Urban Air Mobility: A Comprehensive Review and Comparative Analysis with Autonomous and Electric Ground Transportation

Dr. Laurie A. Garrow (*corresponding author*)
Professor, Georgia Institute of Technology, School of Civil and Environmental Engineering,
790 Atlantic Drive, Atlanta, GA 30332-0355, Email: laurie.garrow@ce.gatech.edu,
Ph: (404) 385-6634

Dr. Brian J. German
Associate Professor, Georgia Institute of Technology, Daniel Guggenheim School of Aerospace Engineering, Atlanta, GA, 30332, Email: brian.german@aerospace.gatech.edu,
Ph: (404) 385-3299

Caroline E. Leonard
MS student, Georgia Institute of Technology, School of Civil and Environmental Engineering,
790 Atlantic Drive, Atlanta, GA 30332-0355, cleonard36@gatech.edu

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Abstract

Urban air mobility (UAM), if successful, will disrupt urban transportation. UAM is not the first disruptive technology in transportation, with recent examples including electric ground vehicles (EVs), autonomous ground vehicles (AVs), and sharing services. In this paper, we conduct a meta-analysis of about 800 articles in the UAM, EV, and AV areas that have been published from January 2015 to June 2020, and compare and contrast research thrusts. Alongside this effort, we conduct an in-depth review of articles related to demand modeling, operations, and integration with existing infrastructure. We use insights from the meta-analysis and comprehensive review to inform future UAM research directions. Some of the potential research directions we identify include: (1) developing more refined demand models that incorporate the timing of when individuals will adopt UAM; (2) developing high-fidelity simulation models for UAM operations that capture interactions among vertiport locations, vertiport topology, demand, pricing, dispatching, and airspace restrictions; (3) explicitly considering one-way demand and parking constraints in demand and operational models; and (4) developing more realistic time-of-day energy profiles for UAM vehicles in order to assess whether the current electrical grid can support UAM operations.

Keywords: urban air mobility, air taxi, electric vehicle, autonomous vehicle, ridesharing, carsharing

Research Highlights

- We compile a database of about 800 UAM, EV, and AV articles.
- We use insights from the EV and AV literature to inform future UAM research directions.
- UAM research has primarily focused on aircraft technologies and operations.
- EV and AV research has a greater emphasis on technology adoption and integration with existing infrastructure.
- To date, the majority of UAM research has been conducted by U.S. researchers.

1. Introduction

In recent years, there has been exponential growth in the number of publications related to aerial on-demand mobility[1]. A search of conference papers and journal publications in the American Institute of Aeronautics and Astronautics (AIAA) database shows that from 2015 to 2019, the number of annual publications in this area grew from 4 to 94. Interest in this area, commonly referred to as urban air mobility (UAM) or advanced air mobility (AAM)[2], is driven in part by advancements in battery, distributed electric propulsion, and autonomy technologies that are leading to the development of a new class of aircraft, commonly referred to as electric vertical takeoff and landing (eVTOL) aircraft. These new eVTOL air taxis are expected to be safer, quieter, and less expensive to operate and maintain than existing vertical takeoff and landing aircraft, i.e., helicopters. Given current battery limitations, much of the research to date has focused on intracity or urban travel; however, extensions to regional and intercity missions are envisioned in the coming decades.

UAM represents a disruptive new technology, particularly if information-enabled platforms such as ridesharing apps are used to connect operators with demand in real time. Never before has the potential for large-scale aerial operations within our cities been so real, as evidenced by the fact that in 2019 there were over 1,000 test flights of full-size eVTOL aircraft, and as of March 2020 at least 12 eVTOL aircraft were in the process of obtaining certification from the U.S. Federal Aviation Administration (FAA) (Dietrich and Wulff, 2020). To date, much of the research in UAM has been driven by the aerospace field and has focused on aircraft technology and aircraft operations, including the interface of UAM in the national airspace system (NAS); however, to be successful, UAM will need to integrate with our existing city infrastructure in ways that are acceptable to local communities, while providing service levels that offer time savings over existing modes at a price point that individuals are willing to pay.

UAM is not the first disruptive technology in transportation. Electric and/or autonomous ground vehicles (EVs and/or AVs) are new technologies that are disrupting travel and share many

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[1] The number of UAM-related articles included in our review from 2015 to 2019 by year are 6, 11, 15, 74, and 120. An exponential curve fit through these datapoints is y=exp(1.0194x) with an R^2 of 0.86.

[2] On March 23, 2020, the U.S. National Aeronautics and Space Administration (NASA) began referring to its on-demand aerial activities as AAM instead of UAM to reflect a more inclusive vision for both urban and rural applications (NASA, 2020). We will use UAM throughout the paper.

similar characteristics with UAM. For example, like UAM, EVs and AVs need to integrate with existing urban infrastructure; their operations are heavily dependent on battery charging and fast-charging capabilities; and their profitability is influenced by factors including community acceptance, consumer willingness to pay, and ridesharing opportunities. Owing to these similarities, insights gained from the EV and AV research communities will be applicable to the UAM community and can help inform future UAM research directions.

The objective of this paper is to provide a comprehensive review of UAM publications that have been published since 2015 and to conduct a comparative analysis with publications during this same time period on EVs and AVs. First, we compile a database of about 800 publications in the UAM, EV, and AV areas and classify their primary area(s) of research. Next, we conduct a meta-analysis comparing the overall research thrusts of the two communities. Finally, we conduct a more detailed analysis comparing the research approaches and results related to demand modeling, operations, and integration with existing infrastructure across the UAM and EV/AV areas. We use the comparative analysis to identify important factors that should be considered in the design and operation of UAM systems and areas of research that will potentially be important for the UAM community to investigate. To the best of our knowledge, our paper represents the first comprehensive review of UAM-related topics that conducts a comparative analysis of the ground vehicle and aircraft literatures for the purposes of identifying research opportunities and needs within UAM. In particular, we focus on identifying papers from the EV and AV areas that contain ideas, modeling assumptions, methods, or results that are applicable and can help inform UAM research. Our paper complements other reviews of UAM research, most notably that of Straubinger et al., published in August of 2020, that classifies UAM research areas into eight broad areas: air vehicles, regulation, infrastructure, operations, market actors, integration, acceptance, and modeling. It is our hope that our paper will become a resource document for those currently pursuing UAM research and will spur new interdisciplinary UAM research.

The balance of this paper contains seven sections. Section 2 provides a brief history of UAM and an overview of different eVTOL aircraft designs. Section 3 documents the methodology we used to conduct our review and the results from the meta-analysis. The comparative analysis of UAM, EV, and AV research over the past five years and directions for UAM research related to demand modeling, integration with existing infrastructure, and operations are discussed in

Sections 4, 5, and 6, respectively. The paper concludes with a summary of main conclusions and limitations of the analysis.

2. History of UAM and eVTOL Aircraft Designs

This section provides an overview of current and prior UAM services and the different classes of eVTOL aircraft that are under development. The discussion explains the perceived market potential for UAM and points to the different business and operational strategies that aircraft manufacturers and UAM operators are pursuing.

2.1 History of UAM Service and Value Estimates for the Emerging eVTOL UAM Market

The concept of urban air mobility is not new, with examples of UAM services using helicopters dating to the 1940s. From 1947 to 1971, Los Angeles Airways used helicopters to transport people and mail in the Los Angeles area, including between Disneyland and the Los Angeles International Airport (LAX). Los Angeles Airways experienced two accidents caused by mechanical failure in 1968 and subsequently ceased operations (Harrison, 2017, as referenced in Thipphavong et al., 2018). From 1953 to 1979, New York Airways used helicopters to fly passengers between Manhattan locations and the three major airports in New York City (Newark Liberty International Airport [EWR], LaGuardia Airport [LGA], and John F. Kennedy International Airport [JFK]). This service similarly ceased due to several accidents caused by mechanical failure (Witken, 1979, as referenced in Thipphavong et al., 2018; Mayor and Anderson, 2019). The cost of a passenger ticket on a New York Airways shuttle was between $5 and $9, or about $47 to $86 in 2019 dollars (Mayor and Anderson, 2019). These early UAM operations successfully operated for more than two decades, ultimately ceasing operations due to safety concerns. These historic examples provide evidence of the potential value to consumers for similar (albeit safer) UAM services today.

Several helicopter operators are providing on-demand urban passenger air service. BLADE operates[3] between various locations in Manhattan and one of the three main airports in New York City (JFK, LGA, and EWR). Flights are bookable within 30 minutes of departure and the one-way

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[3] On-demand service was temporarily suspended during the COVID-19 pandemic (BLADE, 2020).

cost is $195; additional charges starting at $85 apply for baggage above 25 pounds (that is transported via a ground service), last-minute bookings, and cancellations received within three hours of departure (BLADE, 2020). In 2019, Uber partnered with HeliFlite[4] to offer flights from Manhattan to JFK airport between the hours of 1 PM and 6 PM, Monday through Friday. Uber Copter can be booked on demand or up to five days before the flight (Matthews, 2019). The helicopter option appears on the Uber app and the one-way cost ranges from $200 to $225 per person and includes one piece of luggage up to 50 pounds (Ballentine, 2019; Uber, 2020). In 2016, Airbus started Voom, an on-demand booking platform that connected travelers to helicopter service providers in São Paulo, Brazil, and later expanded service to Mexico City and the San Francisco Bay Area before permanently ceasing operations due to COVID-19 in April of 2020 (Airbus, 2020b). Flights in Mexico City were bookable within 60 minutes of departure of the flight or could be reserved up to seven days in advance (Airbus, 2018).

These modern-day on-demand helicopter services have been important to UAM researchers, as they provided information about customer preferences (booking patterns, willingness to pay, most popular routes) and "operational challenges related to a lack of infrastructure, public acceptance, [and] on-demand versus scheduled routes" (Airbus, 2020b). They help set the context for how the UAM community is envisioning the possibilities for stimulating demand through lower per-passenger mile (pax-mile) operating costs with new eVTOL aircraft.

BLADE and Uber Copter charge about $30 per pax-mile in Manhattan, whereas Voom charged about $10 per pax-mile (Booz Allen Hamilton, 2018). Uber Elevate estimates the cost of a passenger helicopter service at about $8.93 per pax-mile (Holden, 2018), and McKinsey and Company estimates the cost between $6 and $8 per seat-mile[5] (Johnson, Riedel, and Sahdev, 2020). Uber Elevate has reported that they anticipate at the launch of their on-demand air taxi that service costs will be $5.73 per pax-mile but will decrease in the near term to $1.84 by increasing utilization through ridesharing (Holden, 2018). In later conferences, Uber Elevate noted that at $2.00 per pax-mile, the flight operating cost would be $662/hr as compared to $1,253/hr that is more common among helicopters operating today (Uber Elevate, 2019). On an hourly basis,

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[4] Uber Copter service was temporarily suspended during the COVID-19 pandemic (Uber, 2020).

[5] Within the airline industry, RPM and ASM are more common definitions used. Revenue passenger miles (RPM) refer to miles flown by paying customers, and available seat-miles (ASM) refer to actual seats available for sale. From the reports we reviewed, we assumed pax-miles are similar in spirit to RPM and seat-miles are similar to ASM.

longer-term, Uber Elevate anticipates that advancements in manufacturing and autonomy will decrease both fixed and variable costs, resulting in $0.44 per pax-mile cost; in comparison, in 2017, the American Automobile Association (AAA) estimated the full cost of auto ownership in the U.S. to be between $0.46 and $0.61 per mile (Holden, 2018; AAA 2017). The McKinsey report estimates near-term costs between $2.50 and $4.50 per seat-mile and long-term costs between $0.50 and $2.50 (Johnson, Riedel, and Sahdev, 2020). The UAM cost estimates provided by Uber Elevate and McKinsey and Company are optimistic compared to other reports, such as one conducted for the National Aeronautics and Space Administration (NASA) that forecasts the costs of a five-seat eVTOL at $6.25/pax-mile in the near term but "in the long term, operational efficiency, autonomy, technology improvements may decrease costs by 60%" (i.e., $3.75/pax-mile) (Booz Allen Hamilton, 2018). Although the cost estimates of providing UAM service vary, near-term and long-term eVTOL operations will likely operate at lower costs compared to current helicopter service, resulting in more demand for UAM service.

Despite these differences, what is notable is the extent that research in the eVTOL area has grown in the last five years, and how quickly some manufacturers are moving toward certifying their aircraft. Part of the interest in designing eVTOL aircraft is due to the value many believe is present for passenger UAM markets. Table 1 summarizes these global valuation estimates, which range from $1B–$3.6B in 2025 to $18.7B–$35B by 2035 or 2040. Many of the valuations of the UAM markets distinguish between intracity markets and intercity or regional markets, reflecting that as battery technologies advance, eVTOL aircraft will be able to fly longer missions. Looking ahead, Roland Berger and Porsche forecast larger UAM valuations for intracity taxis and airport shuttles than for regional intercity flights (Roland Berger, 2018; Porsche Consulting, 2018, as quoted in Volocopter, 2018).

[Insert Table 1 about here]

2.2 Overview of eVTOL Aircraft Designs

Worldwide, there are multiple efforts focused on designing eVTOL aircraft, and more than $2B has been invested in this industry (Sherman, 2020). Collectively, these designs represent fundamentally different design concepts. Multiple publications provide overviews of the different technical specifications and characteristics associated with eVTOL aircraft (e.g., see Roland Berger, 2018; Porsche Consulting, 2018). The Vertical Flight Society (VFS) provides one of the more thorough overviews of the different types of eVTOL aircraft and maintains a database of known eVTOL designs (Electric VTOL News™, 2020). According to VFS, as of March 5, 2020, there were a total of 260 aircraft[6] that included 99 vectored thrust, 39 lift + cruise, 26 wingless multicopters, 46 hover bikes/flying devices[7] and 20 eHelos and eGyros (Sherman, 2020). Across these designs, there are large variations in the number of seats, speed, and range.

Vectored thrust aircraft can use any of their thrusters[8] for both lift and cruise; representative examples include the Lilium Jet (2 to 5 seats; 186 mph; 186-mile range), Airbus A^3 Vahana (1 seat; 118 mph; 31-mile range), and Bell Nexus 4EX (5 seats; 150 mph; 150-mile range) (Lilium, 2020; Hawkins, 2019; Airbus, 2020a; Bell Flight, 2020; Pope, 2019; Goldstein, 2019). According to Sherman, vectored thrust designs—the most common among potential eVTOL designs—will likely be the most efficient eVTOL aircraft but also likely the most difficult to bring to market due to the complexity of designing the aircraft to safety transition between vertical flight and forward flight.

The lift + cruise is another popular aircraft category under development that has two sets of independent thrusters—one set that is used only for cruise and a second set that is used only for vertical lift. Lift during cruise flight is provided by one or several wings. Representative examples include the Aurora Flight Sciences Pegasus (2 seats; 112 mph; 50-mile range; Aurora Flight Sciences, 2020), EmbraerX Eve[9] (5 seats; speed and range not public), and Wisk Cora (2 seats; 100 mph; 25-mile range) (Electric VTOL News™, n.d. 1, n.d. 2; EmbraerX, 2020; Wisk, 2020).

Wingless multicopters are another common design that use their thrusters to produce lift not only for takeoff and vertical flight but for cruise, as well. Representative examples of these aircraft include the Volocopter VC200 (2 seats; 50–62 mph; 19-mile range), the eHang 216 (1 seat; 81 mph; 22-mile range), and the LIFT Aircraft Hexa (1 seat; 60 mph; 12–15 mile range) (Volocopter, 2018, 2020; eHang, 2020a; LIFT Aircraft, 2020). The LIFT Aircraft Hexa is an ultralight passenger air vehicle that seats one passenger who controls the aircraft. Ultralight aircraft will be restricted to recreational use and speeds of under 60 mph but will likely be some of the first

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[6] Not all of these aircraft are serious designs, but the momentum building in this area is clear.

[7] Hover bikes and similar flying devices are outside the scope of our analysis.

[8] VFS uses the word "thruster" as a way to generalize different thrust-producing devices including propellers, rotors, and ducted fans. We maintain their use of the word here for generality.

[9] The EmbraerX DreamMaker was renamed to the EmbraerX Eve in August of 2020 (Alcock, 2020).

eVTOL aircraft to enter the market, as they do not require aircraft and pilot certification under Federal Aviation Regulations Part 103 (FAA, 1982, as noted by Sherman, 2020).

Rotorcraft designs are another area being considered for UAM applications. These concepts include both electric helicopters and novel autogyros (i.e., helicopter-like aircraft in which the rotor rotates not by shaft power from the engine but by the force of air flowing through it; propulsion in forward flight is provided by a separate propeller). Representative examples include the Jaunt Air Mobility gyrocopter (5 seats; 175 mph; range unknown) and the Pal-V Pioneer flying car (2 seats; 99–112 mph; 250–300-mile range) (Jaunt Air Mobility, 2020; Blain, 2020; Pal-V, 2020). Although the popular press often refers to UAM/eVTOL aircraft as "flying cars," these aircraft typically do not meet the historical definition of a "roadable aircraft" that can be both driven on the ground as a car and flown as an airplane. However, the Pal-V *is* a roadable aircraft.

What is clear from the discussion above is that there is currently a lack of convergence in designs and underlying business models envisioned by the eVTOL community. The non-convergence of design concepts reflects the novelty of these new battery and electric propulsion technologies and uncertainties regarding how these new technologies will impact aircraft performance. It also reflects a lack of consensus on which missions (or market segments) these aircraft can profitably serve, and whether the aircraft should be flown by the passenger, an onboard pilot, a remote pilot, or autonomously.

3. Meta-Analysis of Research in UAM, EV, and AV

3.1 Methodology and Scope of Review

To identify relevant publications in UAM, we conducted a keyword search of "urban air mobility," "air taxi," and "UAM" in the AIAA publication database. A similar search was conducted on Scopus using the same keywords but adding exclusion terms for "drone" and "UAV." The searches were initially conducted in the spring of 2020 and were updated in mid-July 2020.

The search results included journal and conference publications relevant to UAM that were published from January 1, 2015, to June 30, 2020, in which the aforementioned keywords appeared in the title or abstract. A total of 251 publications were identified from the AIAA database and an additional 61 from the Scopus search.

To identify relevant EV and AV articles, we reviewed the table of contents of key journals from the transportation field from January 2015 to June 2020[10] and identified articles that were relevant based on their titles and abstracts. We explicitly decided not to use a keyword search for this part of the analysis, so that we could go through the titles and identify publications that were relevant to UAM research, such as ridesharing or carsharing, that may not directly fall into searches returned using EV and AV keywords. EV, AV, carsharing, and ridesharing are synergistic areas within the ground transportation field, given interest in using future AVs as an electric fleet that operates as a carsharing or ridesharing service. However, a simple search of "ridesharing" on Scopus of publications published since 2015 conducted in September 2020 returned over 2,500 publications. Thus, we opted to use a more directed approach by carefully reviewing titles and abstracts from selected journals to identify papers in the ground transportation literature that showed potential for having ideas, concepts, methods, or results that could inform UAM research.

Given our overarching objective in comparing the EV/AV and UAM fields is to glean insights from the EV/AV areas that may be applicable to the UAM area, we excluded some papers in the EV/AV areas that were not directly applicable to the UAM field. For example, papers that discuss strategies for safely merging AV ground vehicles into traffic are not applicable to UAM given UAM has another dimension for conflict avoidance and different traffic management rules than ground transportation modes. Similarly, when doing a detailed analysis of a particular area (such as demand segmentation), we tagged all articles that fit into the category, but then focused our in-depth discussion on the subset of articles most relevant to UAM (e.g., we exclude a discussion of how EV vehicle characteristics like acceleration influence EV purchases).

We reviewed articles from the following journals—the number of articles in total and those we included in our analysis are shown in parentheses: *Transportation Research Part A* (1,392 published; 125 inventoried); *Transportation Research Part B* (970 published; 62 inventoried); *Transportation Research Part C* (1,971 published; 100 inventoried); *Transportation Research*

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[10] In 2019, David Hensher, a transportation professor at the University of Sydney, identified and ranked the quality of transportation journals. We used this list to select the transportation journals that were ranked in the top two (of four) tiers that had published a non-trivial number of AV- and EV-related research over the past five years (Hensher, 2019).

Part D (1,281 published; 124 inventoried), *Transportation* (545 published; 51 inventoried); and *Transportation Science* (444 published; 16 inventoried).

The final number of articles we identified includes 312 for UAM and 478 for EV/AV research. For each of the 790 articles, we identified research themes by associating up to six keywords based on a review of the abstracts (or where unclear, a review of the articles). For each publication, we recorded author and publication information. Information for each of these 790 articles, including DOI links, are included in an Excel sheet as a supplemental document to this paper. Co-author Garrow, an expert in travel behavior modeling from civil engineering, tagged the articles related to EVs and AVs, and co-author German, an expert in aircraft design from aerospace engineering, tagged the articles related to UAM. While the subject classifications are arguably subjective, they nonetheless enable us to identify high-level trends across the fields.

3.2 UAM Publications

Based on our review of UAM-related articles, we conducted a meta-analysis focused on two overarching themes: (1) categorization of the technical content of the articles, and (2) analysis of the affiliations of the authors. The former theme provides insights into the breadth and depth of the topics addressed in UAM research, and the latter provides insights into what nations, organizations, and individuals are actively focused on UAM research.

To categorize the content in the UAM-related articles, we first identified low-level topic categories that were present in multiple articles, and we created corresponding content tags. In defining these categories, we were guided in part by our knowledge of new technical topic areas related to eVTOL aircraft that are being actively addressed within the UAM community, e.g. “Distributed Electric Propulsion” and “Aero-Propulsive Interactions.” We then grouped related low-level tags hierarchically under higher-level categories associated with traditional research disciplines related to aircraft technology and operations, e.g. “Propulsion,” “Aerodynamics,” and “Simulation.” Finally, we grouped these higher-level categories into two overarching categories: “Aircraft Technology” and “Market and Operations.” The resulting categorization reflects our attempt to identify and group common themes in UAM research cogently; however, we do not claim that the categorization is mutually exclusive, collectively exhaustive, or unequivocal.

The hierarchical categories are shown in Figure 1. The numbers in parentheses indicate the number of articles with lower-level tags assigned to the corresponding category. The number of articles indicated for each higher-level parent category are summative of all children tags for the category. Note that any one article is likely to have been assigned more than one tag based on the breadth of topics covered in the article. The individual low-level content tags corresponding to the overall categories are not shown in Figure 1 to limit the size of the figure; however, these tags are provided in the spreadsheet provided as supplemental material to this article.

The first observation from this analysis is that current articles on UAM have a nearly even split of content related to "Aircraft Technology" (295 papers) and "Market and Operations" (248 papers). This thematic balance likely reflects an understanding within the community of the "chicken-and-egg" issue associated with the emergence of UAM, i.e., aircraft must be technically capable of serving the missions required for profitable large-scale UAM operations, and a market must exist for the types of missions and operations that can be supported given the technological limitations of emerging aircraft. A concrete example of this interplay is related to eVTOL aircraft with battery electric propulsion. These aircraft have the capability of being much quieter and more economical than current generation helicopters, potentially allowing widespread operations in urban environments at low ticket prices. However, battery electric eVTOL aircraft have very limited range and speed capability because of the low specific energy of current and near-term batteries, potentially limiting the potential for the aircraft to serve an adequate network of origins and destinations and to offer adequate travel time savings compared to other modes when trip times are dominated by ingress and egress on short-ranged flights.

Within the "Aircraft Technology" category, the majority of papers had content related to "Propulsion" (82 papers) and "Aircraft Design and Performance" (92 papers). The "Propulsion" category includes papers with content related to new propulsion architectures relevant for UAM, including "Electric Propulsion" (battery powered propulsion; 29 papers), "Distributed Electric Propulsion" (multiple electric motors powering rotors or fans located in multiple locations on the aircraft; 9 papers), and "Hybrid Propulsion" (propulsion powered by both batteries and a combustion engine; 18 papers) as well as papers with a focus on associated propulsion component technologies such as "Battery" (12 papers) and "Fuel Cell" (4 papers). The majority of the papers in the "Aircraft Design and Performance" category are related to "Design Methods" (30 papers) or present a "Concept Study" of the design and performance of a novel UAM aircraft configuration (41 papers). The "Aircraft Technology" category has a significant number of papers related to "Aerodynamics" (43 papers), as well, with many papers focused specifically on the aerodynamics associated with eVTOL aircraft and other distributed propulsion configurations, i.e. “Propeller, Rotor, Ducted Fan” (16 papers) and “Aero-Propulsive Interaction” (7 papers).

The large number of papers focused on novel propulsion—especially electric propulsion—and ways to design novel aircraft with new propulsion technology is not surprising. Indeed, electric propulsion is widely recognized as one of the underpinning technical enablers of aircraft capable of serving the UAM market. What is more surprising is that other key technical disciplines for enabling UAM aircraft such as “Autonomy” (11 papers), “Acoustics” (16 papers), and “Safety” (18 papers) have relatively few papers and are arguably underrepresented relative to their importance to the field. The relatively few papers focused on autonomy is likely a result of the very broad character of autonomy research, which focuses on technical fundamentals, as well as a myriad of application domains, including ground AVs. This breadth has likely resulted in few researchers focusing on autonomy research specifically for the emerging field of UAM. Additionally, aviation is a highly-regulated industry with inherent skepticism about the potential of autonomy for replacing pilots in the near future; this viewpoint has led to research in *simplified vehicle operations (SVO)* focused on enabling piloted aircraft with increasingly *automated* but not *autonomous* systems for flight control and navigation (Goodrich and Moore, 2015). The relatively few papers in the “Acoustics” category may result from the ramp-up of the research community to develop fundamentally new foundational computational tools and appropriate metrics for UAM aircraft noise, which differ substantively from traditional aviation noise metrics (Josephson, 2017). The few papers in the “Safety” category may be a result of the need to make initial research progress to address the novelty of UAM aircraft, which require envisioning entirely new paradigms for achieving safety. For example, the simple rotor systems in eVTOL aircraft do not typically offer the potential for “autorotation” for safe descents after an engine failure that is available to helicopters; instead eVTOL aircraft are designed with multiply-redundant powertrain components to prevent a complete propulsion failure in flight (Fredericks, 2016). The few papers in these categories may represent an opportunity for researchers to have impact by engaging in UAM research in these critically important research fields.

Within the “Market and Operations” category, the majority of papers had content related to “Air Traffic Management” (83 papers) and “Aviation Operations” (80 papers). The “Air Traffic Management” category includes papers focused on topics such as exploring paradigms for integrating large volumes of UAM air traffic within the existing NAS (Mueller, Kopardekar, and

Goodrich, 2017; Thipphavong et al., 2018), constraints on UAM operations based on current operations at major airports (Vascik and Hansman, 2017; Vascik et al. 2018), and assessing and increasing airspace density and throughput for UAM operations (Goodrich and Barmore, 2018; Lowry, 2018). The "Aviation Operations" category includes papers with a focus on topics of economic and practical interest to UAM air carriers, including flight planning (Stouffer and Kostiuk, 2020) flight scheduling and dispatch (Roy et al., 2020; Shihab et al., 2019; Shihab et al., 2020), concepts of operations (Nneji, 2017; Kotwicz et al., 2019), and issues associated with electric aircraft recharging for flight operations (Hamilton and German, 2019; Shihab et al., 2020).

A significant number of papers in the "Market and Operations" category was focused on transportation studies and research to assess the potential of UAM for providing an effective and scalable means of reducing travel time in cities, assessments which lend to understanding the market potential of UAM and its value to society. Papers in the "Air Transportation Studies" category (39 papers) assessed specific types of novel UAM aircraft in on-demand or scheduled service, typically through the lens of one or several operational case studies in example cities, and papers in the "Multimodal Transportation Studies" category (14 papers) assessed connections between UAM and other transportation modes such as cars or public transport or at least discussed differences between UAM and other transportation modes. Examples of applied transportation studies include a series of papers on "suburban air mobility" with electric short takeoff and landing (eSTOL) in the south Florida region (Wei et al., 2018; Robinson et al., 2018; Justin and Mavris, 2019; Somers et al., 2019). Papers in the "Demand" category (20 papers) focused on topics such as assessing the potential market size for UAM and other forms of on-demand air mobility based on census data and choice models (Kreimeier et al., 2018; Roy et al., 2020; Ploetner et al., 2020), stated preference surveys to assess UAM demand (Binder et al., 2018; Garrow, Roy, and Newman, 2020; Fu et al., 2019), and agent-based demand simulation (Rothfeld et al., 2018; Fu et al., 2019 Ploetner et al., 2020). Finally, the "Infrastructure" category (12 papers) includes papers focused on optimization-based site selection of new vertiports (Daskilewicz et al., 2018) and STOLports (Wei et al., 2020) to serve the maximum demand, as well as papers that assess capacity constraints of vertiports (Vascik and Hansman, 2019; Maheshwari et al., 2020).

In our meta-analysis of author affiliations, the 251 UAM-related articles from AIAA consisted of a total of 862 listed authors, many of whom were listed on multiple papers, resulting in 554 unique authors. Among the 554 unique authors, 44 percent are affiliated with an academic institution, and 31 percent are associated with NASA. The remaining 25 percent of authors are associated with U.S.-based and international companies and research agencies. The majority of authors in the AIAA database (83 percent) are affiliated with institutions in the U.S., and the country with the second-highest representation (7 percent) is Germany. As these statistics reveal, the majority of UAM research has been conducted by the U.S., and NASA has played a critical role in this research.

A similar meta-analysis was conducted with UAM articles returned from the Scopus search with AIAA publications excluded. The 61 UAM-related articles from the Scopus search consisted of a total of 175 listed authors and 141 unique authors. Of all 141 unique authors, 66 percent are affiliated with an academic institution, and 16 percent are affiliated with NASA. The remaining 18 percent of authors are affiliated with U.S.-based and international companies and research agencies. Similar to the results seen in the AIAA database, the majority of authors (52 percent) are affiliated with institutions in the U.S., and the country with the second-most representation in the Scopus search is Germany (20 percent). The country with the third-most representation is the Republic of Korea (4 percent). These statistics confirm the trends seen in the AIAA search—UAM research has been concentrated primarily among U.S.- and German-based researchers, and NASA has played a critical role.

[Insert Figure 1 about here]

3.3 Ground Transportation Publications

To categorize the content of ground-transportation articles, we first identified broad topics. Many of these topics are overlapping and represent envisioned synergies across new technologies. For example, papers that discuss a future in which a shared fleet of AVs operate on batteries would be classified under the high-level categories of “Electric Vehicles,” “Autonomous Vehicles,” and “Carsharing.” Once we identified broad topics, we tagged themes within each topic area that were potentially relevant for UAM research. The content tags are shown in Figure 2. Later sections present our review of these lower-level tags in depth, so we restrict our discussion here to one key observation: within the top-tier transportation journals identified on Hensher’s list (2019), there were only four articles published on UAM. This highlights the opportunity for the transportation planning community to take a more active role in research related to the design and operations of

UAM systems and apply insights they have gained through related research in the EV and AV fields to UAM.

The 478 ground transportation articles from the journals *Transportation Research Part A (TR-A), TR-B, TR-C, TR-D, Transportation Science*, and *Transportation* consisted of a total of 1,594 listed authors, many of whom were listed on multiple papers, resulting in 1,154 unique authors. Among the 1,154 unique authors, 84 percent are affiliated with an academic institution. The remaining 16 percent of authors are associated with U.S.-based and international companies and research agencies. Among authors associated with academic institutions, 26 percent are affiliated with institutions in the U.S. The country with the second-highest representation (13 percent) in the ground transportation journal database is China, closely followed by Germany (9 percent). As these statistics reveal, the majority of ground transportation research has been conducted by the U.S., but the authors are much more diverse in their affiliated countries than the UAM authors. Ground transportation authors are also much more commonly affiliated with academic institutions compared to UAM authors.

[Insert Figure 2 about here]

4. Demand Modeling

To date, the UAM and ground transportation communities have taken different approaches with respect to modeling demand. The UAM community is currently focused on conducting high-level assessments to understand if there are viable markets for UAM and how mission requirements for these markets (which tie directly to aircraft design specifications) vary across different cities. Identifying where UAM could offer door-to-door travel time savings compared to other modes is a key part of these high-level assessments. To this end, macro-level data of economic activity, aggregate data of commuter flows, and census and other government data are often used to estimate UAM market demand.

In contrast, the ground transportation community often conducts surveys to predict how individuals will respond to different operational, pricing, and policy measures. These surveys enable researchers to understand how opinions and intentions to adopt a new technology vary as a function of socioeconomic and sociodemographic (SED) characteristics, as well as attitudes and perceptions (e.g., is the individual tech-savvy?). Insights from these surveys can be helpful for identifying potential early adopters and designing marketing campaigns. Surveys also allow researchers to focus on specific questions, such as the willingness to travel with strangers in ridesharing situations or the value of times across different modes as a function of trip purpose. These and other questions will be relevant to the UAM community as they start conducting detailed assessments of which particular consumers will use UAM and how much they are willing to pay.

This section provides an overview of demand studies from the UAM and EV/AV literatures, and summarizes key insights from the EV/AV literatures that can help inform future UAM research.

4.1 Review of UAM Demand Studies

This section reviews three types of demand studies that have been conducted by UAM researchers: global market studies that have ranked cities worldwide for their potential to offer UAM services, studies that have compared potential travel times savings with UAM against other modes, and survey-based research.

4.1.1 Global Market Studies

Multiple studies, including those of Becker et al. (2018), Robinson et al. (2018), Booz Allen Hamilton (2018), KPMG (Mayor and Anderson, 2019), and NEXA Advisors (2019), have examined the potential for on-demand mobility for UAM across different cities. These studies used various qualitative and quantitative methodologies to measure the demand potential. For example, Becker et al. (2018) used a gravity model to forecast interurban air passenger demand for 2042 based on socioeconomic factors and generated a list of potential UAM markets. NEXA Advisors (2019) modeled demand for UAM for different use cases including an airport shuttle, a corporate campus shuttle, an on-demand air taxi service, medical and emergency operations and service, and regional air transport service. Various inputs were used including population and density, gross domestic product (GDP) per capita, age distribution, current commercial and business aviation activity, and presence of Fortune 1000 companies (NEXA Advisors, 2019).

KPMG modeled UAM demand using inputs that included city GDP and GDP growth, city population and population growth, city population density, city change in income distribution through 2050, wealth concentration, and information about existing ground services (Mayor and

Anderson, 2019). Mayakonda et al. (2020) estimated the UAM share of total passenger kilometers traveled for the cities identified in the KPMG report as a function of UAM ticket cost, travel time savings, and vertiport density. For UAM service offered at $1.50/km, they found UAM shares of 0.18–0.4 percent across different vertiport densities, but for UAM service offered at $0.30/km, these shares increased to 3.2–8.5 percent.

The study by Booz Allen Hamilton selected 10 cities from a possible pool of 40 cities based on population and population density as case studies for a UAM analysis. The final 10 cities were selected based on qualitative criteria including ground transportation congestion, weather, and existing infrastructure and ground transportation patterns (Booz Allen Hamilton, 2018).

Robinson et al. (2018) identified potential cities for UAM based on qualitative criteria such as the city's level of sprawl, density, presence of water bodies (that could be used to construct barges for potential vertiports), number of airports currently in the city, population wealth, presence of high-tech industries, ground transportation congestion, ground transportation patterns, and weather. The U.S. cities identified as potential candidates for UAM for the reports discussed above are summarized in Table 2 and show that there is a large degree of overlap in the candidates identified in the previous literature, with the NEXA Advisors including more cities in their analysis, and thus having more smaller cities than the other studies.

[Insert Table 2 about here]

4.1.2 Door-to-Door Travel Time Studies Across Modes

Numerous studies have compared door-to-door travel times between UAM and conventional modes and examined the sensitivity of these door-to-door times to different parameters, such as access and egress times, and aircraft cruise speeds. Wei et al. (2018) conducted a door-to-door travel time comparison between personal cars and short takeoff and landing (STOL) aircraft. They found potential demand for STOL operations that have cruising speeds of 160 knots for individuals who have commutes in excess of 45 minutes based on a case study of the South Florida region, which includes Miami. As range decreases, access and egress times to and from the port become increasingly important (and the travel times savings associated with the air taxi decrease compared to auto) (Wei et al., 2018). Roland Berger (2018) found that air taxi trips need to be at least 15 to 25 km (about 9 to 16 miles) to provide travel time savings over existing modes.

Swadesir and Bil (2019) compare travel times, costs, and general convenience of using an air taxi service, bike, auto, and public transport for Melbourne, Australia. Consistent with the results from the South Florida study, Swadesir and Bil (2019) found that demand for an air taxi service is sensitive to access and egress times to the vertiport, as well as the times to board and disembark the aircraft. Based on an analysis of UAM service in Sioux Falls, South Dakota, USA, Rothfeld et al. (2018) found that UAM processing times have a larger influence on UAM adoption than the UAM vehicle cruising speed and that "the current focus on UAM vehicle capacity and speeds should be extended with UAM accessibility and shorter processing times."

Antcliff, Moore, and Goodrich (2016) compared travel times for urban and suburban commutes between ground and air taxis in the Silicon Valley and found travel times that were three to six times lower for some commutes in the area. They also found that a key factor in improving door-to-door travel times for air taxis is to minimize preboarding times (e.g., waiting times and security clearance times) as well as the times to board and disembark the aircraft. Kreimeier, Strumpf, and Gottschalk (2016) assessed the viability of a UAM service in Germany for intercity travel and found that UAM market shares are highly sensitive to UAM prices as well as access and egress times.

Other studies that have compared costs and travel times across modes include those by Roy, Maheshwari, et al. (2018); Akhter et al. (2020); and Vascik, Hansman, and Dunn (2018). The latter compare door-to-door travel times for 32 reference missions in the Boston, Dallas, and Los Angeles areas to identify operational constraints. Their analysis focused on high-income commuter neighborhoods, which they defined as those with annual household incomes of at least $200K or as neighborhoods with average home valuations of at least $1M in Los Angeles and Dallas and at least $900K in Boston (Vascik, Hansman, and Dunn, 2018).

4.1.3 Survey-Based UAM Demand Studies

Several survey-based studies of UAM have been conducted by consulting firms, aircraft manufacturers, and academics. For example, Booz Allen Hamilton (2018) conducted a survey that explored the potential for intercity and intracity UAM service. They sampled approximately 300 individuals in each of the following five cities: Houston, San Francisco, Los Angeles, New York City, and Washington, D.C. Airbus conducted a survey of 1,540 individuals that compared public perceptions of UAM service among residents of Los Angeles, Mexico City, New Zealand, and

Switzerland. Overall, 45 percent of respondents' initial reactions to UAM were positive, with 42 percent believing UAM was safe or very safe. Interest in UAM was higher among males, those with higher educational attainment levels, those who frequently use ridesharing or public transportation, and those from Los Angeles or Mexico City (Yedavalli and Mooberry, n.d.). Deloitte conducted a survey of approximately 10,000 individuals representing the regions of the U.S., Canada, the U.K., France, China, Japan, and Australia and similarly found that nearly half of the respondents viewed autonomous UAM vehicles as a potentially viable solution to roadway congestion, but 80 percent had safety concerns (Lineberger, Hussain, and Rutgers, 2019).

On the academic side, Fu, Rothfeld, and Antoniou (2019) modeled the choice among private car, public transportation, autonomous ground taxi, and autonomous air taxi using multinomial logit, nested logit, and mixed logit models based on a stated preference survey of 248 respondents from the Munich metropolitan area. Two trip purposes were considered and combined into a single estimation dataset: daily commuting and a non-commuting private trip. The authors estimated values of times for these four modes as 27.55, 27.47, 32.57, and 44.68 €/hour respectively, which correspond to[11] 33.89, 33.79, 40.06 and 54.96 USD/hour, respectively.

Based on a survey conducted by Uber of 2,607 residents from Dallas–Ft. Worth (DFW) and Los Angeles (many of whom were drawn from the Uber customer database), Song, Hess, and Decker (2019) estimated a latent class model and found values of time ranging from $11.15 to $36.78 for different travel time components. On average, across two latent classes the access time, egress time, flight time, and in-vehicle travel time in $/hour were found to be 26.03, 34.43, 20.75, and 13.94, respectively.

Binder et al. (2018) and Garrow et al. (2019) conducted two surveys of high-income commuters residing in Atlanta, Boston, DFW, San Francisco, and Los Angeles. The first survey, which contained 2,499 responses, examined competition with current modes, and the second survey, which contained 1,405 responses, was expanded to include competition with autonomous ground vehicles. Results from the first survey showed that individuals who were male, tech-savvy, and frequent users of ridesharing were more likely to take an air taxi for commuting. (Boddupalli, Garrow, and German, 2020). Results from the second survey were consistent with the first survey in that males, tech-savvy, and frequent users of ridesharing were more likely to take an air taxi. In

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[11] An exchange rate of 1€= 1.23 USD was used based on the average exchange rate in February to April of 2018, when the survey data were collected (Pound Sterling Live, 2020c).

addition, those who had positive attitudes toward collective modes (i.e., transit, ridesharing, etc.) and those who felt time pressured were more likely to take an air taxi (Garrow, Roy, and Newman, 2020). In both surveys, the authors found significant heterogeneity in individuals' value of time (VOT), and in the second survey that included AVs, the authors found that compared to the VOT for a conventional auto, the median VOTs for an AV and air taxi were 15 percent lower and 9 percent higher, respectively.

Based on a survey of 221 individuals, the majority of which resided in Europe, Al Haddad et al. (2020) estimated multinomial and ordered logit models, where the ordering corresponds to the time of adoption, and interpreted the results in the context of the Technology Acceptance Model. Among the 221 respondents, 22 percent stated they would adopt UAM in the first year, 37 percent in the second or third year of implementation, 14 percent during the fourth and fifth year, and 3 percent during the sixth year; 3 percent stated they would never adopt the service and 22 percent indicated they were unsure on their adoption time horizon of UAM. Based on a survey of 4,700 individuals conducted in 2019, Ljungholm and Olah (2020) found that 14 percent of respondents would be "ready and comfortable to ride in a flying taxi" right now, 18 percent within the next year, 21 percent within the next five years, 20 percent in more than 10 years' time, and 14 percent would never be comfortable. While the timing of adoption across these studies varies, what is clear is that UAM adoption by all consumers will not be instantaneous.

Finally, Han, Yu, and Kim (2019) examined customers' decision-making processes for adopting electric airplanes for traditional commercial flights. Based on a survey of 321 airline customers in the U.S. who had used an airline for traveling within the last year, they found that reducing consumers' perceived risk and increasing new product knowledge was critical to increasing trust and positive attitudes toward electric airplanes and their willingness to pay.

4.2 Review of EV and AV Demand Studies

Within the ground transportation literature, there have been more than 200 studies over the past five years that have focused on demand. Some of these studies focus on understanding how demand for EV, AV, carsharing, and/or ridesharing services varies as a function of sociodemographic and socioeconomic (SED) characteristics, as well as different attitudes, beliefs, and personality factors. About 50 studies within the ground transportation literature have focused on how adoption of new EV and AV technologies will increase over time. These studies include an assessment of barriers to adoption, analysis of the differences between early adopters and late adopters, and extension and application of different theoretical frameworks used to predict the timing of adoption across a population. Finally, there are two topics that have been explored in the ground transportation literature that are particularly relevant for UAM: studies that have examined individuals' value of time, defined as the amount of money individuals are willing to spend for travel time savings, and studies that have examined individuals' willingness to ride in vehicles with individuals they know or strangers. This section reviews these demand-related topics in depth.

4.2.1 SED Characteristics and Segmentation

Within the ground transportation literature, there are many publications that focus on understanding how SED characteristics influence transportation choices. Segmentation studies that compare the travel behavior of different populations defined by sociodemographic, socioeconomic, and/or geographic characteristics are common. Examining how travel behavior varies across different populations is important from a public policy perspective, as it helps better target limited resources to meet demand, helps ensure that the travel needs of mobility-restricted individuals are met, and helps ensure that policies are equitable across different population segments and geographical areas.

Here, we loosely use the term segmentation to identify studies that examined how consumer preferences for AVs, EVs, or sharing programs vary across demographic and/or socioeconomic and/or geographic segments. Several studies have found that interest in AVs, EVs, and sharing technologies is associated more with individuals who are younger, more educated, have higher incomes, and are male (e.g., see Dong, DiScenna, and Guerra, 2019; Hudson et al., 2019; Kopp et al., 2015; Liu, Guo, et al., 2019; Potoglou et al., 2020; Shabanpour, Golshani et al., 2018; Spurlock et al., 2019; Vij et al., 2020; Wang and Zhao, 2019).

There are subtle differences across studies related to gender and income. For example, while many studies have found that women are more risk-adverse and less likely to adopt AVs (Wang and Zhao, 2019; Kaltenhäuser et al., 2020), Spurlock et al. (2019) found that women are less likely to adopt new transportation technologies except for ride-hailing. While Young and Farber (2019) found that ride-hailing is generally a wealthier, younger phenomena, Spurlock et al. (2019) found that higher-income individuals are disproportionately represented among current adopters of new ground vehicle technologies and that low- to middle-income individuals are just as likely to have adopted pooled ride-hailing. Kim (2015) found that carsharing in low-income and high-income areas of NYC were similar.

Several studies focused on the travel behaviors of the disabled or elderly, who are two populations for which AVs and sharing services could potentially help increase mobility. For example, Bennett, Vijaygopal, and Kottasz (2019) investigated how attitudes toward AVs differ for those with physical disabilities and those without physical disabilities in the U.K. Harper et al. (2016) used the U.S. National Household Travel Survey to predict potential trip increases for older adults and individuals with travel-related medical conditions. Faber and van Lierop (2020) examined preferences for AVs among older adults in Utrecht, the Netherlands. Other studies focused on better understanding particular (and often narrow) market segments. For example, Lee and Mirman (2018) explored parents' perspectives on using AVs to transport their children. Ghasri, Ardeshiri, and Rashidi (2019) compared how perceptions toward EVs vary among younger adults, i.e., Gen X, Gen Y (Millennials) and Gen Z, in New South Wales, Australia, and found that the Millennials showed interest in adopting EVs. Alemi et al. (2019) used a survey of Millennials from California and found that those who frequently use smartphone apps to manage other aspects of their travel (e.g., checking traffic) or who frequently travel by plane for leisure purposes were more likely to rideshare.

Several studies investigated geographic differences. Huang and Qian (2018) explored how preferences for EVs differ across cities with different population sizes in China. They found that consumers in smaller cities are more sensitive to EV purchase price and subsidies. Illgen and Höck (2018) explored the potential for carsharing services in rural regions of Switzerland, and Rotaris and Danielis (2018) explored the potential for ridesharing services in the Friuli Venezia Giulia region, Italy, "a region characterized by small-sized towns and less-densely populated rural areas." Based on a comparison of individuals in Germany, India, Japan, Sweden, the U.K., and the U.S., Potoglou et al. (2020) found that Japanese consumers are generally willing to pay for AVs, whereas European consumers need to be compensated for automation. Finally, Liu, Khattak, et al. (2019) used the U.S. National Household Travel survey to investigate geographic differences in the ownership of alternative-fueled vehicles and found higher ownership rates among high-income households in states in the southeast or northwest, and higher ownership rates among seniors in states in the northeast and northwest.

4.2.2 Attitudes, Beliefs, and Personality Factors

Within the ground transportation literature, a wide body of literature focused on understanding how individuals' attitudes, beliefs, personality, and similar factors influence travel behavior choices, including the adoption of new technologies. Table A1 in the appendix summarizes 18 ground transportation studies that have examined the influence of individuals' attitudes toward EVs, AVs, or sharing programs. Sixteen of the studies used surveys, two used interviews, and one reviewed the literature. The studies were conducted across a range of nations including Australia, Canada, China, Europe, the U.S., and South Korea.

Three key themes emerge from these studies. First, individuals with pro-environmental attitudes are more likely to prefer (and by extension adopt, use, or purchase) EVs and/or AVs over conventional vehicles (Axsen et al., 2016; Biresselioglu et al., 2018; Kim, Ko, and Park, 2015; Potoglou et al., 2020; Smith et al., 2017; Sovacool et al., 2019; Tsouros and Polydoropoulou, 2020). Environmental performance of EVs was a stronger predictor of EV purchase intention than price and range confidence in a study by Degirmenci and Breitner (2017). Given a choice between a hybrid and battery-EV, respondents preferring a battery-EV were drawn to its environmental appeal (Lane et al., 2018). Pro-environmental attitudes were also positively associated with intention to use bike-sharing (Li and Kamargianni, 2019), ridesharing (Wang et al., 2020), and carsharing (Bansal and Kockelman, 2018; Kim, Ko, and Park, 2015). Liu, Ma, and Zuo (2019) found that highlighting the environmental advantages may increase social acceptance of AVs.

Second, tech-savvy individuals who have higher levels of interest in new technology, a technology-oriented lifestyle, and/or are individuals who are the first to try out a new product were found to be early adopters of EVs (Axsen et al., 2016; Biresselioglu et al., 2018), have higher intentions of using AVs (Bennett et al., 2019; Potoglou et al., 2020; Sweet and Laidlaw, 2019), and were more likely to purchase AVs with higher levels of automation (Tsouros and Polydoropoulou, 2020). Individuals from the U.S. who preferred battery-EVs over plug-in EVs were also drawn to its technological appeal (Lane et al., 2018). Early adopters of new technology were positively associated with the intention to use ridesharing (Wang et al., 2020). In a study that included both AV and commercial air, respondents who selected air over AV tended to be more tech-savvy (Kim et al., 2019). For individuals who are anxious about using new AV technologies, one study found that this anxiety could be mitigated through providing safety-related information

(Hohenberger, Spörrle, and Welpe, 2016). Sovacool et al. (2019) found that safety attitudes were positively associated with women's preferences for EV vehicles.

Third, multiple studies have found that social effects are important to AV and EV adoption. Bansal and Kockelman (2018) found that about 50 percent of respondents would time their adoption of AVs in conjunction with their friends. Huang and Qian (2018) and Kim, Ko, and Park (2015) found that social conformity effects (such as word-of-mouth and peer influence) positively influenced consumer preference for EVs. Cherchi (2017) found that word-of-mouth effects were just as important as vehicle characteristics on the intention to purchase EVs.

4.2.3 Acceptance and Adoption

Numerous papers in the ground transportation field have examined general barriers to EV adoption (e.g., see Berkeley et al., 2017, 2018; Kim et al., 2018) and applied or extended theoretical models used to predict the timing of adoption for EVs, AVs, and sharing services. Several review papers have been written, including one by Becker and Axhausen (2017) who reviewed surveys regarding AVs with a focus on methodologies and results as they pertain to acceptance of AVs, and a second by Rezvani et al. (2015) who reviewed the drivers for and barriers against adoption of plug-in EVs and provided an overview of the theoretical perspectives that have been used. In this section, we present an overview of papers that provided general overviews of barriers toward adoption of new ground technologies and papers that modeled the timing of adoption of new ground technologies.

Cunningham et al. (2019) conducted a survey to gauge public acceptability and opinions of AVs within Australia and found that the majority of Australians are currently not willing to pay more for a fully autonomous vehicle than a conventional car. Raj et al. (2020) examined the barriers to AV adoption and found that the lack of customer acceptance is the most prominent barrier.

Multiple authors have applied or extended Davis' Technology Acceptance Model (TAM) to show that perceived usefulness and perceived ease of use are use predictors or behavioral intentions to have or use new ground technologies (Davis, 1989). These include studies by Globisch et al. (2018) and Wolff and Madlener (2019) that examined acceptance of EVs in commercial fleets, and studies by Panagiotopoulos and Dimitrakopoulos (2018) and Lee et al. (2019) that examined acceptance of AVs and found that perceived usefulness, perceived ease to use, perceived trust and social influence helped predict behavioral intentions to have or use AVs. Zhang, Tao, et al. (2020) extended the TAM to show that at the beginning of AV commercialization, perceived ease of use and perceived usefulness help describe intention to use, but social influence and initial trust contributed most to explain whether users would accept AVs or not. Zhang et al. (2019) showed that initial trust could be enhanced by improving perceived usefulness and reducing perceived safety risk. Adnan, Nordin, bin Bahruddin, and Ali (2018); Khastgir et al. (2018); and Xu, Zhang, et al. (2018) also found that trust is important to AV acceptance and that experience with AVs could increase trust (Xu, Zhang, et al., 2018), as well as providing knowledge about the AV system's true capabilities and limitations (Khastgir et al., 2018). Du et al. (2019) found that information about AVs provided to respondents before they participated in a driving simulator experiment helped increase trust in and preference for AVs. Wang et al. (2018) used an extended TAM to show that consumers' lack of knowledge and risk perceptions could be barriers to the acceptance of EVs, and Wang et al. (2020) used an extended TAM to show that personal innovativeness, environmental awareness, and perceived usefulness are positively associated with the intention to use ridesharing services, whereas perceived risk is negatively associated with intention to use and perceived usefulness.

Other theoretical frameworks have been used to model adoption and timing of new ground vehicle technologies. For example, Adnan, Nordin, Amini, and Langove (2018) used the Theory of Planed Behavior (Ajzen, 1985) to examine the adoption of plug-in hybrid vehicles in Malaysia, and Wang et al. (2016) used this theory to examine adoption of hybrid EVs in China. Roger's Diffusion of Innovations Theory (Rogers, 2003) has been used in multiple studies. Kröger et al. (2019) examined potential AV market penetration in the U.S. and Germany; Prieto et al. (2017) examined diffusion of carsharing services in London, Madrid, Paris, and Tokyo; and Zhang, Schmöcker, et al. (2020) examined diffusion of a one-way carsharing system in Tokyo. Shabanpour, Shamshiripour, and Mohammadian (2018) modeled the timing of AVs that considers individuals' desires to innovate and need to imitate the rest of society, and Talebian and Mishra (2018) predicted the adoption of connected AVs and found that information individuals receive from peers was a key influence of adoption.

Two studies have extended discrete choice models to incorporate timing effects associated with adoption. El Zarwi et al. (2017) integrated discrete choice and TAM models to predict the adoption timing of a one-way carsharing service. They found that adoption is influenced by social influences, network effects (e.g., placement of stations), level of service attributes, and sociodemographics and that placing a carsharing location outside a major technology firm induced the highest expected increase in the monthly number of adopters. Liu and Cirillo (2018) used a generalized dynamic discrete choice model to predict the initial and repeat purchases of alternative fuel vehicles that accounts for technology improvements and changes in prices over time.

In summary, studies based on TAM have confirmed that that perceived usefulness and perceived ease of use, perceived trust, and social influence help explain the adoption of EVs, AVs, and ridesharing services, whereas perceived risk is a barrier to adoption. Providing safety information and general information about the technical capabilities and limitations of new transportation technologies are strategies that authors have identified for increasing comfort in the new technologies. Within the UAM, only one study has applied the TAM framework. Al Haddad et al. (2020) extended the TAM framework and confirmed the importance of safety and trust and affinity to automation in the timing of the adoption of UAM.

4.2.4 Value of Time

UAM offers the potential for travel time savings. Several studies within the ground transportation literature have focused on evaluating the value of time for AVs. As air taxis enter the market, they may be competing with AVs, thus the findings from these studies are particularly relevant for UAM demand and pricing studies.

Multiple studies have noted that VOT is related to productivity and two theoretical papers have shown that the VOT for AVs will be less than the VOT in a conventional ground vehicle. Correia et al. (2019) presented a theoretical model for VOT, noting that “full automation will enable passengers to perform other, non-driving, related tasks while traveling to their destination. This may substantially change the way in which passengers experience traveling by car, and, in turn, may lead to considerable changes in [VOT].” Pudāne and Correia (2020) adapted this model, showing that “if automated vehicles provide identical work or leisure experience to out-of-vehicle locations, then the opportunity costs of travel time are erased and the (VOT) equals the intrinsic costs of travel, which is strictly smaller than the VOT in a conventional vehicle.”

Several empirical studies have confirmed this theoretical result. Based on a survey of approximately 500 individuals from the Netherlands, Correia et al. (2019) found that the average

VOT for an AV with an office interior[12] (5.50€/hr; $6.16/hr USD) was lower than the VOT for a conventional car (7.47€/hr; $8.37/hr USD); no significant differences in VOT were found between the AV that contained a leisure interior and a conventional car. Based on a survey of approximately 500 individuals from Germany, Kolarova et al. (2019) found an average value of travel time savings (VTTS) reduction of 41 percent for the AV compared to a conventional car for commuting trips; no significant changes in the average VTTS were found for leisure or shopping trips. Gao et al. (2019) found that VOT was 13 percent lower when being driven in a ride-hailing service than a personal car and, further, that mentioning the ability to multi-task explicitly led to a much lower VOT, approximately half that of driving oneself. However, noting that the ride-hailing service was driverless led to a 15 percent higher VOT compared to driving a personal car, "which may reflect a lack of familiarity and comfort with driverless technology at present" (Gao et al., 2019).

These findings are important, as they suggest that the UAM community should not use an average VOT, but rather incorporate a distribution of VOTs across the population that accounts for "non-adopters."

4.2.5 Willingness to Share Rides with Strangers

As noted by Kolarova et al. (2019), prior results in the literature have shown that using a shared autonomous vehicle alone and sharing the journey are perceived as two distinct mobility options (Krueger et al., 2016), which may be due to psychological barriers or discriminatory attitudes associated with sharing a ride with a stranger (Correia and Viegas 2011; Middleton and Zhao, 2019). For example, based on focus groups of older adults in the province of Utrecht, the Netherlands, Faber and van Lierop (2020) found that participants had a strong interest in using AVs in their daily life and that the option to travel with friends was an important factor in having a positive attitude toward AV adoption. Lavieri and Bhat (2019) noted that an important obstacle to ridesharing adoption is the user's willingness to share rides with strangers and "recent studies indicate that travelers are hesitant about being in an automobile environment with unfamiliar faces, due to a desire for personal space, an aversion to social situations, distrust, and concerns about security and privacy (see, for example, Tahmasseby et al., 2016; Morales et al., 2017; Amirkiaee and Evangelopoulos, 2018)." Based on a 2017 survey of 1,607 commuters in the Dallas–

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[12] We used an exchange rate of 1€=1.12USD based on the average exchange rate in 2019 (Pound Sterling Live, 2020c).

Ft. Worth–Arlington Metropolitan area, Lavieri and Bhat (2019) examined individuals' willingness to share trips with strangers in an AV. They found that privacy is a main deterrent to pooled ride-hailing service, with non-Hispanic whites being more privacy sensitive than individuals of other ethnicities. However, they found that respondents are less sensitive to the presence of strangers when in a commute trip compared to a leisure-activity trip and found evidence that the travel time added to the trip to serve other passengers may be a greater barrier to the use of shared services compared to the presence of a stranger.

Conversely, a study of Australians found that riding with strangers was more onerous than the added trip time. Based on a survey conducted in 2018 of 3,985 Australians that asked for their preferences for a ground on-demand transportation system, Vij et al. (2020) found that consumers are willing to pay[13], on average, AUD \$0.28/km (USD \$0.33/mi) more to avoid sharing a vehicle with other passengers, AUD \$0.17/km (USD \$0.20/mi) more for door-to-door service, and AUD \$0.10/km (USD \$0.12/mi) to be able to book the service in real time as opposed to having to book the service several hours in advance. All trip purposes were included in their analysis.

The willingness to travel with strangers may be related to rideshare usage and whether individuals in general like to interact with other people. Based on a database of 6.3 million Lyft trips taken in Los Angeles County in 2016, Brown (2020) found higher rates of rideshare use among frequent Lyft users compared to moderate and less-frequent users, which "suggests either that repeat users seek more economical service options and/or repeated ride-hail use increases or is associated with peoples' comfort in sharing cars with strangers." Based on focus groups of individuals from Denmark, Nielsen et al. (2015) found that some Danish negatively perceive ridesharing with strangers due to "social awkwardness," whereas other Danish positively perceive ridesharing with strangers due to the ability to "socialize" with others.

The willingness to travel with strangers may also be related to modes, given individuals are more used to traveling with strangers by air than in an automobile. In the UAM context, Garrow, Roy, and Newman (2020) found that the willingness to ride with strangers varied across the AV and air taxi modes, with those ages 18–24 less willing to travel with strangers in an AV than those ages 25–64 in an AV and that the willingness to travel with strangers was about the same for the air taxi (across all ages) as for those ages 25–64 in an AV. Finally, it is important to

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[13] An exchange rate of 1 AUD = 0.7407 USD was used based on the average exchange rate in 2018, when the survey data were collected (Pound Sterling Live, 2020a).

note that while many studies point to the willingness to pay to travel with strangers, the result is not consistent across all studies. Based on a survey of approximately 500 individuals from Germany, Kolarova et al. (2019) did not find any differences between using a shared AV alone or with others.

4.3 Bringing it All Together—Demand Modeling Insights and Research Directions for UAM

As seen from the literature review, demand modeling within the UAM and EV/AV domains have focused on different objectives. Within the UAM field, the primary focus has been on determining if UAM is a viable concept—e.g., will enough people be willing to fly in these new air taxis and can the service be supported across different cities? Within the ground transportation field, EVs, AVs with lower levels of automation, and sharing services have already been implemented, allowing researchers to focus on understanding SED characteristics of early adopters or how individuals respond to different policy incentives and operational policies.

To the extent that individuals who are interested in EV, AV, and sharing modes will also be interested in air taxis, we would expect that early adopters of air taxis will be more likely to be male, have higher incomes, have pro-environmental attitudes and/or be tech-savvy, technology-oriented lifestyles and be the first to try out new products. These expectations have been confirmed in surveys of U.S. commuters by Boddupalli, Garrow, and German (2020) and Garrow, Roy, and Newman (2020).

The EV and AV literature have several findings that are relevant for the UAM community. To date, there has been a significant amount of research in the EV and AV literature that has looked at the timing of when adoption occurs, but only one paper in the UAM area, by Al Haddad et al. (2020). These technology adoption models can provide valuable information on the role of trust, safety, and perceived usefulness on the adoption of UAM. The literature across both the air and ground transportation areas show mixed reactions in the population with respect to autonomy. Finding ways to increase individuals' trust in autonomy would be a valuable direction for future research. For example, we may find that it is important to provide demonstrations of what it would be like to fly in a UAM using virtual reality and/or to provide safety information to increase individuals' comfort levels with the new technology. The role of social effects (like trusting perceptions of friends and family) has been shown to play a role in adoption of ground vehicle technologies and could be investigated in the context of UAM.

Unlike with ground transportation modes, individuals are more likely to expect to travel with strangers in an aircraft. It is, thus, unclear whether the same effects seen for ridesharing services will apply to UAM. One study, by Garrow, Roy, and Newman (2020) did find that younger commuters were less likely to take a UAM with strangers compared to older commuters. However, there is a research need to understand if the willingness to travel with strangers in a UAM aircraft varies across nations and trip purposes.

Perhaps one of the most interesting findings from the AV literature is that the VOT for commuters will decrease when ground AVs enter the market due to the ability for commuters to use their time more productively. From the UAM perspective, this is important as it suggests that AVs will compete more heavily with air taxis than with conventional autos and that additional travel time savings will be required for the air taxi mode relative to the AV. Potential productivity gains in an AV compared to an air taxi have not been explored in the literature, and there is a need to determine what levels of productivity would be achievable in a UAM vehicle and how productivity varies as a function of ride quality, trip duration, and other factors. Given the VOT decreases seen for AV ground research, better understanding of VOT decreases for UAM vehicles—particularly as they relate to commute trips—is an important area of future research.

Another interesting avenue for future research would be to explore how AVs and air taxis will compete across different trip purposes as an air taxi system evolves and adoption rates increase across both new modes.

5. Integration with Existing Modes and Infrastructure

UAM has the potential to transform urban travel by providing faster connections among residential, business, sports, medical, and other facilities. To achieve this goal, air taxis will need to fly close to and/or over high-density population areas and integrate with existing city infrastructure—including other modes of transportation, the electric grid, and the NAS. As such, there will be many questions that the aviation community will need to address with respect to how we can safely integrate UAM into existing infrastructure while ensuring equitable access. This section reviews infrastructure-related topics that have been investigated by the UAM and EV/AV areas.

5.1 Review of UAM Infrastructure Studies

Several UAM researchers have focused on infrastructure-related issues, mostly in the context of UAM operations. This section highlights the tight couplings researchers have observed among vertiport placement, operations, demand, and energy requirements.

5.1.1 Vertiport Placement, Design, and Airspace Integration

Multiple terms have been used for vertiports, including vertipads, vertistops, and skyparks (Vascik and Hansman, 2017). In this paper we will refer to vertiports for eVTOL operations and STOLports for operations that involve short takeoff and landing flights. Multiple types of locations have been suggested as possible infrastructure that could be used to integrate vertiports into cities, including rooftops with parking lots and/or parking decks (Kreimeier et al., 2018; Robinson et al., 2018; Uber Elevate, 2016), vacant land, floating barges, pre-existing airports and helipads (Robinson et al., 2018), the land adjacent to highways and/or in cloverleaf interchanges, parking lots at places of worship that may be used only on weekends, large stadiums or concert venues that are unused for large portions of the year, the corner of a parking lot in large superstores or malls, and technology campuses (Uber Elevate, 2016).

Several studies have examined optimal locations for vertiports to serve different types of demand. Most of these studies are focused on finding which census tracts and/or larger geographic area would be ideal locations, instead of actual siting. For example, Lim and Hwang (2019) investigated how competitive eVTOL would be for commuters in the Seoul metro area by increasing the number of vertiports from 2 to 36; Daskilewicz et al. (2018) found vertiport locations that maximize population-cumulative potential travel time savings compared to driving in San Francisco and Los Angeles; and German et al. (2018) formulated an optimization problem to find vertiport locations for a cargo demand application in the San Francisco Bay area. As part of a broader study that identified eight operational constraints that could limit or prohibit UAM service, Vascik, Hansman, and Dunn (2018) found that the three most stringent constraints concerned community acceptance of aircraft noise, vertiport availability, and air traffic control scalability.

In terms of vertiport designs, several architectural firms have presented visions (Uber Elevate, 2020b). For example, Vascik and Hansman (2019) considered how different vertiport designs (defined by the number of touchdown and liftoff pads, number of aircraft gates, and number of aircraft staging areas/parking spaces) and the layout of these designs (which include linear, satellite, pier, and remote apron topologies) impact vertiport capacity envelopes. They found that the ratio of gates to touchdown and liftoff pads is a key design parameter, that aircraft staging areas can provide significant benefits, and that vertiports with multiple touchdown and liftoff pads can greatly increase throughput.

Several studies have examined how constraints on the paths aircraft use to take off and land from a vertiport restrict the number of locations that can be used for siting vertiports. Conceptually, even though eVTOL aircraft can hover, they typically climb from and approach a vertiport at an angle to conserve energy reserves and to operate in safe areas of their flight envelopes (e.g., see Yilmaz et al., 2019). The same design criteria and guidance used for helipads can be used as a starting point for siting of vertiports, e.g., the departure and approach paths must be free of obstacles and consider historic wind patterns. Two FAA documents that are particularly relevant in this context include *FAA Advisory Circular AC-150/5390-2C Heliport Design* (FAA, 2012) and *FAA Instrument Procedures Handbook FAA-H-8083-16B* (FAA, 2017).

To date, we could find no published studies that explicitly examined the optimal placement of vertiports for eVTOL operations that considered port design criteria; however, work is in progress by Tarafdar et al. (2020) that uses Zillow's Assessor and Real Estate Database (ZTRAX) to identify parcel-level characteristics important for siting (Zillow, 2020). Several studies have examined the optimal placement of STOLports for short takeoff and landing operations in urban and suburban areas of South Florida, which includes the Miami metro area (Robinson et al., 2018; Justin and Mavris, 2019; Somers et al., 2019; Wei et al., 2020). Robinson et al. (2018) found that an average density of 1.66 STOLports per square mile can be achieved with 300-ft-long runways. Subsequent studies by Justin and Mavris (2019), Somers et al. (2019) and Wei et al. (2020) built on this initial analysis by accounting for obstacles and historic wind patterns and formulating an optimal facility location problem among potential sites.

Finally, several authors have pointed out how the placement of vertiports needs to integrate with airspace restrictions. Verma et al. (2019) looked at near-term routes for UAM based on current-day helicopters routes in DFW, and Vascik and Hansman (2017) used radar trajectory data recorded by the FAA Airport Surface Detection Equipment Model X (ASDE-X) from LAX to identify areas where it may be feasible to route future UAM operations due to the low volume of conventional operations. Air taxi trips into a major commercial airport pose particular challenges due to the need to coordinate trajectories with existing commercial operations. Vitalle et al. (2020) looked at route design for eVTOL aircraft transporting passengers into Tampa International Airport (TPA). They consider three possible vertiport locations at or near the airport: a helipad located two miles from the airport, the rooftop of the economy parking lot in the main terminal area, and the rooftop of the rental parking garage. The rooftop of the economy parking lot is ideal from the passengers' point of view in that it reduces the time to reach their commercial gates and remains inside a secure area; however, this location presents greater challenges with designing trajectories, as aircraft would need to land between two parallel runways.

Vascik and Hansman (2020) developed an approach to analytically identify terminal airspace that is procedurally segregated from large aircraft operations and may be appropriate for new airspace cutouts for eVTOL operations. They applied the methodology to the 34 largest metro areas in the U.S. and found that, on average, 65 percent of a city's population was accessible to vertiports operating under visual flight rules and without air traffic control (ATC) limitations. However, on average, only 34 percent of long-duration commuter workplace locations could be accessed by UAM. Further, a very large variation in accessibility measures existed across the metro areas. The authors found that providing access to special-use airspace, and especially temporary flight restrictions for sporting events, increased commuter workplace access to 54 percent for the median U.S. city.

5.1.2 Battery and Electric Grid Considerations

There is a fundamental trade-off between battery size and mission length. On one hand, bigger batteries have more energy, which can translate into longer missions. However, with the increase in battery size comes additional aircraft weight, which can translate to increased acquisition cost. Based on current battery technology, eVTOL aircraft will likely need to be partially or fully recharged after each mission. Given current battery-charging technologies, the time to perform this charging is likely to deter high aircraft utilization, particularly during peak demand periods. The amount of electricity required to power an electric fleet of aircraft is not trivial and will likely have significant impacts on the electric grid, which may not be able to be supported by the current electric grid.

The issues are described by Kohlman and Patterson (2018) as follows:

> *"if UAM vehicles are to be all-electric, as many are proposing, there will be new demands placed on the electrical grid infrastructure that must be understood. Additionally, vehicle-level characteristics such as the recharge time or energy used for a flight will have direct impacts on the efficiency, cost, and ultimate viability of UAM networks. For example, if vehicles must be charged for long periods of times between missions, a very large number of charging stations will be required at vertiports and many vehicles may be required to meet demand for UAM services."*

Further, the cost of grid upgrades to support UAM operations is not trivial. A recent report by Black & Veatch estimates the cost to extend an existing service line to support 31 MW chargers to be between $75K and $100K; the cost for a new feeder line to support up to 83 MW chargers to be between $2.6K and $1.3M per mile; a new transformer bank over 10 MW to support over 15 chargers to be between $3M and $11M; and a new substation bank over 20 MW to support 30 chargers to be between $40M and $80M (Stith, 2020).

The impact of charging on operations and the number of required charging stations has been noted by other authors. In a study of cargo operations in the San Francisco Bay Area, German et al. (2018) found that for a lift + cruise eVTOL concept model and a tiltrotor aircraft model, charging times with a 300 kW charger ranged from 12.5 to 19.1 minutes and 16.0 to 23.1 minutes, respectively. When the charger was increased to 400 kW, these charge times decreased to 9.5 to 14.4 minutes and 12.1 to 17.4 minutes, respectively.

The impacts of UAM operations on the electric grid were clearly demonstrated in a study by Justin et al. (2017). Based on an examination of electric aircraft for regional distances, they generated power profiles for stations where Cape Air and Mokulele Airlines operate. Cape Air's network included 525 daily flights to 43 airports primarily in the New England area using mostly twin-engine piston-powered Cessna 402s. Mokulele's network included 120 daily flights to airports primarily in the Hawaiian Islands using 11 single-engine turboprop Cessna 208s. They found very high peak powers at the airlines' busiest airports, i.e., for Cape Air the peak power exceeded 1 MW in Nantucket Memorial (ACK) airport and in Boston Logan International (BOS) airport, which is the order of magnitude of the demand of approximately 1,000 households. For Mokulele, the peak-power at Molokai airport (MKK) was 517 kW, which is about 1/20th of the total generation capability for the entire island of Molokai (Justin et al., 2017). The authors explored various operational strategies to reduce peak-power demands and the cost of electricity, and found that a strategy that includes optimizing battery recharging with battery swaps can achieve reductions on the order of 20 percent compared to a power-as-needed strategy.

What is clear from these and other publications is that the power requirements on the electric grid are not trivial, and significant opportunities exist to optimize the deployment of charging and fast-charging stations. Furthermore, given that electricity prices vary across cities and providers, the optimal battery recharging solution will likely be city-dependent.

5.2 Review of EV and AV Infrastructure Studies

This section provides an overview of the types of questions that researchers and policy makers have investigated when integrating a new mode into the existing ground transportation network, and the role of parking availability on mode choice. This discussion is followed by a detailed review of a topic that is particularly relevant to UAM: integration with the electric grid.

5.2.1 Integration with Existing Modes and the Ground Transportation Network

As new technologies and transportation modes enter the market, transportation planners need to understand whether these modes will complement or compete with existing modes. For example, is ridesharing complementary with public transit in providing first-mile and/or last-mile access, or does ridesharing replace public transit trips? Transportation planners are also interested in longer-term impacts, such as whether carsharing reduces car ownership or influences households' residential location choices. Finally, transportation planners often model "rebound effects," which occur when new technologies result in increased travel that can have negative environmental impacts, e.g., through the generation of more trips or longer trips. For example, will AVs reduce the need for parking but generate longer trips due to the fact they can drop passengers off and travel back home and/or travel to a less expensive and more remote location to park?[14] As shown in Figure 2, more than 30 studies exist within the ground transportation literature that look at how EV, AV, and/or ridesharing services will integrate or compete with existing infrastructure.

From a UAM perspective, what is most relevant about these studies is not necessarily the results, but rather the underlying motivations for *why* transportation planners are asking these questions. Within the U.S., urbanized areas that have a population of greater than 50K are required to have a metropolitan planning organization (MPO) that is responsible for establishing a long-

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[14] This is of particular concern for airports, which could lose significant parking revenues if AVs simply drop off passengers.

term transportation improvement plan (TIP) that sets transportation investment priorities in the area (FTA, 2019). Major federal transportation authorization bills, such as the Moving Ahead for Progress in the 21st Century Act (MAP-21) and the Fixing America's Surface Transportation (FAST) Act, establish regulations that MPOs must follow in order to receive transportation-related funding. These regulations require that the selection of projects be based on performance metrics, equity considerations, and other criteria (e.g., see US DOT, 2013). In the case of congestion management plans, the regulations state that an MPO's TIP "must include regional goals for reducing peak-hour vehicle miles and improving transportation connections and must identify existing services and programs that support access to jobs in the region … [23 U.S.S. 134(k)(3)]" (FHWA, 2016). Other federal legislation is critical to transportation planning and funding priorities, including the Clean Air Act (CAA), Clean Water Act (CWA), National Environmental Policy Act (NEPA), National Historic Preservation Act (NHPA), and Americans with Disabilities Act (ADA). (EPA, 2020a, 2020b; NPS, n.d.; US DOJ, 2020). From a UAM perspective, it is important to note that as we integrate this new mode into our cities, government funding for infrastructure improvements will likely be tied to these or similar regulations.

Given the focus (not only in the U.S., but in many countries throughout the world) on transitioning to clean energy and reducing the negative impacts of the transportation sector on carbon emissions, many studies that look at integration of new ground technologies with existing modes and infrastructure consider metrics that tie to these goals, including total vehicle miles traveled (VMT) and greenhouse gas emissions. For example, Jones and Leibowicz (2019) examined these issues in the context of shared AVs, and Shen et al. (2018) examined these issues in the context of an integrated AV and public transit system for Singapore. Bansal et al. (2016) examined long-term adoption of shared AVs in Austin, Texas, and simulated long-term adoption under different scenarios to help assess sustainability impacts. Ai et al. (2018) found through siting EV charging stations near public transit in Chicago, Illinois, that commuters can reduce up to 87 percent of personal VMT and 52 percent of carbon emissions, and Muñoz-Villamiza et al. (2017) evaluated environmental impact and delivery cost implications of using an all-electric fleet of delivery vehicles in Bogotá, Colombia.

One of the key findings from the ground transportation literature that is directly applicable to UAM research is the role of parking availability on mode choice. Within the ground transportation field, several researchers have explored the relationships among mode choice, work departure time, ground transportation congestion, and availability of parking at the work destination (e.g., see Tian, Sheu, and Huang, 2019; Mang, Ban, and Huang, 2019). Intuitively, we expect that individuals are more likely to take ridesharing and/or transit modes compared to a conventional auto if there is limited parking availability at their destination. This has important implications for UAM. First, if parking in business centers is expensive and/or limited, using an air taxi for commuting will be more competitive with auto. Similarly, if on-site parking at airports[15] reaches capacity at certain times of the day and/or days of the week, then using an air taxi to travel to and from the airport will be more competitive with auto (although maybe not as competitive with ridesharing).

5.2.2 Integration with the Electric Grid

Within the ground transportation literature, more than a dozen studies have been done examining how plug-in EVs (PEVs) and consumers' charging behaviors will impact the electric grid and how policy strategies can be used to help reduce peak loads on the electric grid and draw more renewal energy from the grid. Hardman et al. (2018) reviewed the literature as it pertains to infrastructure requirements for PEVs and found that PEV charging will not impact electric grids in the short term but may need to be managed long term. Marmaras et al. (2017) modeled the impact of EV driver charging behavior on the transportation and electric grid networks. They found that EV driver behavior has "direct and indirect impacts on both the road transport network and the electricity grid." They examined consumer charging preferences (e.g., normal charging at home, normal or fast charging at a public charging station) and offered operational strategies to help shift peak loads at public charging stations. Multiple studies have shown that controlled-charging of EVs, including time-of-day pricing, can better balance loads on the electric grid and impact power grid loads, voltage, frequency, and power losses (Bailey and Axsen, 2015; Daina et al., 2017; Latinopoulos et al., 2017; Xu et al., 2017). Luo et al. (2020) went one step further by jointly designing charging station and solar power plants with time-dependent charging fees to improve management of transportation and power systems.

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[15] A simple Google search of "how often does airport parking reach capacity" conducted on September 14, 2020, returned multiple results to airport webpages and/or news articles that issued warnings about their parking lots "routinely" reaching capacity. These included airports in Las Vegas, Salt Lake City, Sacramento, San Jose, Honolulu, Denver, Atlanta, Spokane, and many others.

A few studies have analyzed interactions between the electric grid and e-mobility; however, these studies are difficult to conduct in some countries due to limited information that is publicly available about the electric grid (e.g., capacity and loads as a function of different times of the day). Therefore, it is more common to produce EV charging profiles and examine how these profiles are affected by different policies (such as changing time of day pricing), e.g., see Delgado et al. (2018) for a study in Portugal, and Wang, Ban, and Huang (2020) for a study in Singapore. A notable exception is a study by Kannan and Hirschberg (2016) who used a detailed energy model developed for Switzerland and found that the cost effectiveness of e-mobility depends on policy decisions in the electric sector.

Within the ground transportation literature, another interest is in vehicle-to-grid technologies, where energy is stored in EVs and returned to the grid when it is needed, generating revenues for the EV owner (e.g., see Kester et al., 2019; Nourinejad et al., 2016; Sovacool et al., 2019). Within a UAM context, this is likely not a viable option, given the large costs of aerospace-grade battery packs and the battery degradation that would occur through the charging and discharging cycles. Additionally, this use case would likely further add to the challenge of certificating UAM battery packs with national aviation regulatory agencies. However, the concept could be adapted to UAM applications by using batteries that are no longer viable for use onboard the aircraft to store energy on the ground at or near vertiports, e.g., by charging these ground batteries during less-expensive off-peak hours and then using them to charge the flight batteries in the UAM aircraft during peak-period operations.[16]

Given the high cost of batteries, several ground-based studies have examined how different recharging strategies, including battery swapping and fast charging, can be optimized to help regulate the charge profile and enhance battery life (e.g., Amjad et al., 2018; Sweda et al., 2017; Pelletier et al., 2018; Keskin and Çatay, 2016; Liao et al., 2016; Qin et al., 2016; Wu and Sioshansi, 2017; Widrick et al., 2018). The study by Pelletier and colleagues offers one of the more comprehensive optimization models and incorporates realistic charging processes, time-dependent energy costs, battery degradation, grid restrictions, and facility-related demand charges for a fleet of electric freight vehicles. They found that fast chargers may be required for vehicle operation flexibility when longer routes are performed.

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[16] We thank Pascal van Hentenryck for this insight.

Optimal charging strategies have received a lot of attention in ground literature in part because EV charging has a significant impact on EV downtime. For example, in a study by Roni et al. (2019) they noted that in free-floating EV carsharing fleets "downtime due to charging, including time spent traveling to and waiting in queues at charging stations in a sparse charging infrastructure network is a major barrier to sustainable operations." The authors found that fleet vehicle charging time comprises 72–75 percent of the total downtime spent on charging trips and that adding new charging stations reduced total charging trip travel time but did not significantly reduce total downtime. These results are relevant for UAM because they show that a significant operational bottleneck is related not only to battery recharging but to queuing for battery charging. Shen et al. (2019) and Amjad et al. (2018) provided review articles that cover EV charging operations and optimization approaches.

5.3 Bringing it All Together—Infrastructure Insights and Research Directions for UAM

Across both the UAM and EV/AV literature, station placement has been shown to be a critical factor influencing overall system performance. The sheer volume of publications in the EV area that have focused on charging infrastructure or charging type is noteworthy—about one out of every five EV papers we inventoried addressed these topics, as indicated in Figure 2. Within the EV community, significant attention has been placed on understanding individuals' charging behavior and strategies for shifting charging patterns to reduce the peak period load on the electric grid. This is relevant from a UAM perspective, as it suggests that the transportation community is already experiencing challenges associated with charging a ground EV fleet. Some EV research has suggested that current electric grids won't be able to support future EV ground vehicle charging needs. Needless to say, if we are not in a position to handle charging of a ground EV fleet, how are we going to handle charging a UAM fleet that will likely require even faster charge times? There is a clear research need to better understand the power profiles of UAM fleets and develop strategies for how to optimally charge UAM fleets without overwhelming the electric grid. Another interesting topic would be to jointly examine the power profiles for UAM fleets and EV ground fleets, as both technologies will be competing for a limited amount of electricity.

As will become more evident in the next section that focuses on operations, the placement of vertiports is closely coupled with operations and other factors. All of this points to the need to develop high-fidelity simulation models for UAM operations that capture interactions among vertiport locations, vertiport topology, demand, pricing, dispatching, and airspace restrictions.

In comparing the UAM and AV/EV literatures, we could find no mention of the role of parking availability on air taxi mode choice, and we suggest this could be an interesting factor to include in future air taxi mode choice studies, particularly studies that included ridesharing, air taxis, and traditional autos as potential modes. As we integrate UAM into our cities, it will be important to work with local planning organizations to ensure that any infrastructure investments that require public funding align with regulations these organizations need to follow.

6. Operations

This section reviews operations-related topics explored by the UAM and EV/AV research communities and identifies results from the EV/AV areas that can help inform future UAM research.

6.1 Review of UAM Operations Studies

As the UAM community designs an air taxi system capable of high-volume throughput integrated in urban areas, many operations-related questions arise. One of the first steps in the analysis process is to design a concept of operations (ConOps), which is essentially a plan for how UAM operations can be safely integrated into the national airspace system. In June 2020, NASA released its ConOps vision, which includes UAM corridors in the sky in which aircraft could operate without the direct involvement of air traffic control (ATC) (Bradford, 2020). Given the importance of ensuring safe operations within the existing NAS, it is not surprising that the UAM community has focused significant attention on ATC-related issues (as shown in the meta-analysis, Figure 1).

Given a concept of operations, researchers can assess whether a particular aircraft design can successfully and economically perform a given mission, and if it cannot, make modifications to the aircraft design (e.g., see Clarke et al. 2019). To determine whether a mission can be performed successfully for an electric-powered aircraft, researchers need to model the mission's power and energy requirements, which imply the peak current and total capacity required by the battery. For example, Kulkarni et al. (2018) developed an on-board battery monitoring and prognostic architecture for batteries on electric-propulsion aircraft. Alnaqeb et al. (2018) and Prabhakar et al. (2020) developed models to predict mission-based energy and performance metrics; Donateo and Ficarella (2020) proposed a modeling approach for the degradation of the battery performance during its aging; and Shabanpour and Wei (2018) developed energy-efficient trajectory plans for a multirotor eVTOL. Hamilton and German (2017, 2019) optimized airspeeds for electric aircraft operations to maximize energy feasibility in the schedule by balancing energy expended during cruise and energy replenished during recharge.

Several researchers have investigated the relationships among aircraft design parameters and operational requirements such as cruise speed and hover time. For example, using the Uber eCRM 001 eVTOL common reference model (Uber Elevate, 2020a), Ha et al. (2020) jointly optimized aircraft design parameters in addition to operational parameters to achieve a 9.66 percent decrease in required hover power. Other researchers have examined the potential for retrofitting existing aircraft with an electric propulsion system to determine if such aircraft could profitably operate for pilot-training applications (Olson, 2015) or short-haul UAM intracity commuter trips in U.S. cities (Kotwicz et al., 2019).

UAM clearly will not be successful without a ConOps that safely integrates aircraft into the NAS and aircraft that can complete the required missions. Thus, it is not surprising that much of the research by the UAM community has been focused on mission performance and related areas, such as battery design and battery modeling. However, as the vision for UAM ConOps and aircraft designs has become clearer, the UAM community is starting to focus on more complex operational issues that include dispatching algorithms and pricing approaches, which are similar topics explored by the EV and AV communities. For example, Roy et al. (2019) examined how existing infrastructure, resources, and operational strategies could be leveraged with improvements in battery and autonomy for regional air mobility. Roy, Crossley, et al. (2018) jointly optimized aircraft designs, operations, and revenue management, and Roy et al. (2020) developed a dispatch model to optimally schedule UAM flights for a shuttle service to an airport that has both scheduled and on-demand customers. Shihab et al. (2019) developed a model to decide whether to offer on-demand or scheduled flights, and how to dispatch the fleet and schedule operations based on simulated market demand. Munari and Alvarez (2019) assigned aircraft to on-demand requests while accounting for maintenance events, allowing flight upgrades in order to reduce operational and repositioning costs. Narkus-Kramer et al. (2016) examined trade-offs associated with battery-powered, remotely piloted semi-autonomous personal aircraft, and found that profitability is closely tied to high network utilizations (which result in fewer deadhead and repositioning flights) and high daily utilization (or higher average hours flown). Finally, Stouffer and Kostiuk (2020) designed a dispatching tool for UAM operations that enables a dispatcher to plan a UAM flight and check for issues before filing a flight plan.

The majority of the papers to date focused on dispatching and scheduling algorithms have presumed a deterministic framework, but two important consideration in UAM applications are that scheduling and dispatching algorithms may need to be done in real time or using a rolling horizon framework to account for delays and uncertainties, and these algorithms may need to be applied at a network level. As Thipphavong et al. (2018) noted, "due to limited energy reserves, UAM aircraft must have assurances prior to takeoff that their destination landing site will be available when they arrive. The tight coupling between arrivals and departures across the vertiports in a UAM network points to the possible need for continuous network-wide scheduling as a first-order control method for real-time, on-demand resource management."

6.2 Review of EV and AV Operations Studies

EVs have been integrated into many communities throughout the world. As a result, researchers have been able to both develop and validate models using case studies. In the process, researchers have gained many insights regarding how system performance and profitability are affected by fleet size, demand, pricing, and reservation and dispatching strategies. Many of these insights are relevant to the UAM community, particularly given similarities in the directional demand patterns that both ground and UAM communities seek to serve.

From an operations perspective, developing strategies to serve one-way demand while maintaining profitability has been a particularly vexing problem for vehicle-sharing companies. Many travel patterns exhibit strong uni-directional flows, especially during peak periods. For example, in many cities morning rush hour traffic is created by commuters traveling from the suburbs into the city centers to work. Before COVID-19, airports that served predominately business travelers would see peaks of passengers traveling to the airport for Monday morning flights and peaks of passengers leaving the airport Thursday evening and/or Friday to return home. One-way demand patterns result in the need to increase the number of vehicles available to serve peak directional demand (e.g., see Hörl et al., 2019) and/or increase the need to reposition empty vehicles. Staging vehicles to serve peak demand and/or attempting to temporally or spatially shift demand to nearby pick-up and drop-off locations are some strategies that have been explored to serve one-way demand profitably (e.g., see Ströhle et al., 2019).

Within the ground transportation literature, many researchers have focused on the vehicle relocation problem, often in the context of one-way demand systems. Illgen and Höck (2018) provide a review of methods used to relocate vehicles in carsharing networks. Representative studies include those by Wang, Liu, and Ma (2019) and Wang, Yang, and Zhu (2018), who examined one-way electric carsharing systems; Warrington and Ruchti (2019), who studied Philadelphia's public bike-sharing program; and Vasconcelos et al. (2017), who studied a carsharing service in Lisbon, Portugal, and found that relocating vehicles generated an additional 19–24 percent in profits for operators.

Given that "the cost associated with vehicle relocation operations represents a significant proportion of the total operating cost" (Boyacı and Zografos, 2019), many researchers have developed methods for better predicting demand and for tailoring operational strategies to minimize relocation costs while maintaining high service levels. Wen et al. (2019) examined dispatching polices with different types of demand information for an AV shared system and found that individual demand information from in-advance requests improves performance, but the degree of performance depends on the spatial disparity of requests. Boyacı and Zografos (2019) examined temporal and spatial flexibility regarding pick-up and drop-off of vehicles in a one-way electric carsharing system and found that spatial flexibility has a stronger effect than temporal flexibility, but both temporal and spatial flexibility can increase profitably of the system by serving more customers with fewer relocation needs. Hyland and Mahmassani (2018) compared different dispatching policies for an AV service and found that the optimal dispatching policy is a function of demand, with more sophisticated dispatching polices generating higher revenues during the peak demand period and simple dispatching policies (i.e., assigning passengers sequentially to nearest idle AV) working well in low demand periods. This result is consistent with the findings based on a case study of Zurich, Switzerland, that investigated different operational policies for an AV shared mobility system and found that operational policies had a significant impact on vehicle assignment and repositioning, heavily influencing system performance of wait times and cost (Hörl et al., 2019). Both Hyland and Mahmassani (2018) and Hörl et al. (2019) found that the utilization of intelligent demand forecasts and dispatching and rebalancing algorithms were crucial elements of profitability. In addition, Hyland and Mahmassani (2020) found that increases in the mean curbside pick-up time for a shared AV system significantly degrades operational performance in terms of user in-vehicle travel time and user wait time.

The role of advance reservations in the profitability of sharing services is nuanced. On one hand, advance reservations provide more certainty with respect to future demand and allow the operator to position vehicles in advance to the locations where customers have requested service. However, if operators take vehicles out of service too far in advance to guarantee availability for reservations, then vehicle utilization and the ability to serve on-demand requests may decrease, resulting in a less profitable system. As Molnar and Correia (2019) pointed out "while it is convenient for customers to be able to do one-way trips and drop off vehicles anywhere in a service area, this makes it difficult to offer reservations in advance" and there is a need to explore ways to increase advance reservation times by relocating vehicles to shortly before reservation pick-up times.

Several researchers have explicitly focused on the issue of advance reservations and traveler flexibility. Wu et al. (2019) examined the role of guaranteed advance reservations for a free-floating carsharing service in London and found that individuals are willing to pay £0.54 per journey ($0.75 USD)[17] for a guaranteed advance reservation. Duan et al. (2020) examined a system in which individuals can either request immediate rides or reserve an AV taxi service in advance, and optimized a model that considers vehicle-to-passenger assignment with empty vehicle rebalancing. They found that when the number of vehicles is adequate and reservations are made further ahead of time, the completion rate of requests and revenue improve. Allahviranloo and Chow (2019) examined a system in which individuals can buy future time slots for AV and are guaranteed service. They found the spatial temporal distribution of demand impacts the solution to the fleet sizing problems.

Several researchers have jointly optimized fleet size and trip pricing for sharing systems. Xu, Meng, and Liu (2018) jointly optimized EV fleet size and trip pricing for a one-way carsharing service that considers vehicle relocation and personnel assignment based on a case study of Singapore. Jorge et al. (2015) used a theoretical case study network of 75 carsharing stations in

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[17] An exchange rate of 1 GBP = 1.383 USD was used based on the average exchange rate in January 2018, when the survey data were collected (Pound Sterling Live, 2020b).

Lisbon, Portugal, and found that trip pricing can increase profits through more balanced systems; optimal profits are on average 23 percent higher than base prices and serve 18 percent less demand.

Finally, several researchers have noted that the optimal operational policies and/or deployment of charging stations will evolve over time as demand increases. Ghamami, Zockaie, and Nie (2016) found that ignoring delay induced by charging congestion led to suboptimal configuration of charging infrastructure, with effects potentially more prominent as demand increased over time for PEVs. Wu and Sioshansi (2017) found challenges in planning placement of public fast-charging stations for EV due to uncertainty in future demand with initial expansion concentrated around the urban core. Dong, Ma, et al. (2019) found that as additional charging stations are built, the optimal locations start in central London and gradually expand out to suburban areas of London. Zhang, Schmöcker, et al. (2020) found when expanding one-way carsharing stations, demand growth is higher around transit hubs and public facilities than in residential areas.

6.3 Bringing it All Together—Operations Insights and Research Directions for UAM

Based on prior research from the ground transportation literature, it is clear that system performance and profitability is driven by multiple factors, including the spatial and temporal distribution of demand, fleet size, pricing, and operational policies, and that there are strong couplings across these factors. As Repoux et al. (2019) eloquently stated, “The interaction between all parameters and settings in carsharing is complex and highly non-linear. It re-emphasizes the importance for any practitioner to identify the most effective elements (namely fleet size, station capacities, rental rules) as well as the ones specific to the system’s environment and demand.” From a UAM perspective, this highlights a critical need to jointly optimize interactions among fleet, demand, pricing, and dispatching policies. The fact that many use cases for UAM (such as commuting and trips to the airport) exhibit strong directional or one-way demand patterns will likely put further pressure on the profitability of UAM networks. One key difference between the UAM and EV/AV communities relates to the need for real-time optimization and dispatching algorithms. The penalty for running out of battery energy is much more severe in air applications than ground applications; simply stated, an eVTOL aircraft cannot run out of battery power for safety reasons. Consequently, approaches that synchronize takeoffs and landings at a vertiport in real time or under a rolling horizon framework will likely be much more critical (e.g., see Kleinbekman et al., 2020).

The experiences from the ground transportation literature with respect to the potential reduction in utilization caused by guaranteeing advance reservations is particularly relevant for the UAM community, given many customers may expect a high level of availability for their flights. Results from the ground transportation literature that find profitability can be significantly increased by rejecting demand requests is similarly problematic for UAM applications, given customer retention and wide-scale adoption will likely be strongly tied to reliability and availability of air taxis. Some strategies to increase reliability used in public transportation, such as a guaranteed ride home, may be valuable for UAM applications, e.g., if the UAM service cannot fly, the passengers would be given priority and guaranteed a ride via a ground transportation mode (like ridesharing) for a similar or reduced price as UAM. Based on a survey of 2,500 commuters in the U.S., Boddupalli, Garrow, and German (2020) found that individuals were 1.8 times more likely to take an air taxi if a guaranteed ride home were provided.

All of these factors point to the trade-off between system performance and system cost—that is, we can over-design a system by ensuring extra aircraft in the fleet are available to serve peak periods and most customer demand requests, but serving all customer demand requests will likely be prohibitively costly. For example, the former CEO of NetJets, a private business jet company with fractional ownership, noted that in order to be profitable, he needed to cover 98 percent of all requested trips, and that serving 100 percent of all requested trips eliminated profits (Berger, 2001, as quoted in Mane and Crossley, 2007). Findings related to intelligent operational strategies and pricing policies that have been able to improve performance in ground transportation offer promising directions for the UAM community.

Optimizing over different time horizons will be important, particularly given the higher costs of establishing vertiports and charging stations for UAM applications than for EV applications. In addition, planning the deployment of vertiports and charging stations in ways that provide equitable access to citizens will be important if public funding is used for this infrastructure.

7. Conclusions

Research and interest in UAM have grown exponentially over the past five years, but significant questions remain with respect to whether UAM will become the next disruptive technology in urban transportation. As seen in the meta-analysis of UAM publications, much of the emphasis to date has been focused on fundamental questions. How do we design an eVTOL aircraft? How can we create more energy-dense batteries to support eVTOL missions? How do we design the airspace so that high-volume eVTOL operations can occur simultaneously with commercial and drone operations? Will there be demand for an eVTOL air taxi service and, if so, which business cases make the most sense—commuting, business shuttles to an airport, or other trip purposes? In contrast, research in EV/AV and sharing technologies for ground transportation is further along, and researchers and communities have experiences in designing and implementing EV fleets, some of which are part of ridesharing or carsharing applications.

This paper conducted a meta-analysis of UAM, EV, and AV research published over the past five years (i.e., 2015 to 2020) to compare and contrast their research thrusts. By conducting an in-depth review of articles related to demand modeling, operations, and integration with existing infrastructure, we gleaned insights that can inform future UAM research directions.

From a demand perspective, if UAM follows trends seen in EV adoption, we would expect early adopters of UAM to more likely be male, have higher incomes, and have tech-savvy and pro-environmental attitudes; however, differences in adoption across countries is expected, with Asian countries having greater pro-technology inclinations. Importantly, the EV/AV literature has consistently found that individual preferences vary greatly and a polarization often occurs in which some individuals are enthusiastic about the new technology and willing to pay for automation and other technology features, while other individuals are negative about the new technology and state they will never adopt it. One of the reasons the EV community has focused so much research in the technology adoption area is because EV use and adoption rates have not been as high as researchers expected. The UAM community should pay particular attention to this phenomenon, as it suggests that modeling when individuals will adopt UAM will be important for demand estimations and that there is a research need to better understand how to help potential consumers feel more comfortable with the technology. Applying insights from the EV/AV area, this could include designing messages and information campaigns about the safety and limitations of UAM vehicles, and it may involve marketing campaigns that focus on recommendations from trusted family and friends. From a technology adoption perspective, it will be important to model how adoption rates for UAM evolve as AVs enter the market. Based on the theoretical and empirical results reported in the EV/AV literatures that find values of time decrease (and potentially significantly) for commute trips due to the fact individuals can be more productive in an AV compared to a conventional car, we expect that the introduction of AVs into the market will erode demand for commuter air taxis.

Our review of articles focused on infrastructure- and operations-related topics revealed strong couplings among multiple factors, including the spatial and temporal distribution of demand, fleet size, pricing, vertiport placement, vertiport topology, airspace restrictions, and operational policies. Further, many of the articles focused on one or more of these topics showed significant impacts on system performance. An important direction for the UAM research community is to develop high-fidelity simulation models that take these and potentially other factors into account. Given demand profiles today will not be reflective of demand profiles in the future (due to different adoption rates, spatial changes in populations, the introduction of competing technologies such as AVs), it will be important to conduct these simulations over different time periods to ensure results are robust over time.

It will be important for the UAM community to understand how UAM operations will impact the electric grid (and if the grid can even support UAM operations). Given insights from the EV literature that suggest the electric grid will already be stressed handling ground EV charging requirements, jointly considering EV and UAM power profiles may be important to ensure the electric grid can support both EV and UAM charging needs.

As with any analysis, there are limitations to be noted. The classification of keywords we associated with each article is arguably subjective; however, the classification enabled us to identify high-level trends across the fields. Given that researchers may be interested in identifying themes that we did not cover in this paper, we compiled a supplemental spreadsheet file, which is available online as a compendium to this paper. Our intention for this spreadsheet is to help facilitate the ability of other researchers to quickly identify keywords and/or to use the DOI links provided to more quickly identify papers relevant to their own research areas. Additionally, it is important to note that the publications in the AIAA database include both peer-reviewed journal publications as well as non–peer-reviewed conference proceedings.

It is important to note that our review was conducted pre-COVID-19 and that the future of transportation is at this time unclear. Some trends suggest that demand for UAM may actually increase. For example, as individuals move out of cities and into suburbs and work from home multiple days per week, they may be more interested in using an air taxi to commute to work on the days they need to travel to the office. Other trends suggest that demand for UAM may decrease. For example, if business travel decreases, the overall demand for business trips to commercial airports will decrease and fewer individuals would likely take an air taxi to the airport. It is also important to recognize that the momentum we have seen on UAM development may stall as the effects of COVID-19 continue to ripple through the industry. For example, on September 18, 2020, Boeing announced that it was suspending work at its NeXt innovation unit, which is the business division that was responsible for its UAM efforts (Gates, 2020).

In conclusion, it is our hope that both the air and ground transportation communities will find this article to be a valuable resource document, generate discussions as to potential research directions in UAM, and encourage interdisciplinary research in UAM. Never before have we attempted to fly so many air vehicles in our cities—and achieving this goal will not be a problem solved in isolation by the aerospace community.

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References

Adnan, N., Md Nordin, S., Hadi Amini, M., Langove, N., 2018. What make consumer sign up to PHEVs? Predicting Malaysian consumer behavior in adoption of PHEVs. *Transportation Research Part A: Policy and Practice* 113, 259–278. https://doi.org/10.1016/j.tra.2018.04.007

Adnan, N., Md Nordin, S., bin Bahruddin, M.A., Ali, M., 2018. How trust can drive forward the user acceptance to the technology? In-vehicle technology for autonomous vehicle. *Transportation Research Part A: Policy and Practice* 118, 819–836. https://doi.org/10.1016/j.tra.2018.10.019

Ai, N., Zheng, J., Chen, X., 2018. Electric vehicle park-charge-ride programs: A planning framework and case study in Chicago. *Transportation Research Part D: Transport and Environment* 59, 433–450. https://doi.org/10.1016/j.trd.2018.01.021

Airbus, 2018. Voom's Helicopter Service Launches in Mexico City. March 9, 2018. Available online at https://www.airbus.com/newsroom/news/en/2018/03/voom-s-helicopter-commuting-service-launches-in-mexico-city.html. Accessed September 5, 2020.

Airbus, 2020a. Vahana Aircraft. Available online at https://www.airbus.com/innovation/zero-emission/urban-air-mobility/vahana.html. Accessed September 2, 2020.

Airbus, 2020b. Voom: An On-demand Helicopter Booking Service. Available online at https://www.airbus.com/innovation/zero-emission/urban-air-mobility/voom.html. Accessed September 5, 2020.

Ajzen, I., 1985. From intentions to actions: A theory of planned behavior. In J. Kuhl and J. Beckmann (Eds.), *Action-control: From Cognition to Behavior* (pp. 1-63), Heidelberg: Springer.

Akhter, M.Z., Raza, M., Iftikhar, S.H., Raza, M., 2020. Temporal and economic benefits of vertical take-off and landing vehicles in urban transport. 2020 Advances in Science and Engineering Technology International Conferences (ASET). https://doi.org/10.1109/ASET48392.2020.9118256

Al Haddad, C., Chaniotakis, E., Straubinger, A., Plötner, K., Antoniou, C., 2020. Factors affecting the adoption and use of urban air mobility. *Transportation Research Part A: Policy and Practice* 132, 696–712. https://doi.org/10.1016/j.tra.2019.12.020

Alcock, C., 2020. EmbraerX's EVTOL, Formerly Known As DreamMaker, Resurfaces As Eve. Available online at https://www.futureflight.aero/news-brief/2020-08-12/embraerxs-evtol-formerly-known-dreammaker-resurfaces-eve. Accessed October 12, 2020.

Alemi, F., Circella, G., Mokhtarian, P., Handy, S., 2019. What drives the use of ridehailing in California? Ordered probit models of the usage frequency of Uber and Lyft. *Transportation*

Research Part C: Emerging Technologies 102, 233–248. https://doi.org/10.1016/j.trc.2018.12.016

Allahviranloo, M., Chow, J.Y.J., 2019. A fractionally owned autonomous vehicle fleet sizing problem with time slot demand substitution effects. *Transportation Research Part C: Emerging Technologies* 98, 37–53. https://doi.org/10.1016/j.trc.2018.11.006

Alnaqeb, A.H., Li, Y., Lui, Y.-H.., Pradeep, P., Wallin, J., Hu, C., Hu, S., Wei, P., 2018. Online prediction of battery discharge and flight mission assessment for electrical rotorcraft. In *2018 AIAA Aerospace Sciences Meeting*, Kissimmee, Florida. https://doi.org/10.2514/6.2018-2005

American Automobile Association (AAA), 2017. AAA Reveals True Cost of Ownership. Available online at https://newsroom.aaa.com/tag/driving-cost-per-mile/. Accessed September 5, 2020.

Amirkiaee S.Y., Evangelopoulos, N., 2018. Why do people rideshare? An experimental study. *Transportation Research Part F: Traffic Psychology and Behaviour* 55, 9–24.

Amjad, M., Ahmad, A., Rehmani, M.H., Umer, T., 2018. A review of EVs charging: From the perspective of energy optimization, optimization approaches, and charging techniques. *Transportation Research Part D: Transport and Environment* 62, 386–417. https://doi.org/10.1016/j.trd.2018.03.006

Antcliff, K.R., Moore, M.D., Goodrich, K.H., 2016. Silicon Valley as an early adopter for on-demand civil VTOL operations. *16th AIAA Aviation Technology, Integration, and Operations Conference*, 16th AIAA Aviation Technology, Integration, and Operations Conference, Washington, DC, June 13. https://doi.org/10.2514/6.2016-3466

Aurora Flight Sciences, 2020. Pegasus Aircraft Model. Available online at https://www.aurora.aero/pav-evtol-passenger-air-vehicle/. Accessed September 2, 2020.

Axsen, J., Goldberg, S., Bailey, J., 2016. How might potential future plug-in electric vehicle buyers differ from current “Pioneer” owners? *Transportation Research Part D: Transport and Environment* 47, 357–370. https://doi.org/10.1016/j.trd.2016.05.015

Bailey, J., Axsen, J., 2015. Anticipating PEV buyers’ acceptance of utility controlled charging. *Transportation Research Part A: Policy and Practice* 82, 29–46. https://doi.org/10.1016/j.tra.2015.09.004

Ballentine, C., 2019. Uber Copter will now fly you over city gridlock. *Bloomberg*, October 3, 2019. Available online at https://www.bloomberg.com/news/articles/2019-10-03/uber-copter-service-begins-for-all-users-in-new-york. Accessed September 5, 2020.

Bansal, P., Kockelman, K.M., 2018. Are we ready to embrace connected and self-driving vehicles? A case study of Texans. *Transportation* 45(2), March 1, 641–75. https://doi.org/10.1007/s11116-016-9745-z

Bansal, P., Kockelman, K.M., Singh, A., 2016. Assessing public opinions of and interest in new vehicle technologies: An Austin perspective. *Transportation Research Part C: Emerging Technologies* 67, 1–14. https://doi.org/10.1016/j.trc.2016.01.019

Becker, F., Axhausen, K.W., 2017. Literature review on surveys investigating the acceptance of automated vehicles. *Transportation* 44(6), 1293–1306. https://doi.org/10.1007/s11116-017-9808-9

Becker, K., Terekhov, I., Niklaß, M., Gollnick, V., 2018. A global gravity model for air passenger demand between city pairs and future interurban air mobility markets identification. *2018 Aviation Technology, Integration, and Operations Conference*. 2018 Aviation Technology, Integration, and Operations Conference, Atlanta, GA, June 24. https://doi.org/10.2514/6.2018-2885

Bell Flight, 2020. Bell Nexus Aircraft. Available online at https://www.bellflight.com/products/bell-nexus. Accessed September 2, 2020.

Bennett, R., Vijaygopal, R., Kottasz, R., 2019. Attitudes towards autonomous vehicles among people with physical disabilities. *Transportation Research Part A: Policy and Practice* 127, 1–17. https://doi.org/10.1016/j.tra.2019.07.002

Berger, W., 2001. Hey, you're worth it (even now). *Wired*, June 1, 2001. Available online at https://www.wired.com/2001/06/netjets/. Accessed September 21, 2020.

Berkeley, N., Bailey, D., Jones, A., Jarvis, D., 2017. Assessing the transition towards battery electric vehicles: A multi-level perspective on drivers of, and barriers to, take up. *Transportation Research Part A: Policy and Practice* 106, 320–332. https://doi.org/10.1016/j.tra.2017.10.004

Berkeley, N., Jarvis, D., Jones, A., 2018. Analysing the take up of battery electric vehicles: An investigation of barriers amongst drivers in the UK. *Transportation Research Part D: Transport and Environment* 63, 466–481. https://doi.org/10.1016/j.trd.2018.06.016

Binder, R., Garrow, L.A., German, B., Mokhtarian, P., Daskilewicz, M., Douthat, T.H., 2018. If you fly it, will commuters come? A survey to model demand for eVTOL urban air trips. *2018 Aviation Technology, Integration, and Operations Conference*. 2018 Aviation Technology, Integration, and Operations Conference, Atlanta, Georgia, June 25. https://doi.org/10.2514/6.2018-2882

Biresselioglu, M.E., Demirbag Kaplan, M., Yilmaz, B.K., 2018. Electric mobility in Europe: A comprehensive review of motivators and barriers in decision making processes.

Transportation Research Part A: Policy and Practice 109, 1–13. https://doi.org/10.1016/j.tra.2018.01.017

BLADE, 2020. BLADE Airport. Available online at https://blade.flyblade.com/p/about-airport. Accessed September 5, 2020.

Blain, L., 2020. Jaunt's ROSA gyrodyne: The first eVTOL air taxi that actually looks safe. *New Atlas*. Available online at https://newatlas.com/aircraft/jaunt-air-mobility-evtol-gyrodyne-air-taxi/. Accessed September 3, 2020.

Boddupalli, S.-S., Garrow, L.A., German, B.J., 2020. Mode Choice Modeling for an Electric Vertical Take-off and Landing (eVTOL) Air Taxi Commuting Service in Five Large U.S. Cities. Working paper, Georgia Institute of Technology.

Booz Allen Hamilton, 2018. Urban Air Mobility (UAM) Market Study. Technical Out Brief to the National Aeronautics and Space Administration (NASA). Available online at https://ntrs.nasa.gov/citations/20190000517. Accessed September 4, 2020.

Boyacı, B., Zografos, K.G., 2019. Investigating the effect of temporal and spatial flexibility on the performance of one-way electric carsharing systems. *Transportation Research Part B: Methodological* 129, 244–272. https://doi.org/10.1016/j.trb.2019.09.003

Bradford, S., 2020. Urban Air Mobility: Concept of Operations v1.0. Federal Aviation Administration, Office of NextGen, June 26. Available online at https://assets.evtol.com/wp-content/uploads/2020/07/UAM_ConOps_v1.0.pdf. Accessed September 22, 2020.

Brown, A.E., 2020. "Who and where rideshares? Rideshare travel and use in Los Angeles." *Transportation Research Part A: Policy and Practice* 136, 120–134.

Cherchi, E., 2017. A stated choice experiment to measure the effect of informational and normative conformity in the preference for electric vehicles. *Transportation Research Part A: Policy and Practice* 100, 88–104. https://doi.org/10.1016/j.tra.2017.04.009

Clarke, M., Smart, J., Botero, E.M., Maier, W., Alonso, J.J., 2019. Strategies for posing a well-defined problem for urban air mobility vehicles. *AIAA Scitech 2019 Forum*, AIAA Scitech 2019 Forum, San Diego, California, January 7. https://doi.org/10.2514/6.2019-0818

Correia, G.H. de A., Looff, E., van Cranenburgh, S., Snelder, M., van Arem, B., 2019. On the impact of vehicle automation on the value of travel time while performing work and leisure activities in a car: Theoretical insights and results from a stated preference survey. *Transportation Research Part A: Policy and Practice* 119, 359–382. https://doi.org/10.1016/j.tra.2018.11.016

Correia, G.H.d.A., Viegas, J.M., 2011. Carpooling and carpools clubs: clarifying concepts and assessing value enhancement possibilities through a stated preference web survey in Lisbon, Portugal. *Transportation Research Part A: Policy and Practice* 45, 81–90.

Cunningham, M.L., Regan, M.A., Horberry, T., Weeratunga, K., Dixit, V., 2019. Public opinion about automated vehicles in Australia: Results from a large-scale national survey. *Transportation Research Part A: Policy and Practice* 129, 1–18. https://doi.org/10.1016/j.tra.2019.08.002

Daina, N., Sivakumar, A., Polak, J.W., 2017. Electric vehicle charging choices: Modelling and implications for smart charging services. *Transportation Research Part C: Emerging Technologies* 81, 36–56. https://doi.org/10.1016/j.trc.2017.05.006

Daskilewicz, M.J., German, B.J., Warren, M.W., Garrow, L.A., Boddupalli, S.S., Douthat, T.H., 2018. Progress in vertiport placement and estimating aircraft range requirements for eVTOL daily commuting. *2018 Aviation Technology, Integration, and Operations Conference*. 2018 Aviation Technology, Integration, and Operations Conference, Atlanta, GA, June 25–29. https://doi.org/10.2514/6.2018-2884

Davis, F.D., 1989. Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly* 13(3), 319–340. https://doi.org/10.2307/249008

Degirmenci, K., Breitner, M.H., 2017. Consumer purchase intentions for electric vehicles: Is green more important than price and range? *Transportation Research Part D: Transport and Environment* 51, 250–260. https://doi.org/10.1016/j.trd.2017.01.001

Delgado, J., Faria, R., Moura, P., de Almeida, A T., 2018. Impacts of plug-in electric vehicles in the Portuguese electrical grid. *Transportation Research Part D: Transport and Environment* 62, 372–385. https://doi.org/10.1016/j.trd.2018.03.005

Dietrich, A., Wulff, Y., 2020. Urban air mobility: Adding the third dimension to urban and regional transportation. Presentation for: An Introduction to Urban Air Mobility for State and Local Decision Makers: A Virtual Workshop, sponsored by the Community Air Mobility Initiative (CAMI). Available online at https://www.communityairmobility.org/uam101.

Donateo, T., Ficarella, A., 2020. A modeling approach for the effect of battery aging on the performance of a hybrid electric rotorcraft for urban air-mobility. *Aerospace* 7(5), 56. https://doi.org/10.3390/aerospace7050056

Dong, G., Ma, J., Wei, R., Haycox, J., 2019. Electric vehicle charging point placement optimisation by exploiting spatial statistics and maximal coverage location models. *Transportation Research Part D: Transport and Environment* 67, 77–88. https://doi.org/10.1016/j.trd.2018.11.005

Dong, X., DiScenna, M., Guerra, E., 2019. Transit user perceptions of driverless buses. *Transportation* 46(1), 35–50. https://doi.org/10.1007/s11116-017-9786-y

Du, N., Haspiel, J., Zhang, Q., Tilbury, D., Pradhan, A.K., Yang, X.J., Robert, L.P., 2019. Look who's talking now: Implications of AV's explanations on driver's trust, AV preference, anxiety and mental workload. *Transportation Research Part C: Emerging Technologies* 104, 428–442. https://doi.org/10.1016/j.trc.2019.05.025

Duan, L., Wei, Y., Zhang, J., Xia, Y., 2020. Centralized and decentralized autonomous dispatching strategy for dynamic autonomous taxi operation in hybrid request mode. *Transportation Research Part C: Emerging Technologies* 111, 397–420. https://doi.org/10.1016/j.trc.2019.12.020

eHang, 2020a. EHang 216 Aircraft. Available online at https://www.ehang.com/ehangaav/. Accessed September 2, 2020.

eHang, 2020b. The Future of Transportation: White Paper on Urban Air Mobility Systems. eHang white paper. Available online at https://www.ehang.com/app/en/EHang%20White%20Paper%20on%20Urban%20Air%20Mobility%20Systems.pdf. Accessed September 2, 2020.

Environmental Protection Agency (EPA), 2020a. Summary of the Clean Air Act. Available online at https://www.epa.gov/laws-regulations/summary-clean-air-act. Accessed September 27, 2020.

Environmental Protection Agency (EPA), 2020b. Summary of the Clean Water Act. Available online at https://www.epa.gov/laws-regulations/summary-clean-water-act. Accessed September 27, 2020.

El Zarwi, F., Vij, A., Walker, J.L., 2017. A discrete choice framework for modeling and forecasting the adoption and diffusion of new transportation services. *Transportation Research Part C: Emerging Technologies* 79, 207–223. https://doi.org/10.1016/j.trc.2017.03.004

Electric VTOL News™, n.d. 1. Aurora Flight Sciences Pegasus PAV. Available online at https://evtol.news/aurora/#:~:text=The%20aircraft%20is%2030%20ft,an%20independent%20subsidiary%20of%20Boeing. Accessed September 2, 2020.

Electric VTOL News™, n.d. 2. EmbraerX Eve. Available online at https://evtol.news/embraer/. Accessed September 2, 2020.

Electric VTOL News™, 2020. eVTOL Aircraft Directory. Available online at https://evtol.news/aircraft. Accessed September 26, 2020.

EmbraerX, 2020. DreamMaker Aircraft. Available online at https://embraerx.embraer.com/global/en/evtol. Accessed September 2, 2020.

Faber, K., van Lierop, D., 2020. How will older adults use automated vehicles? Assessing the role of AVs in overcoming perceived mobility barriers. *Transportation Research Part A: Policy and Practice* 133, 353–363. https://doi.org/10.1016/j.tra.2020.01.022

Federal Aviation Administration (FAA), 1982. Federal Aviation Regulation 103: Ultralight Vehicles. Available online at https://www.usua.org/Rules/faa103.htm#rule.

Federal Aviation Administration (FAA), 2012. FAA Advisory Circular AC-150/5390-2C – Heliport Design. Available at https://www.faa.gov/airports/resources/advisory_circulars/index.cfm/go/document.current/documentnumber/150_5390-2. Accessed September 26, 2020.

Federal Aviation Administration (FAA), 2017. FAA Instrument Procedures Handbook FAA-H-8083-16B. Available at https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/instrument_procedures_handbook/media/FAA-H-8083-16B.pdf. Accessed September 26, 2020.

Federal Highway Administration (FHWA), 2016. Fixing America's Surface Transportation Act or “FAST Act.” Fact Sheet. Available at https://www.fhwa.dot.gov/fastact/factsheets/metropolitanplanningfs.cfm. Accessed September 26, 2020.

Federal Transit Association (FTA), 2019. Transportation Improvement Program (TIP). Available at https://www.transit.dot.gov/regulations-and-guidance/transportation-planning/transportation-improvement-program-tip. Accessed September 26, 2020.

Fredericks, W.J., 2016. Impact of operational requirements on intra-urban VTOL conceptual design. Presented at: The 16th AIAA Aviation Technology, Integration, and Operations Conference, Washington, DC, June 13–17.

Fu, M., Rothfeld, R., Antoniou, C., 2019. Exploring preferences for transportation modes in an urban air mobility environment: Munich case study. *Transportation Research Record: Journal of the Transportation Research Board* 2673(10), 427–444. https://doi.org/10.1177/0361198119843858

Gao, J., Ranjbari, A., MacKenzie, D., 2019. Would being driven by others affect the value of travel time? Ridehailing as an analogy for automated vehicles. *Transportation* 46(6), 2103–2116. https://doi.org/10.1007/s11116-019-10031-9

Garrow, L.A., German, B., Mokhtarian, P., Glodek, J., 2019. A survey to model demand for eVTOL urban air trips and competition with autonomous ground vehicles. *AIAA Aviation 2019 Forum*, AIAA Aviation 2019 Forum, Dallas, Texas, June 17. https://doi.org/10.2514/6.2019-2871

Garrow, L.A., Roy, S., Newman, J.P., 2020. Competition among Traditional Modes, A Fully Autonomous Auto, and a Piloted Air Taxi for Commuting Trips in the U.S**.** Working paper, Georgia Institute of Technology.

Gates, D., 2020. Boeing suspends work at its futuristic NeXt innovation unit. *The Seattle Times*, September 16. Available at https://www.seattletimes.com/business/boeing-aerospace/boeing-suspends-work-at-its-futuristic-next-innovation-unit/. Accessed September 28, 2020.

German, B., Daskilewicz, M., Hamilton, T.K., Warren, M.M., 2018. Cargo delivery by passenger eVTOL aircraft: A case study in the San Francisco Bay area. *2018 AIAA Aerospace Sciences Meeting*, 2018 AIAA Aerospace Sciences Meeting, Kissimmee, Florida, January 8. https://doi.org/10.2514/6.2018-2006

Ghamami, M., Zockaie, A., Nie, Y., 2016. A general corridor model for designing plug-in electric vehicle charging infrastructure to support intercity travel. *Transportation Research Part C: Emerging Technologies* 68, 389–402. https://doi.org/10.1016/j.trc.2016.04.016

Ghasri, M., Ardeshiri, A., Rashidi, T., 2019. Perception towards electric vehicles and the impact on consumers' preference. *Transportation Research Part D: Transport and Environment* 77, 271–291. https://doi.org/10.1016/j.trd.2019.11.003

Globisch, J., Dütschke, E., Schleich, J., 2018. Acceptance of electric passenger cars in commercial fleets. *Transportation Research Part A: Policy and Practice* 116, 122–129. https://doi.org/10.1016/j.tra.2018.06.004

Goldstein, M., 2019. Bell Nexus VTOL air taxi makes a splash at 2019 consumer electronics show. *Forbes*. Available online at https://www.forbes.com/sites/michaelgoldstein/2019/01/14/bell-nexus-vtol-air-taxi-makes-a-splash-at-2019-consumer-electronics-show/#338f564a2e31. Accessed September 2, 2020.

Goodrich, K., Barmore, B. 2018. Exploratory analysis of the airspace throughput and sensitivities of an urban air mobility system. *2018 Aviation Technology, Integration, and Operations Conference*. 2018 Aviation Technology, Integration, and Operations Conference, Atlanta, GA, June 25. https://doi.org/10.2514/6.2018-3364

Goodrich, K., Moore, M., 2015. Simplified Vehicle Operations Roadmap. Presentation at: On-Demand Mobility Forum, Oshkosh, WI, July 22. Available at http://www.nianet.org/ODM/odm/docs/Industry%20forum%20OSH%20Ease%20of%20Use%20and%20Safety%20Pathway%202015.pdf. Accessed October 1, 2020.

Ha, T.H., Lee, K., Hwang, J.T., 2020. Large-scale multidisciplinary optimization under uncertainty for electric vertical takeoff and landing aircraft. *AIAA Scitech 2020 Forum*. AIAA Scitech 2020 Forum, Orlando, FL, January 6. https://doi.org/10.2514/6.2020-0904

Hamilton, T.K., German, B., 2017. Airspeeds for scheduled electric aircraft operations. *17th AIAA Aviation Technology, Integration, and Operations Conference*. 17th AIAA Aviation Technology, Integration, and Operations Conference, Denver, CO, June 5. https://doi.org/10.2514/6.2017-3284

Hamilton, T., German, B.J., 2019. Optimal airspeeds for scheduled electric aircraft operations. *Journal of Aircraft* 56(2), 545–555. https://doi.org/10.2514/1.C035051

Han, H., Yu, J., Kim, W., 2019. An electric airplane: Assessing the effect of travelers' perceived risk, attitude, and new product knowledge. *Journal of Air Transport Management* 78, 33–42. https://doi.org/10.1016/j.jairtraman.2019.04.004

Hardman, S., Jenn, A., Tal, G., Axsen, J., Beard, G., Daina, N., Figenbaum, E., Jakobsson, N., Jochem, P., Kinnear, N., Plötz, P., Pontes, J., Refa, N., Sprei, F., Turrentine, T., Witkamp, B., 2018. A review of consumer preferences of and interactions with electric vehicle charging infrastructure. *Transportation Research Part D: Transport and Environment* 62, 508–523. https://doi.org/10.1016/j.trd.2018.04.002

Harper, C.D., Hendrickson, C.T., Mangones, S., Samaras, C., 2016. Estimating potential increases in travel with autonomous vehicles for the non-driving, elderly and people with travel-restrictive medical conditions. *Transportation Research Part C: Emerging Technologies* 72, 1–9. https://doi.org/10.1016/j.trc.2016.09.003

Harrison, S., 2017. From the archives: Los Angeles Airways helicopter overturns. *The Los Angeles Times*, March 10. Available online at http://www.latimes.com/visuals/photography/la-me-fw-archives-airways-helicopter-overturn-20170221-story.html. Accessed September 5, 2020.

Hawkins, A.J., 2019. Electric air taxi startup Lilium completes first test of its new five-seater aircraft. *The Verge*. Available online at https://www.theverge.com/2019/5/16/18625088/lilium-jet-test-flight-electric-aircraft-flying-car. Accessed September 2, 2020.

Hensher, D.A., 2019. ITLS Journal Rankings List 2018–2019: Transportation. Available at https://www.sydney.edu.au/content/dam/corporate/documents/business-school/research/itls/ITLS-Journal-Rankings-List-2018-2019.pdf. Accessed September 28, 2020.

Hohenberger, C., Spörrle, M., Welpe, I.M., 2016. How and why do men and women differ in their willingness to use automated cars? The influence of emotions across different age groups. *Transportation Research Part A: Policy and Practice* 94, 374–385. https://doi.org/10.1016/j.tra.2016.09.022

Holden, J., 2018. Uber Keynote: Scaling Uber Air. Uber Elevate Summit, Los Angeles, CA, May 8. Available online at https://www.uber.com/us/en/elevate/summit/2018/. Accessed September 5, 2020.

Hörl, S., Ruch, C., Becker, F., Frazzoli, E., Axhausen, K.W., 2019. Fleet operational policies for automated mobility: A simulation assessment for Zurich. *Transportation Research Part C: Emerging Technologies* 102, 20–31. https://doi.org/10.1016/j.trc.2019.02.020

Huang, Y., Qian, L., 2018. Consumer preferences for electric vehicles in lower tier cities of China: Evidences from south Jiangsu region. *Transportation Research Part D: Transport and Environment* 63, 482–497. https://doi.org/10.1016/j.trd.2018.06.017

Hudson, J., Orviska, M., Hunady, J., 2019. People's attitudes to autonomous vehicles. *Transportation Research Part A: Policy and Practice* 121, 164–176. https://doi.org/10.1016/j.tra.2018.08.018

Hyland, M., Mahmassani, H.S., 2018. Dynamic autonomous vehicle fleet operations: Optimization-based strategies to assign AVs to immediate traveler demand requests. *Transportation Research Part C: Emerging Technologies* 92, 278–297. https://doi.org/10.1016/j.trc.2018.05.003

Hyland, M., Mahmassani, H.S., 2020. Operational benefits and challenges of shared-ride automated mobility-on-demand services. *Transportation Research Part A: Policy and Practice 134*, 251–270. https://doi.org/10.1016/j.tra.2020.02.017

Illgen, S., Höck, M., 2018. Establishing car sharing services in rural areas: A simulation-based fleet operations analysis. *Transportation*. https://doi.org/10.1007/s11116-018-9920-5

Jaunt Air Mobility, 2020. Jaunt Air Mobility reduced rotor operating speed aircraft (ROSA) aircraft. Available online at https://www.jauntairmobility.com/aircraft/#:~:text=In%20over%20100%20hours%20of,18%2C000'%20(VFR%20limited). Accessed September 3, 2020.

Johnson, T., Riedel, R., Sahdev, S., 2020. To take off, flying vehicles first need places to land. *McKinsey and Company*. Available online at https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/to-take-off-flying-vehicles-first-need-places-to-land#. Accessed September 9, 2020.

Jones, E.C., Leibowicz, B.D., 2019. Contributions of shared autonomous vehicles to climate change mitigation. *Transportation Research Part D: Transport and Environment 72*, 279–298. https://doi.org/10.1016/j.trd.2019.05.005

Jorge, D., Molnar, G., Correia, G.H. de A. 2015. Trip pricing of one-way station-based carsharing networks with zone and time of day price variations. *Transportation Research Part B* 81(2), 461–482. https://doi.org/10.1016/j.trb.2015.06.003

Josephson, D., 2017. Urban aircraft design for low noise. Presentation at: The AIAA Aviation Forum, Denver, CO. Available online at https://evtol.news/__media/PDFs/Josephson_Urban_Aircraft.pdf. Accessed October 1, 2020.

Justin, C.Y., Mavris, D.N., 2019. Environment impact on feasibility of sub-urban air mobility using STOL vehicles. *AIAA Scitech 2019 Forum*. https://doi.org/10.2514/6.2019-0530

Justin, C.Y., Payan, A., Briceno, S., Mavris, D.M., 2017. Operational and economic feasibility of electric thin haul transportation. In *AIAA Aviation Forum*, Denver, CO. https://doi.org/10.2514/6.2017-3283

Kaltenhäuser, B., Werdich, K., Dandl, F., Bogenberger, K., 2020. Market development of autonomous driving in Germany. *Transportation Research Part A: Policy and Practice* 132, 882–910. https://doi.org/10.1016/j.tra.2020.01.001

Kannan, R., Hirschberg, S., 2016. Interplay between electricity and transport sectors – Integrating the Swiss car fleet and electricity system. *Transportation Research Part A: Policy and Practice* 94, 514–531. https://doi.org/10.1016/j.tra.2016.10.007

Keskin, M., Çatay, B., 2016. Partial recharge strategies for the electric vehicle routing problem with time windows. *Transportation Research Part C: Emerging Technologies* 65, 111–127. https://doi.org/10.1016/j.trc.2016.01.013

Kester, J., Zarazua de Rubens, G., Sovacool, B.K., Noel, L., 2019. Public perceptions of electric vehicles and vehicle-to-grid (V2G): Insights from a Nordic focus group study. *Transportation Research Part D: Transport and Environment* 74, 277–293. https://doi.org/10.1016/j.trd.2019.08.006

Khastgir, S., Birrell, S., Dhadyalla, G., Jennings, P., 2018. Calibrating trust through knowledge: Introducing the concept of informed safety for automation in vehicles. *Transportation Research Part C: Emerging Technologies* 96, 290–303. https://doi.org/10.1016/j.trc.2018.07.001

Kim, K., 2015. Can carsharing meet the mobility needs for the low-income neighborhoods? Lessons from carsharing usage patterns in New York City. *Transportation Research Part A: Policy and Practice* 77, 249–260. https://doi.org/10.1016/j.tra.2015.04.020

Kim, S.H., Circella, G., Mokhtarian, P.L., 2019. Identifying latent mode-use propensity segments in an all-AV era. *Transportation Research Part A: Policy and Practice* 130, 192–207. https://doi.org/10.1016/j.tra.2019.09.015

Kim, D., Ko, J., Park, Y., 2015. Factors affecting electric vehicle sharing program participants' attitudes about car ownership and program participation. *Transportation Research Part D: Transport and Environment* 36, 96–106. https://doi.org/10.1016/j.trd.2015.02.009

Kim, M.-K., Park, J.-H., Kim, K., Park, B., 2018. Identifying factors influencing the slow market diffusion of electric vehicles in Korea. *Transportation* 47, 663–688. https://doi.org/10.1007/s11116-018-9908-1

Kleinbekman, I.C., Mitici, M., Wei, P., 2020. Rolling-horizon electric vertical takeoff and landing arrival scheduling for on-demand urban air mobility. *Journal of Aerospace Information Systems* 17(3), 150–159. https://doi.org/10.2514/1.I010776

Kohlman, L.W., Patterson, M.D., 2018. System-level urban air mobility transportation modeling and determination of energy-related constraints. *2018 Aviation Technology, Integration, and Operations Conference*. 2018 Aviation Technology, Integration, and Operations Conference, Atlanta, GA, June 25. https://doi.org/10.2514/6.2018-3677

Kolarova, V., Steck, F., Bahamonde-Birke, F.J., 2019. Assessing the effect of autonomous driving on value of travel time savings: A comparison between current and future preferences. *Transportation Research Part A: Policy and Practice* 129, 155–169. https://doi.org/10.1016/j.tra.2019.08.011

Kopp, J., Gerike, R., Axhausen, K.W., 2015. Do sharing people behave differently? An empirical evaluation of the distinctive mobility patterns of free-floating car-sharing members. *Transportation* 42(3), 449–469. https://doi.org/10.1007/s11116-015-9606-1

Kotwicz, H.M., Garbo, A., Lau, M., German, B., Garrow, L.A., 2019. Exploration of near-term urban air mobility operations with retrofitted electric general aviation aircraft. *AIAA Aviation 2019 Forum*. AIAA Aviation 2019 Forum, Dallas, TX, June 17. https://doi.org/10.2514/6.2019-2872

Kulkarni, C.S., Roychoudhury, I., Schumann, J., 2018. On-board battery monitoring and prognostics for electric-propulsion aircraft. *2018 AIAA/IEEE Electric Aircraft Technologies Symposium*. 2018 AIAA/IEEE Electric Aircraft Technologies Symposium, Cincinnati, OH, July 9. https://doi.org/10.2514/6.2018-5034

Kreimeier, M., Strathoff, P., Gottschalk, D., Stumpf, E., 2018. Economic assessment of air mobility on-demand concepts. *Journal of Air Transportation* 26(1), 23–36. https://doi.org/10.2514/1.D0058

Kreimeier, M., Stumpf, E., Gottschalk, D., 2016. Economical assessment of air mobility on demand concepts with focus on Germany. *16th AIAA Aviation Technology, Integration, and Operations Conference*. 16th AIAA Aviation Technology, Integration, and Operations Conference, Washington, DC, June 13. https://doi.org/10.2514/6.2016-3304

Kröger, L., Kuhnimhof, T., Trommer, S. 2019. Does context matter? A comparative study modelling autonomous vehicle impact on travel behaviour for Germany and the USA. *Transportation Research Part A: Policy and Practice* 122, 146–161. https://doi.org/10.1016/j.tra.2018.03.033

Krueger R., Rashidi T.H., Rose J.M., 2016. Preferences for shared autonomous vehicles. *Transportation Research Part C: Emerging Technologies* 69, 343–355.

Lane, B.W., Dumortier, J., Carley, S., Siddiki, S., Clark-Sutton, K., Graham, J.D., 2018. All plug-in electric vehicles are not the same: Predictors of preference for a plug-in hybrid versus a battery-electric vehicle. *Transportation Research Part D: Transport and Environment* 65, 1–13. https://doi.org/10.1016/j.trd.2018.07.019

Latinopoulos, C., Sivakumar, A., Polak, J.W., 2017. Response of electric vehicle drivers to dynamic pricing of parking and charging services: Risky choice in early reservations. *Transportation Research Part C: Emerging Technologies* 80, 175–189. https://doi.org/10.1016/j.trc.2017.04.008

Lavieri, P.S., Bhat, C.R., 2019. Modeling individuals' willingness to share trips with strangers in an autonomous vehicle future. *Transportation Research Part A: Policy and Practice* 124, 242–261. https://doi.org/10.1016/j.tra.2019.03.009

Lee, J., Lee, D., Park, Y., Lee, S., Ha, T., 2019. Autonomous vehicles can be shared, but a feeling of ownership is important: Examination of the influential factors for intention to use autonomous vehicles. *Transportation Research Part C: Emerging Technologies* 107, 411–422. https://doi.org/10.1016/j.trc.2019.08.020

Lee, Y.-C., Mirman, J.H., 2018. Parents' perspectives on using autonomous vehicles to enhance children's mobility. *Transportation Research Part C: Emerging Technologies* 96, 415–431. https://doi.org/10.1016/j.trc.2018.10.001

Li, W., Kamargianni, M., 2019. An Integrated Choice and Latent Variable Model to Explore the Influence of Attitudinal and Perceptual Factors on Shared Mobility Choices and Their Value of Time Estimation. *Transportation Science*, trsc.2019.0933. https://doi.org/10.1287/trsc.2019.0933

Liao, C.-S., Lu, S.-H., Shen, Z.-J.M., 2016. The electric vehicle touring problem. *Transportation Research Part B: Methodological* 86, 163–180. https://doi.org/10.1016/j.trb.2016.02.002

LIFT Aircraft, 2020. Hexa personal aircraft vehicle. Available online at https://www.liftaircraft.com.

Lilium, 2020. Lilium Jet aircraft. Available online at https://lilium.com/the-jet. Accessed September 2, 2020.

Lim, E., Hwang, H., 2019. The selection of vertiport location for on-demand mobility and its application to Seoul metro area. *International Journal of Aeronautical and Space Sciences* 20(1), 260–272. https://doi.org/10.1007/s42405-018-0117-0

Lineberger, R., Hussain, A., Rutgers, V., 2019. Change is in the air: The elevated future of mobility: What's next on the horizon? *Deloitte Insights*. Available online at https://www2.deloitte.com/content/dam/Deloitte/us/Documents/energy-resources/di-the-elevated-future-of-mobility.pdf. Accessed September 2, 2020.

Liu, J., Khattak, A.J., Li, X., Fu, X., 2019. A spatial analysis of the ownership of alternative fuel and hybrid vehicles. *Transportation Research Part D: Transport and Environment* 77, 106–119. https://doi.org/10.1016/j.trd.2019.10.018

Liu, P., Guo, Q., Ren, F., Wang, L., Xu, Z., 2019. Willingness to pay for self-driving vehicles: Influences of demographic and psychological factors. *Transportation Research Part C: Emerging Technologies* 100, 306–317. https://doi.org/10.1016/j.trc.2019.01.022

Liu, P., Ma, Y., Zuo, Y., 2019. Self-driving vehicles: Are people willing to trade risks for environmental benefits? *Transportation Research Part A: Policy and Practice* 125, 139–149. https://doi.org/10.1016/j.tra.2019.05.014

Liu, Y., Cirillo, C., 2018. A generalized dynamic discrete choice model for green vehicle adoption. *Transportation Research Part A: Policy and Practice* 114, 288–302. https://doi.org/10.1016/j.tra.2018.01.034

Ljungholm, D.P., Olah, M.L., 2020. Will autonomous flying car regulation really free up roads? Smart sustainable air mobility, societal acceptance, and public safety concerns. *Linguistic and Philosophical Investigations* 19, 100–106. https://doi.org/10.22381/LPI1920206

Lowry, M. 2018. Towards high-density urban air mobility. *2018 Aviation Technology, Integration, and Operations Conference*. 2018 Aviation Technology, Integration, and Operations Conference, Atlanta, GA, June 25–29. https://doi.org/10.2514/6.2018-3667

Luo, Z., He, F., Lin, X., Wu, J., Li, M., 2020. Joint deployment of charging stations and photovoltaic power plants for electric vehicles. *Transportation Research Part D: Transport and Environment* 79, 102247. https://doi.org/10.1016/j.trd.2020.102247

Mane, M., Crossley, W., 2007. An approach to predict impact of demand acceptance on air taxi operations. *7th AIAA ATIO Conference, 2nd CEIAT International Conference on Innovation and Integration in Aerospace Sciences,* Belfast, Northern Ireland, September 18. https://doi.org/10.2514/6.2007-7787

Marmaras, C., Xydas, E., Cipcigan, L., 2017. Simulation of electric vehicle driver behaviour in road transport and electric power networks. *Transportation Research Part C: Emerging Technologies* 80, 239–256. https://doi.org/10.1016/j.trc.2017.05.004

Maheshwari, A., Crossley, W., DeLaurentis, D., Mudamba, S., Sells, B., 2020. Identifying and analyzing operations limits for passenger-carrying urban air mobility missions. AIAA Aviation 2020 Forum, virtual event, June 15–19. https://doi.org/10.2514/6.2020-2913

Matthews, L., 2019. I took Uber Copter from Manhattan to JFK – Here's what it's like. *AFAR*, October 3. Available online at https://www.afar.com/magazine/what-its-like-to-fly-uber-copter-from-manhattan-to-jfk-airport. Accessed September 5, 2020.

Mayakonda, M., Justin, C.Y., Anand, A., Weit, C.J., Wen, J., Zaidi, T., Mavris, D., 2020. A top-down methodology for global urban air mobility demand estimation. AIAA Aviation 2020 Forum, virtual event, June 15–19. https://doi.org/10.2514/6.2020-3255

Mayor, T., and Anderson, J., 2019. Getting Mobility Off the Ground. KPMG Insight. Available online at https://institutes.kpmg.us/content/dam/advisory/en/pdfs/2019/urban-air-mobility.pdf. Accessed September 2, 2020.

Middleton, S., Zhao, J., 2019. Discriminatory attitudes between ridesharing passengers. *Transportation* 47, 2391–2414. https://doi.org/10.1007/s11116-019-10020-y

Molnar, G., Correia, G.H. de A., 2019. Long-term vehicle reservations in one-way free-floating carsharing systems: A variable quality of service model. *Transportation Research Part C: Emerging Technologies 98*, 298–322. https://doi.org/10.1016/j.trc.2018.11.017

Morales S.J., Escovar A.G., Blynn, K., Alesbury, A., Scully, T., Zhao, J., 2017. To Share or Not to Share: Investigating the Social Aspects of Dynamic Ridesharing. *Transportation Research Record: Journal of the Transportation Research Board* 2605, 109–117.

Mueller, E., Kopardekar, P., and Goodrich, K., 2017. Enabling airspace integration for high-density on-demand mobility operations. *17th AIAA Aviation Technology, Integration, and Operations Conference*. 17th AIAA Aviation Technology, Integration, and Operations Conference, Denver, CO, June 5. https://doi.org/10.2514/6.2017-3086.

Munari, P., Alvarez, A., 2019. Aircraft routing for on-demand air transportation with service upgrade and maintenance events: Compact model and case study. *Journal of Air Transport Management* 75: 75–84. https://doi.org/10.1016/j.jairtraman.2018.11.005

Muñoz-Villamizar, A., Montoya-Torres, J.R., Faulin, J., 2017. Impact of the use of electric vehicles in collaborative urban transport networks: A case study. *Transportation Research Part D: Transport and Environment* 50, 40–54. https://doi.org/10.1016/j.trd.2016.10.018

Narkus-Kramer, M.P., Tejeda, J., Stouffer, V.L., Hemm, R.V., Trajkov, S., Creedon, J.F., Ballard, B.D., 2016. Net present value, trade-space, and feasibility of on-demand aircraft. Presented at: The 16th AIAA Aviation Technology, Integration, and Operations Conference, American Institute of Aeronautics and Astronautics, Washington, DC. https://doi.org/10.2514/6.2016-3302

NASA, 2020. One Word Change Expands NASA's Vision for Future Airspace Mobility, March 23. Available online at https://www.nasa.gov/aeroresearch/one-word-change-expands-nasas-vision-for-future-airspace/#:~:text=Bottom%20line%3A%20The%20thinking%20on,using%20to%20describe%20our%20efforts. Accessed September 6, 2020.

National Parks Service (NPS), n.d. National Historic Preservation Act of 1966 as amended through 1992. Available at https://www.nps.gov/history/local-law/nhpa1966.htm. Accessed September 30, 2020.

NEXA Advisors, 2019. *UAM Study Prospectus*. Available online at https://www.nexaadvisors.com/uam-global-markets-study. Accessed September 3, 2020.

Nielsen, J.R., Hovmøller, H., Blyth, P.-L., Sovacool, B.K., 2015. Of "white crows" and "cash savers:" A qualitative study of travel behavior and perceptions of ridesharing in Denmark. *Transportation Research Part A: Policy and Practice* 78, 113–123. https://doi.org/10.1016/j.tra.2015.04.033

Nourinejad, M., Chow, J.Y.J., Roorda, M.J., 2016. Equilibrium scheduling of vehicle-to-grid technology using activity based modelling. *Transportation Research Part C: Emerging Technologies* 65, 79–96. https://doi.org/10.1016/j.trc.2016.02.001

Olson, M.D., 2015. A Conceptual Approach to Flight-Training Mission and Cost Analysis of an All-Electric Aircraft Equipped with Regenerative Energy Devices. Presented at: The 15th AIAA Aviation Technology, Integration, and Operations Conference, American Institute of Aeronautics and Astronautics, Dallas, TX, June 22–26. https://doi.org/10.2514/6.2015-3189

PAL-V, 2020. PAL-V Pioneer Flying Car. Available online at https://www.pal-v.com/en/explore-pal-v. Accessed September 3, 2020.

Panagiotopoulos, I., Dimitrakopoulos, G., 2018. An empirical investigation on consumers' intentions towards autonomous driving. *Transportation Research Part C: Emerging Technologies* 95, 773–784. https://doi.org/10.1016/j.trc.2018.08.013

Pelletier, S., Jabali, O., Laporte, G., 2018. Charge scheduling for electric freight vehicles. *Transportation Research Part B: Methodological* 115, 246–269. https://doi.org/10.1016/j.trb.2018.07.010

Ploetner, K.O., Al Haddad, C., Antoniou, C. Frank, F., Fu, M., Kabel, S, Llorca, C., Moeckel, R., Moreno, A.T., Pukhova, A., Rothfeld, R., Shamiyeh, M., Straubinger, A., Wagner, H., Zhang, Q., 2020. Long-term application potential of urban air mobility complementing public transit: An upper Bavaria example. *CEAS Aeronautical Journal*. https://doi.org/10.1007/s13272-020-00468-5.

Pope, S., 2019. Bell unveils Nexus eVTOL air taxi. *Flying*. Available online at https://www.flyingmag.com/bell-unveils-nexus-evtol-air-taxi/#:~:text=Five%2Dseat%20hybrid%2Dpropulsion%20air,top%20speed%20of%20150%20mph. Accessed September 2, 2020.

Porsche Consulting, 2018. The Future of Vertical Mobility. A Porsche Consulting Study, March. Available online at: https://www.porsche-consulting.com/us-en/press/insights/detail/study-the-future-of-vertical-mobility-1/. Accessed September 2, 2020.

Potoglou, D., Whittle, C., Tsouros, I., Whitmarsh, L., 2020. Consumer intentions for alternative fuelled and autonomous vehicles: A segmentation analysis across six countries. *Transportation Research Part D: Transport and Environment* 79, 102243. https://doi.org/10.1016/j.trd.2020.102243

Pound Sterling Live, 2020a. The Australian Dollar to U.S. Dollar Historical Exchange Rates Conversion Page for 2018. Available online at https://www.poundsterlinglive.com/best-exchange-rates/best-australian-dollar-to-us-dollar-history-2018. Accessed September 8, 2020.

Pound Sterling Live, 2020b. British Pound to U.S. Dollar Spot Exchange Rates for 2018 from the Bank of England. Available online at https://www.poundsterlinglive.com/bank-of-england-spot/historical-spot-exchange-rates/gbp/GBP-to-USD-2018. Accessed September 21, 2020.

Pound Sterling Live, 2020c. The Euro to U.S. Dollar Historical Exchange Rates Conversion Page for 2018 and 2019. Available online at https://www.poundsterlinglive.com/best-exchange-rates/best-euro-to-us-dollar-history-2019. Accessed September 12, 2020.

Prabhakar, N., Karbowski, D., Liu, I.-H., Torelli, R., 2020. Dynamic UAS simulation framework for energy and mission performance optimization. *AIAA Scitech 2020 Forum*. AIAA Scitech 2020 Forum, Orlando, FL. https://doi.org/10.2514/6.2020-2120

Pradeep, P., Wei, P., 2018. Energy efficient arrival with RTA constraint for urban eVTOL operations. AIAA Aerospace Sciences Meeting, Kissimmee, Florida. https://doi.org/10.2514/6.2018-2008

Prieto, M., Baltas, G., Stan, V., 2017. Car sharing adoption intention in urban areas: What are the key sociodemographic drivers? *Transportation Research Part A: Policy and Practice* 101, 218–227. https://doi.org/10.1016/j.tra.2017.05.012

Pudāne, B., Correia, G., 2020. On the impact of vehicle automation on the value of travel time while performing work and leisure activities in a car: Theoretical insights and results from a stated preference survey – A comment. *Transportation Research Part A: Policy and Practice* 132, 324–328. https://doi.org/10.1016/j.tra.2019.11.019

Qin, N., Gusrialdi, A., Paul Brooker, R., T-Raissi, A., 2016. Numerical analysis of electric bus fast charging strategies for demand charge reduction. *Transportation Research Part A: Policy and Practice* 94, 386–396. https://doi.org/10.1016/j.tra.2016.09.014

Raj, A., Kumar, J.A., Bansal, P., 2020. A multicriteria decision making approach to study barriers to the adoption of autonomous vehicles. *Transportation Research Part A: Policy and Practice* 133, 122–137. https://doi.org/10.1016/j.tra.2020.01.013

Repoux, M., Kaspi, M., Boyacı, B., Geroliminis, N., 2019. Dynamic prediction-based relocation policies in one-way station-based carsharing systems with complete journey reservations. *Transportation Research Part B: Methodological* 130, 82–104. https://doi.org/10.1016/j.trb.2019.10.004

Rezvani, Z., Jansson, J., Bodin, J., 2015. Advances in consumer electric vehicle adoption research: A review and research agenda. *Transportation Research Part D: Transport and Environment* 34, 122–136. https://doi.org/10.1016/j.trd.2014.10.010

Robinson, J.N., Sokollek, M.-D., Justin, C.Y., Mavris, D.N., 2018. Development of a methodology for parametric analysis of STOL airpark geo-density. *2018 Aviation Technology, Integration, and Operations Conference*. 2018 Aviation Technology, Integration, and Operations Conference, Atlanta, GA, June 25–29. https://doi.org/10.2514/6.2018-3054

Rogers, E.M., 2003. *Diffusion of Innovations* (5th ed.). New York, NY: Free Press.

Roland Berger, 2018. Urban Air Mobility: The Rise of a New Mode of Transportation. Available at https://www.rolandberger.com/en/Publications/Passenger-drones-ready-for-take-off.html#:~:text=As%20the%20Roland%20Berger%2Dstudy,ease%20the%20existing%20traffic%20situation. Accessed September 2, 2020.

Roni, M.S., Yi, Z., Smart, J.G., 2019. Optimal charging management and infrastructure planning for free-floating shared electric vehicles. *Transportation Research Part D: Transport and Environment* 76, 155–175. https://doi.org/10.1016/j.trd.2019.09.021

Rotaris, L., Danielis, R., 2018. The role for carsharing in medium to small-sized towns and in less-densely populated rural areas. *Transportation Research Part A: Policy and Practice* 115, 49–62. https://doi.org/10.1016/j.tra.2017.07.006

Rothfeld, R.L., Balac, M., Ploetner, K.O., Antoniou, C., 2018. Initial analysis of urban air mobility's transport performance in Sioux Falls. *2018 Aviation Technology, Integration, and Operations Conference*. 2018 Aviation Technology, Integration, and Operations Conference, Atlanta, GA, June 25–29. https://doi.org/10.2514/6.2018-2886

Roy, S., Crossley, W.A., Moore, K.T., Gray, J.S., Martins, J.R.R.A., 2018. Next generation aircraft design considering airline operations and economics. 210049. 2018 AIAA/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference, Kissimmee, FL, January 8–12. https://doi.org/10.2514/6.2018-1647

Roy, S., Kotwicz, M.H., Leonard, C., Jha, A., Wang, N., German, B., Garrow, L., 2020. A multi-commodity network flow approach for optimal flight schedules for an airport shuttle air taxi service. *AIAA Scitech 2020 Forum*. AIAA Scitech 2020 Forum, Orlando, FL, January 6. https://doi.org/10.2514/6.2020-0975

Roy, S., Maheshwari, A., Crossley, W.A., Delaurentis, D.A., 2018. A study on the impact of aircraft technology on the future of regional transportation using small aircraft. *2018 Aviation Technology, Integration, and Operations Conference*. 2018 Aviation Technology, Integration, and Operations Conference, Atlanta, GA, June 25–29. https://doi.org/10.2514/6.2018-3056

Roy, S., Maheshwari, A., Crossley, W.A., DeLaurentis, D.A., 2019. A study to investigate total mobility using both CTOL and VTOL-capable aircraft. *AIAA Aviation 2019 Forum*. AIAA Aviation 2019 Forum, Dallas, TX, June 17. https://doi.org/10.2514/6.2019-3518

Shabanpour, R., Golshani, N., Shamshiripour, A., Mohammadian, A. (Kouros), 2018. Eliciting preferences for adoption of fully automated vehicles using best-worst analysis. *Transportation Research Part C: Emerging Technologies* 93, 463–478. https://doi.org/10.1016/j.trc.2018.06.014

Shabanpour, R., Shamshiripour, A., Mohammadian, A., 2018. Modeling adoption timing of autonomous vehicles: Innovation diffusion approach. *Transportation* 45(6), 1607–1621. https://doi.org/10.1007/s11116-018-9947-7

Shen, Y., Zhang, H., Zhao, J., 2018. Integrating shared autonomous vehicle in public transportation system: A supply-side simulation of the first-mile service in Singapore. *Transportation Research Part A: Policy and Practice* 113, 125–136. https://doi.org/10.1016/j.tra.2018.04.004

Shen, Z.-J.M., Feng, B., Mao, C., Ran, L., 2019. Optimization models for electric vehicle service operations: A literature review. *Transportation Research Part B: Methodological* 128, 462–477. https://doi.org/10.1016/j.trb.2019.08.006

Sherman, J., 2020. eVTOLS – What are they? Presentation for: An Introduction to Urban Air Mobility for State and Local Decision Makers: A virtual workshop sponsored by the Community Air Mobility Initiative (CAMI). Available online at https://www.communityairmobility.org/uam101.

Shihab, S.A.M., Wei, P., Shi, J., Yu, N. 2020. Optimal eVTOL Fleet Dispatch for Urban Air Mobility and Power Grid Services. AIAA Aviation 2020 Forum, virtual event, June 15–19. https://doi.org/10.2514/6.2020-2906

Shihab, S.A.M., Wei, P., Ramirez, D.S.J., Mesa-Arango, R., Bloebaum, C., 2019. By Schedule or On Demand? A Hybrid Operation Concept for Urban Air Mobility. *AIAA Aviation 2019 Forum*. AIAA Aviation 2019 Forum, Dallas, TX, June 17. https://doi.org/10.2514/6.2019-3522

Smith, B., Olaru, D., Jabeen, F., Greaves, S., 2017. Electric vehicles adoption: Environmental enthusiast bias in discrete choice models. *Transportation Research Part D: Transport and Environment* 51, 290–303. https://doi.org/10.1016/j.trd.2017.01.008

Somers, L.A., Justin, C.Y., Mavris, D.N., 2019. Wind and Obstacles Impact on Airpark Placement for STOL-based Sub-Urban Air Mobility. *AIAA Aviation 2019 Forum*. AIAA Aviation 2019 Forum, Dallas, TX, June 17. https://doi.org/10.2514/6.2019-3121

Song, F., Hess, S., Dekker, T., 2019. Fancy sharing an air taxi? Uncovering the impact of variety seeking on the demand for new shared mobility services. Working paper, Institute for Transport Studies, University of Leeds. Available online at https://pdfs.semanticscholar.org/73a1/fd6f648e9ea3b1223d757b15ae2713d18adb.pdf?_ga=2.227001565.1548836095.1592830089-1396384243.1592830089.

Sovacool, B.K., Kester, J., Noel, L., Zarazua de Rubens, G., 2019. Are electric vehicles masculinized? Gender, identity, and environmental values in Nordic transport practices and vehicle-to-grid (V2G) preferences. *Transportation Research Part D: Transport and Environment* 72, 187–202. https://doi.org/10.1016/j.trd.2019.04.013

Spurlock, C.A., Sears, J., Wong-Parodi, G., Walker, V., Jin, L., Taylor, M., Duvall, A., Gopal, A., Todd, A., 2019. Describing the users: Understanding adoption of and interest in shared, electrified, and automated transportation in the San Francisco Bay Area. *Transportation Research Part D: Transport and Environment* 71, 283–301. https://doi.org/10.1016/j.trd.2019.01.014

Stith, P., 2020. Powered for Take Off: NIA-NASA Urban Air Mobility Electric Infrastructure Study. Available online at https://www.bv.com/eVTOLs. Accessed September 22, 2020.

Stouffer, V.L., Kostiuk, P.F., 2020. CAMEOS: UAM flight planning, deconfliction, and monitoring tool. AIAA Aviation 2020 Forum, virtual event, June 15–19. https://doi.org/10.2514/6.2020-3251

Straubinger, A., Rothfield, R., Shamiyeh, M., Büchter, K.-D., Kaiser, J., Plotner, K.O., 2020. An overview of current research and developments in urban air mobility – Setting the scene for UAM introduction. *Journal of Air Transport Management* 87, 101852. https://doi.org/10.1016/j.jairtraman.2020.101852

Ströhle, P., Flath, C.M., Gärttner, J., 2019. Leveraging Customer Flexibility for Car-Sharing Fleet Optimization. *Transportation Science* 53(1), 42–61. https://doi.org/10.1287/trsc.2017.0813

Swadesir, L., Bil, C., 2019. Urban Air Transportation for Melbourne Metropolitan Area. *AIAA Aviation 2019 Forum*. AIAA Aviation 2019 Forum, Dallas, TX, June 17. https://doi.org/10.2514/6.2019-3572

Sweda, T.M., Dolinskaya, I.S., Klabjan, D., 2017. Adaptive Routing and Recharging Policies for Electric Vehicles. *Transportation Science* 51(4), 1326–1348. https://doi.org/10.1287/trsc.2016.0724

Sweet, M.N., Laidlaw, K., 2019. No longer in the driver's seat: How do affective motivations impact consumer interest in automated vehicles? *Transportation* 47, 2601–2634. https://doi.org/10.1007/s11116-019-10035-5

Tahmasseby, S., Kattan, L., Barbour, B., 2016. Propensity to participate in a peer-to-peer social-network-based carpooling system. *Journal of Advanced Transportation* 50(2), 240–254.

Talebian, A., Mishra, S., 2018. Predicting the adoption of connected autonomous vehicles: A new approach based on the theory of diffusion of innovations. *Transportation Research Part C: Emerging Technologies* 95, 363–380. https://doi.org/10.1016/j.trc.2018.06.005

Tarafdar, S., Rimjha, M., Li, M., Hinze, N., Hotle, S., Trani, A., Smith, J., Dollyhigh, S., Marien, T., 2020. Comparative Study of Urban Air Mobility (UAM) Landing Sites for Three Study Areas. Working paper, Virginia Institute of Technology.

Thipphavong, D.P., Apaza, R., Barmore, B., Battiste, V., Burian, B., Dao, Q., Feary, M., Go, S., Goodrich, K.H., Homola, J., Idris, H.R., Kopardekar, P.H., Lachter, J.B., Neogi, N.A., Ng, H.K., Oseguera-Lohr, R.M., Patterson, M.D., Verma, S.A. 2018. Urban air mobility airspace integration concepts and considerations. *2018 Aviation Technology, Integration, and Operations Conference*. 2018 Aviation Technology, Integration, and Operations Conference, Atlanta, GA, June 25. https://doi.org/10.2514/6.2018-3676

Tian, L.-J., Sheu, J.-B., Huang, H.-J., 2019. The morning commute problem with endogenous shared autonomous vehicle penetration and parking space constraint. *Transportation Research Part B: Methodological* 123, 258–278. https://doi.org/10.1016/j.trb.2019.04.001

Tsouros, I., Polydoropoulou, A., 2020. Who will buy alternative fueled or automated vehicles: A modular, behavioral modeling approach. *Transportation Research Part A: Policy and Practice* 132, 214–225. https://doi.org/10.1016/j.tra.2019.11.013

Uber, 2020. Uber Copter. Available online at https://www.uber.com/us/en/ride/uber-copter/. Accessed September 5, 2020.

Uber Elevate, 2016. Fast Forwarding to a Future of On-Demand Urban Air Transportation. Available online at https://www.uber.com/elevate.pdf. Accessed September 23, 2020.

Uber Elevate, 2019. Day 2: Uber Elevate Summit 2019. YouTube video, Cost estimates provided at 6:02:42. Available online at https://youtu.be/E0Ub9Z8ifiQ?t=22176. Accessed September 26, 2020.

Uber Elevate, 2020a. eVTOL Common Reference Models. Available online at https://www.uber.com/us/en/elevate/uberair/. Accessed September 22, 2020.

Uber Elevate, 2020b. Skyports. Available online at https://www.uber.com/us/en/elevate/uberair/. Accessed September 23, 2020.

U.S. Department of Justice (US DOJ), 2020. A Guide to Disability Guide Rules. Available at https://www.ada.gov/cguide.htm. Accessed September 30, 2020.

U.S. Department of Transportation (US DOT), 2013. Equity. Available at https://www.transportation.gov/mission/health/equity. Accessed September 30, 2020.

Vascik, P.D., Hansman, R.J., 2017. Evaluation of key operational constraints affecting on-demand mobility for aviation in the Los Angeles Basin: Ground infrastructure, air traffic control and noise. *17th AIAA Aviation Technology, Integration, and Operations Conference*. 17th AIAA Aviation Technology, Integration, and Operations Conference, Denver, CO, June 5. https://doi.org/10.2514/6.2017-3084

Vascik, P.D., Hansman, R.J., 2019. Development of vertiport capacity envelopes and analysis of their sensitivity to topological and operational factors. AIAA Scitech 2019 Forum, San Diego, CA, January 7–11. https://doi.org/10.2514/6.2019-0526

Vascik, P.D., Hansman, R.J., 2020. Allocation of airspace cutouts to enable procedurally separated small aircraft operations in terminal areas. AIAA Aviation Forum, virtual event, June 15–19. https://doi.org/10.2514/6.2020-2905

Vascik, P.D., Hansman, R.J., Dunn, N.S., 2018. Analysis of urban air mobility operational constraints. *Journal of Air Transportation* 26(4), 133–146. https://doi.org/10.2514/1.D0120

Vasconcelos, A.S., Martinez, L.M., Correia, G.H.A., Guimarães, D.C., Farias, T.L., 2017. Environmental and financial impacts of adopting alternative vehicle technologies and relocation strategies in station-based one-way carsharing: An application in the city of Lisbon, Portugal. *Transportation Research Part D: Transport and Environment* 57, 350–362. https://doi.org/10.1016/j.trd.2017.08.019

Verma, S., Keeler, J., Edwards, T.E., Dulchinos, V., 2019. Exploration of Near term Potential Routes and Procedures for Urban Air Mobility. *AIAA Aviation 2019 Forum*. AIAA Aviation 2019 Forum, Dallas, TX, June 17. https://doi.org/10.2514/6.2019-3624

Vij, A., Ryan, S., Sampson, S., Harris, S., 2020. Consumer preferences for on-demand transport in Australia. *Transportation Research Part A: Policy and Practice* 132, 823–839. https://doi.org/10.1016/j.tra.2019.12.026

Vitalle, R.F., Zhang, Y., Normann, B., Shen, N., 2020. A model for the integration of UAM operations in and near terminal areas. AIAA Aviation Forum, virtual event, June 15–19. https://doi.org/10.2514/6.2020-2864

Volocopter, 2018. Pioneering the Urban Air Taxi Revolution. Volocopter white paper. Available at https://press.volocopter.com/images/pdf/Volocopter-WhitePaper-1-0.pdf. Accessed September 2, 2020.

Volocopter, 2020. Volocopter VC200 aircraft. Available online at https://www.volocopter.com/en/. Accessed September 2, 2020.

Wang, J.-P., Ban, X. (Jeff), Huang, H.-J., 2019. Dynamic ridesharing with variable-ratio charging-compensation scheme for morning commute. *Transportation Research Part B: Methodological* 122, 390–415. https://doi.org/10.1016/j.trb.2019.03.006

Wang, S., Fan, J., Zhao, D., Yang, S., Fu, Y., 2016. Predicting consumers' intention to adopt hybrid electric vehicles: Using an extended version of the theory of planned behavior model. *Transportation* 43(1), 123–143. https://doi.org/10.1007/s11116-014-9567-9

Wang, L., Liu, Q., and Ma, W., 2019. Optimization of dynamic relocation operations for one-way electric carsharing systems. *Transportation Research Part C: Emerging Technologies* 101, 55–69. https://doi.org/10.1016/j.trc.2019.01.005

Wang, S., Wang, J., Li, J., Wang, J., Liang, L., 2018. Policy implications for promoting the adoption of electric vehicles: Do consumer's knowledge, perceived risk and financial incentive policy matter? *Transportation Research Part A: Policy and Practice* 117, 58–69. https://doi.org/10.1016/j.tra.2018.08.014

Wang, Y., Wang, S., Wang, J., Wei, J., Wang, C., 2020. An empirical study of consumers' intention to use ride-sharing services: Using an extended technology acceptance model. *Transportation* 47(1), 397–415. https://doi.org/10.1007/s11116-018-9893-4

Wang, X., Yang, H., Zhu, D., 2018. Driver-rider cost-sharing strategies and equilibria in a ridesharing program. *Transportation Science* 52(4), 868–881. https://doi.org/10.1287/trsc.2017.0801

Wang, S., Zhao, J., 2019. Risk preference and adoption of autonomous vehicles. *Transportation Research Part A: Policy and Practice* 126, 215–229. https://doi.org/10.1016/j.tra.2019.06.007

Warrington, J., Ruchti, D., 2019. Two-stage stochastic approximation for dynamic rebalancing of shared mobility systems. *Transportation Research Part C: Emerging Technologies* 104, 110–134. https://doi.org/10.1016/j.trc.2019.04.021

Wei, L., Justin, C.Y., Briceno, S.I., Mavris, D.N., 2018. Door-to-door travel time comparative assessment for conventional transportation methods and short takeoff and landing on demand mobility concepts. *2018 Aviation Technology, Integration, and Operations Conference*. 2018 Aviation Technology, Integration, and Operations Conference, Atlanta, GA, June 25. https://doi.org/10.2514/6.2018-3055

Wei, L., Justin, C.Y., Mavris, D.N., 2020. Optimal placement of airparks for STOL urban and suburban air mobility. *AIAA Scitech 2020 Forum*. AIAA Scitech 2020 Forum, Orlando, FL, January 6. https://doi.org/10.2514/6.2020-0976

Wen, J., Nassir, N., Zhao, J., 2019. Value of demand information in autonomous mobility-on-demand systems. *Transportation Research Part A: Policy and Practice* 121, 346–359. https://doi.org/10.1016/j.tra.2019.01.018

Widrick, R.S., Nurre, S.G., Robbins, M.J., 2018. Optimal policies for the management of an electric vehicle battery swap station. *Transportation Science* 52(1), 59–79. https://doi.org/10.1287/trsc.2016.0676

Wisk, 2020. Cora aircraft. Available online at https://wisk.aero/. Accessed September 2, 2020.

Witken, R., 1979. New York Airways acts to file for bankruptcy. *The New York Times*, May 16. Available online at https://www.nytimes.com/1979/05/16/archives/new-york-airways-acts-to-file-for-bankruptcy-suing-sikorsky.html. Accessed September 5, 2020.

Wolff, S., Madlener, R., 2019. Driven by change: Commercial drivers' acceptance and efficiency perceptions of light-duty electric vehicle usage in Germany. *Transportation Research Part C: Emerging Technologies* 105, 262–282. https://doi.org/10.1016/j.trc.2019.05.017

Wu, C., Le Vine, S., Sivakumar, A., Polak, J., 2019. Traveller preferences for free-floating carsharing vehicle allocation mechanisms. *Transportation Research Part C: Emerging Technologies* 102, 1–19. https://doi.org/10.1016/j.trc.2019.02.019

Wu, F., Sioshansi, R., 2017. A stochastic flow-capturing model to optimize the location of fast-charging stations with uncertain electric vehicle flows. *Transportation Research Part D: Transport and Environment* 53, 354–376. https://doi.org/10.1016/j.trd.2017.04.035

Xu, M., Meng, Q., Liu, Z., 2018. Electric vehicle fleet size and trip pricing for one-way carsharing services considering vehicle relocation and personnel assignment. *Transportation Research Part B: Methodological* 111, 60–82. https://doi.org/10.1016/j.trb.2018.03.001

Xu, M., Meng, Q., Liu, K., Yamamoto, T., 2017. Joint charging mode and location choice model for battery electric vehicle users. *Transportation Research Part B: Methodological* 103, 68–86. https://doi.org/10.1016/j.trb.2017.03.004

Xu, Z., Zhang, K., Min, H., Wang, Z., Zhao, X., Liu, P., 2018. What drives people to accept automated vehicles? Findings from a field experiment. *Transportation Research Part C: Emerging Technologies* 95, 320–334. https://doi.org/10.1016/j.trc.2018.07.024

Yedavalli, P., Mooberry, J., n.d. An assessment of public perception of urban air mobility (UAM). Airbus UTM: Defining Future Skies. Available online at https://storage.googleapis.com/blueprint/AirbusUTM_Full_Community_PerceptionStudy.pdf. Accessed September 21, 2020.

Yilmaz, E., Warren, M., German, B., 2019. Energy and landing accuracy considerations for urban air mobility vertiport approach surfaces. *AIAA Aviation 2019 Forum*. Presented at: The AIAA Aviation 2019 Forum, American Institute of Aeronautics and Astronautics, Dallas, TX. https://doi.org/10.2514/6.2019-3122

Young, M., Farber, S., 2019. The who, why, and when of Uber and other ride-hailing trips: An examination of a large sample household travel survey. *Transportation Research Part A: Policy and Practice* 119, 383–392. https://doi.org/10.1016/j.tra.2018.11.018

Zhang, C., Schmöcker, J.-D., Kuwahara, M., Nakamura, T. and Uno, N., 2020. A diffusion model for estimating adoption patterns of a one-way carsharing system in its initial years. *Transportation Research Part A: Policy and Practice* 136, 135–150.

Zhang, T., Tao, D., Qu, X., Zhang, X., Lin, R., Zhang, W., 2019. The roles of initial trust and perceived risk in public's acceptance of automated vehicles. *Transportation Research Part C: Emerging Technologies* 98, 207–220. https://doi.org/10.1016/j.trc.2018.11.018

Zhang, T., Tao, D., Qu, X., Zhang, X., Zeng, J., Zhu, H., Zhu, H., 2020. Automated vehicle acceptance in China: Social influence and initial trust are key determinants. *Transportation Research Part C: Emerging Technologies* 112, 220–233. https://doi.org/10.1016/j.trc.2020.01.027

Zillow, 2020. Zillow's Assessor and Real Estate Database (ZTRAX). Available online at https://www.zillow.com/research/ztrax/. Accessed September 30, 2020.

List of Tables and Figures

Table 1: Valuation estimates for passenger UAM markets

Report	Market	Valuation
Booz Allen Hamilton[1]	Airport shuttle and intracity air taxi	$500B unconstrained market 0.5% captured near term at $2.5B
Deloitte[2]	Intracity and regional markets	$1B in 2025 for intracity $13.8B in 2040 for intracity $2.6B in 2025 for regional $3.9B in 2040 for regional
Frost and Sullivan[3]	Passenger service	$0.3M in 2018 to $3B in 2023
KPMG[4]	Intracity and regional service	12M enplanements per year by 2040 400M enplanements by 2050
Porsche Consulting[5]	Passenger service (intracity and regional)	$1B by 2025 $21B intracity by 2035 $11B regional by 2035

References: [1]Booz Allen Hamilton (2018); [2]Lineberger, Hussain, and Rutgers (2019); [3]as quoted in eHang (2020b); [4]Mayor and Anderson (2019); [5]Porsche Consulting (2018).

Table 2: U.S. cities identified in the literature as having potential for UAM service

	Studies	Rank among U.S. cities in KPMG report in 2040
Atlanta	Robinson, KPMG, NEXA	8
Baltimore	NEXA	
Boston	Robinson, KPMG, NEXA	12
Chicago	Robinson, KPMG, NEXA	3
Dallas–Ft. Worth	Robinson, BAH, KPMG, NEXA	4
Denver	BAH, NEXA	
Detroit	NEXA	
Honolulu	BAH	
Houston	Robinson, BAH, KPMG, NEXA	5
Los Angeles	BAH, KPMG, NEXA	2
Miami	Robinson, BAH, KPMG, NEXA	6
New York City	Robinson, BAH, KPMG, NEXA	1
Philadelphia	KPMG, NEXA	9
Phoenix	BAH, KPMG, NEXA	11
San Diego	NEXA	
Seattle	NEXA	
Silicon Valley	Robinson, BAH, KPMG, NEXA	7
Washington, D.C.	BAH, KPMG, NEXA	10

Note: Additional cities included by NEXA are San Jose, Charlotte, Tampa, Nashville, Las Vegas, Salt Lake City, Raleigh–Durham–Chapel Hill, and Syracuse.

Reference Key: Robinson = Robinson et al. (2018); BAH= Booz Allen Hamilton (2018); KPMG = Mayor and Anderson (2019); NEXA= NEXA Advisors (2019).

Figure 1: UAM themes from AIAA and Scopus search, January 2015 to June 2020

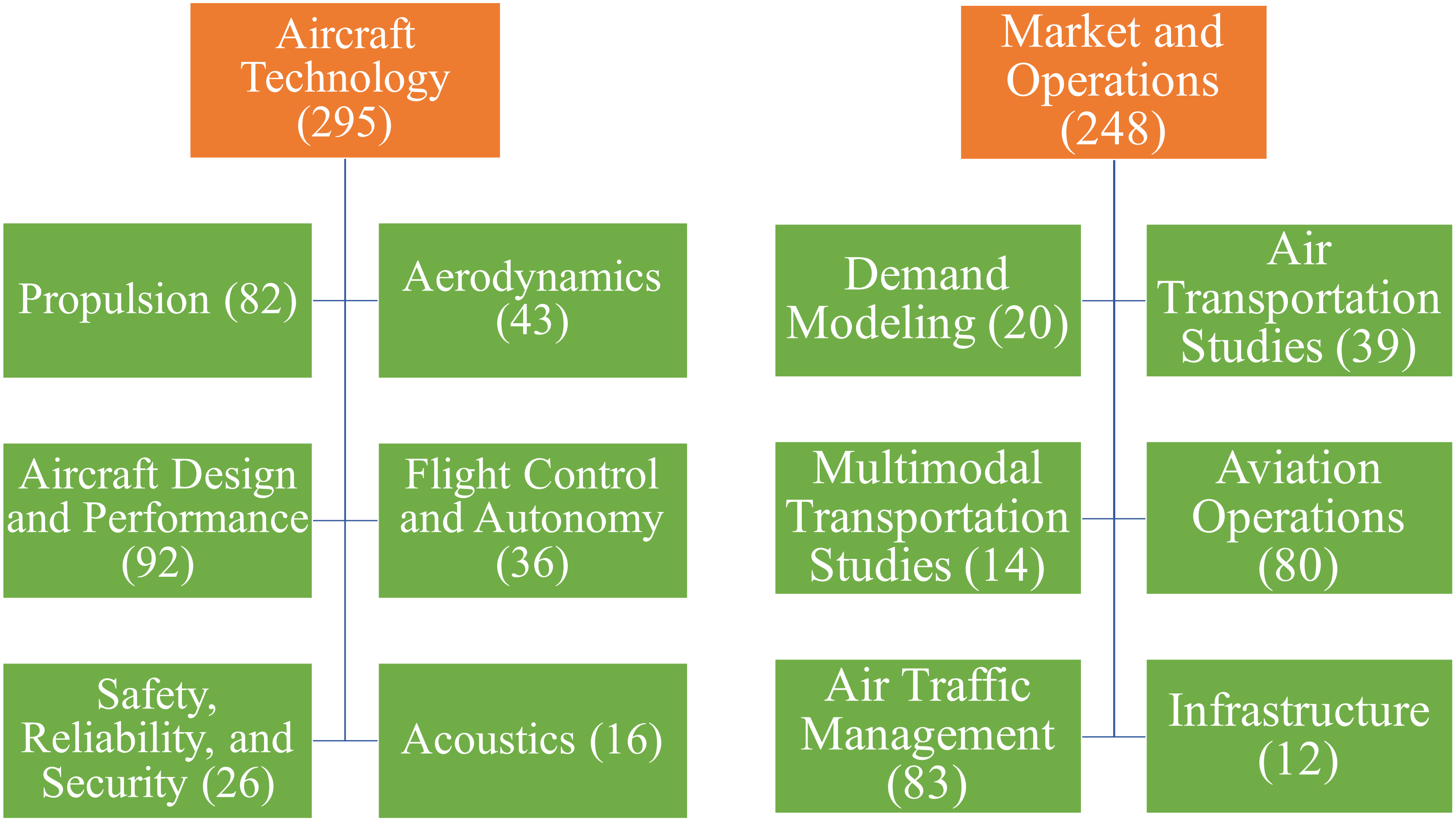

Figure 2: Themes from transportation journals' table of contents search, January 2015 to June 2020

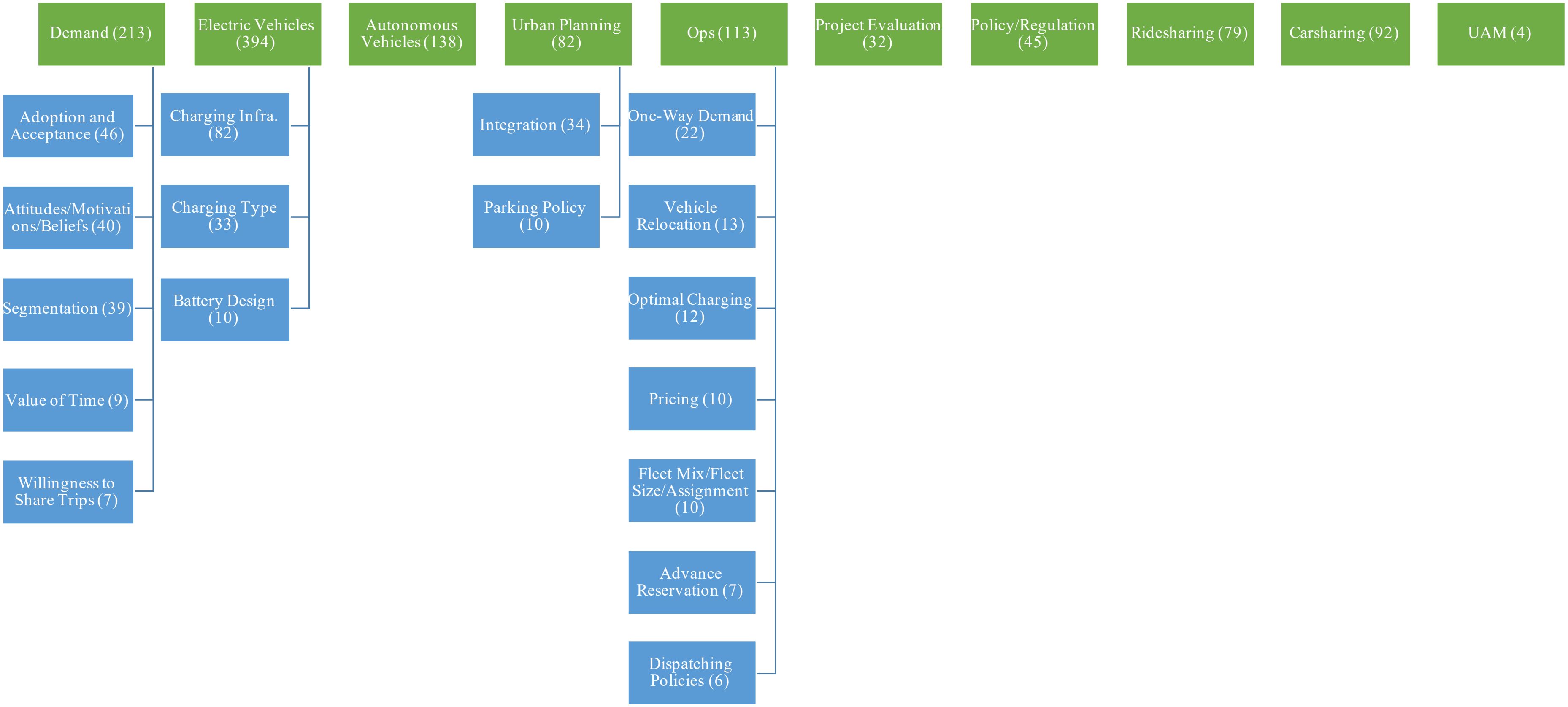

Table A1: Ground transportation studies that have examined the influence of customer attitudes towards EVs, AVs, or sharing programs

Study	Location	Sample Size	Key Findings
Axsen, Goldberg and Bailey (2016)	Canada	94 plug-in EV owners and 1,754 conventional auto owners	Early adopters of EVs have higher levels of environmental concerns and higher engagement in environment- and technology-oriented lifestyles.
Bansal and Kockelman (2018)	Texas, USA	1,088	About 50% of respondents will likely time their AV adoption in conjunction with their friends. Environmental friendliness and cost savings were factors in current carsharing users.
Bennett, Vijaygopal, and Kottasz (2019)	UK	444 physically disabled; 353 with no physical disability	Higher levels of interest in new technology associated with intention to use AVs.
Biresselioglu et al. (2018)	Review article with focus on Europe	N/A	Motivation to purchase EVs are influenced by environmental, economic, and technical benefit.
Cherchi (2017)	Denmark	2,363	Social conformity effects (e.g., word of mouth) were just as important as vehicle characteristics on intention to purchase EV.
Degirmenci and Breitner (2017)	Germany	40 interviews	Environmental performance of EVs is a stronger predictor of EV purchase intention than price value and range confidence.
Hohenberger et al. (2016)	Germany	1,603	Anxiety associated with AVs can be mitigated through providing safety-related information.
Huang and Qian (2018)	South Jiangsu region, China	348	Social conformity effects (word of mouth, peer influence) positively influenced consumer preference for EVs; risk-aversion negatively influenced EV preference.
Kim et al. (2019)	Georgia, USA	2,890	Respondents who would select air over AV tended to be more tech-savvy.
Kim et al. (2015)	Seoul, Korea	533 participants in an EV carsharing program	Individuals with higher environmental concerns and higher concern for what others think are more likely to purchase an EV.
Lane et al. (2018)	United States	1,080	Respondents preferring a battery EV over a plug-in EV were drawn to its environmental and technical appeal.
Li and Kamargianni (2019)	Taiyuan, China	3,486	Pro-environmental attitudes are positively associated with an intention to use bike-sharing.
Liu, Ma, and Zuo (2019)	China	213 college students	Highlighting the environmental advantages of AVs and increasing public trust in AVs may increase societal acceptance of AVs.
Potoglou et al. (2020)	Germany, India, Japan, Sweden, U.K., and U.S.	6,033	Individuals self-identifying as having a pro-environmental identity and as being innovators were more in favor of automation and AVs.
Smith et al. (2017)	Perth, Australia	440	Individuals who always selected EVs as preferred choice among six trade-off questions were more concerned with the environment.
Sovacool et al. (2019)	Denmark, Finland, Iceland, Norway, Sweden	5,067 online surveys and 257 interviews	Pro-environmental and safety attitudes are positively associated with women's preferences for EV vehicles.
Sweet and Laidlaw (2019)	Toronto and Hamilton, Canada	3,201	Individuals who are first to try out a new product and live a hectic life are positively associated with interest in using AVs.
Tsouros and Polydoropoulou (2020)	Greek Islands of Lesvos and Chios	550	Tech-savvy individuals are more likely to purchase vehicles with higher levels of automation, and pro-environmental individuals are more likely to purchase hybrids.
Wang, Wang, et al. (2020)	China	426, primarily university students	Early adopter of new technology, environmental awareness, and perceived usefulness is positively associated with intention to use ridesharing.