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From Gridlock to Airflow? Understanding the Total Travel Time for Advanced Air Mobility Demand at the Hamburg Airport

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Abstract

This study examines the potential Advanced Air Mobility (AAM) passenger market in Hamburg, Germany, focusing on airport shuttle services. Therefore, the model uses structured data of the metropolitan area of Hamburg, including population data, status of employment and historical traffic between traffic analysis cells. Based on the structured data of Hamburg, this study implements a four-step model. The modelling of a four-step model allows for investigating the different modes of transport individually. At this point, the AAM alternative consists of an access stage, a main AAM flight and an egress stage. Since passengers decide on travel time and travel cost primarily, the model uses a multinomial logit model to estimate the utility, hence the market share of the considered alternatives. Consequently, the model investigates the impact of travel time for the AAM in detail. As a result, the AAM market reacts to variations of the travel time, which entail AAM operation limitations and capacity requirements for air and ground infrastructure. To evaluate the AAM accessibility of the Hamburg Airport with road traffic, the model compares AAM travel time with the car road traffic. Results show an average AAM time benefit when considering road itineraries that take longer than 43 minutes.

Keywords: Advanced Air Mobility; Urban Air Mobility; demand; discrete choice model; airport shuttle; road traffic;

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1. Introduction

In industry, the Original Equipment Manufacturers (OEM) present their configurations for AAM aircraft in various stages of development. Progress in battery research, autonomy, material compounds, and Distributed Electrical Propulsion (DEP) enables innovative configurations for Advanced Air Mobility (AAM). Here, aircraft with a comparatively low Maximum Take-Off Mass (MTOM), compared to manned aviation, transport passengers similarly to helicopter services in São Paulo, Brazil, or New York, USA (Evandro, 2024, Heliny, 2023). Depending on the manufacturer, an entry into service of AAM configurations is expected by 2030 (IFAR AAM Working Group, 2023, Drone Industry Insights, 2022). AAM, as a new transport system, cannot be considered in isolation as merely a new aircraft technology. Instead, AAM comes with an entire ecosystem surrounding it. From the perspective of demand estimation, the most important stakeholders are airlines, OEMs, traditional transport systems, and passengers.

Currently, no drone service operator is known to be operating in the AAM ecosystem. The airline business is directly linked to demand estimation, as airlines have a major influence on total travel time and ticket prices. Through its business model, an airline shapes the attractiveness of this transport system. To operate an AAM transport mode, airlines depend on the OEMs, who are developing and working on different vehicle configurations worldwide. The diverse vehicle market presents configurations in varying stages of certification (Savani et al., 2021). These configurations are a key input for airlines' business models.

Similar to manned aviation, AAM is characterised by an intermodal transport system, including access and egress phases in addition to the main flight. Because of this, AAM requires an integration with traditional transport systems such as public transportation, individual traffic, and non-scheduled services like taxis. As the source of revenue, passenger behaviour and decisions are key input factors for airline business models. By understanding this stakeholder group, airlines can design their offerings and optimise their business models. Passenger behaviour may vary over time and across specific routes and is primarily influenced by travel purpose and motivation (Straubinger et al., 2020, Brunelli et al. 2023).

Additionally, the AAM transport system includes stakeholders from government and regulatory bodies, maintenance facilities, communication providers, Air Traffic Management (ATM) providers, vertiport operators, infrastructure contractors, and real estate holders. At this stage, these stakeholders have an ancillary influence on AAM demand estimation, as their impact is expected to be secondary. No information on a business and revenue model from potential AAM airlines is available, since market sizes of certain metropolitan areas are unknown. The analysis of a local market size serves as an important input for both AAM airlines and vertiport operators. For Hamburg in particular, where road traffic is slow, AAM could offer an alternative to relax the load factor on the road. Previous studies already investigated potential traffic shifts from ground-based transportation systems to AAM (Al Haddad et al. 2020).

2. Methods and Data

2.1. Geo-referenced data for the metropolitan area of Hamburg

This research examines the potential AAM passenger market in the metropolitan area of Hamburg, Germany. As a data input, this study uses the population structure and traffic data of 2019, provided by the Hamburg authority for traffic and mobility transition (Kröger, 2021). The metropolitan area of Hamburg is a defined area of about 150km in length (Dohrmann, 2024). In total, the considered area is split into 1940 geo-referenced traffic analysis cells, varying in size and shape. The further the cell is outside of the city centre of Hamburg, the larger they are. Each cell contains information about the population living or working in the cells, number of employees and further data about infrastructure and the status of employment.

2.2. Hamburg Airport

Hamburg Airport (IATA: HAM, ICAO: EDDH) transported 17.3 million passengers in 2019 and is located close to the city in the Fuhlsbüttel district (Hamburg Airport, 2019). Its accessibility is limited to local public transport as well as individual road and taxi traffic, while there is no direct connection to long-distance transport or highways. The

Hamburg Airport is not a hub for manned aviation, but rather a final destination for passengers of manned aviation. It can therefore be assumed that all airport passengers will be distributed in the metropolitan area and will not travel on a connecting flight. In sum, this study considers 25500 airport passenger one way per day as a total market size.

3. Methodology

3.1. Four-Step-Model

This research applies the first three steps of a four-step-model for forecasting AAM demand. The first step is about the trip generation. In the beginning, each scenario defines its passenger class and their motivation, that influence the following modelling. This study focuses on the airport shuttle transportation as a representative for centralized networks. The trip distribution defines the total market size between all traffic analysis cells. Here, a gravity model sets the passenger market based on the population of each traffic analysis cell. To set the passenger distribution from the airport, the total market of 25500 passengers is dispersed based on the number of people living in each traffic analysis cells and the distance to the airport. That means, the more people live in a certain traffic analysis cell, the merrier airport passenger are expected here. In the same way the market scales with the distance, meaning the closer a cell is located to the airport, the merrier passengers are going there. All itineraries are one way only, since transport attributes as well as passenger behaviour will not change when returning to the origin cell. When considering an origin-destination-pair, a mode choice model splits the market to the different transport modes. Each passenger selects its own mode by choosing between the alternative's car, public transport, taxi and AAM. At this point, this research uses a multinomial discrete choice model with the total travel time and travel cost as the main attributes.

$$U_{ni} = \gamma_i + \beta_{TC} \cdot TC_{ni} + \beta_{TT} \cdot TT_{ni} + \epsilon_{ni} \tag{1}$$

In Eq. (1), U_{ni} describes the Utility for each Alternative i for each individual decision maker n. Every alternative is characterized by its alternative specific constant γ_i, summarizing non-measured aspects of each transport mode that are not covered by the attributes. In transport modelling, γ covers aspects of comfort, safety, acceptance, reliability and further, if not modelled as β parameter directly. In this study the β parameters include the total travel costs (TC) and the total travel time (TT), weighted by the regression parameter β. The error term ϵ corresponds to a Gumbel distribution (Ben-Akiva and Lerman, 2018). Furthermore, this research models the AAM transport mode from door-to-door, to calculate a total travel time and the total travel cost for each itinerary. The last step trip assignment is not part of the modelling in this research, since every ground and air infrastructure are handled as available and capacity aspects are not considered in this study.

3.2. Modelling the transportation modes

The AAM transport mode is modelled comprehensively, including access- or pre-stage, the main flight and egress- or post-stage (Figure 1).

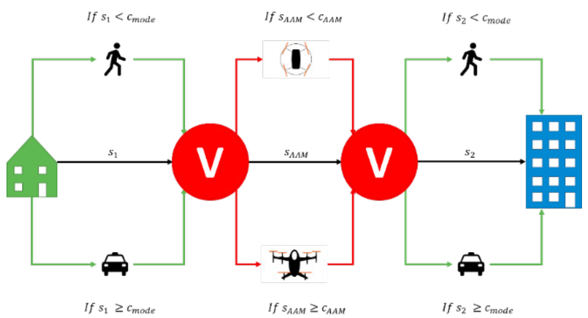

Figure 1 AAM transport mode including the pre stage, main flight and post stage

The origin, symbolized as a green house, is at an individual distance s_1 from the starting vertiport (white V on red circle). The sample of vertiports in this study consists of an input data including 21 locations in the city centre of Hamburg as well as 22 locations at the biggest surrounding cities in the metropolitan area of Hamburg. All coordinates are listed in Table 2 in the Appendix. Depending on this distance, passengers either walk or take a taxi, influencing travel time and cost. The decision variable c_{mode} is set to 1.7 km universally and linked to the median walking distance presented in the mobility report for Hamburg (Follmer, 2020). Afterwards, ground handling and vertiport services require additional time, according assumptions. The main flight uses either a multicopter for short urban routes or a vectored thrust aircraft for longer metropolitan distances, depending on the threshold linked to the multicopter's maximum range. Both configurations have distinct flight parameters and ticket fares (Pertz et al. 2023b). The post-stage phase mirrors the pre-stage phase, but s_2 is used as critical parameter for the post-stage mode.

The individual transport mode car and taxi services are calculated with the Open Trip Planner (OTP) by multiplying the raw travel time by the TomTom Traffic Index of 1.36 for Hamburg (TomTom International BV, 2019). The public transport is calculated as the available connection on a working day at 15pm with the public transport service provider HVV (HBT Hamburger Berater Team GmbH, 2023).

4. Results

4.1. Airport Passenger Behaviour

Based on historical data in Hamburg, the model estimates the parameter for the mode choice model. In consideration of the network, mainly designed by trip generation and trip distribution, and the behaviourally homogeneous groups, this scenario presents a centralized network with a market of 25500 traveller. Table 1 shows the estimated parameters for the utility function U_{ni}.

Table 1 Estimated Mode Choice Parameters for Airport shuttle passenger.

Parameter	Value	p-Value	t-test
γ_{public}	0	1	0
γ_{car}	-0.145	0.269	-1.11
γ_{taxi}	-1.270	0	-11.9
β_{TC}	-0.786	0.00241	-3.03
β_{TT}	-0.635	0.113	-1.59
Sample Size	1694		
$\bar{\rho}$	0.303		
VOT	48 €/h		

All parameters were calibrated and validated by a k-fold cross validation (k=5) on a dataset of passengers going to or leaving the airport. Based on the passenger behaviour and the assessment of total travel time and cost, this passenger group has a willingness-to-pay of around 48 €/h. Previous studies for business travel and commuting in Hamburg show a lower Value of Time (VOT) (Pertz et al. 2022, 2023a). Passenger behaviour does not change when going to or coming back from the airport, but the analysis considers the forward run to the airport only. In total, the airport scenario reaches an AAM market of 1874 passengers, which corresponds to 7.35 % market share. While the market share can vary on individual itineraries, the average travel time for AAM passengers' is 52.5 mins. The mean total travel costs are 115 € per trip. The special feature of this scenario lies in the side run, which consists exclusively of a pre-run. Passengers arriving at the airport vertiport already reached the local transport destination and dispersed in the Hamburg Airport terminal to continue their journey via manned aviation.

The most active route connects the airport with the vertiport at the Hanseatic City Lübeck. Here, 218 passengers choose the AAM system to go to the airport. They pay 101 € per trip, which lasts 52 min, including the access stage as well as the main flight. In comparison, the same itinerary takes 97 min and costs 65 € by car. When matching the time benefit versus the cost benefit, AAM shows an above-average attractiveness on this itinerary with a 13 % market share. The second and third most active routes via the vertiports in Neumünster and Lüneburg show the same characteristics, but the lower total market size leads to less AAM demand of 69 and 25 passengers.

4.2. Understanding the total travel time

Figure 1 already shows the connection between the access stage, the main flight and the egress-stage run. When considering the travel time by car, it represents an approximately sufficient measure for the travel distance. Figure 2 shows the regression of the AAM travel time over the car travel time for each phase of the intermodal AAM transport system. The regression data only considers itineraries with at least one AAM passenger.

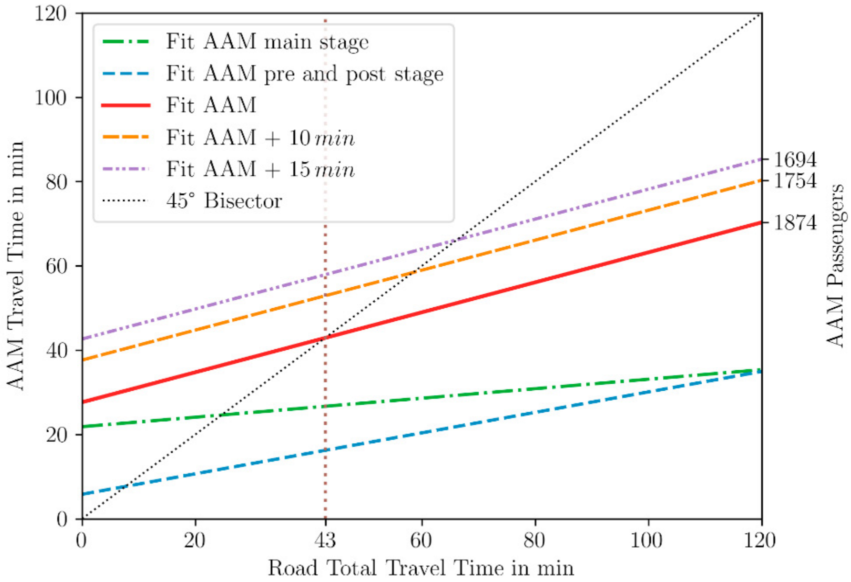

Figure 2 Travel time influence on the AAM airport market

The solid red line represents the total travel time, including the main run (green dash-dotted line) and the secondary run (blue dashed line). The main run takes longer when the flight distance increases, representatively the travel time by car. However, the narrow slope of the green dash-dotted line shows the minor influence of the travel distance on the travel time. Instead, the travel time for the secondary run increases from just a few minutes to more than 20 minutes if the equivalent itinerary lasts 2 hours by car. In the airport scenario in special, the secondary run includes pre or post stage only, since the vertiport at the Hamburg Airport is located exactly on the passenger terminal. For long-distance itineraries, AAM passengers accept secondary runs almost as long as the main flight.

With the benchmark system, the airport market reaches 1874 passengers one-way. If 10 or 15 minutes are needed additionally, the airport market is reduced to 1754 (-6.40%) or 1694 (-9.61%) passengers. Additional total travel time can be caused by waiting time at the vertiport when vertiport capacities are reached or the vehicle allocation is delayed due to an airline's business model. The black dotted line at an angle of 45° separates the figure into a bisector. Whenever an AAM itinerary is located on the right side of the angle bisector, the AAM transport mode offers a time benefit to the passenger. The regression line hits the bisector at 43 minutes of travel time by car. The calculated travel time parity sets the threshold, after which AAM reveals a travel time benefit on average. Since the airport scenario describes a centralised network, the catchment area by car can be calculated with the airport terminal as the point of centre. Figure 3 shows the isochrone for the catchment area by car within 43 minutes of travel time.

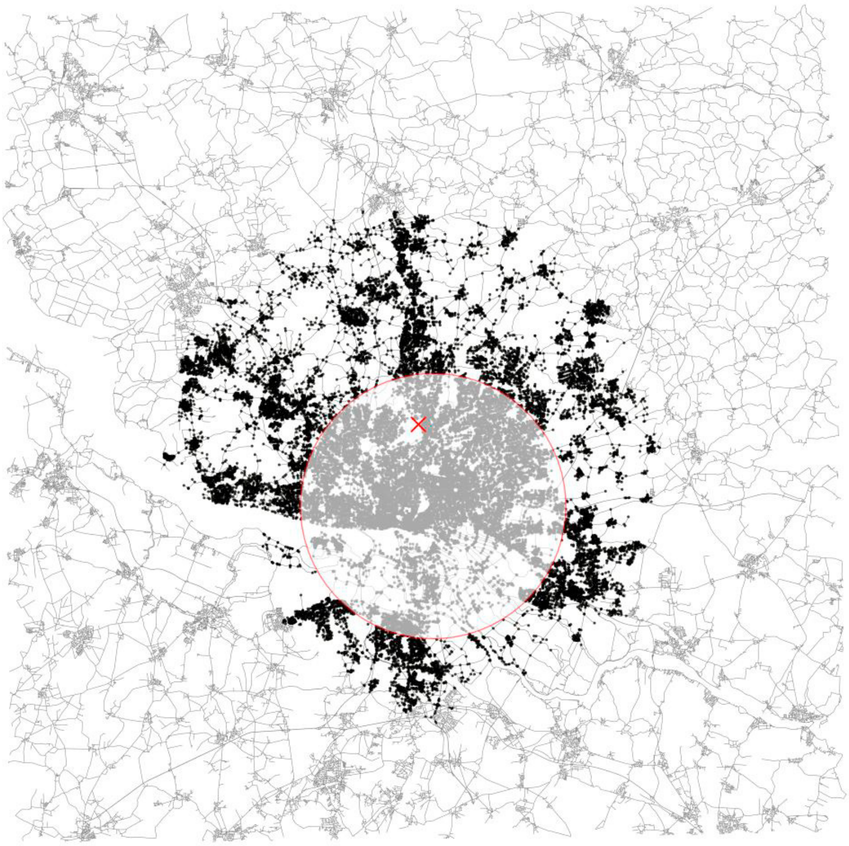

Figure 3 Catchment area by car within 43min around the Hamburg Airport

The red cross shows the vertiport at the Hamburg Airport, while the red circle roughly covers the city of Hamburg with a diameter of approx. 30 km. Areas in the south, in particular, show the limited accessibility where the river Elbe represents a natural obstacle and road traffic is restrained. Because of this, AAM reaches a time benefit earlier and can be an alternative mode for airport access to avoid congestions and gridlocks. According to Eq. (1) AAM reaches higher values for the utility function U_{ni} in comparison to road traffic.

5. Discussion and conclusion

This analysis modelled the potential AAM market for airport shuttles based on the daily passenger market size at the Hamburg Airport. Therefore, a four-step model is implemented. The trip distribution is based on the inhabitants in 1940 geo-referenced traffic analysis cells in the metropolitan area. A discrete choice model, including the total travel time and the total travel cost, divides the market for the individual trips to the different mode choices: individual car, public transport, taxi and AAM. Here, the AAM transport system consists of the pre stage, main flight and post stage. In relation to traditional transport systems, AAM will be a more expensive but time-beneficial mode of transportation. When considering passenger preferences and user scenarios as key input parameters for business models, AAM airlines can establish competitive transport services by designing their fleet assignments to match the estimated AAM demand market.

Based on an estimated one-way demand of 1,874 AAM airport passengers and an assumed 16-hour operational timeframe at Hamburg Airport, there will be a take-off or landing every 45 seconds at the Hamburg Airport vertiport, considering three passengers per AAM flight. This scenario requires adequate capacity both in the airspace surrounding the vertiport and on the ground. In the immediate vicinity of Hamburg Airport, airspace restrictions limit AAM flight operations to prevent disruptions to manned aviation. This means that AAM air traffic near the airport may experience interruptions, leading to increased total travel time. Airport passengers are characterised by a VOT of 48 €/h. The total number of 1874 AAM passengers decreases immediately if additional travel time is needed, caused by delay or operational waiting time. A delay of 10 minutes already causes a market decrease of more than 6 %. As a result, the overall AAM system has to provide enough capacity for passenger handling and transport to reach an undisrupted airflow and to keep the calculated AAM market share.

Most AAM passengers travel via the vertiports in Lübeck, Neumünster and Lüneburg, which are located around 50 km around the Hamburg Airport. Travel time by car going from those vertiports takes longer than the calculated time parity. Those itineraries are expected to have a time benefit when travelling by AAM. As long as the airflow due to AAM capacities can be guaranteed, AAM offers an alternative for on-time travelling to the Hamburg Airport while avoiding road congestion. However, the AAM market is calculated to be a niche, so no road traffic relief is expected.

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Appendix

Location	Longitude	Latitude	Location	Longitude	Latitude
Luebeck	10,67732	53,86622	HAM, outside	10,00792	53,63414
Neumuenster	9,98154	54,07574	HAM, inside	9,99819	53,62291
Itzhoe	9,51104	53,92409	Harburg	9,98818	53,45589
Elmshorn	9,65921	53,75469	Finkenwerder	9,84735	53,53656
Norderstedt	9,99246	53,70729	Elbe Philharmonic Hall	9,98589	53,54118
Ahrensburg	10,23921	53,67078	Winterhude	10,02090	53,58359
Geesthacht	10,36817	53,43748	Main Train Station	10,00503	53,55401
Seevetal	10,03481	53,37741	Millerntor-Stadium	9,96962	53,55262
Buchholz	9,87259	53,32416	Volksparkstadium	9,90407	53,58672
Lueneburg	10,41607	53,24787	Wilhelmsburg	9,98511	53,50398
Uelzen	10,55381	52,96757	Hamburger Meile	10,02864	53,57214
Soltau	9,83775	52,98714	Altona Cruise Center	9,94354	53,54366
Rotenburg	9,39613	53,10941	Bergedorf	10,20419	53,48943
Buxtehude	9,69016	53,47055	Blankenese	9,81383	53,56355
Stade	9,47803	53,59730	Eppendorf	9,97773	53,58960
Bad Oldesloe	10,37798	53,80689	Rahlstedt	10,15320	53,60474
Schneverdingen	9,78744	53,11878	Schnelsen	9,90650	53,63376
Neugraben	9,85773	53,47666	Wohldorf-Ohlstedt	10,13738	53,69481
Moelln	10,68418	53,62526	Congress Hall	9,97620	53,56214
Bremervoerde	9,14310	53,48254	Wandsbek	10,06693	53,57173
Wedel	9,71375	53,58238	Alstertal	10,09402	53,65489
Lauenburg	10,54798	53,37408			