to **deliver something harmful**."
People worry about the environmental impact	"I think they will be harmful to birds and bats, **I'm worried about wildlife and the environment in general**. I would think this technology would increase **injury to birds/wildlife and disruption to their nesting or flight patterns**."
	"My main concern would be **energy efficiency and environmental impact.** It just seems like flying things would **require a lot more fuel and power**"
Loss of jobs is a big concern	""My biggest concern is **that they will cut jobs for people that currently drive for transportation or delivery services**... This technology will take away jobs from people who make their living providing these services."
	"My main concern is **the impact this will have on job opportunities for people**. If this takes off, there will be no need for humans to do these jobs. **What becomes of the people whose jobs are in transportation and delivery services?**"

Other concerns surfaced in interviews and press searches include theft of goods, privacy, and noise pollution

SOURCE: Consumer survey, expert interviews, press search
All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

B Interviews with community stakeholders and industry leaders suggest that privacy and safety concerns may be overstated and that younger consumers may be the first to adopt

Takeaway	Quote
Industry could market autonomous safety more effectively	"Right now no one is getting the message across that **this technology isn't just safe, it's actually *safer* than current options**…people in **the industry should be working on a market campaign today** because public acceptance of this fact will be slow"
	"We're confident that not having pilots fly these vehicles will be much safer and more reliable, but **people initially will not trust automated systems**…Just like with the automation of elevators, people are not going to like it at first"
Early accidents may catalyze public resistance	""Demonstrating the robustness of the safety of air taxis is key…**if there is an accident during early pilot programs in a place with less stringent regulation, consumers in the US will get scared away from the technology**""
	""Drone manufacturers have not yet created sufficient redundancy and safety systems, and haven't put enough thought into counter-UAS…**the public is not going to respond well if the industry can't answer these questions of security and accidents happen**"
Privacy concerns may stem from lack of understanding	"When we hosted town halls**, people were bringing extreme and unrealistic concerns about their privacy** – they came in assuming we didn't have any data management plan and that we had not thought through how to protect privacy in any way"
	"**People have an immediate negative reaction to the idea of cameras on drones**…even when we explain the methods we use for protecting privacy on paper, **people still need to hear that reassurance in-person**"
Younger consumers may be more accepting of autonomous technology	"Where you see the split is between people younger than 25 and older than 25**…the younger demographic is completely accepting** of autonomous technology, and **that divide is only going to increase** as other autonomous technology like cars becomes ubiquitous"
	"**Millennials are the key to the market** since they're used to the technology…once you get them on board, **they can introduce it to older members of their families** to make them more comfortable"

SOURCE: Expert interviews, press search

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

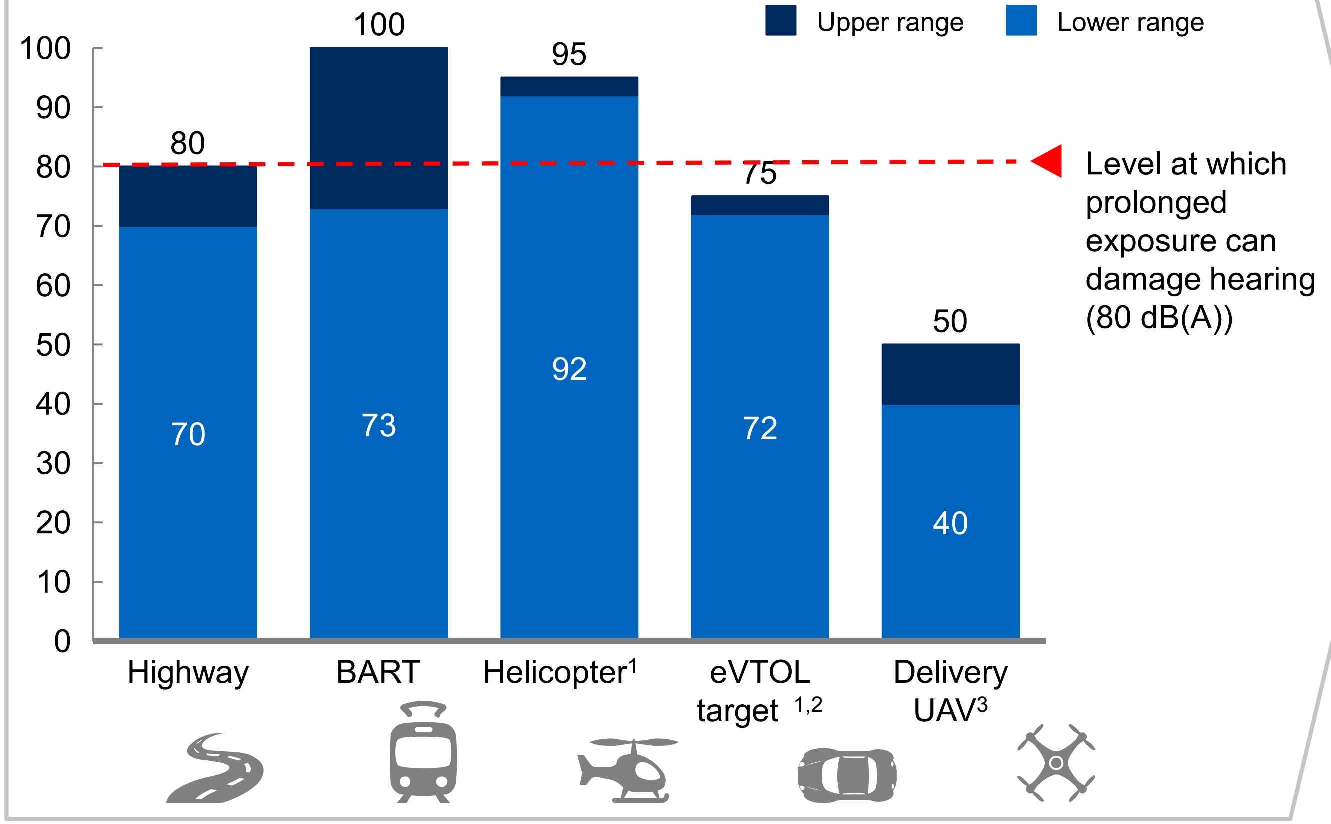
Appendix

- **Econometric and public acceptance analysis**
  - Enabler Analysis
  - **Public acceptance deep-dive**
    - Transportation
    - Delivery
    - **Noise and visual impacts**
  - Model equations
  - Demand deep-dive
  - Supply deep-dive

Estimates of noise improvement technology suggest noise levels near vertiports may be comparable to levels adjacent to highways

Noise levels of current transit and projected UAM options

Perceived noise levels (dB(A))



Takeaways

Trans-portation

- Likely requires significant improvement in noise abatement technology to meet 67 dB(A) estimates
- Even using EVTOL noise estimates, activity around vertiports approach levels that can be damaging to human health[1]
- Improving noise abatement technology may require large investments in R&D

Delivery

- Delivery fleet noise may be lower if UAS travel is not limited to current roadways for delivery routes
- Noise impact per vehicle could potentially be decreased with higher flying altitudes

General

- Decibel levels alone are not sufficient to estimate community impact of vehicle sounds (e.g., pitch, non-acoustic factors)

Noise levels around vertiports may increase during takeoff and landing operations or if more than six eVTOLs are in the vicinity at any given time

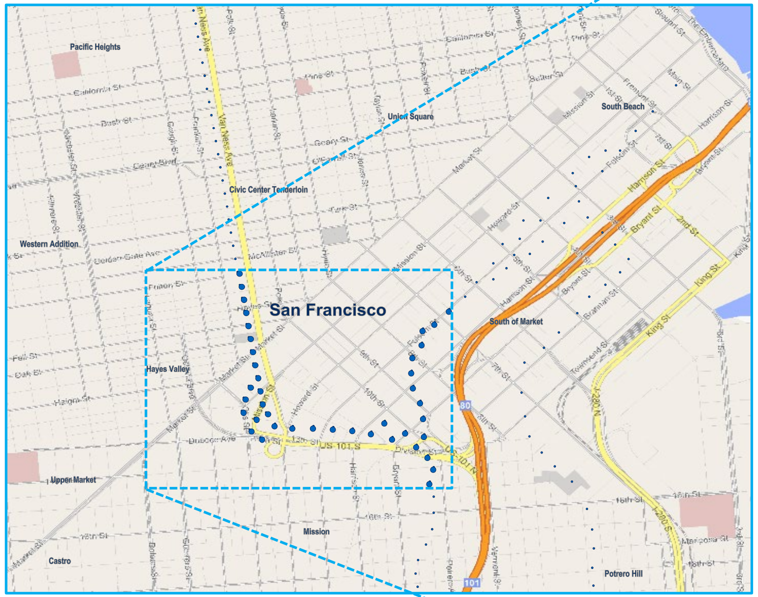
1 Assumes scenario of 3-6 vehicles flying in close proximity while approaching heliport/vertiport at altitude of 250 feet (based on assumption that vertiport can accommodate 3 eVTOLs at any given time)
2 Based on 67-dB(A) VTOL noise projected in Uber elevate paper
3 Assumes even distribution of all delivery vehicles in operation over all roads in San Francisco city proper (<3 drones per mile)), so at any given square mile no drone would be flying over the same receiving vessel; flight altitude of 100 feet

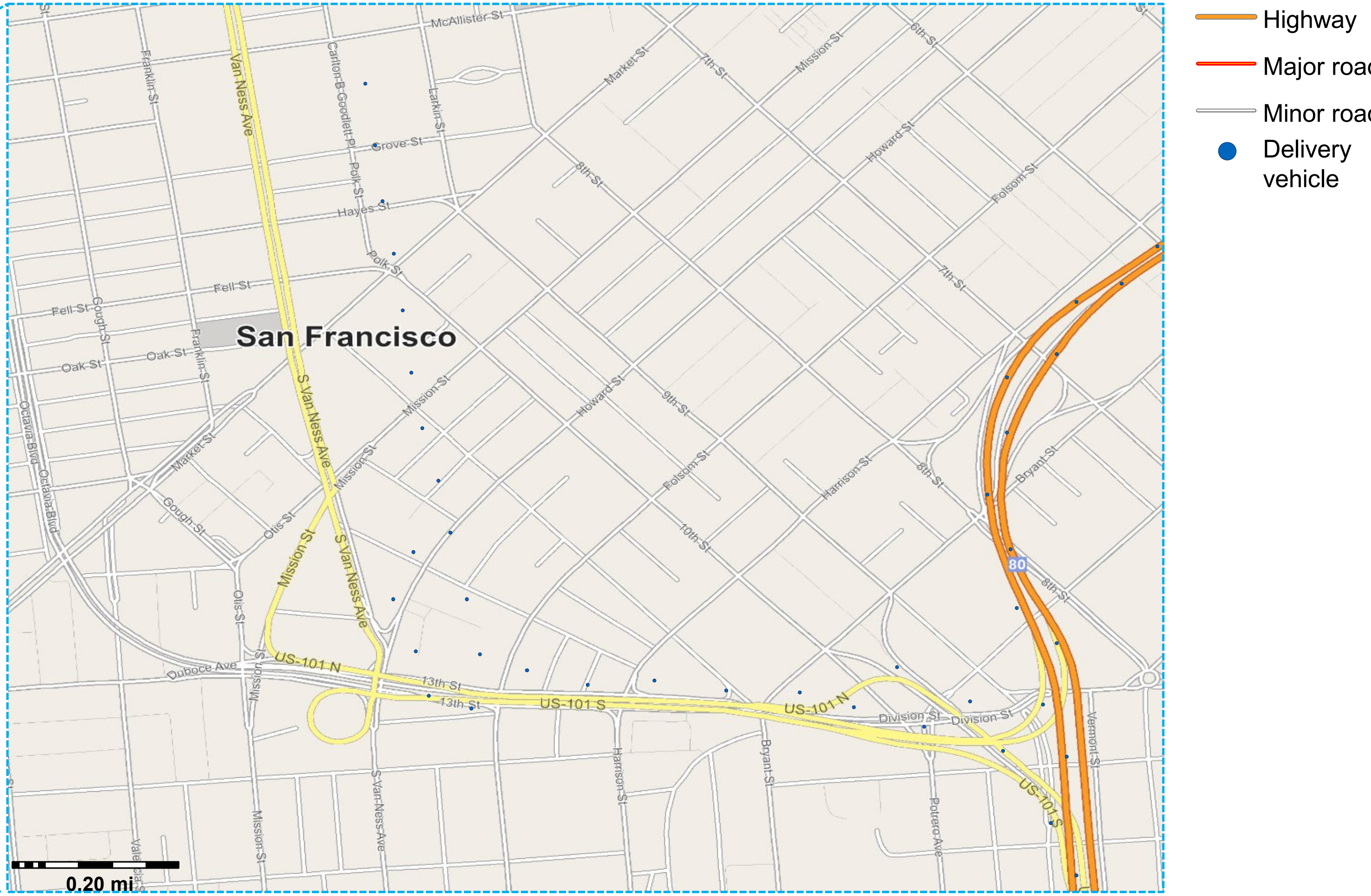
SOURCE: US Department of Transportation, US Bureau of Transportation Statistics, Uber Elevate, expert interviews, team analysis

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

Visual example: Distribution of delivery UAS, in a case that assumes all vehicles in model are in the air at once, only flying over major roads and highways

EXAMPLE



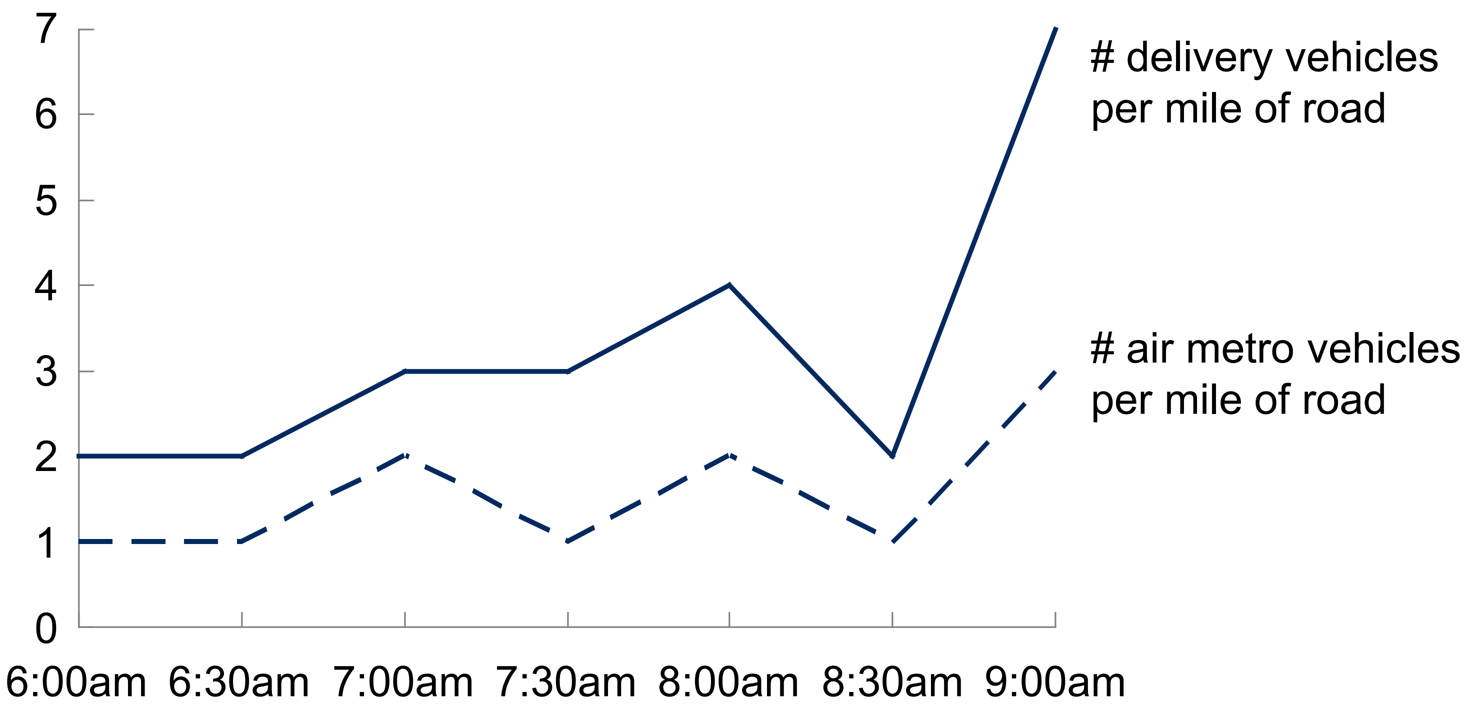


Visual example: Distribution of eVTOLs in an Air Metro use case, in a case that assumes all vehicles in the model are in the air at once, only flying over major roads and highways

EXAMPLE

Visual pollution even at rush hour could have a small impact across both the last-mile delivery and air metro use cases

Anticipated rush hour air metro traffic
Number of rides demanded per 30-minute increment



Key assumptions:

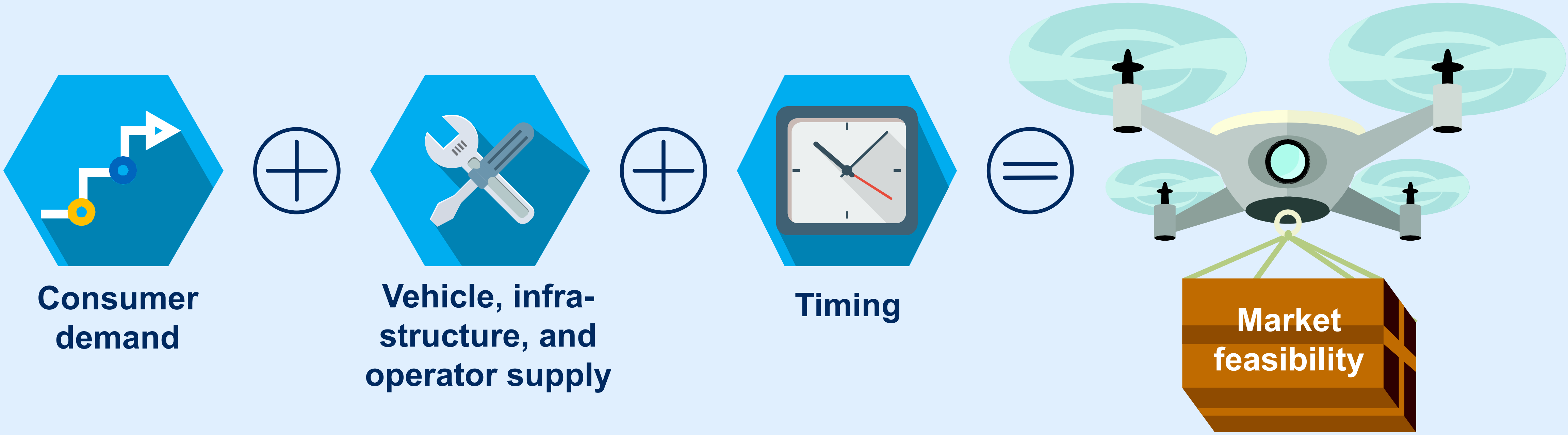
- **Peak timing for delivery requests will mirror rush hour** patterns for city transit
- **Vehicle flights will be restricted to travel over major roads** for both delivery and air metro use cases
- There will be a relatively **even distribution of vehicles** over all available mileage
- **Flight altitude will be low enough to be perceived** by those on the ground

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

Appendix

- **Econometric and public acceptance analysis**
  - Enabler Analysis
  - Public acceptance deep-dive
  - **Model equations**
  - Demand deep-dive
  - Supply deep-dive

Econometric models were structured around supply, demand, and time to develop a perspective on market feasibility



[Market feasibility uses net market profitability across the value chain as a proxy for viability[1]]

1 The net profitability across the value chain is used as an assumption for market viability, but there may be cases (e.g., well funded actors investing ahead of market profitability or market subsidies) that drive investment in the market well ahead of the assumed 3- to 5-year market ramp up time.

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

Econometric models are built on classic demand and supply modeling approaches suited to evaluating new markets

	Model equation	Equation name	Rationale for selection
Demand	max $U = D^{a} * S^{b}$ subject to $I = P_D * D + P_s * S$ D = number of UAS demanded P_D = price of UAS demanded S = number of substitutes P_S = price of substitutes I = income	Cobb-Douglas utility function	▪ Most widely used equation to model consumer choice in marketing ▪ Models the non-linear relationship in choosing between many products/services ▪ Coefficient of each factor is the demand sensitivity to that factor
Supply	$lnC^* = \alpha_0 + \gamma_q \ln q + \frac{1}{2} * \gamma_{qq} (\ln q)^2 + \sum_i \gamma_q \ln q * \ln w_i + \sum_i \alpha_i \ln w_i + \frac{1}{2} * \sum_i \sum_j \gamma_{qq} \alpha_i \ln w_i$ lnC^* = log of total cost $\ln q$ = log of number of UAS $\ln w$ = log in component prices	Translog cost equation	▪ Empirical function that embodies all of the economic assumptions and results of the cost minimization model ▪ Allows for the calculation of price sensitivities, scale economies, rate of technical change

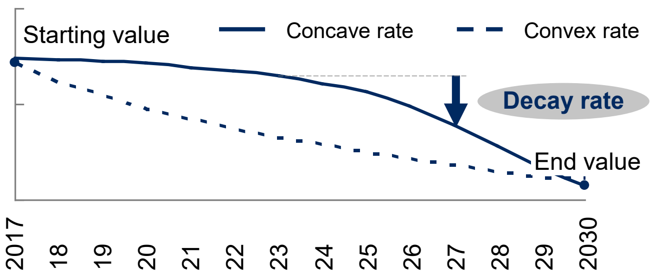
The supply and demand equations are built on a series of cost and production curves

EXAMPLE DATA

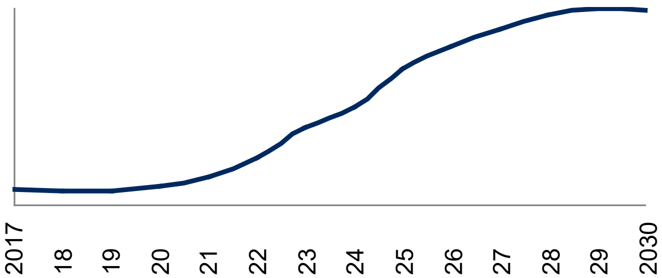
Assum-ptions

2030 component costs calculated from end value estimates or assumed rates of decay...

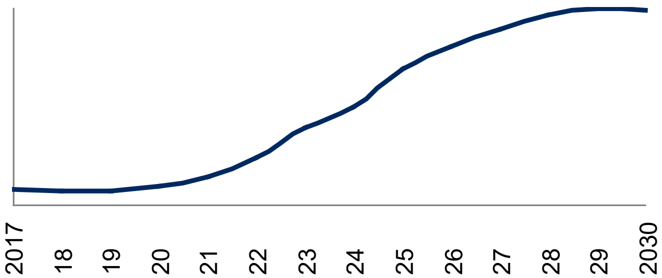
Price of components



of vehicles produced



Total cost of producing vehicles



Forecast

...And forecasted costs each year between now and 2030

Year	Airframe	Avionics	Sensing Systems	Other Components	Total Cost	Cost share #1	S #2	S #3	# UAS produced
2017	$3,500	$3,000	$11,500	$3,000	$20,000	0.18	0.15	0.58	2,000
…	…	…	…	…	…	…	…	…	…
2030	$700	$2,700	$5,750	$1,025	$10,175	0.15	0.56	0.07	40,000

Estimation of cost function

Forecasted data are fed into the translog function…

$$VP = \alpha_0 + \sum_{i=1}^{n} \alpha_i * ln\,(ri)$$

$$ES = \sum_{i=1}^{n} B_{iQ}\, ln\,(r_i) * ln\,(QP)$$

$$TI = \sum_{i=1}^{n} g_{it} * t * ln\,(r_i) + gtQ * t * ln\,(QP)$$

- α_i ▪ Sensitivity to component i
- r_i ▪ Input price of component i
- ES ▪ Impact of scale on cost
- Q_P ▪ Number of UAS produced
- B_{iD} ▪ Sensitivity of component to number of UAS
- TI ▪ Impact of innovation on cost
- t ▪ Time (year)
- Y_{it} ▪ Sensitivity of component to time
- Y_{tQ} ▪ Sensitivity of number of UAS to time
- VP ▪ Total cost of UAS production

Translog estimation algorithm

$$\ln(C) = VP + ES + TI$$

Using an iteratively seemingly unrelated regression

Cost and production model

…And the parameters from the translog cost function are used to compute the economies of scale and impact of technological change on cost

Taking partial derivatives of the above equations with respect to quantity and time provides the following equations to observe how changes in quantity and time impact the price.

$$Economies\ of\ scale = \beta_Q + \beta_{QQ} * \ln(Q_P) + \sum \alpha_i \ln(r_i) + g_{tQ} * t$$

$$Rate\ of\ technological\ change = -(gt + gtq * t + gtt * t + a_{r11} * \ln(r_1) + a_{r12} * \ln(r_2) + a_{r13} * \ln(r_3))$$

Demand was driven by the target market, consumer willingness to pay, and technology availability

What is the target market(s)?

Consumers living within the 15 largest metropolitan areas in the US (by 2030 population)

- Total population of 15 target metropolitan areas
- Population segmentations by age, income, and length (in time) of travel

How much will the target market grow?

The population is projected to grow in targeted metropolitan areas in the US; the projected segment growth was determined for each sub-segment (e.g., by age and income for delivery)

How much does the target market spend?

Defined current transportation and delivery spend within target markets, including current transportation and delivery options and costs

How much more is the target market willing to spend?

Determined the willingness to pay for increased transportation and delivery speed

- Customer key buying factors (e.g., speed, price, comfort)
- Willingness to pay for increased speed

What competing technologies may the target market choose in the future?

Driverless cars, driverless car rideshares, robo taxis, AGV lockers and other technologies that are likely to provide the same service in the future

- Projected adoption rate for future technologies
- Projected costs for future technologies

What portion of the market will adopt new UAM technologies?

Defined percentage of consumers willing to pay for improved speed who are open to autonomous air taxis, air metros, and UAS, including projected public acceptance by income segment, age, and average trip duration

The UAM delivery demand price in 2030 is likely driven by competitor pricing and increased delivery time premiums

ILLUSTRATIVE: DELIVERY USE CASE

Who is/are the target market(s)?

How much does the target market spend and how?

What are competing technologies the target market may choose in the future?

A F D C E

Demand price: $P_D = f(\boxed{CS}, \boxed{AR_I}, \boxed{WTP}, \boxed{P_{comp}})$

What portion of the market will adopt new UAS technologies?

How much more is the target market willing to spend?

Variable		Description	Explanation
CS	Consumer segment	Target consumer segment (broken up by income bracket)	Different income brackets tend to have different delivery needs, willingness to pay, and general adoption rates
AR_I	Adoption rate by segment	Percentage of consumers who are open to autonomous delivery or transportation	Even if the technology is cost effective for the consumer, some may not be willing to adopt UAM due to safety, noise, etc.
WTP	Willingness to pay	Willingness to pay or for UAM (delivery, air taxi, or air metro) under standard conditions	WTP data for delivery and both transportation use cases is based on the B2B and B2C survey data
P_{comp}	Price of competitors	Competitor pricing for express delivery both today and in the future (no comparable price for transportation use cases because of speed of air metro and air taxi options)	Derived from interviews and calculations of future autonomous van delivery, ATV lockers, and other competing options

The UAS delivery market size in 2030 is a function of demand for 20-minute delivery and e-commerce growth

ILLUSTRATIVE: DELIVERY USE CASE

Delivery market size in 2030: $Q_D = (\boxed{V_{T15}} * ED_D) / DY_y$

B

How much will the target market grow?

Variable		Description	Explanation
V_{T15}	Number of express deliveries expected	Total number of expected express, courier, and food deliveries in top 15 cities in 2030	The B2B and B2C markets expect to grow by 2-5% and 6-10% respectively in the US, at a faster rate than the population of the top 15 cities
ED_D	Percent of deliveries eligible for UAS delivery	Out of all of the deliveries, only a certain percentage will be eligible for UAS delivery, mostly driven by weight (under 5lbs)	Amazon published a report suggesting that 86% of their deliveries will be eligible for their UAS delivery service
DY_y	Number of deliveries per vehicle	Specifies the number of deliveries one UAS can make in a given year	UAS will be able to make a given amount of deliveries based on UAS speed, expected distance, loading/unloading time, and hours of operation

The air metro and air taxi market size in 2030 is a function of demand for 10-20-minute commute and non-commute trips and GDP growth

ILLUSTRATIVE: TRANSPORTATION USE CASES

Transportation market size in 2030: $Q_D = \left(\underbrace{\boxed{T_{T15}}}_{\text{B}} * ET_D\right) / TY_y$

How much will the target market grow?

Variable		Description	Explanation
T_{T15}	Number of commute and non-commute trips expected	Total number of expected commuter and non-commuter trips in top 15 cities in 2030	The commuter and non-commuter markets are expected to grow by the GDP rate in the US, at a faster rate than the population of the top 15 cities
ET_D	Percent of trips eligible for air metro and air taxi use	Percent of air commuter and non-commuter trips that are eligible for air taxi or air metro use case	Non-commute rides eligible for air metro are cut by 75% to account for lesser urgency to arrive within a 20 minute time frame
TY_y	Number of trips per vehicle	Specifies the number of trips one eVTOL can make in a given year	eVTOLs will be able to make a given amount of trips based on vehicle speed, expected distance, loading/unloading time, number of passengers, and hours of operation

Potential variable ranges for demand and market sizing in 2030

EXAMPLE MODEL INPUTS

	Variable unit	Last-mile delivery	Air metro
Willingness to pay	$/trip	$4-$32	$7-$50
Adoption rate	% people adopting new tech	45%-95%	38%-73%
P_{comp}	$/trip	$2.90-$4.40	N/A[1]
No. of express deliveries/ passenger trips expected	No. of trips	0.4B - 0.6B	0.7B - 0.8B
ED_D	% eligible for UAS delivery/UAM transport	86%	100% commute 25% non-commute
DYy	No. deliveries/trips per vehicle per year	12k-14k	30k-35k

1 For the air metro case, there is no true comparable or "alternative means" given the lack of existing technology to cut down travel times to a guaranteed 20 minute commute time even in high traffic areas.

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

UAM supply is a function of OEM, infrastructure provider, and operator cost structures

What is the cost structure for infrastructure providers?

What is the cost structure for UAM operators and service providers?

What is the cost structure for OEMs?

Sensitivity curve of volume supplied by cost point

The total cost of a delivery or transportation vehicle is a function of infrastructure, operator, and OEM costs

ILLUSTRATIVE: DELIVERY USE CASE

What is the cost structure for UAS operators and service providers?

G H I

Supply cost in 2030: $C_S = \boxed{IS}_{G} + \boxed{OP}_{H} + \boxed{OEM}_{I}$

What is the cost structure for infrastructure providers?

What is the cost structure for OEMs?

Variable		Description	Explanation
IS	Infrastructure cost per year per vehicle	Amount infrastructure components will cost to build, depreciated over the life of the asset and by vehicles	Retrofitting distribution hubs and building hundreds of receiving vessels likely comprises most of the infrastructure cost for delivery, vertiport construction cost is likely the bulk of transportation infrastructure cost
OP	Operator cost per year per vehicle	The cost associated with the operators, such as maintenance, energy, corporate costs, etc.	As infrastructure and OEM costs drop with economies of scale and improved technology, operator costs likely become an increasingly significant component
OEM	OEM cost per year per vehicle	All costs that go into producing the vehicle, including components, factories, and certification	For delivery, 2030 OEM costs may be mostly driven by avionics, while per tail certification and factory costs for producing vehicles are likely significant contributors to 2030 transportation OEM costs

Potential variable ranges for supply in 2030

EXAMPLE MODEL INPUTS

	Variable unit	Last-mile delivery	Air metro
OEM costs	$/vehicle	$15k-17k	$350-400k
Infrastructure costs	$/vehicle	$24k-26k	$65-75k
Operator costs	$/vehicle	$12k-14k	$350-450k

Supply and demand for the delivery case are limited by technical constraints of the vehicle…

ILLUSTRATIVE: DELIVERY USE CASE

	Equation	Variables	Assumptions
A **How many deliveries can each delivery UAS perform each year?**	$DY_Y = \left(\frac{60}{T_{avg}}\right) * H_d * Hw * 52$	DY_Y ▪ Number of deliveries per vehicle T_{avg} ▪ Average delivery time (min, round trip) H_d ▪ Operational hours/day H_w ▪ Operational days/week	▪ Average delivery time ▪ # of operational hours/day ▪ # of operational days/week – (Under ideal conditions)
B **What is the delivery UAS utilization?**	$Q_P = QD * (1 + \alpha)$	Q_P ▪ Number of UAS produced Q_D ▪ Number of UAS demanded a ▪ Adjustment for availability (slack/peak in demand)	▪ α is largely assumed based on reasonable estimates

... And the air metro and air taxi use cases will be similarly limited

ILLUSTRATIVE: TRANSPORTATION USE CASES

	Equation	Variables	Assumptions
A **How many trips can each air metro UAS perform each year?**	$DY_Y = \left(\frac{60}{T_{avg}}\right) * H_d * Hw * NPA * 52$	DY_Y ▪ Number of trips per vehicle T_{avg} ▪ Average trip time (min, round trip) H_d ▪ Operational hours/day H_w ▪ Operational days/week N_{PA} ▪ Number of paying passengers per trip	▪ Average trip time ▪ # of operational hours/day ▪ # of operational days/week – (Under ideal conditions)
B **What is the air metro UAS utilization?**	$Q_P = QD * (1 + \alpha)$	Q_P ▪ Number of UAS produced Q_D ▪ Number of UAS demanded a ▪ Adjustment for availability (slack in demand, unexpected breakdowns, etc.)	▪ α is largely assumed based on reasonable estimates

Potential variable ranges for technology constraints in 2030

EXAMPLE MODEL INPUTS

	Variable unit	Last-mile delivery	Air metro
Average vehicle trip time	No. of minutes	20-30	7-15
Operation hours/day	No. of hours	20-24	7-11
Operational days/week	No. of days	6-7	5-6
Number vehicles produced	No. of vehicles	35k-40k	21-25k
Availability adjustments	% of time not available	15%	15%
Number of passengers	No. of passengers in typical trip	N/A	3

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

Appendix

- **Econometric and public acceptance analysis**
  - Enabler Analysis
  - Public acceptance deep-dive
  - Model equations
  - **Demand deep-dive**
    - Delivery
    - Transportation
  - Supply deep-dive

Demand was driven by the target market, consumer willingness to pay, and technology availability

What is the target market(s)?

Consumers living within the 15 largest metropolitan areas in the US (by 2030 population)

- Total population of 15 target metropolitan areas
- Population segmentations by age, income, and length (in time) of travel

How much will the target market grow?

The population is projected to grow in targeted metropolitan areas in the US; the projected segment growth was determined for each sub-segment (e.g., by age and income for delivery)

How much does the target market spend?

Defined current transportation and delivery spend within target markets, including current transportation and delivery options and costs

How much more is the target market willing to spend?

Determined the willingness to pay for increased transportation and delivery speed

- Customer key buying factors (e.g., speed, price, comfort)
- Willingness to pay for increased speed

What competing technologies may the target market choose in the future?

Driverless cars, driverless car rideshares, robo taxis, AGV lockers and other technologies that are likely to provide the same service in the future

- Projected adoption rate for future technologies
- Projected costs for future technologies

What portion of the market will adopt new UAM technologies?

Defined percentage of consumers willing to pay for improved speed who are open to autonomous air taxis, air metros, and UAS, including projected public acceptance by income segment, age, and average trip duration

Demand was modeled for the 15 largest US cities, and 5 representative cities were surveyed

	All US cities[1]	Largest US cities[2] (2030)	Representative cities (2017)
Number of US cities[3]	**338**	**15**	**5**
Population (in millions)	**277**	**121**	**42**

Representative cities (2017):

New York City
Dallas
Washington, D.C.
San Francisco
Detroit

Largest US cities (2030): Basis for the econometric model

Representative cities (2017): Basis for the survey; cities provide representative sample of density, public transit use, personal car use, and congestion

1 As defined by the US Office of Management and Budget (OMB).
2 15 largest metropolitan areas (by city name): New York City, Los Angeles, Chicago, Dallas, Houston, Miami, Atlanta, Washington DC, Phoenix, Philadelphia, San Francisco, Boston, Riverside, Seattle, Detroit.
3 Defined as the metropolitan statistical area.

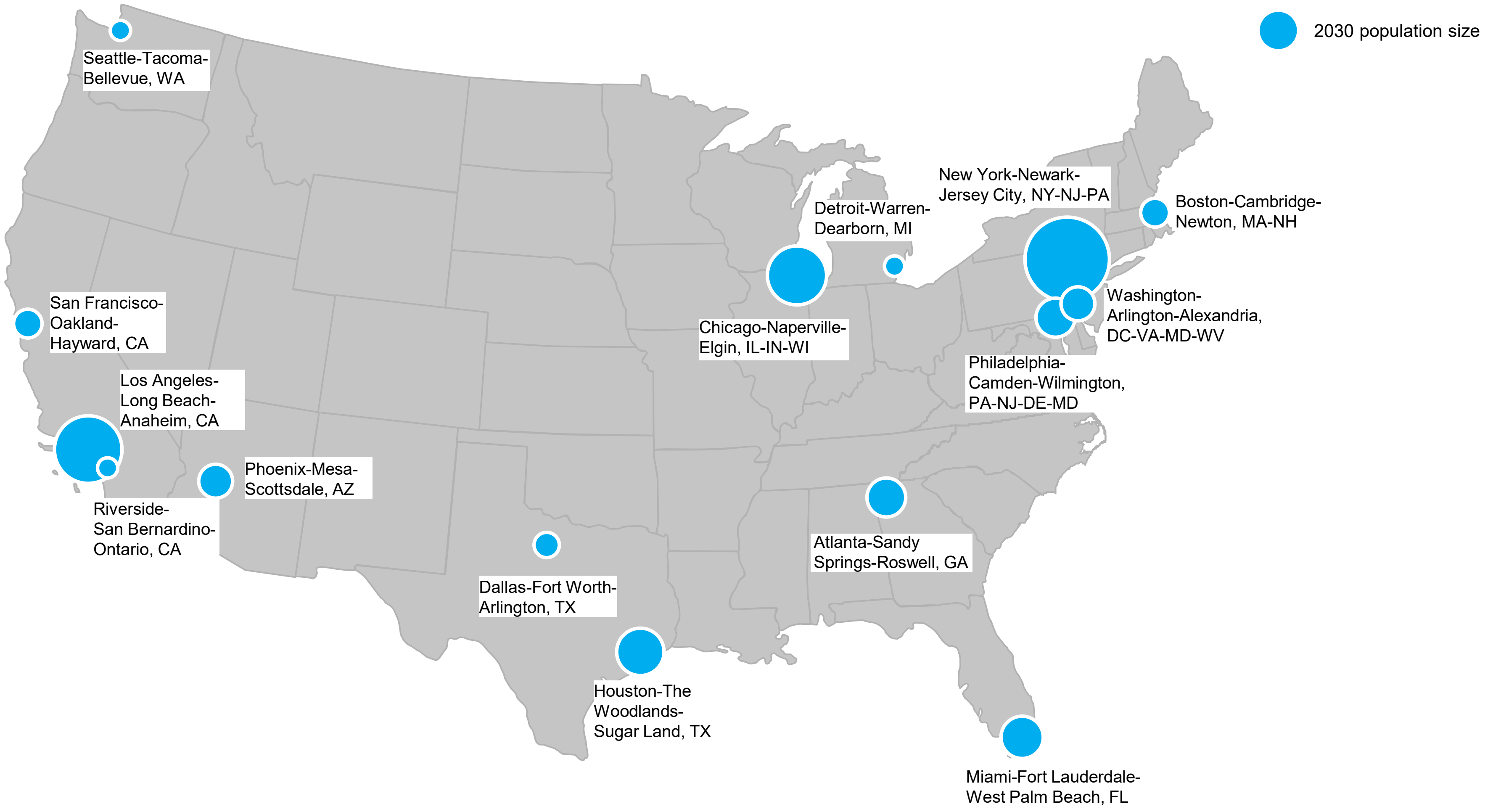
Source: United States Census, BOC, Moody's Analytics.

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

The econometric model is based on a projected 2030 population of 121M in the biggest 15 US cities

Populations of 15 largest US cities[1]

Millions of people



1 Defined as the metropolitan statistical area

SOURCE: BOC, Moody's Analytics

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

Willingness to pay and adoption rates were derived from surveys with over 2,500 respondents

ILLUSTRATIVE

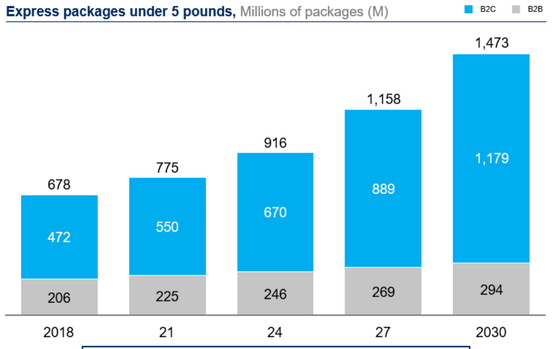
Methodology for determining consumer demand

- Representative cities (New York City, Dallas, Washington, DC, San Francisco, and Detroit) were selected for survey distribution based on their market characteristics
- Surveys included >2,500 consumers and >200 shipping and logistics coordinators in businesses, and were weighted to reflect the demographic characteristics (e.g., age, income) of the 15 MSAs
- Respondents were asked about current package delivery and travel preferences, their willingness to pay for immediate delivery (<20 minutes) and rapid travel times (<20 minutes and <10 minutes), and their willingness to adopt autonomous delivery and transportation technology
- Responses were examined across multiple demographic characteristics, including age, income, and current commute length, to determine the best predictors of willingness to pay and adoption rates
- The last-mile delivery model was segmented into business-to-consumer (B2C) and business-to-business (B2B) categories; willingness to pay and adoption rates were sub-segmented by age and income of the consumer (B2C) and number of employees (B2B)
- The air metro and air taxi models were segmented into commuter and non-commuter categories; willingness to pay and adoption were sub-segmented by average trip time and income
- Model sub-segments (e.g., number of individuals age 25 to 34 making $75,000-$100,000) and their willingness to pay and adoption rates were used to determine demand for the econometric models

Illustrative outputs of demand sub-segments

LAST-MILE DELIVERY: DEMAND INPUTS | DRAFT: PRE-DECISIONAL

By 2030, there will be over 1.4B express packages that could delivered by UAS



The number of packages that could be delivered by UAS would increase dramatically if the price of UAS delivery becomes competitive with non-express delivery options[5]

Key assumptions & modeling approach

Overall	▪ Only express (2 day or less) deliveries considered in-scope
B2C	▪ 9% CAGR from 2017-2022, 5% CAGR after 2022 ▪ Assumes 86% of packages are <5lbs[1] ▪ Incorporates 22% haircut for consumers with $0 willingness to pay[2] ▪ Demand, adoption rate, and willingness to pay are segmented by population age and income
B2B	▪ 3% CAGR 2017-2030 ▪ Assumes 40% of packages are <5lbs[3] ▪ Demand and willingness to pay are segmented by company size (number of employees) ▪ Adoption rate increases from 21% (2017) to 70% (2030)[4]

1 Amazon 2 Calculated from B2C survey data 3 From McKinsey B2B UAM survey 4 Theoretical 2017 adoption rate based on technology adoption rates in businesses in Ardent Partners "Technology adoption report: business networks", 2030 adoption rate is calculated as 3.33x increase from 2017 number, a haircut from 4.9x 15-year digital usage growth of digital leaders in "Digital America: the haves and the have mores" 5 Excludes impact of 3D printing, which may increase number of packages as local distribution hubs serve as central location for 3D printing

SOURCE: McKinsey proprietary knowledge on last mile delivery, team analysis

123

LAST-MILE DELIVERY: DEMAND INPUTS | DRAFT: PRE-DECISIONAL

For B2C, demand is broken down by age and household income

Low demand[1] | Mid demand | High demand

Household income ($) / Age	Number of respondents[2]	18-24	25-34	35-44	45-54	>54
Number of respondents	1445	215	479	356	257	138
<50,000	286	6.4%	6.5%	4.9%	4.3%	3.0%
50,000-74,999	388	3.5%	7.1%	4.3%	4.2%	1.7%
75,999-99,999	284	2.9%	4.8%	3.6%	2.3%	1.9%
100,000-149,999	333	2.9%	5.7%	5.4%	4.0%	2.1%
150,000-199,999	88	1.0%	2.1%	1.9%	2.2%	0.8%
>200,000	66	1.6%	2.4%	3.3%	1.8%	1.1%

Total number of packages in 2030[3] **1.18B**

Packages in scope are less than 5 pounds and exclude meals and groceries

1 "Low demand" = <2%; "Mid demand" = 2-4%; "High demand" = >4% 2 Excludes respondents whose willingness to pay for 20 minute delivery is zero 3 Includes demand haircut of 22% for express packages where willingness to pay for express delivery is zero

SOURCE: Survey of n = 2500 respondents across five representative US metropolitan areas: New York City, Washington, D.C., Dallas, Detroit, and San Francisco

124

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

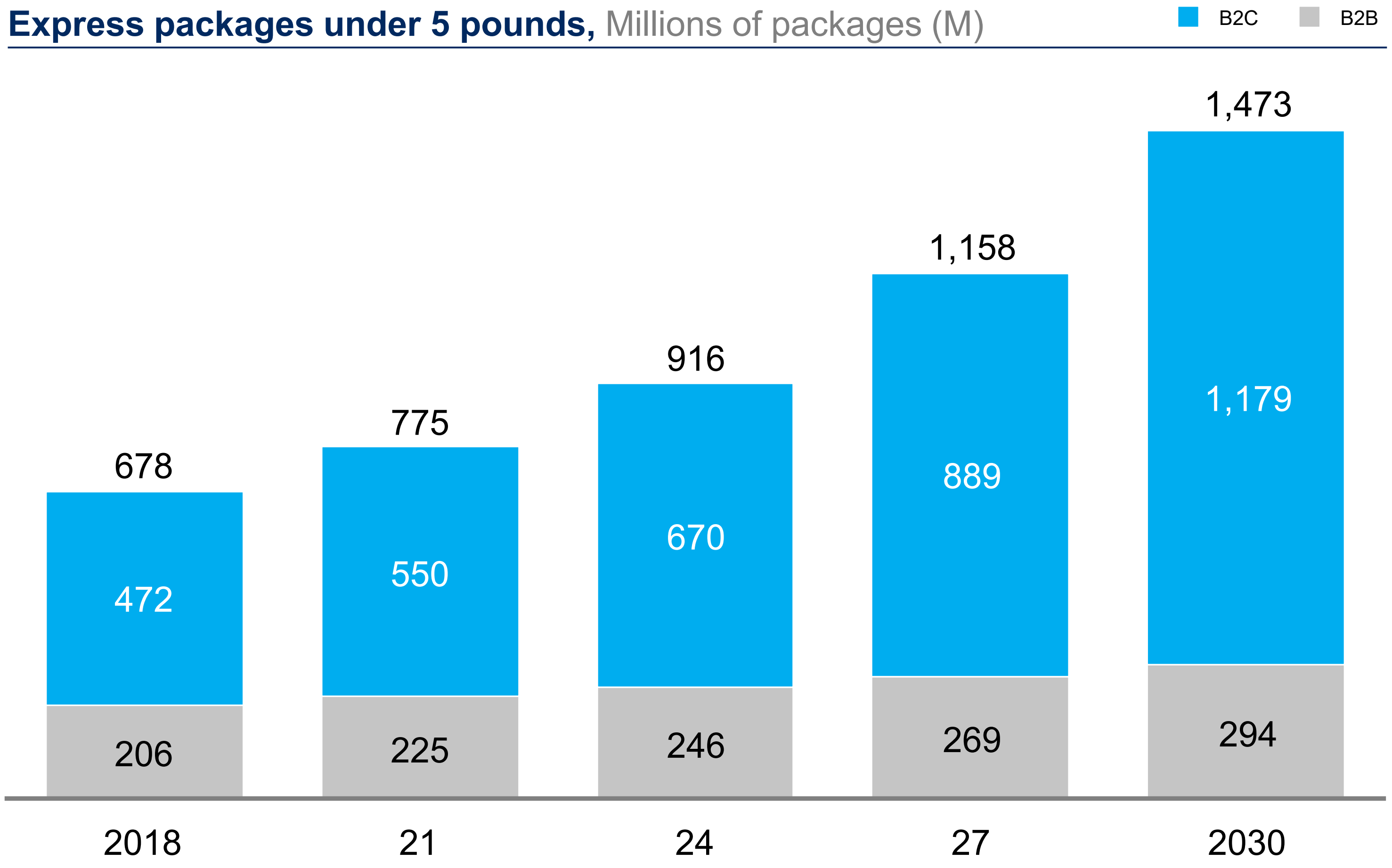
Appendix

- **Econometric and public acceptance analysis**
  - Enabler Analysis
  - Public acceptance deep-dive
  - Model equations
  - **Demand deep-dive**
    - **Delivery**
    - Transportation
  - Supply deep-dive

By 2030, there may be over 1.4B express packages that could delivered by UAS

EXAMPLE MODEL INPUTS

Express packages under 5 pounds, Millions of packages (M)



The number of packages that could be delivered by UAS would increase dramatically if the price of UAS delivery becomes competitive with non-express delivery options[5]

Key assumptions & modeling approach

Overall

- Only express (2 day or less) deliveries considered in-scope

B2C

- 9% CAGR from 2017-2022, 5% CAGR after 2022
- Assumes 86% of packages are <5lbs[1]
- Incorporates 22% haircut for consumers with $0 willingness to pay[2]
- Demand, adoption rate, and willingness to pay are segmented by population age and income

B2B

- 3% CAGR 2017-2030
- Assumes 40% of packages are <5lbs[3]
- Demand and willingness to pay are segmented by company size (number of employees)
- Adoption rate increases from 21% (2017) to 70% (2030)[4]

1 Amazon 2 Calculated from B2C survey data 3 From McKinsey B2B UAM survey 4 Theoretical 2017 adoption rate based on technology adoption rates in businesses in Ardent Partners "Technology adoption report: business networks", 2030 adoption rate is calculated as 3.33x increase from 2017 number, a haircut from 4.9x 15-year digital usage growth of digital leaders in "Digital America: the haves and the have mores" 5 Excludes impact of 3D printing, which may increase number of packages as local distribution hubs serve as central location for 3D printing

SOURCE: McKinsey proprietary knowledge on last mile delivery, team analysis

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

For B2C, demand is broken down by age and household income

Low demand[1] | Mid demand | High demand

Household income ($) / Age	Number of respondents[2]	18-24	25-34	35-44	45-54	>54
Number of respondents	1445	215	479	356	257	138
<50,000	286	6.4%	6.5%	4.9%	4.3%	3.0%
50,000-74,999	388	3.5%	7.1%	4.3%	4.2%	1.7%
75,999-99,999	284	2.9%	4.8%	3.6%	2.3%	1.9%
100,000-149,999	333	2.9%	5.7%	5.4%	4.0%	2.1%
150,000-199,999	88	1.0%	2.1%	1.9%	2.2%	0.8%
>200,000	66	1.6%	2.4%	3.3%	1.8%	1.1%

Total number of packages in 2030[3] **1.18B**

Packages in scope are less than 5 pounds and exclude meals and groceries

1 "Low demand" = <2%; "Mid demand" = 2-4%; "High demand" = >4% 2 Excludes respondents whose willingness to pay for 20 minute delivery is zero 3 Includes demand haircut of 22% for express packages where willingness to pay for express delivery is zero

SOURCE: Survey of n = 2500 respondents across five representative US metropolitan areas: New York City, Washington, D.C., Dallas, Detroit, and San Francisco

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

B2C willingness to pay is also broken down by age and income

Low WTP[1] | Mid WTP[1] | High WTP[1]

Household income ($) / Age	Number of respondents[2]	18-24	25-34	35-44	45-54	>54
Number of respondents	1445	215	479	356	257	138
<50,000	286	$6.30	$5.09	$4.98	$4.21	$4.08
50,000-74,999	388	$6.42	$6.27	$5.31	$5.14	$4.15
75,999-99,999	284	$6.53	$6.39	$5.40	$5.23	$4.23
100,000-149,999	333	$7.00	$6.84	$5.79	$5.61	$4.53
150,000-199,999	88	$7.12	$6.96	$5.88	$5.70	$4.61
>200,000	66	$7.23	$7.07	$5.98	$5.80	$4.68

1 WTP: willingness to pay; Low WTP = <$5Mid WTP = $5-$6.50; High WTP = >$6.50 2 Excludes respondents whose willingness to pay for 20 minute delivery is zero

SOURCE: Interpolated from survey of n = 2500 respondents across five representative US metropolitan areas: New York City, Washington, D.C., Dallas, Detroit, and San Francisco; Average of responses to question "How much would you be willing to pay for guaranteed 20-minute delivery for each product category?"

For B2B, demand and willingness to pay are broken down by the number of company employees

Number of employees	Number of respondents	Percentage of packages less than 5 lbs.	Willingness to pay for 20-min delivery
11-50 people	20	17%	$22.93
51-100 people	10	11%	$32.30
101-500 people	27	31%	$26.61
501-1000 people	13	18%	$25.08
1,001-5,000 people	9	12%	$31.00
>5,000 people	13	12%	$26.08
Total	92	100%	n/a

Total packages in 2030 **294M**

Key assumptions

- 40% of B2B packages are less than five pounds[1]
- 2017 theoretical adoption rate is 21%, and linearly increases to 70% in 2030[2]

1 Calculated from B2B survey data 2 Theoretical adoption rate based on technology adoption rates in businesses in Ardent Partners "Technology adoption report: business networks", 2030 adoption rate is calculated as 3.33x increase from 2017 number, a haircut from 4.9x 15-year digital usage growth of digital leaders in "Digital America: the haves and the have mores"

SOURCE: Survey of n = 213 respondents across five representative US metropolitan areas: New York City, Washington, D.C., Dallas, Detroit, and San Francisco

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

Assumed B2C 2017 adoption rate

Low adoption[1] | Mid adoption | High adoption

Household income ($) / Age	Number of respondents[2]	18-24	25-34	35-44	45-54	>54
Number of respondents	1445	215	479	356	257	138
<50,000	286	38%	31%	32%	27%	18%
50,000-74,999	388	37%	34%	39%	27%	27%
75,999-99,999	284	38%	40%	37%	23%	37%
100,000-149,999	333	24%	45%	38%	27%	29%
150,000-199,999	88	29%	31%	47%	26%	11%
>200,000	66	80%	50%	55%	14%	50%

1 "Low adoption" = <25%; "Mid adoption" = 25-34%; "High adoption" = >35% 2 Excludes respondents whose willingness to pay for 20 minute delivery is zero

SOURCE: Survey of n = 2500 respondents across five representative US metropolitan areas: New York City, Washington, D.C., Dallas, Detroit, and San Francisco, Respondents answered question “Which of the following best describes your level of comfort with future autonomous aerial delivery services?” Calculated as percent of respondents who responded with answer choice 5 (“I will be comfortable with using them, and I think other people should be able to as well.”

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

Assumed B2C 2030 adoption rate

Low adoption[1] | Mid adoption | High adoption

Household income ($) / Age	Number of respondents[2]	18-24	25-34	35-44	45-54	>54
Number of respondents	1445	215	479	356	257	138
<50,000	286	84%	79%	89%	80%	82%
50,000-74,999	388	79%	85%	77%	75%	70%
75,999-99,999	284	83%	87%	84%	80%	76%
100,000-149,999	333	80%	90%	81%	78%	76%
150,000-199,999	88	71%	85%	68%	74%	44%
>200,000	66	100%	93%	86%	64%	100%

1 "Low adoption" = <75%; "Mid adoption" = 75-84%; "High adoption" = >84% 2 Excludes respondents whose willingness to pay for 20 minute delivery is zero

SOURCE: Survey of n = 2500 respondents across five representative US metropolitan areas: New York City, Washington, D.C., Dallas, Detroit, and San Francisco. Respondents answered question "Which of the following best describes your level of comfort with future autonomous aerial delivery services?" Calculated as percent of respondents who responded with answer choices 3 ("I'm not sure if I will be comfortable using them, but I don't mind if others do," 4 ("I'm not sure I'll be comfortable using them, and I'm not sure I want others to use them either," and 5 ("I will be comfortable with using them, and I think other people should be able to as well."

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

Alternative delivery technologies in 2030 could be competitively priced with UAS but will likely have longer delivery times

	Delivery option	2017[1], $/delivery	2030[1], $/delivery	Delivery time
Closest com-petitors	Unmanned aerial delivery vehicle	NA	4.20	~20 minutes
	AGV lockers[2]	~15.20	~2.50-2.80	~2-4 hours
	Autonomous trucks	~27.60	~3.50-3.90[3]	~2-4 hours
Other delivery services	Standard ground shipping	~8.20	~4.80-5.30[4]	5 days
	Bike courier	~7.30	~7.00-7.50	<1 hour
	Car courier (e.g., Uber, GrubHub)	~8.60	~8.40-8.80	<1 hour

Because autonomous truck delivery may be competitive with UAS delivery in terms of cost, the model assumes that the demand for express delivery will be split between these technologies

1 Assumes 4.5% mark-up on cost of each competing technology, all numbers in 2017 dollars
2 Requires customer to pick-up package at AGV locker and parking location for vehicle during dropoff window
3 Includes $1 for cost of droid-to-door delivery or human delivery cost
4 Based on 35% decrease in price between 2017 and 2030

SOURCE: Team analysis, external expert interviews

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

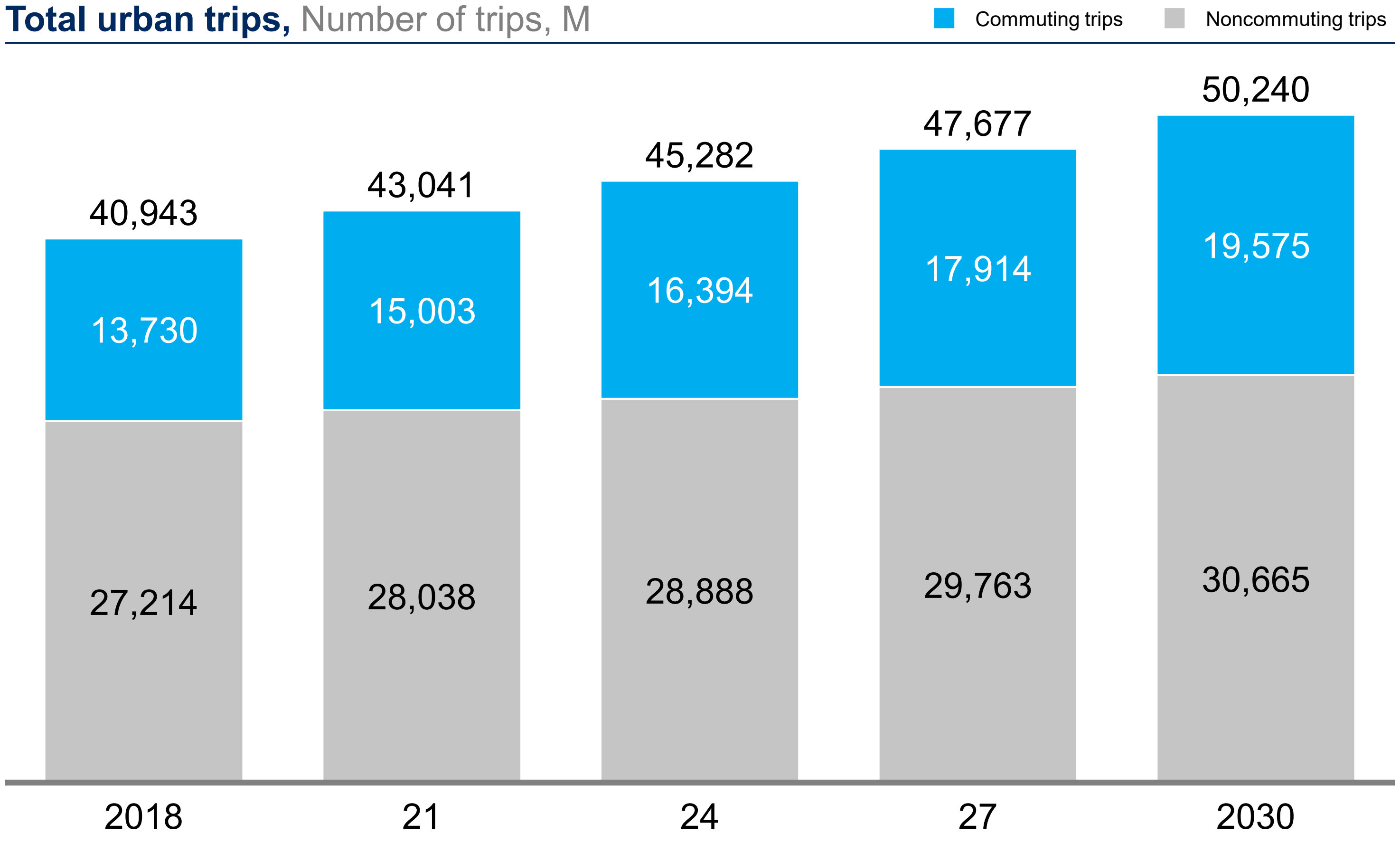
Appendix

- **Econometric and public acceptance analysis**
  - Enabler Analysis
  - Public acceptance deep-dive
  - Model equations
  - **Demand deep-dive**
    - Delivery
    - **Transportation**
  - Supply deep-dive

By 2030, there may be more than 50 billion trips that could be addressed by urban air mobility (VTOLs)

EXAMPLE MODEL INPUTS

Total urban trips, Number of trips, M



Both commute and non-commute trips within scope include all non-walking trips, but exclude trips demanded by consumers with $0 willingness to pay

Key assumptions & modeling approach

Commute
- 3% CAGR from 2017-2030
- 18% of commuters are part-time and 82% are full-time
- Part-time commuters are assumed to make 4 trips per week, Full-time commuters make 10 trips per week
- All workers assumed to commute 45 weeks per year

Non-commute
- 1% CAGR 2017-2030
- All trips more than 10 minutes and less than 70 miles addressable
- Assumes 75% of consumers will choose alternative transit options

Overall
- Commuter and non-commuter demand, adoption rate, and willingness to pay for air taxi and air metro services is segmented by income and trip length

SOURCE: McKinsey, team analysis, Bureau of Labor Statistics, US Census 2016, US Department of Transportation, National Household Travel Survey

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

For commuters, demand, in billions of trips, is broken down by average commute time and household income

Low demand[1] | Mid demand | High demand

Household income ($) / Length of commute (1 way)	Number of respondents	10-15 minutes	15-30 minutes	30-45 minutes	45 minutes - 1 hour	>1 hour
Number of respondents	1987	343	639	406	238	138
<50,000	399	1.02	1.67	0.82	0.61	0.31
50,000-74,999	528	0.87	1.62	0.98	0.46	0.26
75,999-99,999	412	0.62	1.03	0.84	0.49	0.33
100,000-149,999	431	0.41	1.47	1.09	0.76	0.41
150,000-199,999	124	0.29	0.51	0.49	0.23	0.17
>200,000	93	0.18	0.52	0.53	0.3	0.28

Total number commuting trips in 2030 19.6B

1 "Low demand" = <0.5B; "Mid demand" = 0.5B-1.0B; "High demand" =>1B

SOURCE: Survey of n = 2500 respondents across five representative US metropolitan areas: New York City, Washington, D.C., Dallas, Detroit, and San Francisco
All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

Similarly, non-commuting demand, in billions of trips, is broken down by average trip time and household income

Low demand[1] Mid demand[1] High demand[1]

Household income ($) / Length of trip (1 way)	Number of respondents	10-15 minutes	15-30 minutes	30-45 minutes	45 minutes - 1 hour	>1 hour
Number of respondents	2135	455	727	311	183	140
<50,000	447	3.89	6.22	2.42	0.78	0.99
50,000-74,999	567	1.59	2.24	0.62	0.20	0.18
75,999-99,999	438	1.35	2.05	0.58	0.18	0.23
100,000-149,999	448	1.12	1.72	0.56	0.18	0.12
150,000-199,999	138	0.49	0.80	0.27	0.08	0.05
>200,000	97	0.58	0.77	0.26	0.08	0.06

Total number non-commuting trips in 2030 **30.7B**

1 "Low demand" = 0-0.99B trips; "Mid demand" = 1.00-1.99B trips; "High demand" = 2.00-6.99B trips

SOURCE: Survey of n = 2500 respondents across five representative US metropolitan areas: New York City, Washington, D.C., Dallas, Detroit, and San Francisco

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

Assumed commuter willingness to pay for air taxis

Low WTP[1] | Mid WTP[1] | High WTP[1]

Household income ($) / Length of commute (1 way)	Number of respondents	10-15 minutes	15-30 minutes	30-45 minutes	45 minutes - 1 hour	>1 hour
Number of respondents	2133	382	671	417	246	151
<50,000	579	$11	$15	$20	$23	$35
50,000-74,999	477	$12	$16	$22	$25	$41
75,999-99,999	338	$13	$17	$22	$26	$43
100,000-149,999	400	$14	$19	$23	$27	$45
150,000-199,999	164	$15	$21	$25	$27	$47
>200,000	175	$16	$24	$27	$50	$70

1 WTP: willingness to pay; "Low WTP" = $0.01-19.99; "Mid WTP" = $20.00-39.99 "High WTP" = $40.00-79.99

SOURCE: Survey of n = 2500 respondents across five representative US metropolitan areas: New York City, Washington, D.C., Dallas, Detroit, and San Francisco. Average of responses to question "At what price point would you consider a transport service that would make your total commute time 10 minutes, as starting to get expensive, but would still consider purchasing?"

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

Assumed commuter willingness to pay for air metro

Low WTP[1] | Mid WTP[1] | High WTP[1]

Household income ($) / Length of commute (1 way)	Number of respondents	10-15 minutes	15-30 minutes	30-45 minutes	45 minutes - 1 hour	>1 hour
Number of respondents	2133	382	671	417	246	151
<50,000	579	$8	$10	$13	$16	$19
50,000-74,999	477	$9	$13	$14	$17	$20
75,999-99,999	338	$10	$13	$16	$18	$25
100,000-149,999	400	$11	$14	$17	$19	$32
150,000-199,999	164	$12	$17	$20	$25	$35
>200,000	175	$13	$19	$25	$30	$50

1 WTP: willingness to pay; "Low WTP" = $0.01-14.99; "Mid WTP" = $15-19.99; "High WTP" = $20-59.99

SOURCE: Survey of n = 2500 respondents across five representative US metropolitan areas: New York City, Washington, D.C., Dallas, Detroit, and San Francisco. Average of responses to question "At what price point would you consider a transport service that would make your total commute time 20 minutes, as starting to get expensive, but would still consider purchasing?"

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

Assumed non-commuter willingness to pay for air taxis

Low WTP[1] | Mid WTP[1] | High WTP[1]

Household income ($) / Length of trip (1 way)	Number of respondents	10-15 minutes	15-30 minutes	30-45 minutes	45 minutes - 1 hour	>1 hour
Number of respondents	2390	525	787	333	195	149
<50,000	669	$9	$13	$18	$19	$22
50,000-74,999	529	$10	$14	$20	$23	$25
75,999-99,999	374	$11	$15	$21	$25	$31
100,000-149,999	443	$12	$16	$23	$28	$38
150,000-199,999	188	$13	$16	$25	$30	$40
>200,000	187	$14	$17	$27	$44	$55

1 WTP: willingness to pay; “Low WTP” = $0.01-19.99; “Mid WTP” = $20.00-29,99; “High WTP” = $30-59.99

SOURCE: Survey of n = 2500 respondents across five representative US metropolitan areas: New York City, Washington, D.C., Dallas, Detroit, and San Francisco. Averages of responses to question “At what price point would you consider a transport service that would make your non-commute travel time 10 minutes, as starting to get expensive, but would still consider purchasing?”

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

Assumed non-commuter willingness to pay for air metro

Low WTP[1] | Mid WTP[1] | High WTP[1]

Household income ($) / Length of commute (1 way)	Number of respondents	10-15 minutes	15-30 minutes	30-45 minutes	45 minutes - 1 hour	>1 hour
Number of respondents	2390	525	787	333	195	149
<50,000	669	$7	$9	$12	$14	$20
50,000-74,999	529	$9	$11	$14	$20	$25
75,999-99,999	374	$10	$13	$15	$23	$30
100,000-149,999	443	$11	$13	$16	$25	$32
150,000-199,999	188	$12	$14	$18	$26	$40
>200,000	187	$13	$14	$20	$28	$45

1 WTP: willingness to pay; “Low WTP” = $0-14.99; “Mid WTP” = $15.00-24.99; “High WTP” = $25.00-49.99

SOURCE: Survey of n = 2500 respondents across five representative US metropolitan areas: New York City, Washington, D.C., Dallas, Detroit, and San Francisco. Averages calculated from question “At what price point would you consider a transport service that would make your non-commute travel time 20 minutes, as starting to get expensive, but would still consider purchasing?”

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

Assumed 2017 air taxi and air metro adoption rate for commuters and non-commuters

☐ Low adoption[1] ■ Mid adoption ■ High adoption

Household income ($) / Length of commute (1 way)	Number of respondents	10-15 minutes	15-30 minutes	30-45 minutes	45 minutes - 1 hour	>1 hour
Number of respondents	1391	265	503	323	189	111
<50,000	252	14%	22%	28%	29%	35%
50,000-74,999	359	24%	25%	27%	28%	35%
75,999-99,999	295	24%	32%	19%	25%	28%
100,000-149,999	314	30%	27%	21%	24%	21%
150,000-199,999	98	18%	31%	32%	27%	10%
>200,000	73	38%	50%	32%	30%	27%

1 "Low adoption" = <25%; "Mid adoption" = 25-35%; "High adoption" = >35%

SOURCE: Survey of n = 2500 respondents across five representative US metropolitan areas: New York City, Washington, D.C., Dallas, Detroit, and San Francisco. Respondents answered question “Which one of the following statements best describes your level of comfort with future autonomous air taxi services?” Calculated as a percentage who responded with answer choice 5 (“I will be comfortable with using them, and I think other people should be able to as well.”)

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

Assumed 2030 air taxi and air metro adoption rate for commuters and non-commuters

☐ Low adoption[1] ■ Mid adoption[1] ■ High adoption[1]

Household income ($) / Length of commute (1 way)	Number of respondents	10-15 minutes	15-30 minutes	30-45 minutes	45 minutes - 1 hour	>1 hour
Number of respondents	1391	376	663	410	243	150
<50,000	252	48%	51%	60%	61%	69%
50,000-74,999	359	50%	54%	60%	46%	59%
75,999-99,999	295	58%	55%	48%	55%	57%
100,000-149,999	314	59%	56%	52%	52%	50%
150,000-199,999	98	58%	56%	56%	63%	38%
>200,000	73	73%	71%	63%	58%	63%

Adoption rates in 2030 will likely not yet be at "steady state," as autonomous UAM will still be relatively new to the market

1 "Low adoption" = <55%; "Mid adoption" = 55-60%; "High adoption" = >60%

SOURCE: Survey of n = 2500 respondents across five representative US metropolitan areas: New York City, Washington, D.C., Dallas, Detroit, and San Francisco. Interpolated from 2017 adoption rate and "steady state" adoption rate

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

Assumed 2040 “steady state” air taxi and air metro adoption rate for commuters and non-commuters

Low adoption[1] | Mid adoption[1] | High adoption[1]

Household income ($) / Length of commute (1 way)	Number of respondents	10-15 minutes	15-30 minutes	30-45 minutes	45 minutes - 1 hour	>1 hour
Number of respondents	1391	265	503	323	189	111
<50,000	252	74%	74%	85%	85%	95%
50,000-74,999	359	70%	77%	85%	59%	76%
75,999-99,999	295	73%	71%	78%	80%	76%
100,000-149,999	314	81%	78%	76%	75%	71%
150,000-199,999	98	88%	75%	75%	91%	60%
>200,000	73	100%	86%	86%	80%	91%

“Steady state” adoption rates will likely be much higher as consumers become accustomed to autonomous UAM

1 "Low adoption" = <75%, "Mid adoption"=75-85%, "High adoption" = >85%

SOURCE: Survey of n = 2500 respondents across five representative US metropolitan areas: New York City, Washington, D.C., Dallas, Detroit, and San Francisco. Respondents answered question “Which one of the following statements best describes your level of comfort with future autonomous air taxi services?” Calculated as a percentage who responded with answer choices 3 (“I’m not sure I’ll be comfortable using them, but I don’t mind if others do”), 4 (“I’m not sure I’ll be comfortable using them, and I’m not sure I want others to use them either”), and 5 (“I will be comfortable with using them, and I think other people should be able to as well.”)

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

It is unlikely that future alternative technologies could be competitive with UAM in terms of trip speed

	Transport option	**2017,** $/trip[1]	**2030,** $/trip[1]	**Approx. time of 20-mile trip**
UAM use cases	**Air taxi**	NA	NA[2]	10-20 minutes
	Air metro	NA	30	20-30 minutes
Closest competitors for speed	**Helicopter personal charter**	~2,000-6,000	NA[3]	10-20 minutes
	Helicopter rideshare	~400-900	NA[3]	10-20 minutes
Closest competitors for price	**Car rideshare[4]**	~50-110	~5-18[5]	>1 hour
	Autonomous personal car[6]	~675	~20-30	1 hour
	Human-driven personal car[6]	~15	~5-15	1 hour
	Public transit[7]	~15	~10-20	>1 hour

The model assumes that 75% of non-commuting trips with a high enough willingness to pay will be satisfied by cheaper and slower alternatives

1 All prices in 2017 dollars, trips defined as 25 miles 2 No 2030 price since no projected market viability 3 Assumes VTOLs will replace any future helicopters used for trips in scope 4 Prices reflect surge value, assumption of human driver in 2017 and autonomous car in 2030 5 Range includes EV and ICE vehicles 6 Assumes 15,000 miles per year and cost using electric vehicle in 2030 7 Assumes traditional public transit price stays constant

SOURCE: Team analysis, McKinsey internal experts, external expert interviews, American Automobile Association, American Public Transportation Association

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

Appendix

- **Econometric and public acceptance analysis**
  - Enabler Analysis
  - Public acceptance deep-dive
  - Model equations
  - Demand deep-dive
  - **Supply deep-dive**

The cost structures were modeled at a detailed level[1]

Infrastructure	Air traffic management (ATM)		Airspace integration systems that combine unmanned and manned traffic
Infrastructure	Service centers		Storage areas for UAS with maintenance services and staff
Infrastructure	Distribution hubs (Hubs)		Warehouses with docking stations and inventory for delivery
Infrastructure	Vertiports/vertistops		Areas where VTOLS and UAS can land, park, and pick-up packages/passenger
Infrastructure	Receiving vessels		Vessels that will be receiving and launch pads for delivery UASs
Infrastructure	Refueling / charging stations		Areas to rapidly fuel, charge or swap batteries
Infrastructure	Docking stations		Stations for UAS downtime and package or passenger reloading
OEM	Sensing systems	Detection and avoidance	Ability to detect and avoid aircraft and other obstacles without intervention
OEM	Sensing systems	Counter-UAV (C-UAV)	Systems to neutralize UAS that pose a safety concern
OEM	Sensing systems	Operations in GPS-denied environments	Ability to effectively and autonomously operate in GPS-lacking regions
OEM	Battery performance		Effective charge density and time to make electric VTOLs (eVTOLs) economically viable
OEM	Autonomous flight		Ability to fly without pilot guidance in variable regions
OEM	Vehicle costs		Cost of delivery UASs and VTOLs
OEM	Factory costs		Costs associated with the capital investment to design and build a factory
OEM	Certification costs		Costs for trials to demonstrate safety to Federal Aviation Administration (FAA) to certify vehicles
Operators	Operator certification		Certification of operators to manage and "pilot" UAS and VTOLs
Operators	Corporate costs		Associated overhead management of operators
Operators	Energy costs		Costs associated with energy consumption by UAS and VTOLs
Operators	Insurance		Cost of insuring vehicles, public docking stations, distribution hubs, etc.
Operators	Size of fleet		Capital expenditure (CapEx) and operating expense (OpEx) associated with fleet scale
Operators	Digital services (apps, websites)		Hosting and development costs associated with services
Operators	Useful life of vehicles		Depreciation and associated costs of replacing vehicles
	Payment systems		Associated costs to implement payment systems for air taxis and delivery

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

1 Analysis relates solely to cost structures for supply; regulatory aspects are excluded as they will be used separately to develop timing and sequencing of market events.

There are at least seven key pieces of infrastructure that need to be taken into account

NOT EXHAUSTIVE

Infrastructure costs

	Annual costs: Delivery	Annual costs: Air metro	Key assumptions
A Air traffic management (ATM)	▪ **2017:** $5-10M ▪ **2030:** $30-50M		▪ Costs include the creation of control towers, server management and vehicle add-ons as suggested by UAS and IoT experts
B Service centers	▪ No service center costs, all maintenance by operator	▪ $1-2M in capex costs, depreciated over 50 years ▪ Labor costs are in maintenance costs, at $50-100/flight hour	▪ Likely to be opex for heavy maintenance at OEMs for large vehicles only, line maintenance may be used for the delivery UAS as recommended by aerospace experts
C Receiving vessels	**Per vessel:** ▪ **2017:** ~$8-12k in capex, ~$2-5k in opex ▪ **2030:** ~$10,000-15,000	▪ N/A	▪ Receiving vessels will likely largely be placed onto rooftops using a critical mass to reduce walking time to pick up package to <5-10 minutes roundtrip
D Distribution hubs (Hubs)	▪ **2017:** ~$100-300k in capex, ~$1.5-2.0M in opex ▪ **2030:** ~$400-500k	▪ N/A	▪ Only incremental costs will be incurred to retrofit hubs (~1 per ~200-300k people) to be able to effectively host the UAS
E Vertiports/ vertistops	▪ N/A	▪ **Vertiports:** ~3,000 'metro' style stops	▪ Assumes the number of ports to have sufficient coverage for the service
F Charging stations	▪ **2017:** ~$75-125 ▪ **2030:** ~$50-100	▪ **2017:** ~$100-200k ▪ **2030:** ~$100-150k	▪ Delivery UAS will have low cost docks ▪ Air metro will use superchargers
G C-UAV	▪ N/A	▪ N/A	▪ This cost is already being incurred by the market today due to already-occurring threats

1 Variable is being refined through additional expert interviews.

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

OEM costs include components of vehicles and associated ancillary products

NOT EXHAUSTIVE

OEM costs

Annual costs

	Delivery	Air metro	Key assumptions
H Sensing systems	▪ **2017:** ~$8-15k per vehicle ▪ **2030:** ~$4-7k per vehicle	▪ **2017:** $60-100k per vehicle ▪ **2030:** $30-50k per vehicle	▪ Using a hybrid system of LiDAR, cameras, and other sensors
I Docking stations	▪ Costs incorporated into charging stations	▪ N/A	▪ Docking stations will fall under the costs of the associated charging stations
J Batteries	▪ Cost of ~$300-600 for a 1-2kWh battery lasting 1-2 trips	▪ Cost of ~$20-30k for a 100kwh battery[1]	▪ Both delivery and air metro vehicles will have modular batteries
K Vehicle costs	▪ **2017:** ~$15-25k for all components – Battery: 6x ~$200-300 – Propulsion tech: ~$300-600 – Sensing &comms: $10-13k – Airframe: ~$3-5k – Avionics: ~$2-4k – Auto. flight tech: $0.5-2k ▪ **2030:** $8-12k for all compon.	▪ **2017:** $400-500k for all components – Battery: 4x~$20-30k – Propulsion tech: ~$80-90k – Sensing & comms: $70-90k – Airframe: ~$100-150k – Avionics: ~$50-100k – Auto. flight tech: $0.5-2k ▪ **2030:** $250-300k for all comp.	▪ Includes costs such as motor, avionics, communication and sensor systems, air frame ▪ Accounts for highly modular delivery UAS ▪ Systems are put in place to have significant redundancy for end-state autonomous functions and ability to maintain safe flight in off nominal events
L Certification costs	▪ **Type certification:** ~$5-10M ▪ **Tail certification:** ~$0.5-2k	▪ **Type certification:** ~$50-150M ▪ **Tail certification:** ~$0.5-1.5M	▪ Includes costs such as motor, avionics, communication and sensor systems, air frame

1 Variable is being refined through additional expert interviews.

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

Operator variables cover the fleet size and the vehicle costs

NOT EXHAUSTIVE

Operator variables

	Annual costs: Delivery	Annual costs: Air metro	Key assumptions
M Operator certification	Assumes there are skilled workers to support exceptions and accidents, going through a training system such as air traffic management courses, costing roughly ~$10k per operator		
N Corporate overhead	Will use Amazon as proxy, roughly 50% of cost base[1], due to similarities in capital investments and costs		
O Energy costs	~10-20c/kw	~10-20c/kw	Energy costs for operator will be determined by local governments and remain flat
P Insurance	2-7% of vehicle costs[1]	2-7% of vehicle costs[1]	Insurance experts suggest using helicopters as a proxy
Q Number of vehicles	**2017:** ~1,000-3,000 **2030:** ~35,000-40,000	**2017:** ~500-2,500 **2030:** ~20,000-25,000	Takes into account demand and UAS downtime to formulate number of vehicles required (i.e. includes all produced)
R Useful life of vehicles	~1 year, while replacing many components	Only ~7-13 years in early market (2030) to account for rapidly changing tech	Assumes that high-frequency of use and high-utilization will drive useful life of vehicles down from standards today
S Ownership costs	Varies by locality, but likely isn't a core variable (i.e. new car fees, fuel surcharges)[1]		

1 Variable is being refined through additional expert interviews.

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

It is expected that weather may reduce active number of days for the vehicles due to flying constraints, which must be defined on a vehicle-type basis

	Criteria[1]	Implications	Number of days grounded
Rain/snow	▪ Rain is assumed to ground vehicles when there is more than 1mm of rain paired with temperatures below 32F	▪ Rain is unlikely to ground vehicles unless the temperatures are also at or below freezing point ▪ Technologies may also improve the ability for these vehicles to work in freezing rain	▪ Min: 0 (e.g., Dallas, LA) ▪ Max: ~32 (e.g. Detroit) ▪ Avg: ~5-10
Low temperatures	▪ Temperatures below 32F will likely ground vehicles	▪ Extreme temperatures will likely limit range and potentially ground vehicles due to reduced battery efficiencies	▪ Min: 0 (e.g., Dallas, LA) ▪ Max: ~110 (e.g., Detroit) ▪ Avg: ~35-40
High temperatures	▪ Temperatures above 104F will likely ground vehicles		▪ Min: 0 (e.g., Seattle) ▪ Max: ~45 (e.g., Phoenix) ▪ Avg: ~3-5
Wind	▪ Wind above 25mph will likely ground vehicles	▪ Wind is unlikely to ground vehicles for extended periods of time, but will likely impact accuracy of flying and safety considerations ▪ It is more likely that wind will reduce the range in which vehicles can travel due to increase in battery usage	▪ Days with fastest 2 minutes greater than criteria: – Min: ~8-10 (e.g., Riverside) – Max: ~140-145 (e.g., SF) – Avg: ~55-60

1 Estimates are highly conservative because inclement weather will likely significantly reduce range, and vehicle type (i.e. multi-rotor, fixed wing) may have significant impact on ability to withstand inclement weather.

UTM costs are born by the operators, OEMs, and infrastructure providers

	Technology	Costs in 2030	Sector
Infra-structure	▪ Beacons	▪ Assuming ~2-5 beacon per square mile ▪ Unit cost: ~$100 per beacon, total cost of $45-55M	▪ Private
	▪ Flight exception management locations	▪ Assuming number of flight management centers is ~10-20 ▪ Cost of individual building: ~$500,000-2,000,000	▪ Private
OEM	▪ Communications systems and software	▪ Computer and onboard systems to allow for autonomous flight ▪ Unit cost: ~$300-500 per vehicle	▪ Private
Operators	▪ Servers for autonomous functionality	▪ Assuming that the maintenance and running of servers that contain UTM and routing data is the only major cost associated with integration at ~2% of cost base	▪ Private
	▪ Remote operators certification and labor costs	▪ Using air traffic controllers as a proxy it is assumed that it costs ~$5-15k per remote operator for certification and ~$60-80k for annual salaries ▪ For delivery it is assumed there is 1 operator per 100 UAS, and for metro and taxi 1 operator per 2 eVTOL is assumed	▪ Private

- Although cost components are significant, the **biggest implementation hurdle** will likely be the **definition and verification of operational standards and components**
- Viability of this market likely **depends on an effective regulatory standard** as well as a **workable, integrated ATM system** coming to fruition

ATM technologies will likely need to be supplemented for future needs to be met, primarily the automation and integration of air traffic systems to ensure safe airspace

UTM system

- Experts project that the UTM system will likely contain a combination of beacons and algorithms to develop routes and manage vehicles
- Radar is seen as unlikely to be part of this system given its limitations at low altitude and urban areas
- The biggest challenges are likely to be developing a system that can handle route and weather changes and manage significant amounts of external data
- Additionally, non-compliant vehicles should be taken into account and how they may impact the broader airspace
- Overlapping sections of airspace that allow for both vTOLs and commercial aircraft may pose the most significant challenge
- Experts note sensing systems (i.e., solid state components, GPS denied specificity) and computational ability (i.e., ability to incorporate many factors at a very high accuracy level) as potentially the biggest technological challenges

Integrating UTM into the NAS

- The greatest challenge that will likely occur may be integrating the UTM system into the current NAS and existing ATM infrastructure
- Automated systems will likely have to be incredibly streamlined and also able to be manipulated by air traffic controllers who hold the control over commercial aircraft
- The primary cost may be server costs to manage significantly more data than any systems in place today
- To enable these systems there may be a need to position monitoring systems and remote operators for VTOL systems flying above 400 feet
- Current positioning systems are not capable of tracking low flying assets in cities, and there is no widely adopted software or mapping systems to help guide these vehicles even in piloted flight
- Verbal serialized communications would bottleneck operations, and the ATM system would likely need to be digitized further to minimize time constraints
- Developing initiatives (NASA's UTM) for craft monitoring aim to fill the void, but prices and timeline are unknown
- Integration will likely require the cooperation of many private entities as well as regulatory bodies to ensure that systems for each vTOL operator can integrate with each other as well as commercial operators

Sensing systems will likely have to be capable of pilot-level sensing to allow for autonomous flight, including many redundant systems and those that work in states of failure

Detect and avoid

Description

- Technology will likely need to be able to supplement autonomous systems to detect a range of objects that could impede the route, including other UAS and vehicles, commercial aircraft, birds and other animals, trees, as well as non-compliant UAS
- These systems may include a number of technologies that offer redundancy and overlap to ensure that unmanned systems will be able to fly safely in all environments

State of development

- Moderate:
  - LiDar systems are being developed at a rapid pace for autonomous cars, and are expected to be developed in solid state in the next 5-10 years
  - Camera technology and other sensor systems likely need to be developed further to improve accuracy

GPS-denied environments

Description

- GPS-denied environments are ample in urban areas, especially at high altitudes and areas dense with buildings
- This challenge poses the risk of either inability to continue to rely on GPS, or a lag time in response from GPS systems
- Considering the potential for use of UAS in these areas there may need to be a redundant system that allows for vehicles to communicate with each other and continuously navigate despite loss of communication

State of development

- Low to moderate:
  - Use of beacons and offline technologies (i.e. software to calculate based on trajectory and last point of online contact) is fairly developed
  - ADS-B technologies have not been developed further for vehicle to vehicle communication in UAS, an alternative may be needed

---

- Although cost components are significant, the **biggest implementation hurdle** will be likely the **definition and verification of operational standards and components**
- Viability of this market may **depend on an effective regulatory standard** as well as a **workable, integrated ATM system** coming to fruition

Development costs for vertiports and vertistops will likely vary with solutions ranging in cost from repurposing existing infrastructure to building entirely new facilities in urban areas

NON-EXHAUSTIVE

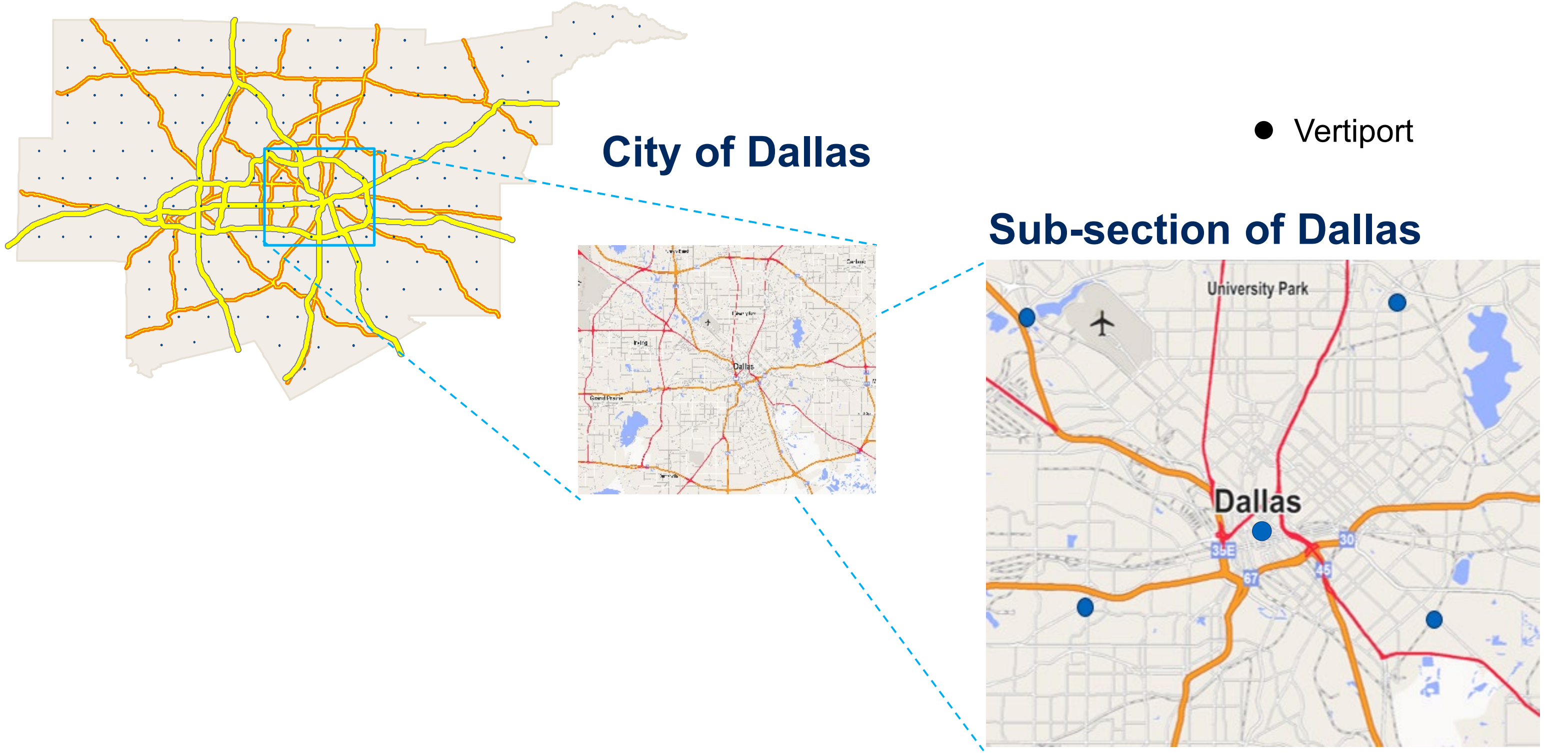
	Repurposing of available infrastructure and facilities	Renovation of facilities with similar layout and physical structure	Development of new facilities and infrastructure
Vertiport	▪ Adapt existing public and private airports, potentially with limited new capital needed	▪ Existing transportation infrastructure (e.g., parking structures) offer exposed areas suitable for adaptation	▪ Urban transport hubs could be built in the same model as rail or bus hubs
Vertistop	▪ Repurposing, refurbishing and opening to the public existing urban helipads (e.g., private pads on skyscrapers)	▪ Highway on ramps offer clear space for landing for a small number of vehicles	▪ Landing pads could be added to many urban high rises or incorporated into new construction

SOURCE: GSMA, METIS, Ericsson' 5G Whitepaper, Huawei, Japan's ARIB 2020 and Beyond Ad Hoc, Press

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

Vertiports could be effectively placed in cities to maximize demand and potential routes, mimicking subway stops but with a great focus on highly trafficked areas (i.e. airports)

Dallas-Fort Worth-Arlington MSA



- By using metro stops as a proxy the model assumes ~2,000-4,000 vertiports across the selected 15 MSAs
- **In this use case the ports could be placed in highly trafficked areas (i.e., airports and concert halls)**
- These ports could facilitate rapid movement of people where a significant amount of people would demand the route

Distribution centers may need to be modified for the use of UAM in shipping, and may come in the form of centralized or decentralized shipment points

	Description	Assumption	Considerations	Current maturity of industry
Centralized	▪ Centralized hubs will likely range in size and inventory levels ▪ These centralized hubs may have docking, charging, and maintenance areas for the drone fleets ▪ Drone fleets could pick-up packages and be launched from centralized warehouses	▪ Only incremental costs may be incurred to retrofit hubs (~1 per 200-300k people) to be able to effectively host the UAS ▪ Retrofit includes conveyer belts, automated loading stations ▪ Labor will decrease due to automation over next decade	▪ High levels of automation and scale may be required to effectively implement these centralized warehouses ▪ These hubs could allow centralized fleet maintenance and inspection	▪ **Moderate:** automated fulfillment facilities and automotive production facilities have led the way for robotic automation and logistics. By leveraging these technologies that have been tailored for the use of UAS centralized centers could be readily created
Decentralized	▪ Decentralized distribution centers may focus on companies looking to fulfill localized orders ▪ These decentralized centers would likely be less automated and for more exception based packages and orders	▪ Could be a new docking/charging station at each location to allow de-centralized shipping (cost of charging station alone)	▪ Using decentralized warehouses could reduce inventory costs for businesses and allow them to have a broader network with less capital investment, despite potential for greater labor and training costs	▪ **Low:** retailers, businesses and logistics companies may be largely unprepared for decentralized ability to ship packages using UAS

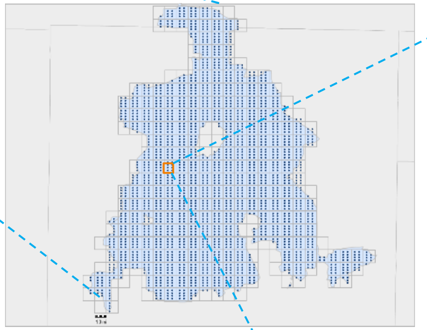
SOURCE: Expert interviews

All numbers or assumptions in these materials represent an internally consistent set of numbers from the UAM models, and should only be considered in conjunction with models

To establish an effective market, receiving vessels could be strategically placed to minimize incremental time spent walking to pick-up expedited packages

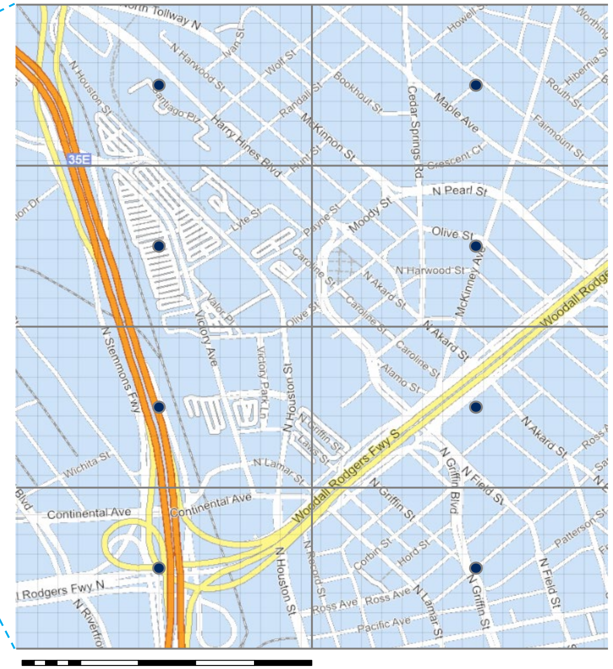
Dallas-Fort Worth-Arlington MSA

City of Dallas



● Receiving vessel

Sub-section of a square mile



- By selecting a density of roughly **6-10 receiving vessels per square mile for densely populated areas,** there could be a roundtrip **pick-up time of <5-10 minutes in Dallas**
- In more suburban areas of the Dallas MSA, this number has been decreased to roughly 2-6 per square mile
- The model uses the numbers from Dallas to triangulate the ratio of people served per vessel and apply that value across the 15 MSAs
- The assumption is that 400-500 people are served per vessel in dense areas, and 800-900 for less dense areas
- Retailers' aim to place lockers **no greater walking distance than 0.2 miles but have lower requirement for areas that rely primarily on cars**