URBAN AIR MOBILITY 2030+: PATHWAYS FOR UAM – A SCENARIO-BASED ANALYSIS

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Abstract

In current discussions, Urban Air Mobility (UAM) is often mentioned as a promising future means of transport, reducing journey times by avoiding traffic jams on roads and cumbersome journeys on public transport. The paper at hand provides insights into possible pathways for UAM until 2030 and after, using a scenario-based approach. Therefore, three different scenarios for the UAM market development will be presented. We thus want to contribute to a more open discussion of opportunities and challenges for UAM by depicting the possible range of future developments of that new transport system.

The scenario methodology used enables us to develop consistent pictures of the future while incorporating the uncertainty of related important factors. We thereby consider a variety of environment factors influencing the development of UAM, ranging from economics and politics to societal factors such as acceptance, but also to infrastructural and technological aspects such as powertrain development. Analyzing the system's environment and the uncertainty as well as impacts of each identified factor helped to determine consistent developments that led to the definition of scenario frameworks. The resulting three scenarios will be described in detail, followed by a comparison of key scenario factors. The method used for developing the three scenarios shows possible system set-ups rather than the probability of each scenario. The identified scenarios represent a range of outcomes, from prosperous to rather challenging scenarios for the development of UAM. Implications for business and operating models, respective key customer groups, resulting transport chains as well as cost and revenue structures are drawn. Thereby, different business models evolve, all having distinct customers and using specific vehicles according to their requirements. The resulting key requirements for UAM vehicles as well as ground infrastructure on a scenario-specific basis are being developed. With our contribution we aim to lay a basis for a critical examination of postulated UAM business cases. Deeper insights into different elements of these operating models help us to identify possible show stoppers and extract promising ideas from vague expectations. The impact of the COVID-19 crisis on UAM development was not in the scope of this project. As an outlook, however, we address effects of the ongoing crisis on core scenario factors of the UAM scenarios and show uncertainties connected to this situation.

Keywords

Urban Air Mobility, Scenario Analysis, Future Mobility Concepts

ABBREVIATIONS

ATM	Air Traffic Management
EASA	European Union Aviation Safety Agency
eVTOL	electrical Vertical Take-Off and Landing
FAA	Federal Aviation Administration
KPI	Key Performance Indicator
NOx	Nitrogen Oxygen
OEM	Original Equipment Manufacturer
RAHS	Risk Assessment and Horizon Scanning
UAM	Urban Air Mobility
UTM	Unmanned Traffic Management

1. MOTIVATION AND INTRODUCTION

Since 2007, more than half of the world's population has been living in cities, and according to the U.N. that share is projected to rise to 60 per cent by 2030 [1]. This significant urban population growth is expected to create a real need for innovative mobility options as ground infrastructure becomes increasingly congested. Urban Air Mobility (UAM) can be defined as passenger transportation in the proximity of urban settlements using highly automated or fully autonomous passenger drones and is seen as option

to provide people with a safe, sustainable and convenient solution that leverages the airspace above cities.
The idea of aviation in urban mobility is not new. E.g. helicopter taxis are available for years in mega cities like São Paulo, Mexico City, New York City or Tokyo, see e.g. [2-4]. However, fast air connections are still associated with high costs and sound levels as well as high energy consumption. The vision of UAM is providing a safe and efficient air transportation system where everything from small package delivery drones to passenger-carrying air taxis operate above populated areas.
To make UAM a safe and viable passenger transport option several challenges need to be solved [5]. The engagement of the UAM industry stakeholder with people, cities, regulators and other third parties is crucial in order to architect all elements of the UAM eco-system. The overall ecosystem can be broken down into five major building blocks: the eVTOL vehicle and services related to the operation of the vehicle, e.g. maintenance, training, connected services. Further blocks are fleet operations, the required air traffic management system, the integration into the city infrastructure, as well as the operation within an intermodal transport network which includes the entire passenger journey [5].
E. g. Airbus has created a dedicated business division covering all elements of the UAM eco system. A key responsibility for the new organization is understanding how UAM can introduce an additional mobility solution to a city's existing network for the benefit of its citizens [6]. By gathering urban flow data from cities like Paris or Beijing and using advanced modelling software, designers, urban architects and sociologists try to simulate and understand how people move around to develop sustainable urban development strategies.
Different players, from startups to well established aerospace companies, are exploring these new markets with demonstrator projects and simulating the different building blocks of the UAM ecosystem. However, the uncertainty of how the UAM business will develop in the future is still high. Hence the scenario study will try to answer some of the following questions:

- How will UAM applications evolve in the next 10 – 15 years?
- Will UAM develop as a main transport system or stay in a niche?
- What kind of business and operational models could be successful?
- What are the infrastructure requirements and who will secure investments?
- What are successful overall vehicle concepts and cabin interior requirements?

2. SCENARIO ANALYSIS PROCESS

In the following section, the scenario process as applied in the study at hand is presented. The process follows the methodology in the form described by Will et al. [7] and was applied in this form by Michelmann et al. [8]. The basic process, however, was developed in cooperation works of the Technical University of Munich and Airbus during the last two decades and proven by several cases, e.g. in [9-13].
The general process as depicted in Fig. 1 was applied to our research question. The process starts with the definition of the problem which has to be investigated. This was already described in Section 1 of this paper. Furthermore, the general setup of the scenario process has to be defined. The current scenario project was conducted as a cooperation between the Institute of Aircraft Design and the Transport Systems Engineering chair, both Technical University of Munich, as well as Airbus, Bauhaus Luftfahrt e.V. and Munich Airport. Goal of the scenario process is to derive three consistent scenarios, describing as wide of a range as possible plausible developments of UAM, as illustrated by the scenario cone in Fig. 1.

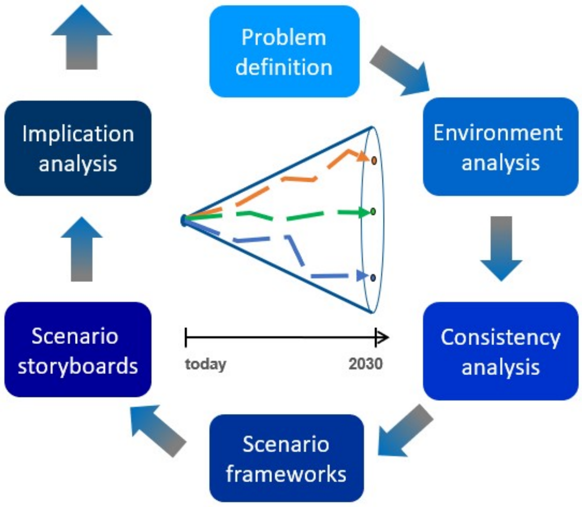

FIGURE 1: General scenario process, from Will et al. [7]

After the scope of the investigation was defined, environment factors were derived from an environment analysis. These factors should cover all aspects having an influence on the future development of that system. In order to reduce the complexity, the focus of the analysis is concentrated on the most important factors, the so-called core scenario factors, identified in an uncertainty-impact analysis. These core scenario factors are described in Section 3.1. Furthermore, projections for possible future developments of the factors are developed. With this information, a consistency analysis was performed. The goal of that step was to identify relations between the occurrences of distinct projections of the core scenario factors. This information is required for generating consistent scenario frameworks based on the core scenario factors. Towards that goal, the Risk Assessment and Horizon Scanning Tool (RAHS) [14] of the German armed forces was utilized. The tool is able to cluster the high amount of resulting scenarios, helping to find those scenarios with the highest values of overall consistency. Three scenarios are used for further investigation towards the expression of all environment factors as well as the implications described in Section 4. These scenarios are classified by A, B and C and shown in more detail in Section 3.3. While Scenario A presents a prosperous outlook on the development of UAM as a complimentary mean of public transport, Scenario C covers a more pessimistic view with UAM only serving niche markets and having a low market significance. Scenario B lies in between these outviews featuring UAM shuttle services run by airlines. In a final step, implications of these different scenario setups regarding key aspects of prevailing business models as well as requirements for vehicles, route networks and infrastructural elements are derived. These are presented in Section 4.

3. SCENARIOS FOR URBAN AIR MOBILITY 2030+

This section presents the scenarios developed within the study at hand. It begins with the core scenario factors derived from the environment analysis. Then follows a general comparison of scenarios before describing the respective scenarios in detail.

3.1. Environment Factors

Following the Uncertainty-Impact Analysis, several factors were selected as core scenario factors for the further analysis and then divided under six main categories, namely: 1) economic, 2) political, 3) regulatory, 4) technological, 5) societal and passenger-related, and 6) infrastructure-related (vertiports). These factors often follow possible constraints to UAM operations [5]. The first category considered global economic development, political support, investments (public or private), and regulatory aspects such as airspace accessibility, ATM (Air Traffic Management) integration, and certification frameworks. Technological factors assessed the progress in power train options, automation levels, but also cyber-security threats. Societal factors focused on the safety levels of UAM systems, passengers' acceptance in relation to commercial aviation, non-safety related public acceptance, and finally transport prices. Finally, infrastructure considerations parameters reflected vertiport infrastructure standardization, but also infrastructure network density. The above-mentioned factors are presented in Table 1 below.
The three scenarios are built upon different, distinct developments of these factors.

3.2. General Comparison of the Scenarios

In the following, the three selected scenarios which were generated using the abovementioned core scenario factors are described. Besides high values for plausibility, the scenarios were chosen in order to reflect a wide range of different developments. Accordingly, Scenario A reflects a positive development with regards to UAM in all factors.
Amongst others, the fulfillment of expectations made by UAM manufacturers in the past plays a key role here: The fast technical development in Scenario A leads to a widespread introduction of UAM services which are affordable for all people for frequent use. This in turn leads to high public acceptances and political support, which eases the installment of a dense infrastructure and a fast introduction of new regulations enabling such operations. The wide range of use cases gives operators equally diverse business opportunities.
In contrast, Scenario C shows a rather limited picture for most core scenario factors. A slow technical development limits the operational usability of UAM to niche markets with ticket prices not affordable to most people. The high expectations built up by UAM Original Equipment Manufacturers (OEM) beforehand cannot be fulfilled. From this follows low public and political support as well as slow development of regulations and an own infrastructure. UAM is still introduced by manufacturers in order to be able to further develop the technology.

TABLE 1: Core scenario factors.

Factor type	Factor selected
Economic	• Global economic development • Profitability of business models • Investments (public or private)
Political	• Political support
Regulatory	• Airspace accessibility • ATM integration → Unmanned Traffic Management (UTM) • Certification frameworks
Technological	• Progress of powertrain options • Threat development → cyber security • Degree of automation
Societal and passenger-related	• Safety levels of UAM (vehicle and system) • Safety acceptance of commercial aviation • Transport price → Adoption
Infrastructure-related	• Standardization of vertiport • Network density and intermodality

Scenario B lies between the other two scenarios, tending to have a rather positive outlook for most core scenario factors. The scenario rather describes a slow development of different business cases for the main operator, airlines. These are expected to be possible starting operators due to their expertise in aviation processes. Therefore, Scenario B might reflect a description of the start of UAM operations. Although not all expectations might be fulfilled, politics and the public still see sufficient progress in the development of UAM to further support its implementation. Public acceptance is also attributed to ticket costs in a range so that most people can afford to use UAM at least infrequently.

3.3. Scenario Storyboards

The following section presents the storyboards of the three scenarios as seen from the point of view of the year 2030, highlighting the distinct development of the different environment factors.

3.3.1. Scenario A: "Urban Air Mobility as a Service"

Within Scenario A, Urban Air Mobility develops under an optimistic technological and economic outlook together with political support worldwide. Thanks to strong global economic growth and continuous

political stability, the average living standard is rising and people are travelling more. Over the years, ground transport transferred worldwide to a seamless, intermodal door-to-door transport system. This concept of “Mobility as a Service” integrates now different modes of public transport to comply with the need for a personalized door-to-door travel experience.
The strong technological progress leads to an availability of significantly enhanced battery systems with very high capacities. The batteries now can be recharged quickly and offer energy densities that are several times higher than in year 2019. Over the years, the UAM industry transformed from demonstrator levels to technologically matured eVTOL vehicles meeting aviation’s autonomy and safety requirements with a high level of automation. Enabled by ultra-fast 7G wireless network and blockchain technology, UAM efficiently uses the airspace and its autonomous operations is organized via local ATM providers. Global manufacturers are working together worldwide with regional branches of governmental bodies as well as certification authorities such as the FAA and EASA which develop required standards.
Urban Air Mobility can thus be implemented profitably by keeping travel costs low. Short travel times, seamless intermodal transport and flexible UAM services are established. Urban Air Mobility has become an integrated part of the urban transport system and is highly accepted regarding safety and environment aspects within the general public. UAM services are offered on-demand as well as scheduled. The UAM concept has been developed into a mass market and UAM’s daily usage has become possible to a broad public in the USA, Europe, the Middle East and China. Public acceptance regarding sustainability as well as visual and sound nuisance contributes to the rapid integration of UAM.
Strong synergies between the government and private investors lead to optimal operational conditions and subsidies for infrastructure. The willingness to invest paves the way for high private investments in UAM. National governments do not only support the construction of the vertiport infrastructure, but also commission it.

3.3.2. Scenario B: “Airline Business Expansion through Urban Air Mobility”

Under Scenario B, Urban Air Mobility develops within rather favorable conditions including stable economic growth in all industrial sectors, political stability, and therefore political support for UAM. This leads to an increase in investment, promoting research and development for UAM. Certification processes are facilitated in regions where a strong political support is given to this new mode, such as in the Middle East or other fast-growing metropolitan regions. Private (manufacturer) investments for new vehicle concepts result in faster technological advancements in powertrain technologies as well as avionic systems, secure from any cyber-security threats.
Progress in research leads to more efficient vehicle concepts based on hybrid powertrains, combining batteries with turbine powered generators, to overcome the lift, weight and range limits due to still low battery capacities. This would then reduce the aircraft weight and enhance the flight ranges compared to fully electric eVTOL. The proposed technology also promises low emissions due to the use of sustainable fuels, making it more competitive with solutions featuring fuel cell or hydrogen combustion technologies.
The developed concepts prove to be safe and reliable, similar to commercial airline standards, further facilitating certification processes and granting complete airspace access. Despite reaching full automation level, i.e. UAM vehicles can fly without a pilot, an operator is still on-board for guidance and supervision, ground operations, check-in and boarding and to meet safety regulations. The presence of the operator also contributes to the feeling of safety by passengers.
Staffing costs are reduced in case of high degrees of automatization for vertiport operations. Commercial airlines are encouraged to enter the UAM market, benefiting from their expertise in the aviation industry, and becoming the main UAM operators. Their know-how in aircraft maintenance and operation, particularly in handling turbine engines, gives them an advantage, as UAM vehicles employ technologies similar to those in transport aircraft. As airlines can optimize their costs by applying their well-established operational concepts (high aircraft utilization, fees for additional services, staff reduction – vehicle operator performs all ground duties), UAM is not only profitable, but also affordable for passengers. Airlines can thereby expand their business and acquire new customer segments. As a start they are expected to establish airport shuttle services on an on-demand basis. However, the business might be expanded as further described in Section 4.3. The key performance indicators (KPI) for airport shuttle services are low travel times and a seamless journey enabling the traveler to use the commuting time to the airport e.g. for work. Towards these KPI, a better offer has to be made by UAM in comparison to existing means of transport in order to successfully establish UAM services.
Suitable infrastructure development is promoted as additional investors from big energy and electrical supply companies (such as BP, RWE and Euro Grid) are encouraged to build vertiport stations with charging and refueling facilities, standardized to comply with the manufacturers’ requirements. Stations are mostly located on top of petrol stations, on top of buildings, or on the ground as standard heliports, to meet with the requirements; vertiports’ operation is not automated and an operator is needed on the ground. Energy providers thereby open new fields of business with low investments. This paves the way for a good vertiport network, supported by UAM-operating airlines and local authorities. To further ensure accessibility to vertiports, shuttles are set up to increase access and egress to and from the respective vertiports. Moreover, as energy companies tighten their bonds with UAM operators, investments are promoted in the area of sustainable fuels, allowing for the above-mentioned emission reductions. The successful implementation of an efficient network layout allows UAM-tariffs to be in the range of taxi prices, leading to a customer base bigger than just a niche clientele.
Overall, the economic growth, investments, and research are conditions favourable for the growth of UAM. The development of hybrid vehicles leads to airline networks to extend their networks, and provide connecting services to smaller towns in the area of larger metropolitan areas, improving thereby their accessibility and increasing their visibility.

3.3.3. Scenario C: “The Challenges of UAM”

The final scenario describes UAM as a niche solution for only few specialized transport tasks. It could, therefore, be regarded as a technologically advanced evolutionary development of today’s helicopter markets. Main limitations for a further development of UAM arise from insufficient technological progress, especially in the field of battery technology. Due to the high investments necessary, the UAM sector is dependent on battery developments from the automotive sector, which might reach its preliminary development goal at energy densities only sufficient for very short range, low payload UAM applications. Few UAM OEM experiment with hybrid propulsion technologies, however leading to high operating costs and low environmental acceptance.

After initially strong advertisement, disappointment develops about not meeting expectations for an affordable, high capacity alternative transportation mode and investments in the field from public as well as private side almost come to a stop. Likewise, due to the slow development and missed expectations political support for UAM decreases. This development slows down processes for general introduction of UAM services, such as certification processes on vehicle level as well as regarding airspace access for the respective vehicles. Without the necessary funding, additional cost intensive technological developments cannot be accomplished in time, especially in the fields of automated flying and high precision navigation. This, in turn, has negative influence on the airspace integration of UAM, making missions in the vicinity of airports as well as over highly populated areas in big number hardly possible. Part of the political disinterest is attributed to an in general difficult political situation. A downturn in economic growth leads to a shift in fields receiving governmental support and to a general decline in public investments. This results in investments being concentrated on low-risk ventures. It might, therefore, be expected that the UAM OEM sector sees massive consolidation with only few companies remaining (probably backed by bigger aviation related enterprises). UAM OEM being subsidiaries of bigger aircraft OEM as well as such OEM with military background might have advantages due to higher financial resilience. These OEM might seek to develop UAM vehicles as part of a technical maturation program.

In accordingly economically difficult times most people cannot afford to travel with a means of transport with prices much higher than for taxi rides. In connection with the economic insignificance of limited UAM services, people do not see any added value by UAM. Indeed, mostly negative aspects are usually perceived in connection with UAM. Examples are privacy aspects as well as sound. That these might be factors even in the consideration of very low frequency transport is evidenced for example by protests against rescue helicopter operations, e.g. in Munich [15], even concerning transport missions with wide societal benefit. All this finally leads to a very low public and consequently low political acceptance of UAM, at least on a local level. In order to get the necessary acceptance towards the system’s safety from customers as well as the general public, safety levels at least as good as in commercial aviation are required for operations above densely populated areas.

Very limited applications and low standardization following from missing regulatory acceptable means of compliance lead to specialized niche solutions for UAM. OEM take responsibility for both, manufacturing and operation of the vehicles. By offering tailor-made services to their customers, OEM try to slowly develop their business and product range. Transport fees for UAM services will be very high in a range of about 5-18 €/km, just below today’s helicopter services. This is a consequence of high investments in vehicle and infrastructure development as well as the according operational costs with very low transport demand and frequencies flown at the same time. An example for that is the vertiport infrastructure, with most vertiports requiring cost intensive charging equipment due to low network densities. The operational costs also include costs for pilots due to the slow technological development towards automated flight.

As mentioned above, UAM operations will mainly be limited to the amount of helicopter operations today. The route network will mainly be focussed on existing heliports due to high investment costs for new vertiports. Possible applications are on demand services for business and premium travellers who want to avoid traffic jams and long journey times in big cities. Longer range flights will not be possible due to technical limitations. Flights might also include rare and infrequent shuttle services to airports at off-peak times as far as conventional flight movements at airports are not impaired. Limited ambulance transports are used to increase public acceptance. Enhanced operations take place at few locations as showcase projects for technology companies or to promote broader techno-political visions of local political leaders. These limited operations might, however, well serve as a preparation for later market uptake in case of improvement of the general political and economic situation as well as of necessary technology.

4. SCENARIO-SPECIFIC IMPLICATIONS FOR UAM BUSINESS MODELS

The scenarios as described above yield various implications. In the following, we will depict implications regarding the business models in the form of as key customer groups and cost structures. Furthermore, resulting networks as well as vehicle and infrastructure requirements are developed.

4.1. Key Customer Groups

The three scenarios build on totally different business models, including different key customers as well as varying approaches with regards to value chain, value proposition and revenue streams.

While Scenario A aims at answering demand from the premium sector as well as from the mass market, by targeting commuters, families, people with reduced mobility and also business travellers, from low to high income, the UAM provider in Scenario B already aims at a smaller market. Focusing on business and leisure travellers, as well as tourists from higher income groups the service offer rather targets a smaller premium market. The service in Scenario C targets only a niche for high-income travellers that value an exclusive and fully personalized service. Figure 2 visualizes the different key customer groups and shows a differentiation between trip purposes (business and leisure) on the y-axis and premium and mass market in the x-axis. Scenario A covers all of the mass market and reaches into the premium segment for both trip purposes. Scenario B includes parts of both trip purposes but has a strong focus on the premium market. Scenario C only covers the premium market and only targets small parts of the business and leisure trips. The size of the respective boxes can be seen as a proxy for the size of the target group and hence overall market potential.

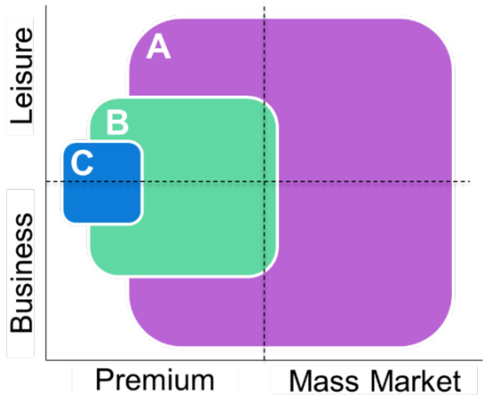

FIGURE 2: Schematic illustration of customer segmentation for the different scenarios

These differences in customer segments also reflect the key values that the services promise to deliver over the three scenarios. While luxury and comfort as well as brand values and travel time savings are the core of the UAM provider's offer in Scenario C, Scenario B already has a broader scope that focuses on high connectivity and comfortable traveling through single ticketing options. Offering a flight experience rather than only a transport service the service provider has a unique selling proposition. In Scenario A the key value is to offer a zero tail-pipe emission integrated urban mobility option that is time-efficient and cheap.

Along these lines the key activities and key partners of the UAM service provider for each of the scenarios also differ. As visualized in Figure 3, the service provider in Scenario A engages in a significantly smaller part of the value chain than this is the case in Scenario B and C. While the provider in scenario A only is active in the operation of the booking platform

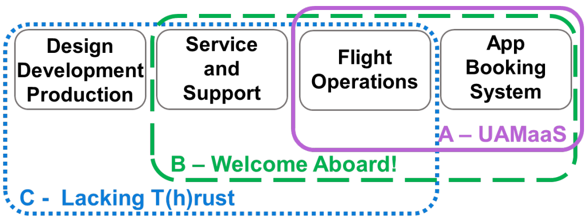

FIGURE 3: Core competences of UAM Mobility Provider for the different scenarios

and flight operation, the provider in Scenario B additionally engages in service and support (maintenance, repair and overhaul). In Scenario C the service is operated by the vehicle manufacturer, meaning that additionally vehicle development and production is part of the provider's key activities. In all scenarios the infrastructure is operated by an external company, which of course is one of the key partners. The other key partners differ according to the UAM service provider's own core activities. In Scenario A key partners are: ATM providers, leasing companies and public transport providers. In Scenario B partnerships with manufacturers, airports, energy suppliers and national aviation authorities are of interest. While in Scenario C good relationships to ground handling partners and last mile transport service providers are maintained.

The scenarios give first indications for possible business models. Yet, a full discussion of business models and their direct implications is out of scope of this paper. The interested reader is referred to [16] for a more detailed discussion.

4.2. Cost Structure

The three different scenarios impact not only the overall costs of UAM transport services but also the main cost drivers and their shares (see Fig. 4). In the scenario process, all possible direct operating costs were summarized in four different cost elements: 1) crew costs, 2) handling, landing & ATM costs, 3) capital costs and 4) energy costs. Crew costs cover all personnel costs for the pilots. Handling, landing & ATM costs cover costs for processes and infrastructure at the vertiport (handling & landing) and for provision of air traffic management (ATM). Capital cost includes all elements for owning or leasing and insuring the UAM vehicle. Energy costs cover all costs associated with energy supply and consumption.

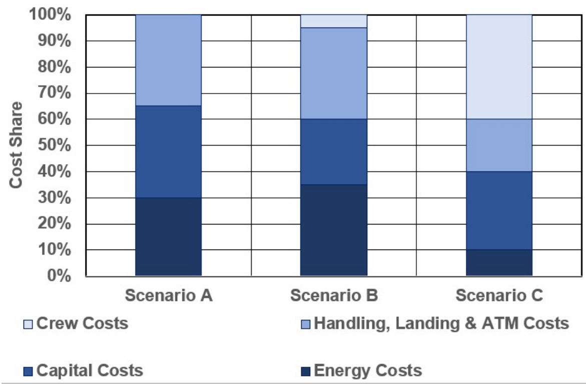

FIGURE 4: Share of crew, handling, landing ATM, capital and energy costs a spart of direct operating costs for UAM scenarios A-C

For scenario A, a high automation of the vehicle leads to neglectable personnel costs. Instead, a very high degree of automation at the vertiports, of the vehicles and costs of batteries plays a major role. Therefore, handling, landing & ATM costs as well as capital costs have the highest share. The high performance of batteries allows an energy-efficient UAM vehicle design with a lower energy consumption. All these developments lead to very low operating costs for UAM compared to helicopter services in 2019 attracting now a large share of daily commuters.

For scenario B, although UAM vehicles are able to fly completely autonomous, an operator is still on-board for guidance and supervision, ground operations, check-in and boarding in order to meet on-board safety regulations. Hence, crew costs can be significantly lowered compared to scenario C and even compared to today's helicopter services. The hybrid

system offers an operating range advantage but also increases complexity and costs for handling and operating the vehicle. Energy costs have a higher share as artificially produced sustainable fuels comes at higher production costs compared to electricity. Therefore, significant cost reduction efforts compared to helicopter services in 2019 could be achieved. UAM is still a more expensive mode of transport attracting business travelers, tourists or leisure passengers with non-regular trips.
For scenario C, limited automation at vehicle level leads to a significant high share of crew costs. Missing automation at air space and vertiport level leads to relevant cost shares for handling, landing and ATM costs. The limited battery performance results in higher battery depreciation costs. As market shares are very low, economy of scale for research, development and production of the UAM vehicles cannot be reached. Both aspects result in significant high shares of capital costs for scenario C.
Therefore, only a limited reduction in overall transport costs could be achieved compared to conventional helicopter services in 2019.

4.3. Transport chain and network

Scenario A sees a wide utilization of UAM integrated into public transport systems. They operate not in competition to but complement other means of public transport through high levels of intermodality. Consequently, most customers arrive at vertiports by other means of public transport. Users can find the fastest combination of transports via an app booking system. To reach high levels of intermodality, vertiports need to be placed at places reachable by bike and by foot as well as by other means of public transports such as busses, tramways and subways. Long distances between these different modes of transport would mean a loss in travel time, meaning the loss of the advantages of UAM. Therefore, vertiports are located at mobility hubs central in urban settlements and neighborhoods. This is encouraged by the high acceptance in the public living around vertiports, as described in Section 3.3.1.
Routes flown by UAM in this scenario are illustrated in Fig. 5. They usually cover long distances inside large cities with a focus on tangential routes in order not to surpass infrastructural capacities in the city center. Furthermore, connections to smaller towns and suburbs in the city's vicinity are targeted. The latter makes these small towns and villages, formerly barely connected to urban centers, interesting new living

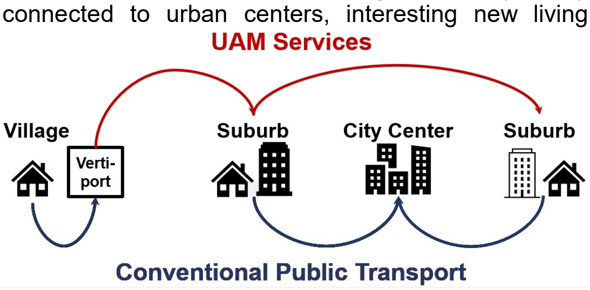

FIGURE 5: Exemplary UAM and conventional public transport travel chains, Scenario A

places for people who work in the citiesbut accept short commuting times in order to live at quiet places near to the nature with faster accessibility to recreational areas.
With airlines operating the UAM system, first services flown within scenario B are those between airports and city centers in certain towns which want to utilize these services also as promotion for their own projects. Afterwards, services are first extended to more airports worldwide. A major business field becomes the connection of secondary cities and smaller towns to the airport which formerly were only connected by individual transport or by transfer connections via the city the airport is primarily serving. Problems are arising in the airport access of these concepts. While many sources describe the advantages of UAM airport shuttles assuming a direct connection between the city center and the airport terminal (see e.g. [17], [18]), it is probable that terminals can only be reached by frequent UAM services if these do not cross runways and the respective approach path for conventional aircraft. The latter requirement is based on the goal not to impair traffic at potentially capacity constrained airports and is applicable even if comprehensive airspace access is granted for UAM. These observations lead to a high influence of airport layouts on possibilities for UAM systems [16]. If terminals are not directly reachable, alternative airport access vertiports are built near airports and connected to the terminal by public transport (e.g. fast airport access trains) or by individual transport services (taxis) as illustrated by Fig 6.
Emphasis has to be taken that these transfers between different means of transport are achieved fast and seamless in order not to impair the main KPI defined in Section 3.3.2. Still, such restrictions exclude many connections with good access at least for individual transport. Therefore, at many airports the improvement of connections to smaller towns at higher distance are in the focus of UAM operations. Experience gained thereby enables airlines to open further connections for smaller communities to larger cities and hereby improve the attractiveness of rural areas for commuters.
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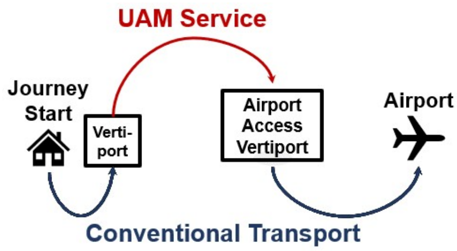

FIGURE 6: Travel chain for UAM airport shuttle including airport access vertiport

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In neither case UAM is seen as a first mile transport. Even more, the means how to reach UAM services as well as the accessibility of vertiports is crucial for bringing the advantages of UAM regarding a reduction in travel time into play [19].
The limited use and small customer base of UAM in

scenario C leads to a low density vertiport network. Vertiports are only located on the grounds of partner companies utilizing UAM for example for executives commuting between different company sites. Other applications such as luxury shuttles or air ambulance services, utilize existing heliports. The abovementioned company shuttles might thereby be an enabler for further business opportunities [16]. If transport to the vertiport is required, passengers mostly use means of individual transport such as taxis or limousines.

4.4. Vehicle and Infrastructure Requirements

The three scenarios as described above lead to different specific requirements towards the vehicle operational parameters as well as towards the equipment for infrastructural elements. In the following we will depict such requirements in the form of vehicle speeds and ranges on the one hand. On the other hand, required recharging / refuelling infrastructure and its density in the vertiport network are elaborated.

To begin with, we will derive vehicle requirements for the three scenarios. In Scenario A, a wide range of destinations and route lengths is served by UAM. For the sake of simplification, we assume that two different range classes exist. The first one covers intra-city flights in the range of about 10 km – 50 km, mainly the abovementioned tangential routes as well as the connection of outer suburbs with transport hubs nearer to the centre. Flights into the city centre are comparably rare. Vehicles on these routes do not require high cruise speeds. Therefore, flight speeds in the order of 80 km/h are sufficient, while more emphasis is taken on configurations with minimum sound signatures for overflying densely populated areas at low altitudes of a few hundred meters. Possible vehicle designs include multicopter configurations. The second group of routes covers regional flights with higher distances in the range 50 km to a few hundred kilometres. These include the connection of small towns with the city and touristic leisure flights to nearby sights of interest. For such distances, higher flight speeds in a range of up to 200 km/h are required, while sound aspects play a smaller role due to the overflight of less densely populated areas at higher altitudes of up to one kilometre. Possible vehicles feature a fixed-wing configuration, including for example tilt-wing configurations [20].

The majority of flights in Scenario B covers a range in the transition zone between both cases described for Scenario A. This implies a range in the order of 25 km – 50 km. Due to the competition from other means of transport on the main market of airport connections as well as the potential necessity of additional changes of transport (see Fig. 6), high flight speeds of about 150 km/h are required. Again, fixed-wing configurations are likely to be chosen. The same counts for Scenario C with main mission ranges between 25 km and 100 km. Missions in the upper part of this range have to be flown with the help of hybrid powertrains. Possible configurations include e.g. lift and cruise concepts.

The resulting vehicle requirements are summarized for speeds and ranges in Fig. 7.

In the second part of this section we derive some primary requirements for vertiports. One of the main prerequisites of a functioning vertiport in Scenarios A and B are minimized vertiport access and process times. Besides the vertiport positions as described in the previous section, this requires a high level of automation. This does not only count for passenger processes but as well for processes regarding the vehicle operation. A high frequency of flights over a small area in airspace not accessible for widespread operations necessitates new levels of automated flight, new ATM procedures and new regulations. Niche operations, as in Scenario C, do not require the same amount of automation. Processes as known from helicopter operations can be adopted.

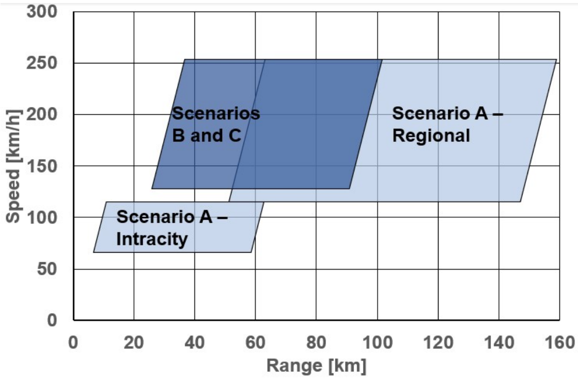

FIGURE 7: Vehicle speed and range requirements for the three scenarios

Another important aspect of vertiports is the infrastructure needed for reloading or refuelling of the vehicles. Scenarios A and B require a completely new infrastructure for a fast recharging of vehicle batteries. Especially in the hybrid Scenario B, further refuelling stations are necessary due to the use of hybrid concepts. This makes vertiports in the vicinity of gas stations an attractive option. When utilized on short range flights in the near vicinity of cities not all vertiports need to have recharging/refuelling options because vehicles can accomplish several flight missions in a row. This stands in contrasts to vertiports in outer or in general not dense portions of the network, including the whole network of Scenario C. The destinations of flights from these points are often far, so that only one mission might be possible before recharging is required.

5. CONCLUSION

Besides general conclusions in the first part of this section, we give a first outlook on possible impacts of the COVID-19 crisis on the core scenario factors as described in Section 3.1.

5.1. General Conclusions

The paper at hand describes three different scenarios for the development of Urban Air Mobility. We thereby aim to depict the range of possible as well as plausible developments going beyond advertising promises of manufacturers. Furthermore, the scenario storyboards and implications gave indications on exemplary systems apart from the business model and processes directly associated with the operation of UAM systems, which need to be thoroughly addressed for a successful implementation of UAM. Examples for that are network and flight scheduling aspects. This counts especially if scheduled as well as on-demand services need to be considered, like in Scenario A. Special attention should be put on the integratability of the envisioned services into the air space as well. This comprises operations at low altitudes over inhabited areas, operations of high numbers of (autonomous) vehicles in small air space volumes and operations near airports. Only considering such secondary aspects in business planning will result in valid concepts for UAM.

Further infrastructural elements are as well often not considered in detail by literature so far. An example are requirements towards the vehicle's maintenance such as the required network density of maintenance shops. It might be expected, that for example in Scenario C most vertiports should be equipped with maintenance equipment due to generally low network densities. Especially fields like network development, operational planning or maintenance and vehicle route planning should undergo further future research. First hints can, for example, be derived from the works of Kohlman and Patterson [21] for different aspects of operational modelling of UAM as well as from Sieb [22] for issues regarding the maintenance of UAM vehicles.

The results of this study, however, show that if a comprehensive view on UAM is developed, promising concepts might evolve. Towards that goal, existing concepts should further be critically evaluated in future research work. The scenarios presented in this study should support this analysis with first hints about general opportunities and hurdles for UAM.

5.2. Outlook – Possible Impacts of COVID-19

The current crisis around the COVID-19 pandemic will undoubtedly have a strong influence on the development of UAM in the short- and mid-term. Work on this study was conducted before the outbreak of that crisis. Therefore, no reference to that topic was given so far. As of the time of writing of the paper at hand, the crisis' impacts were unforeseeable at most. Still, we want to give a first outlook on possible effects on the core scenario factors presented in Section 3.1.

On a global scale, a significant downturn in economic development is to be expected. Although a fast recovery is plausible in the mid-term, key economic figures are probable to only recover to the pre-crisis level in the time-frame covered by this study. As a consequence, public as well as private investments in UAM become sparse since investors concentrate on recovering their existing core businesses and refrain from risk investments. Companies are furthermore reducing their research budgets for technologies as well as investments outside their core businesses. Airlines and manufacturers have to cut investments, namely in research and development, and have to find new employment schemes or to lay off staff [23, 24].

Political support might be concentrated rather on new technologies for mass transports supporting the Green Deal instead of new means of individual transport. Together with manufacturers, focus will be put on the "protection of key technologies" [25]. First indicators for this can be seen in the political support for Airbus by the French government targeting stronger development efforts towards significant emission reductions in commercial air transport [25]. Efforts of the German government towards the support of hydrogen-powered technologies follows a similar direction [26].

However, it cannot be ruled out that these efforts lead to an accelerated development of technologies, especially in the propulsion sector, required for competitive UAM systems. It is also possible that vehicles which can be further developed for the use in UAM serve as technology demonstrators for new technologies to be implemented in conventional aviation.

When it comes to societal factors, there might be an increase of critical views on UAM especially towards systems which only allow for limited use in the high-price segment and which do not fulfil expectations towards a climate-friendly means of transport. Contrarily, there is a possibility that UAM as a means for medical and emergency transport could build up a higher public acceptance. Being an individual means of transport might support the development of UAM as a niche market for people refraining from travel with means of mass transport in order to follow social distancing.

Effects on factors related to infrastructure and regulations are expected to be low as compared to the other factors. Sparse investments might, however, lead to a preference of existing infrastructure rather than the construction of new infrastructure.

In summary, the wide ranges of possible developments especially regarding political support and societal acceptance of UAM are an expression of the high level of uncertainty introduced by the COVID-19 crisis. Therefore, COVID-19 still has to be seen as a living lesson, which affects many core elements of travel such as overall travel demand and possible travel routes. Mid- and long-term effects still remain unforeseeable.

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