# [HED] Size Matters: Optimizing Your Advanced Air Mobility Air Taxi Fleet to Meet Scheduling and Traffic Demands

# [byline] By Aaliyah Mora-Khan

# Planning aircraft fleet size based on current demands and future needs is tough enough for established air carriers that operate conventional aircraft. Taking into consideration things like expected demand, average load factors, and aircraft productivity – and getting it right – can make or break an air carrier’s bottom line. Fleet planning for an as-yet untested aircraft in a market where passenger demand and acceptance is still unknown is a greater challenge is by an order-of-magnitude (or two!).

# Nevertheless, undaunted by the challenge, a quartet of scientists from the Technical University of Dresden’s Institute of Logistics and Aviation, Martin Lindner, Robert Brühl, Marco Berger, and Hartmut Fricke took up the gauntlet and devised a method and a plan which future AAM fleet operators can use to maximize operational efficiencies and, in the process improve service and enhance air taxi operators’ bottom lines. The result is their paper, “[The Optimal Size of a Heterogeneous Air Taxi Fleet in Advanced Air Mobility: A Traffic Demand and Flight Scheduling Approach](file:///C%3A%5CUsers%5CDave%5CDesktop%5CFlying%20Cars%5CPublished%20Articles%5CFuture%20Transportation%20%7C%20Free%20Full-Text%20%7C%20The%20Optimal%20Size%20of%20a%20Heterogeneous%20Air%20Taxi%20Fleet%20in%20Advanced%20Air%20Mobility%3A%20A%20Traffic%20Demand%20and%20Flight%20Scheduling%20Approach%20%28mdpi.com%29).”



[caption] Map of European cities and regions participating in the [UIC2](https://civitas.eu/urban-air-mobility) initiative for the implementation of AAM. (Image copyright and courtesy of the Urban Air Mobility Initiative Cities Community (UIC2), an European Commission initiative within the Smart Cities Marketplace.)

[subhed] How many passengers, how many eVTOLs, traffic patterns, and, of course: price

Many an airline has struggled with ‘getting it right’ in terms of what types of aircraft to buy, what size, which routes to operate, how much to charge, and the unpredictability of weather and/or mechanical delays on operations. And these carriers have a hundred-plus years of operational data from which to plan their schedules and fleet purchases. Advanced air mobility (AAM) operators don’t have that luxury. They’re going to have to figure it out with aircraft which have yet to be type-certified, infrastructure that is still in the planning stages, and passengers who probably don’t even know that they want, need, or could significantly benefit from this type of service to enhance their travel experience. So, what did these Dresdeners do?

They employed mobility data from a Dresden traffic survey and modal shift rates to estimate demand for AAM operations by organizing them into an air taxi rotation schedule using a Mixed Integer Linear Programming (MILP) optimization model and set a tolerance level for slight deviations from planned operations. They took into account flight performance, energy consumption, battery charging requirements and tailored them to three discrete types of air taxi fleets. Their theory, if proven accurate will yield an efficient computational time of 1.5 hours.

[subhed] A Dozen (Trips) a Day x Optimal Travel Routes = Profitability for AAM Operators

Their methodologies provide insight into air taxi utilization, charging times across the route operations zone, and adapts to the uncertainties inherent in air traffic demand. The study shows an average productivity of 12 trips per day per eVTOL across routes from 13km (about 8 miles) to 99km (about 60 miles). The theory is this methodology, focused on commercial business travelers, operational considerations, and vertiport capacities, can guide the way for air taxi operators to meet customer demands and shareholders’ expectations. The shortest distance between two points is often a straight line. But when your straight line necessitates the third dimension of height, and the fourth dimension of time, a good plan is your best bet for success.



#AAM #advancedairmobility #UAM #eVTOL #MILP optimization, #aamtoday #air taxi

# The Optimal Size of a Heterogeneous Air Taxi Fleet in Advanced Air Mobility: A Traffic Demand and Flight Scheduling Approach

by

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## Abstract

Introducing Advanced Air Mobility (AAM) as a novel transportation mode poses unique challenges due to limited practical and empirical data. One of these challenges involves accurately estimating future passenger demand and the required number of air taxis, given uncertainties in modal shift dynamics, induced traffic patterns, and long-term price elasticity. In our study, we use mobility data obtained from a Dresden traffic survey and modal shift rates to estimate the demand for AAM air taxi operations for this regional use case. We organize these operations into an air taxi rotation schedule using a Mixed Integer Linear Programming (MILP) optimization model and set a tolerance for slight deviations from the requested arrival times for higher productivity. The resulting schedule aids in determining the AAM fleet size while accounting for flight performance, energy consumption, and battery charging requirements tailored to three distinct types of air taxi fleets. According to our case study, the methodology produces feasible and high-quality air taxi flight rotations within an efficient computational time of 1.5 h. The approach provides extensive insights into air taxi utilization, charging durations at various locations, and assists in fleet planning that adapts to varying, potentially uncertain, traffic demands. Our findings reveal an average productivity of 12 trips per day per air taxi, covering distances from 13 to 99 km. These outcomes contribute to a sustainable, business-focused implementation of AAM while highlighting the interaction between operational parameters and overall system performance and contributing to vertiport capacity considerations.

To aid their study, the scientists relied on the work and findings of the Urban Air Mobility Initiative Cities Community (UIC2), an initiative of the European Commission (EC) as an integral component of its Smart Cities Marketplace. The initiative based its findings on:

• The complexities of eVTOL designs including fuel cell technology, charging requirements in limited space, and certification requirements

• Airspace management in already congested urban environment and the need for advanced airspace management technologies to ensure safe operations.

• Infrastructure development – everything from vertiports to environmental considerations, privacy, and noise concerns

• A societal shift in the way travelers choose to adopt, adapt, and interact with this new urban aviation option offered them.

[subhed] Braving a brave new world of air travel



#AAM #advancedairmobility #UAM #eVTOL #MILP optimization, #aamtoday #air taxi

* The complexity of the design of air taxis, involving modern battery resp. fuel cell technology and charging management within very limited space, including certification aspects;
* Airspace management in (congested) urban environments requiring advanced technologies to overcome safety concerns;
* Infrastructure development, such as the construction of landing and takeoff areas and charging stations (‘vertiports’) in potentially downtown urban areas with significantly limited space;
* Regulatory and legal challenges pertaining to air traffic management, privacy, environmental impact, and noise abatement;
* Concerns related to a potential societal shift, requiring coordination and cooperation among various stakeholders.

**Keywords:**

[**advanced air mobility**](https://www.mdpi.com/search?q=advanced+air+mobility); [**traffic demand**](https://www.mdpi.com/search?q=traffic+demand); [**mobility data**](https://www.mdpi.com/search?q=mobility+data); [**flight scheduling**](https://www.mdpi.com/search?q=flight+scheduling); [**MILP optimization**](https://www.mdpi.com/search?q=MILP+optimization); [**productivity**](https://www.mdpi.com/search?q=productivity); [**delay management**](https://www.mdpi.com/search?q=delay+management); [**battery charging**](https://www.mdpi.com/search?q=battery+charging); [**air taxi**](https://www.mdpi.com/search?q=air+taxi); [**eVTOL**](https://www.mdpi.com/search?q=eVTOL)

## Introduction

Advanced Air Mobility (AAM) integrates urban and regional air transportation systems, and is expected to play a significant role in future mobility systems. By utilizing the third dimension, AAM can offer faster transportation using direct connections over longer distances while enhancing accessibility over competing transport modes due to very limited infrastructure-related requirements. Technological advancements, such as electric or hybrid engines and autonomous air taxis (also called eVTOLs), may further contribute to the acceptance and cost-effectiveness of air transportation.

However, the integration of AAM into existing transportation systems introduces several challenges:

* The complexity of the design of air taxis, involving modern battery resp. fuel cell technology and charging management within very limited space, including certification aspects;
* Airspace management in (congested) urban environments requiring advanced technologies to overcome safety concerns;
* Infrastructure development, such as the construction of landing and takeoff areas and charging stations (‘vertiports’) in potentially downtown urban areas with significantly limited space;
* Regulatory and legal challenges pertaining to air traffic management, privacy, environmental impact, and noise abatement;
* Concerns related to a potential societal shift, requiring coordination and cooperation among various stakeholders.

In Europe, various cities are part of the Urban Air Mobility Initiative Cities Community (UIC2), an initiative of the European Commission (EC) as an integral component of its Smart Cities Marketplace [[**1**](https://www.mdpi.com/2673-7590/4/1/10#B1-futuretransp-04-00010),[**2**](https://www.mdpi.com/2673-7590/4/1/10#B2-futuretransp-04-00010)]. The primary objective of the UIC2 is to facilitate collaboration among cities actively implementing AAM, fostering knowledge-sharing and mutual support. [**Figure 1**](https://www.mdpi.com/2673-7590/4/1/10#fig_body_display_futuretransp-04-00010-f001) visually depicts the locations of these cities and regions, marked by orange points [[**3**](https://www.mdpi.com/2673-7590/4/1/10#B3-futuretransp-04-00010)]. Each region within the UIC2 framework possesses a distinct focus on AAM applications, with priorities ranging from logistics and medical services to artificial intelligence [[**4**](https://www.mdpi.com/2673-7590/4/1/10#B4-futuretransp-04-00010)]. The Saxon government’s exploration of AAM diverges from UIC2, focusing on rural areas with limited transportation infrastructure, rather than integrating AAM into already well-connected urban transit systems. Its primary aim is to advance these regions technologically and socially through AAM. Consequently, Dresden, the capital of Saxony and not a part of UIC2, is represented as a green point in [**Figure 1**](https://www.mdpi.com/2673-7590/4/1/10#fig_body_display_futuretransp-04-00010-f001).



**Figure 1.** Map of European cities and regions participating in the UIC2 initiative for the implementation of AAM.

The successful integration of AAM depends on accurately determining the required fleet size of air taxis needed to match the projected demand within an anticipated operational framework. However, predicting this demand poses a challenge due to uncertainties surrounding the public acceptance of this novel mode of transportation and the dynamic nature of urban travel demands, which is currently still not foreseeable. Furthermore, the absence of a standardized model to evaluate fleet size, considering factors, like air taxi flight characteristics, existing transportation infrastructure, traffic regulations, population density, and pricing strategies, compound this challenge. The complexities are further compounded when examining rural areas, which exhibit distinct traffic dynamics, limited infrastructure, and unique economic considerations. Given the novelty of the AAM concept and the numerous questions, there are currently few approaches for developing an AAM network (cf. [**Section 2**](https://www.mdpi.com/2673-7590/4/1/10#sec2-futuretransp-04-00010). Current approaches to fleet size determination predominantly rely on traffic simulations incorporating air taxis as an additional transport mode or traditional methodologies such as ongoing updates based on current bookings and forecasts, typically in commercial aviation fleet planning.

This study aims to address the research questions arising from the aforementioned constraints, aiming to bridge several gaps in the field. Firstly, it seeks to develop methodologies that translate mobility survey data into temporally and spatially resolved demand forecasts for AAM. Secondly, it aims to determine the optimal fleet size required to serve specific rural areas based on passenger demand and travel patterns. Thirdly, it investigates the impact of varying fleet sizes on performance metrics like travel time, passenger wait time, and overall system efficiency. This will provide valuable insights for efficient AAM, helping inform policymakers and stakeholders on the best strategies for implementing air taxi services. We assume that the necessary infrastructure and technology for AAM is available and there are no relevant regulatory constraints for scheduling and offering flights.

This paper is structured as follows: [**Section 2**](https://www.mdpi.com/2673-7590/4/1/10#sec2-futuretransp-04-00010) provides an overview of demand modeling and a state-of-the-art on AAM technologies. Additionally, we explore the literature on capacity evaluation and the modeling of the number of required air taxis, considering different demand assumptions. [**Section 3**](https://www.mdpi.com/2673-7590/4/1/10#sec3-futuretransp-04-00010) introduces the methodology for translating mobility data into forecasts for AAM demand. This section outlines the air taxi demand estimation approach from [[**5**](https://www.mdpi.com/2673-7590/4/1/10#B5-futuretransp-04-00010)], which evaluates a segment of potential air taxi users and includes comprehensive calculations for air taxi flight performance. [**Section 4**](https://www.mdpi.com/2673-7590/4/1/10#sec4-futuretransp-04-00010) presents the estimation of the number of air taxis required for AAM through a Mixed-Integer Linear Programming (MILP) model. This kind of vehicle and resource planning involves integrating flight scheduling, air taxi assignment, flight repositioning strategies, and considers additional waiting times due to battery charging during operations. [**Section 5**](https://www.mdpi.com/2673-7590/4/1/10#sec5-futuretransp-04-00010) identifies the parameters for flight performance of each air taxi category to calculate estimated flight times and energy consumption. The comprehensive results are generated and presented in [**Section 6**](https://www.mdpi.com/2673-7590/4/1/10#sec6-futuretransp-04-00010), followed by a thorough discussion in [**Section 7**](https://www.mdpi.com/2673-7590/4/1/10#sec7-futuretransp-04-00010) within a broader context.

## 7. Discussion

#### *7.1. Practical and Theoretical Implications*

In the preceding sections, we investigated an air taxi network’s operational dynamics under various fleet-sizing scenarios for Advanced Air Mobility (AAM). We created a model to predict the number of air taxis required based on AAM demand, illustrating its application in a specific case in Saxony. This section discusses the implications of our findings, placing them in the context of prior studies and addressing our research questions.

In addition to predicting traffic demand for AAM, our primary focus lies in seamlessly integrating daily flights and a predetermined quantity of air taxis into a comprehensive flight schedule. The cornerstone of our investigation is our MILP optimization model, designed to compute a cost-minimum flight schedule and air taxi assignment. Each air taxi is categorized as one of three types: *Vectored Thrust*, *Lift and Cruise*, and *Multicopter*. For each type, we detail flight performance, energy consumption, and process duration, calculating a rotation plan for each air taxi of a given type, inclusive of repositioning flights and battery charging times.

The model further introduces the capability to incorporate a planned delay into the system. This planned delay, set at an acceptable 4 min per flight, remains imperceptible to passengers during the day of operation. Instead, it serves as a metric measuring the deviation from preferred departure times derived from initial demand data in comparison to the actual flight schedule. While moderate delays have the potential to enhance system efficiency and reduce the number of required air taxis, excessive delays deviate departure times too significantly from the ideal, eliminating crucial time buffers from the schedule. Aligning with established practices in airport capacity assessments, the considered 4 min delay per flight ensures a balanced approach to system optimization.

Given the early stage of air taxi technology and the absence of regulatory approval or operational experience, our study necessitated several key assumptions. A crucial assumption involved the development of a streamlined air taxi demand network, focusing on flights to and from Dresden—the epicenter of the network. This network is informed by previous studies [[**5**](https://www.mdpi.com/2673-7590/4/1/10#B5-futuretransp-04-00010),[**74**](https://www.mdpi.com/2673-7590/4/1/10#B74-futuretransp-04-00010)], utilizing current mobility data and a daily traffic pattern derived from a survey on potential shifts to air taxis [[**29**](https://www.mdpi.com/2673-7590/4/1/10#B29-futuretransp-04-00010)]. These findings are extrapolated to encompass the entire population of specific locations within the network. Notably, the assumed modal shift rates play a significant role in influencing the outcome as trips per day, with other studies highlighting their dependence on future air taxi prices.

In addition, further assumptions were introduced, potentially exerting a significant impact on the results. The assumption of uninterrupted flight operations, while aiding in modeling, may oversimplify the practical complexities of travel. Uncertainties, including specific assumptions related to aircraft performance, demand projections, and flight durations, are context-dependent and may not universally hold true for all AAM scenarios. These assumptions underscore the need for a nuanced understanding of the limitations and contextual relevance of our study’s findings. In our work, we have demonstrated how a change in parameters affects the outcome for the respective network.

In the optimal solution for the defined standard of our case study with a specific demand distribution and air taxi performance parameters, we achieve an average daily utilization of approximately 6.96.9 flight hours per day of operation within the operational timeframe from 6 a.m. to 10 p.m. (no nighttime operations, i.e., 16 h). Events of non-availability, such as maintenance, must be factored in based on their duration. In the context of an adequately sized fleet and an accepted average delay of 4 min per flight, identified in the optimal solution, a notable portion (30%) of delay events is short-lived, lasting less than 5 min. Instances of longer delays are rare, indicating that delays within the accepted threshold minimally impact the resulting flight schedule. As the predefined threshold for tolerated delay increases, the daily utilization of air taxis rises. Simultaneously, the integration of additional air taxis into the flight plan effectively mitigates unacceptable delays.

The flight schedule inherently reflects the performance characteristics of the three categories of air taxis. *Multicopters*, despite having a comparable number of daily flights, exhibit lower average distance and total consumption due to their limited battery capacity and speed. Consequently, they are well-suited for short-distance operations within our network, covering a maximum distance of approximately 30 km. This fleet is particularly suitable for mobility in urban regions, where flight distances and charging times are correspondingly low. While *Multicopters* complete more cycles due to their shorter range, *Lift and Cruise* air taxis prove to be more efficient on longer routes and are accordingly assigned to such routes. *Vectored Thrust*, although used less frequently due to higher energy consumption, serves longer routes and could gain popularity with increasing demand due to their higher seating capacity.

The flight schedule includes unintended repositioning flights with additional operating costs depending on the network, demand distribution, and the goal of maximizing air taxi utilization. Their number decreases with a higher number of available air taxis, as more air taxis allow for idle times at individual stations, eliminating the need for virtual delay. Moreover, the schedule encompasses numerous charging events, which, with a 150 kW charging power, are nearly as long as the flight operations themselves. Increasing the charging power to around 450 kW results in shorter charging times, enhancing productivity by up to 20%, equivalent to about 1.3 flight hours per air taxi per day. This productivity increase primarily occurs during assumed turnaround times, making them a critical path. The assumption here is that charging is performed at full power as soon as the air taxi is on-site. While pre- and post-preparation tasks for charging could potentially impact productivity, they are not considered at this stage and can be adjusted by increasing the durations for ground activities, which inherently restrict charging.

Contrary to the hypothesis that uncertainty in demand estimation can be addressed solely by scaling the number of air taxis based on daily utilization and available passenger kilometers per air taxi, our findings do not confirm this approach. While effective for minor variations (up to 10%) in demand, larger deviations result in an increasing error, leading to an underestimation of the actual required number of air taxis.

#### *7.2. Conclusions and Future Research*

Our findings demonstrate the suitability of our approach in determining fleet size according to demand. Essential parameters such as loading time, flight time, etc., can be modeled and integrated into the evaluation function. Utilizing heuristics, qualitatively excellent results can be achieved within acceptable computation times. In conclusion, our results, coupled with insights from the parameter study, contribute to a comprehensive understanding of the robustness and adaptability of AAM and air taxi networks under various demand scenarios.

Given the novelty of this transportation mode, limited scientific literature focuses on AAM demand and their networks. Existing studies diverge significantly, each highlighting unique aspects, e.g., transport simulation with modeled air taxi agents [[**17**](https://www.mdpi.com/2673-7590/4/1/10#B17-futuretransp-04-00010),[**19**](https://www.mdpi.com/2673-7590/4/1/10#B19-futuretransp-04-00010),[**34**](https://www.mdpi.com/2673-7590/4/1/10#B34-futuretransp-04-00010),[**92**](https://www.mdpi.com/2673-7590/4/1/10#B92-futuretransp-04-00010)]. Notably, there are no directly comparable studies known concerning demand estimation, fleet planning, and while accepting moderate flight delays for rural areas. Furthermore, all known studies share a commonality in making specific assumptions regarding potential demand and the technical characteristics of air taxis, with the modal shift rate towards AAM being particularly uncertain [[**29**](https://www.mdpi.com/2673-7590/4/1/10#B29-futuretransp-04-00010)]. Despite the divergent scopes of these case studies, certain similarities, such as the average utilization of air taxis found, suggest methodological robustness.

Moving forward, it is important to mention the need for a buffer to handle disruptions or maintenance for practical implementation as a robust solution. There is a great opportunity to enhance the simulation model by incorporating knowledge from commercial aviation flight traffic and delay statistics. Additionally, for a more comprehensive understanding, future research will explore additional demand scenarios beyond the current scaled model. Examples include scenarios with uniformly distributed and symmetrically shaped demand throughout the day or scenarios reflecting daily patterns and asymmetry. However, increased detailing is anticipated to introduce more complexity and computational challenges in solving the optimization problem. A subsequent focus on identifying suitable heuristics is expected to expedite solutions, particularly when experimenting with various scenarios. Simultaneously, highly adaptable simulation-based approaches, e.g., agent-based simulations, might generate similar solutions, and the preferred path for generating these solutions needs to be scientifically explored.

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## Author Contributions

[HED] Urban Air Mobility Needs a New Wind Flow to Fly Right

[subhed] From Chicago to Wellington, wind flows will challenge UAM operators



[caption] The urban canopy layer (UCL) and the urban boundary layer (UBL) substantially affect wind flows UAM operators need to consider as they maneuver their aircraft in the inner city. (Illustration copyright and courtesy *Journal of Applied Meteorology and Climatology*)

In their paper, “[Review of Wind Flow Modelling in Urban Environments to Support the Development of Urban Air Mobility](https://www.mdpi.com/2504-446X/8/4/147), aerospace researchers D.S. Nithya, Giuseppe Quaranta, Vincenzo Muscarello, and Man Liang, reviewed the current (deficiency of) existing data of wind flow modeling in urban environments with an eye toward enhancing urban air mobility (UAM) operations as this new mode of transportation increasingly integrates into cities’ daily flight operations in the coming years.

Published in the April 2024 issue of [Drones](https://www.mdpi.com/journal/drones), the team uses microscale wind modelling to study atmospheric dynamics, weather forecasting, and turbine blade load, among others factors to best estimate and forecast wind flow modelling methods. The scientists use a compare-and-contrast study of the methods which are currently used in the wind engineering and atmospheric sciences within the context of wind flow conditions.

[subhed] No one wants to be gone with the wind

The research team, comprised of scientists from Italy’s Politecnico di Milano and Australia’s RMIT University, recognized the challenges facing UAM operators in an environment where they will be operating at lower altitudes than current commercial aircraft operations and the unique wind flows posed by city skylines as diverse as Chicago (aka “The Windy City”) or Wellington, New Zealand.

The team also took account of the fact that the UAM and eVTOL vehicles currently undergoing design, manufacture, and certification substantially vary in size, configuration, and weight. They also differ in the ways their electric propulsion systems distribute energy and the degrees to which they will, or will not be autonomously operated. These differences can impose substantially more safety risks, including trajectory deviation, loss or difficulty in control, and even the rapid deterioration of battery charge. All of these factors could result in operational delays, decreased passenger comfort, and even some risks which are, as yet, unknown.



[caption] Illustration of urban environment from above, where squares equal buildings and the numbers equal their height in meters. (Illustration courtesy *Boundary-Layer Meteorology*).

[subhed] Time, space, and wind

The study revealed a host of factors which impact urban wind flow. These include: diurnal variations, the Coriolis effect, geographic positioning, topography, surface roughness, flow incidence angle, building and street configurations, building aspect ratios, roof shapes, and building heights. Jointly, the characteristics uniquely form the wind flow characteristics with the urban boundary layer (UBL). Consequently, wind velocity and fluctuation components frequently produce spatio-temmporal variations, and complex flow patterns different than those which pilots typically experience at higher altitudes. These variations only reinforce the need, the authors say, for more study of this unique flying environment and prompt a need to place more sensors on different sides of buildings and at different heights.

[subhed] The answer is blowin’ in the wind

Optimal wind flow modeling, the group discovered can be broken into temporal and spatial evaluations. While the current research is disparate in its approach and conclusions, integrating existing methods and developing new ones will lead to better, more efficient wind flow models for the adoption and implementation of UAM worldwide.



[**urban air mobility**](https://www.mdpi.com/search?q=urban+air+mobility); [**urban wind flow modelling**](https://www.mdpi.com/search?q=urban+wind+flow+modelling); [**urban wind forecasting**](https://www.mdpi.com/search?q=urban+wind+forecasting); [**urban wind data**](https://www.mdpi.com/search?q=urban+wind+data); [**eVTOL certification**](https://www.mdpi.com/search?q=eVTOL+certification); [**UAM operation**](https://www.mdpi.com/search?q=UAM+operation)

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