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Proposing a Scenario-Based Estimation of Global Urban Air Mobility Demand

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Rapid technological advancements enable the development of novel vertical take-off and landing (VTOL) vehicles that in the future may allow to take aerial mobility into densely populated urban settlements. This research proposes a method for a scenario-based estimation of urban air mobility (UAM) vehicle demand. In order to assess the potential development pathways for VTOL vehicle demand multiple steps have been taken. The method encompasses four dimensions and distinguishes between three different UAM use-cases (inner-city transport, airport shuttle and regional transport), six different city archetypes (Addis Ababa, Johannesburg, Mumbai, Warsaw, Munich and Tokyo), three different scenarios and years 2020-2050. The method assumes UAM market penetration rates to differ over the four dimensions. Trip lengths, demand distribution over the day and the overall number of trips that could potentially be substituted by UAM trips vary per use-case and city archetype. Using existing mobility data allows to compute specific numbers and to relate them to numbers from existing studies in the field.

I. Introduction

Urban air mobility (UAM) is often discussed as novel mobility solution in and around cities. Technological enhancements, especially in distributed and electric propulsion, appear to make safe, sustainable and quiet passenger drones a viable option. With a current focus on the UAM vehicle, the activities show a very broad and high dynamic in terms of new vehicle configurations, initiatives and collaborations even during the Corona pandemic. Figure 1 shows the geographical location of the company, the company size and the type of organisation based on public data of June 2020.

Figure 1: Overview of Passenger UAM Vehicles Companies (Status June 2020, public data only)

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This dynamic is primarily taking place in the USA, EU and Asia and includes activities from various industries such as aviation, electronics, tech companies and automotive. Currently, more than 200 vehicles for passenger transport or comparable payloads are under development (Vertical Flight Society). The involved companies are very heterogeneous in terms of company size and age, as well as aviation-specific knowledge. The number of activities and involved companies is declining significantly at higher technology readiness levels (see Figure 2). More than 120 activities worldwide can be found with at least a concept description or rendering, whereas only 13 and 10 vehicles are full scale flight demonstrators in the USA and Europe respectively. Only four vehicles worldwide are in the status of a product prototype, two of which are products from the company Ehang (China/Asia) and Volocopter 2X (Europe). Comparing the size of the companies, we see in Figure 3 that there is only a small number of large companies with over 500 or more employees developing an UAM vehicle. The majority of the companies have a workforce of less than 200 people, and many of these start-up companies are in an early development stage.

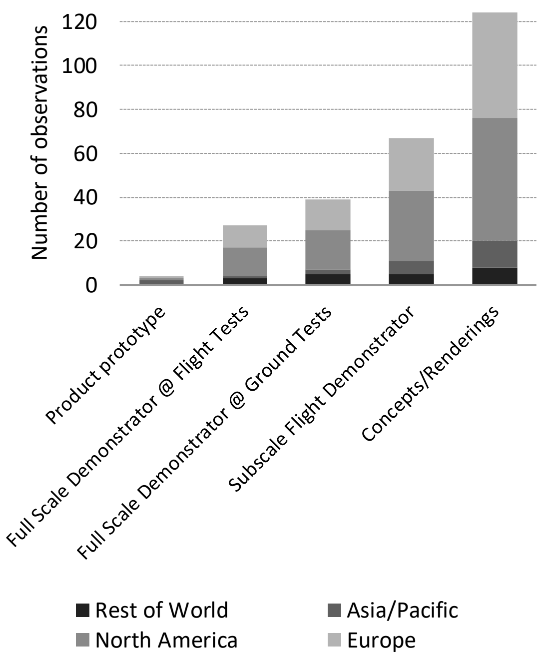

Figure 2: UAM vehicle developers per region and degree of technological maturity

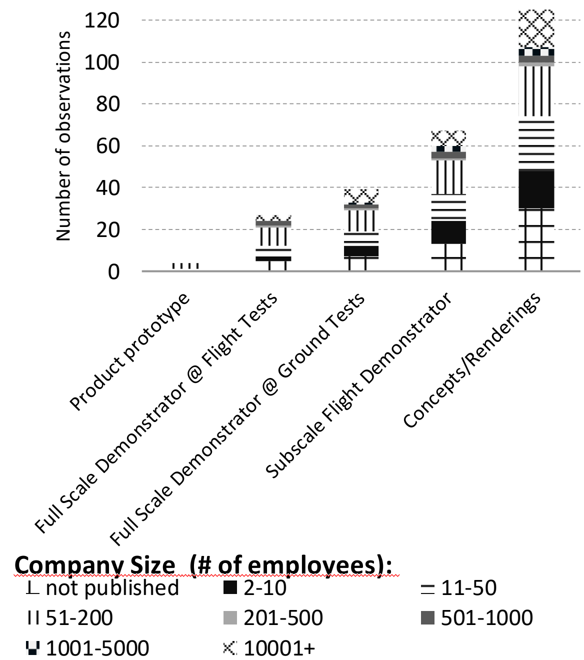

Figure 3: UAM vehicle developers per number of company employees and degree of technological maturity

While vehicle design and development is advancing, companies have problems to plan production and production up scaling as the market size of UAM is still unknown. Most estimates on numbers of required vehicles stem from consulting firms (Booz-Allen and Hamilton Inc., 2018; Horvath & Partners, 2019; Porsche Consulting, 2018; Roland Berger, 2018), while there is only a limited number of such estimates from a scientific background (Mayakonda et al., 2020). We want to add to this literature by proposing a scenario-based estimation method for global UAM vehicle demand. The proposed method has four dimensions: use cases, scenarios, city archetypes and time. We consider three UAM application cases relevant: airport shuttle, intra-city UAM and inter-city UAM. Taking all cities worldwide of a certain size, we define clusters of cities, which we expect to have similar UAM demand patterns and refer to the clusters as city archetypes. Additionally we consider three scenarios that give us the possibility to model different development pathways for UAM from restrictive to UAM friendly. We assume market penetration rates to differ across the four dimension but to be the same for all cities within a specific archetype. Using current mobility allows to compute the VTOL vehicle demand for different scenarios, use-cases, cities and time steps.

The remainder of the paper is structured as follows: section 2 will review existing literature in the fields of UAM market studies, demand modelling and city clustering. Section 3 will then closely described the applied methods, to ensure replicability. The methods section will include the clustering and the detailed approach for each of the use cases. Detailed results for each scenario will be described in section 5 of this paper. Limitations of the approach and pathways for future work will be given in the conclusion.

II. Literature Review

Urban or advanced air mobility describes the concept of passenger transport using small VTOL vehicles for short haul trips either on demand or scheduled (Straubinger & Rothfeld, 2018). While nowadays this kind of mobility is only possible through helicopters, novel vehicles promise to make UAM less noisy, safer, and cheaper and thus accessible for a wider group of potential users (Al Haddad et al., 2020). In the following study three UAM use cases find consideration that amongst others are often being discussed by literature (Ploetner et al., 2020; Porsche Consulting, 2018; Roland Berger, 2018; Straubinger et al., 2021):

1.) Inner-city flights / air taxi: UAM as a fast means of transport for routes within a city or agglomeration. The literal interpretation of the term UAM already suggests this application.
2.) Airport shuttle: UAM serves as a shuttle to the airport. Since in many cities the airport is located outside the city centre, but at the same time business travellers in particular have a high willingness to pay for travel time savings, this is often discussed as a use case for UAM shortly after its market launch (Booz-Allen and Hamilton Inc., 2018; Roland Berger, 2018). As early as the 1960s (Straubinger et al., 2020), airlines used helicopter flights to provide fast and convenient access to the airport, especially for their premium customers.
3.) Inter-city flights / Rural Air Mobility: UAM as a way to connect different cities and regions as well as the rural hinterland with the economic centre (ITF, 2021). However, this application of UAM presupposes strong technological progress on the one hand, which makes greater distances possible. On the other hand, political support or drastic cost savings are necessary to make flights to less densely populated areas profitable. Connecting rural and hard-to-reach areas is already done in Russia, for example, where state-subsidised helicopters are operated to give residents in hard-to-reach areas access to necessary infrastructure.

Yet, despite research being active in various fields around UAM such as vehicles, infrastructure, operations, acceptance and adoption (Straubinger et al., 2020), services are not yet active and development pathways uncertain. Michelmann et al. (2020) therefore propose a scenario based approach that takes a broad range of environment factors like political support, certification frameworks, battery technology, vertiport network and their development over time into account. In relation to these factors the authors develop three scenarios that reach from rather restrictive, with UAM being a niche service to a positive future for UAM in which UAM is offered on-demand to a large share of people around the globe. Building on these scenarios also this research constructs different scenarios in which the market penetration rates of UAM and their development over time strongly differ.

The implementation of technical and socio-economic scenarios was also found in comparable UAM market estimations. Horvath & Partners (2019) used a market model to determine inner-city and regional transportation. Their approach focusses on gradual waves of implementation, whereas sets of cities roll-out UAM networks. These sets of cities are primarily selected based on their population. The most optimistic market environment is therefore defined as the reference scenario, so that the realistic and pessimistic scenario are derived as predefined fractions of 50 % and 25 % respectively of the optimistic case. To express the forecasted production quantities, Horvath & Partners (2019) relate the cumulative flight hours on UAM capacities and their expected life cycles.

A different approach was described by Roland Berger (2018), who based their UAM fleet forecast for inner-city, airport and regional applications on a detailed topographic analysis for a set of archetypical cities. For four archetypical cities, points of interests were identified and connected. By taking local commuter data into account potential UAM connections were derived. The resulting networks were assumed to be representative for cities with comparable population densities and urban areas – so that the remaining 94 metropolitan areas were clustered accordingly. The calculation of the required fleet per archetype followed a route-based consideration of UAV vehicles per peak hour.
A different econometric approach with a strong focus on predicted cost levels was conducted by Reiche et al. (2018)for inner-city passenger and express cargo flights. As they based their research on extensive household surveys, they were able to model passenger's UAM demand depending on assumed cost levels. UAM costs have been derived based on expert interview's and production volumes.

As the collection of commuter data for such large sets of agglomerations would be prohibitively expensive, many publications apply clustering algorithms, which aim to group agglomerations with similar conditions, so that available transportation characteristics could be transformed to other agglomerations with comparable conditions.

This heuristic approach is executed by a k-means clustering algorithm, which subdivides an n-dimensioned set of data points (each clustering variable is a dimension) into *k* distinctive clusters. Resulting partitions assign the points to clusters in order to minimize the squared distance to the centre of the cluster. The general procedure of a k-means algorithm as described by Jain and Dubes (1988) suggest an iterative process, whereas the first step is to select an initial value for k and random locations for the centres. The algorithm moves the centres of the clusters until the sum of squared distances is minimized. As the number of clusters *k* is typically unknown for heuristic approaches, the most meaningful result was chosen as a comparison for different values of *k* with existing socio-economic clustering of agglomerations (GaWC, 2018; Shell, 2017).

III. Methodology

The market estimations have been conducted by separating the use-cases and applying calculation models, which have taken account of the specific characteristics of each application. The calculation approaches consider only the transportation of passengers and differ between inner-city, airport shuttle and regional services. These use-cases have been studied in the context of three scenarios which have been developed by Michelmann et al. (2020). The scenarios reach from A to C, where A is the most pessimistic scenario and C the most optimistic. The scenarios show possible pathways for development and are not able to foresee occurrence probabilities of different scenarios. A detailed description of the calculation logic is offered in the following.

The base for the studied use-cases is a set of worldwide cities and agglomerations. This set of relevant agglomerations has been structured and assigned into six distinct clusters, which share major characteristics of their transportation system. For generalisation, each cluster is represented by an archetypical agglomeration for which detailed transportation data are available.

The development of the archetypes is described in the subsequent paragraph. Followed by a detailed description of the applied UAM demand forecast mechanisms for each use-case.

Using the UN-Urbanisation dataset, all agglomerations with a population exceeding one million inhabitants in 2020 have been considered as relevant for UAM applications. This resulted in 575 agglomerations and cities for which the following characteristics were analysed.

Table 1: Data for clustering

Characteristic	Data	Source
Population of Agglomeration	Inhabitants in 2020	(United Nations, 2020)
Income	Country GDP per capita (2019, or latest available data)	(World Bank, 2019)
Inequality of Income	Country Gini Coefficient (2018, or latest available data)	(World Bank, 2018)
International Trade and Commerce	Ranking of “World Cities”	(GaWC, 2018)

In accordance with literature on city clustering (Angel, 2011; Arthur D. Little, 2011; Shell, 2017) and UAM (Porsche Consulting, 2018; Roland Berger, 2018; Straubinger & Rothfeld, 2018) these characteristics provide a solid base to assume a high similarity in the development of an UAM network for these agglomerations. Based on these variables, a heuristic multi-stage clustering approach was carried out. This consisted of an iterative loop of hierarchical clustering and an evaluation of the resulting clusters to validate the similarity in available transportation data. The hierarchical clustering revealed that six major clusters can be identified. Based on this, a k-means clustering has been carried out to assign each agglomeration to its distinct cluster and its representative archetype. Table 2 gives first insights into the developed clusters.

Table 2: City Archetypes

Archetype	Addis Ababa	Johannesburg	Mumbai	Warsaw	Munich	Tokyo
Number of cities	401	43	8	44	78	1
Daily motorized trips	1.17	0.66	0.95	1.56	2.14	1.57
Distance [km]	15.09	19	13.73	8.8	11.17	21.6

For the following calculations, the clusters have major impact on the market penetration rates of each use-case, scenario and year, as well as on the inner-city transportation characteristics. The market penetration rates follow existing literature on UAM demand (Booz-Allen and Hamilton Inc., 2018; Fu et al., 2019; Garrow et al., 2019; Mayakonda et al., 2020; Ploetner et al., 2020; Rothfeld et al., 2019) and are main determinants for the demand in each scenario. Due to the high uncertainty in the area of UAM regarding e.g. prices, travel speed, network density, access times and choice behaviour, the different market penetration rates capture all of these aspects in only one number. For transparency the full set of market penetration rates is available in Appendix A-C.

A. General Approach

The general calculation layout allows a high level of differentiation by applying modified forecasting models for each use-case on a common base of agglomerations and scenarios. Based on the clustered set of agglomerations, which has been kept constant over the study period from 2020-2050, the calculation of the forecasted UAM vehicles for each use-case has been subdivided as follows.

Firstly, the demand for UAM in each agglomeration and year was calculated in terms of trips per day and trips per peak hour.

Secondly, the average transportation capacity per UAM vehicle was calculated in terms of trips per hour. This calculation considered the average trip distances, as well as process times, cruise speeds, seat capacities and seat load factors of the available vehicles as defined by the scenarios.

Thirdly, the forecasted number of vehicles per city and use-case was determined by dividing the demand for UAM in passenger trips in peak hour by the average transport capacity of UAM vehicles per hour. Despite transport systems in general not being designed for peak-performance, we make this assumption. At the same time, we do not consider vehicles to be unavailable due to maintenance or repair. The resulting numbers, thus on the one hand might be relatively high, as we optimize towards peak load, on the other hand, we omit unavailability due to maintenance and repair, hence slightly underestimating the number of vehicles. We assume the two effects to approximately even out.

These calculations were performed in steps of five years. Whereas the major drivers for the dynamic are the growth in population, which was calculated for each agglomeration at its recent 10 years floating average growth rate, the growth in airline passengers, which grew with an average rate of 3.5 % per year, and the market penetration rates, which were assumed to grow as defined in the scenario definitions.

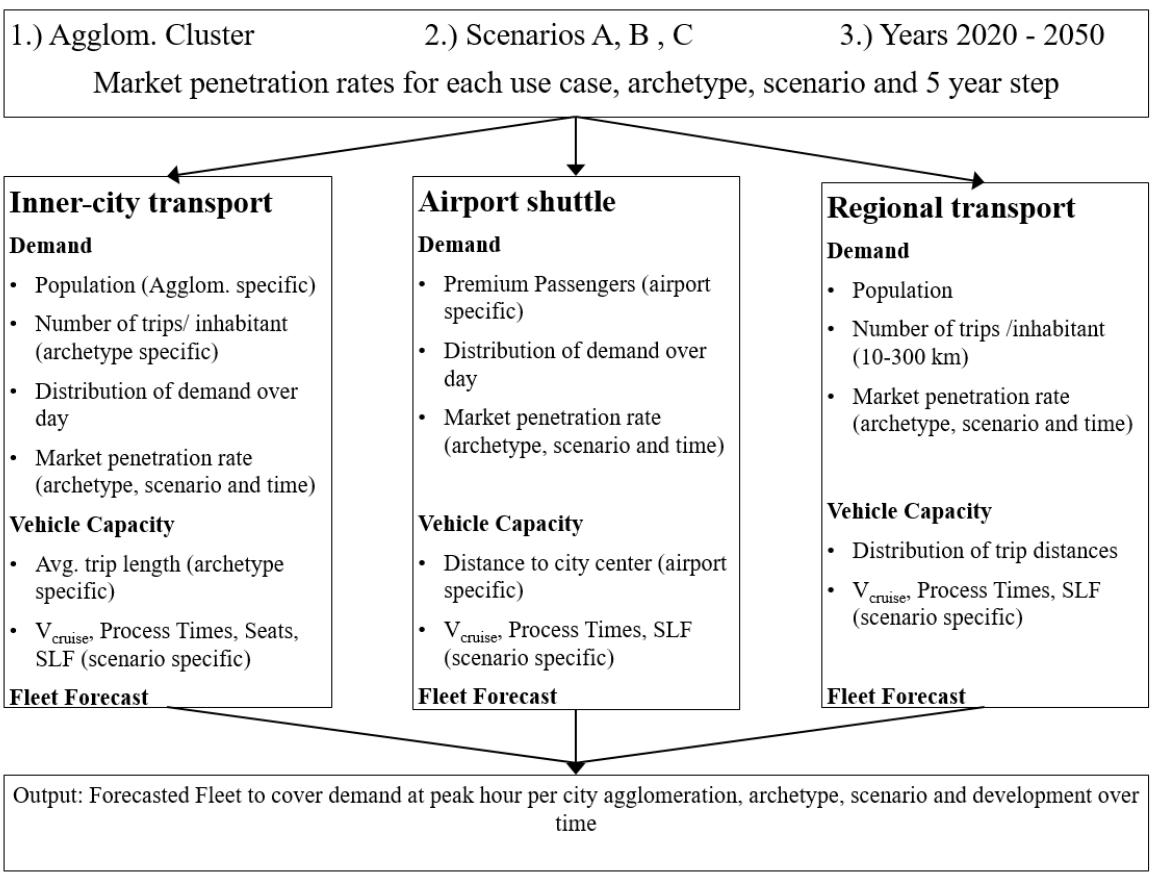

Figure 4: Methodological approach

The derived UAM vehicle demand results from a comparison of the UAM traffic demand – depending on population and transportation characteristics of the agglomerations – and the UAM supply – depending on the transport productivity of a UAM vehicle (depending on seat load factor, vehicle capacity, time for take-off, landing and charging). This approach allows to derive vehicle demand per agglomeration [*i*], cluster [*k*], scenario [*l*] and a development over time [*j*].

B. Inner-city transport

The inner-city transport application focuses on the traffic within the boundaries of an agglomeration. As described in the general approach, the forecasted UAM vehicle fleet is calculated in a 3-step subdivided approach.

To determine the demand for inner-city UAM trips per day ($Inner\ City\ Trips_{i,j,l}$), the overall motorized transportation pattern of each agglomeration is calculated by multiplying the agglomeration's population ($Population_{i,j}$) with the average number of motorized trips per inhabitant and day. Subsequently, the number of motorized trips per day ($Average\ Trips_k$) is multiplied with the assumed market penetration rates for UAM ($Market\ Penetration\ Rate_{k,j,l}$). The number of motorized trips is a figure, which is calculated for each cluster as the average of motorized trips per day for those agglomerations with available data in the UITP database (UITP 2015), whereas the UAM market penetration rates depend on the agglomeration's cluster assignment, as well as the scenario and year of calculation.

$$Inner\ City\ Trips_{i,j,l} = Population_{i,j} * Average\ Trips_k * Market\ Penetration\ Rate_{k,j,l} \tag{1}$$

To take into account an unequal distribution of traffic during the day, the daily trips are distributed by using a twin-peaked traffic distribution for an average bank day as described by (Xydas et al., 2013). For further calculations only the peak hour UAM trip demand for each agglomeration is considered, as we assume this to be the maximum number of vehicles needed per agglomeration.

In a second step, the average transportation capacity ($UAM\ Capacity_{i,j,l}$) was calculated with the aim to allow for a broad field of variation in UAM vehicle capabilities taking into account the existing uncertainties of their design parameters ($Seat\ Capacity_{j,l}$). Therefore, UAM vehicle's transport capabilities are calculated in pax-trips per hour at an assumed $Seat\ Capacity_{j,l}$ and average load factor (LF_l). The LF_l considers the actual seat load factors for revenue flights and a fixed assumed quota of repositioning flights. The trips per hour capabilities result from the reciprocal relation between trip per time unit and the average trip durations, whereas the average trip duration depends on the vehicle's cruise speed (V_{cruise_l}), process times (charging, boarding, take-off and landing) ($\sum Process\ Time_l$) and the average distance of motorized trips ($Avg.\ Distance\ motorized\ Trip_k$) within the assigned cluster of cities. Average distances of motorized trips per cluster are derived in reference to the average number of motorized trips.

$$\begin{aligned} UAM\ Capacity_{i,j,l} &= Seat\ Capacity_{j,l} * LF_l * \frac{Trips\ per\ Hour_{i,j,l}}{1\ [h]} = \\ Seat\ Capacity_{j,l} * LF_x &* \frac{60\ [min]}{\sum Process\ Time_l[min] + 60\left[\frac{min}{h}\right] * \frac{Avg.Distance\ motorized\ Trip_k\ [km]}{V_{cruise_l}\left[\frac{km}{h}\right]}} \end{aligned} \tag{2}$$

In a last step, the UAM vehicle fleet has been calculated for each agglomeration as the number of vehicles (each with the calculated UAM capacity) which is required to cover the peak hour UAM demand.

$$UAM\ Vehicle\ Fleet_{i,j,l} = \frac{Inner\ City\ Trips\ \ in\ Peak\ Hour_{i,j,l}\ [\frac{Pax}{h}]}{UAM\ Capability_{i,j,l}\ [\frac{Pax}{h}]} \tag{3}$$

The calculations are conducted in steps of 5 years. Population data have been updated for each individual agglomeration considering the growth years of the last 10 years.

C. Airport shuttle

The second considered use-case for UAM applications is the traffic between airports and city centres – so called airport shuttles. Per definition, UAM vehicles used for airport shuttles were assumed for larger seating capacities and higher cruise velocities than for inner-city applications. In order to assess the demand, the previously selected set of 575 agglomerations with at least one million inhabitants was linked to 543 corresponding airports, whereas 154 agglomerations were served by multiple airports and 126 by no Airport were assigned to the same cluster as their corresponding agglomerations. If multiple agglomerations were in question, the one closest to the airport was decisive.

Following the basic three-step structure of the inner-city use-case, only the calculation for the demand differs significantly. As UAM airport shuttles are expected to reduce travel times to / from the airports at a significantly higher fare than comparable journeys by taxi or train, UAM airport shuttle applications are assumed to aim especially for less price-sensitive passengers with premium fares. Therefore, this approach assumes that predominantly passengers with business and first class tickets are targeted as potential passengers. For each of the relevant airports, the number of passengers with business and first class tickets who either started or ended their journey at this airport has been recorded based on passenger data (Sabre Data & Analytics Market Intelligence, 2016). The demand was expressed in trips per day, whereas the major input factors are the number of arriving and departing premium passengers ($Premium\ Passengers_{m,j}$) and the market penetration rates ($Market\ Penetration_{j,l}$,). Market penetration rates reflect the assumptions of the defined scenarios, they depend on the simulation year and cluster the airport's agglomeration is assigned to.

$$Airport\ Trips = Premium\ Passengers_{m,j} * Market\ Penetration_{j,l}, \tag{4}$$

As the considered airports differ significantly in the distribution and structure of their traffic flow, a general twin-peaked traffic distribution over the day, similar to the inner-city use-case, was selected to calculate the trips per peak hour.

UAM vehicle's capacity was calculated following equation (2)of the inner-city use-case, whereas the number of trips per hour was calculated as a function of the actual geographic distance between airport and city centre, instead of the average distance within the city,

The calculation of the forecasted UAM vehicle fleet corresponds to general approach. Calculations are conducted in steps of 5 years. Over the years, the number of air passengers increases constantly at 3 % annually for all airports.

D. Regional transport

The third UAM application focusses on the regional transport between agglomerations and their surrounding areas. The term regional transportation therefore excludes the inner-city-traffic which was already considered in the first use-case. It has been assumed that distances of 10 km and less are inner-city. The upper limitation has been set to 300 km and results from the predicted vehicles range capabilities for the study period (Shamiyeh et al., 2017).

To derive traffic demand, this approach has been based on US mobility data as provided by the Bureau of Transportation. These data allow distance-depending information about personal, motorized trips per inhabitant in the US. The average number of motorized daily trips within the relevant range of 10-300km was 1.54 per inhabitant and day. Furthermore, the data allow to derive a distribution of trips over distance. Despite the risk, that these data do not match all clusters, these mobility characteristics were kept constant over all clusters as the availability for other clusters was too limited to allow a reasonably analysis.

The demand is calculated as follows:

$$Regional\ Trips_{i,j,l} = 1.54 * Population_{i,j,l} \tag{5}$$

Similar to the inner-city and airport shuttle use-case, a twin-peaked traffic distribution has been applied to derive the peak hour demand. Although the calculation of the UAM vehicle's capacity follows the general approach, whereas the weighted average distance of all motorized trips between 10-300 km was considered as the average distance for Equation (5).

The calculation of the forecasted UAM vehicle fleet corresponds to the general approach. Calculations are conducted in steps of 5 years, with the population figures being updated according to the floating average growth rates of the past ten years.

IV. Results

The above described methods were used to estimate vehicle demand over different scenarios and for different time steps. In order to validate the results and the approach we take two steps. Firstly, we take vehicle numbers for one city and compare them to today's taxi licences (Figure 5), secondly, we compare our results to existing estimations on the development of global vehicle demand (Figure 6).

Figure 5 gives the number of UAM vehicles required during peak hour for Tokyo over different years and scenarios. The figure also includes the number of taxi licences (35,000) currently available in Tokyo (Mukai, 2013). The visualization shows that even in the most optimistic case there will be less UAM vehicles than taxis until 2035. For scenario C the number of UAM vehicles is expected to stay significantly below the number of current taxi licences up to 2050. This gives confidence in the order of magnitude of the estimates, as well as the directions the different scenarios take.

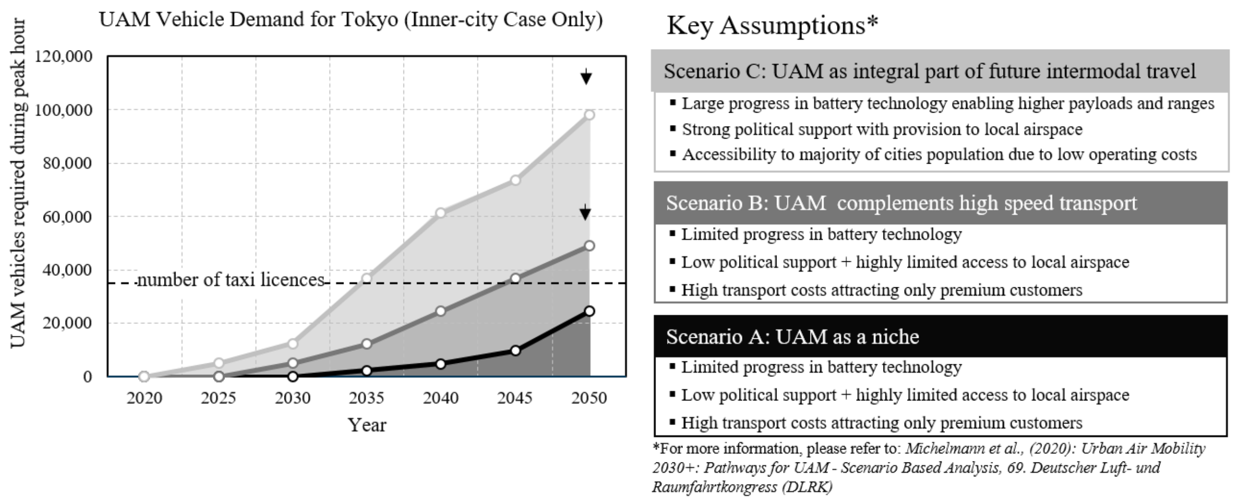

Figure 5: Benchmarking against current Taxi licences

When comparing our numbers to existing estimates on vehicle demand, we see several differences (Figure 6). While Scenario A is in the same order of magnitude as the estimates by Roland Berger (2018) and Horvath & Partners (2019). For 2050 the latter foresee similar vehicle demand as our Scenario C does, yet the increase in numbers from 2045 to 2050 appears rather extreme. The Roland Berger (2018) numbers stay well below our estimates. Whereas it is important to highlight that our numbers represent demand for all cities with more than one million inhabitants, while their study only considers some cities.

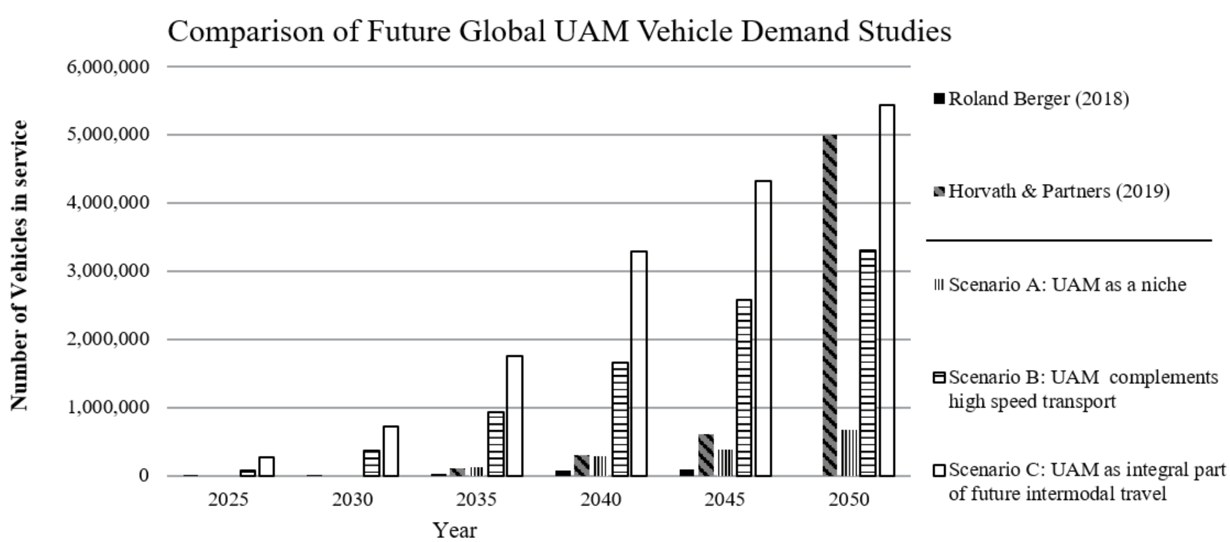

Figure 6: Comparison of Future Global UAM Vehicle Studies

A. Scenario results

In the following, our estimates are described in more detail. In scenario A, where UAM is assumed to be a niche product, global UAM vehicle demand in the peak hour is expected to stay well below one million vehicles globally. Figure 7 shows the development over time in sum (dark line with dots), for the inner-city use-case (squares), for the airport shuttle (triangles) and the regional transport use-case (circles).

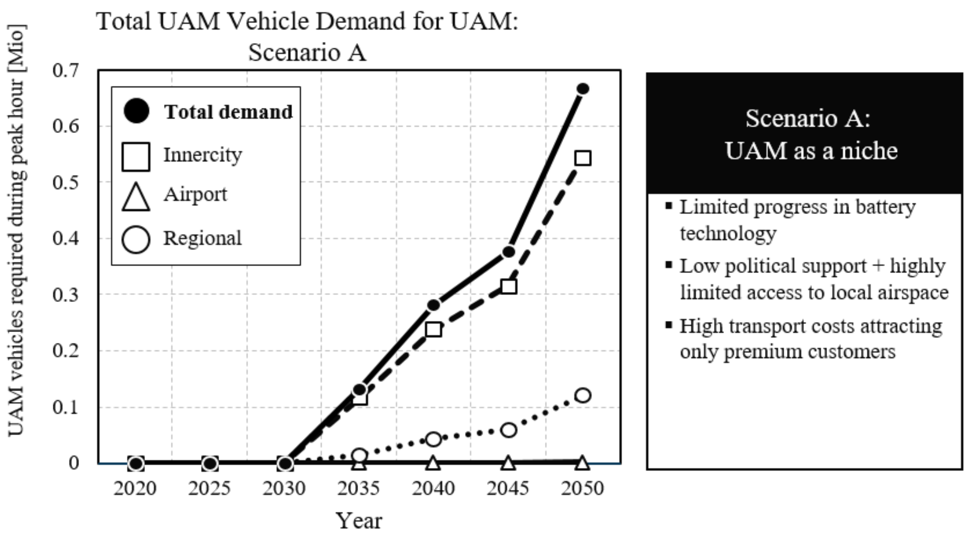

Figure 7: Global UAM vehicle demand Scenario A

Despite airport access being one of the most often proposed application cases for UAM we see that this use case only results in little vehicle demand. The inner-city application, in contrast is the main driver of vehicle demand. This is not due to high market penetration rates for this use-case but rather results from the large number of trips conducted within cities every day.

Figure 8 shows vehicle demand for scenario B. The expected global vehicle demand 2050 is estimated to be approximately 5 times higher than in scenario A. Still airport access only accounts for a small share of demand. Again, the main driver is inner-city transport. Scenario B assumes demand to significantly go up after 2030.

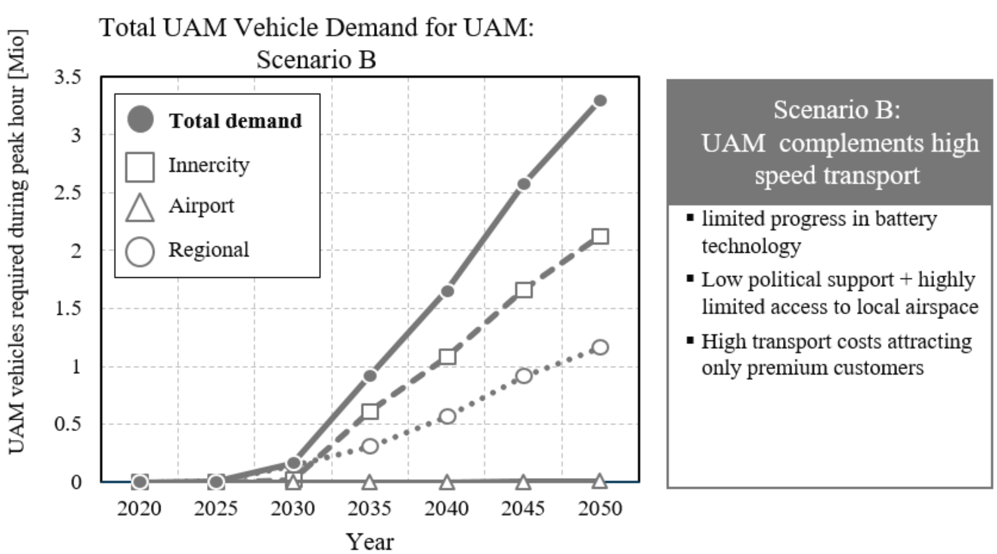

Figure 8: global UAM vehicle demand Scenario B

Scenario C is the most optimistic scenario and sees UAM as an integral part of intermodal travel. Again, Inner-city transport is the main driver for vehicle demand. In sum, the global demand for UAM vehicles in 2050 is expected to reach nearly 5.5 million vehicles at peak hour.

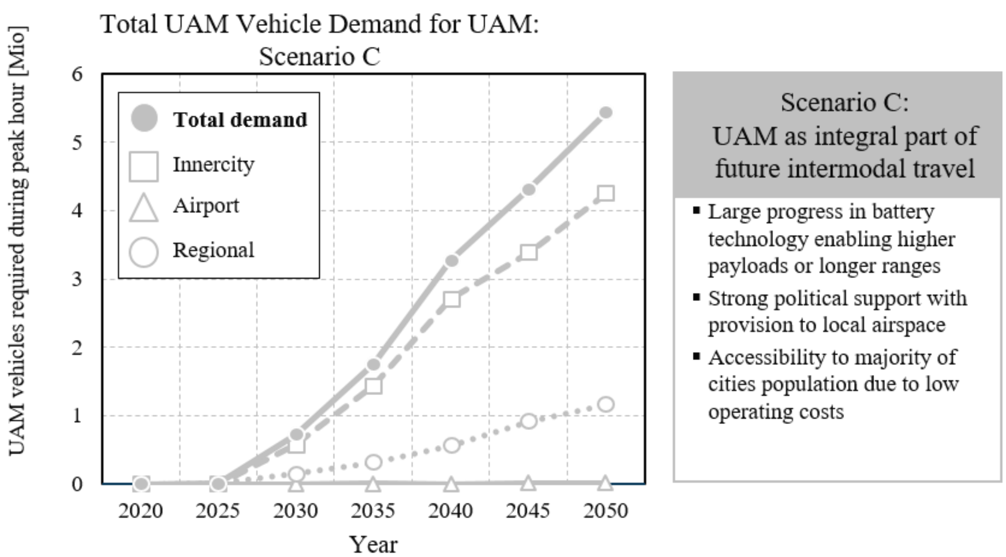

Figure 9: Global UAM vehicle demand Scenario C

B. Overall results

Figure 10 gives the expected vehicle demand for the different scenarios (A = light grey, B = grey, C = dark grey) over time. Summing over all use-cases shows a large difference in overall vehicle demand for each of the scenarios and shows quiet well that growth rates in the beginning can be key to a successful market. While growth rates in Scenarios B and C are expected to massively increase for 2035 and after, Scenario A expects a more linear growth of demand over time.

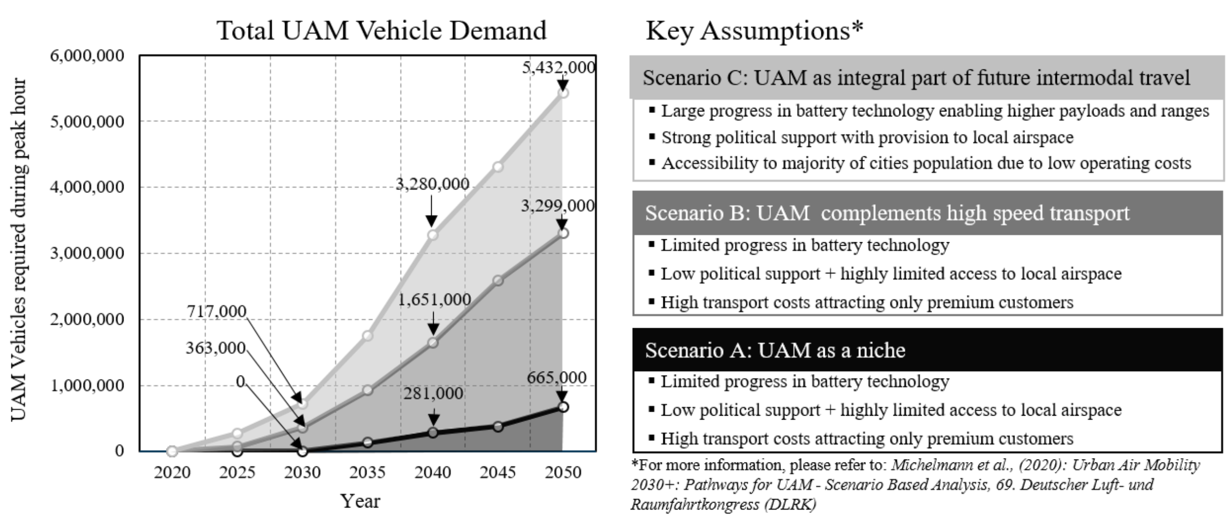

Figure 10: Global UAM vehicle demand for the various scenarios

V. Conclusion

This research proposes a method for a scenario-based assessment of UAM vehicle demand. The method encompasses three use-cases (airport access, regional transport and inner-city transport), six city clusters including all cities with more than one million inhabitants and three scenarios from UAM as a niche (Scenario A) to UAM as integral part of intermodal travel (Scenario C). The method estimates a global vehicle demand of 665,000 (Scenario A) to 5,432,000 (Scenario C) in 2050. With inner-city transport being the main driver for vehicle demand in all scenarios due to the high number of trips within cities. The airport access use-case in contrast contributes to the overall vehicle demand only to a small extent.

The main limitation of this approach is the uncertainty regarding market penetration rates. The numbers were determined at the best of the authors' knowledge, as given in Appendix A. While all other values are based on openly available statistics, it is hard to foresee the market penetration rates for a service that is not yet available. The method tries to tackle this shortcoming by working with scenarios and by being very transparent. Yet, of course, this leaves space for further research.

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Appendix A – Inner-city market penetration rates [Share UAM trips all inner-city transport]

	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6
A2020	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
B2020	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
C2020	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
A2025	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
B2025	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
C2025	0.10%	0.10%	0.10%	0.00%	0.00%	0.10%
A2030	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
B2030	0.10%	0.10%	0.10%	0.00%	0.00%	0.10%
C2030	0.25%	0.25%	0.25%	0.10%	0.10%	0.25%
A2035	0.05%	0.05%	0.05%	0.00%	0.00%	0.05%
B2035	0.25%	0.25%	0.25%	0.10%	0.10%	0.25%
C2035	0.50%	0.75%	0.75%	0.30%	0.30%	0.75%
A2040	0.10%	0.10%	0.10%	0.00%	0.00%	0.10%
B2040	0.40%	0.50%	0.50%	0.20%	0.20%	0.50%
C2040	1.00%	1.25%	1.25%	0.50%	0.50%	1.25%
A2045	0.10%	0.20%	0.20%	0.00%	0.00%	0.20%
B2045	0.60%	0.75%	0.75%	0.40%	0.40%	0.75%
C2045	1.25%	1.50%	1.50%	0.75%	0.75%	1.50%
A2050	0.10%	0.50%	0.50%	0.00%	0.00%	0.50%
B2050	0.75%	1.00%	1.00%	0.50%	0.50%	1.00%
C2050	1.50%	2.00%	2.00%	1.00%	1.00%	2.00%

Appendix B – Airport Shuttle market penetration rates [Share of UAM users of long-haul premium PAX]

	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6
A2020	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
B2020	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
C2020	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

A2025	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
B2025	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
C2025	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
A2030	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
B2030	0.50%	1.00%	1.00%	0.50%	0.50%	1.00%
C2030	1.00%	3.00%	3.00%	1.00%	1.00%	3.00%
A2035	0.00%	0.20%	0.20%	0.00%	0.00%	0.20%
B2035	1.00%	2.00%	2.00%	1.00%	1.00%	2.00%
C2035	3.00%	7.00%	7.00%	3.00%	3.00%	7.00%
A2040	0.25%	0.40%	0.40%	0.25%	0.25%	0.40%
B2040	2.00%	3.00%	3.00%	2.00%	2.00%	3.00%
C2040	6.00%	10.00%	10.00%	6.00%	6.00%	10.00%
A2045	0.50%	0.70%	0.70%	0.50%	0.50%	0.70%
B2045	3.00%	5.00%	5.00%	3.00%	3.00%	5.00%
C2045	8.00%	12.00%	12.00%	8.00%	8.00%	12.00%
A2050	1.00%	1.00%	1.00%	1.00%	1.00%	1.00%
B2050	5.00%	7.00%	7.00%	5.00%	5.00%	7.00%
C2050	10.00%	15.00%	15.00%	10.00%	10.00%	15.00%

Appendix C – Regional transport market penetration rates [Share of UAM users of all commuters travelling to or from the city]

	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6
A2020	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
B2020	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
C2020	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
A2025	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
B2025	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
C2025	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%
A2030	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
B2030	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%
C2030	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%
A2035	0.00%	0.10%	0.00%	0.00%	0.00%	0.10%
B2035	0.30%	0.50%	0.30%	0.30%	0.30%	0.50%
C2035	1.00%	1.00%	1.00%	1.00%	1.00%	1.00%
A2040	0.00%	0.30%	0.00%	0.00%	0.00%	0.30%
B2040	0.70%	1.00%	0.70%	0.70%	0.70%	1.00%
C2040	2.50%	3.00%	2.50%	2.50%	2.50%	3.00%
A2045	0.00%	0.50%	0.00%	0.00%	0.00%	0.50%
B2045	1.00%	2.00%	1.00%	1.00%	1.00%	2.00%
C2045	4.00%	5.00%	4.00%	4.00%	4.00%	5.00%
A2050	0.00%	1.00%	0.00%	0.00%	0.00%	1.00%
B2050	2.00%	3.00%	2.00%	2.00%	2.00%	3.00%

C2050	5.00%	7.00%	5.00%	5.00%	5.00%	7.00%

Appendix D – General scenario assumptions

	Seats	Loadfactor	Boarding [min]	Charging [min]	Start [min]
A2020	1	100.00%	5	60	5
B2020	2	50.00%	2	30	4
C2020	2	50.00%	1	30	3
A2025	1	100.00%	5	60	5
B2025	2	50.00%	2	30	4
C2025	2	50.00%	1	30	3
A2030	2	50.00%	5	50	5
B2030	2	50.00%	2	30	4
C2030	4	50.00%	1	20	3
A2035	2	50.00%	5	40	5
B2035	2	50.00%	2	30	4
C2035	4	50.00%	1	20	3
A2040	2	50.00%	5	40	5
B2040	4	50.00%	2	30	4
C2040	4	50.00%	1	10	3
A2045	2	50.00%	5	30	5
B2045	4	50.00%	2	20	4
C2045	4	50.00%	1	10	3
A2050	2	50.00%	5	30	5
B2050	4	50.00%	2	20	4
C2050	4	50.00%	1	10	3

Appendix E – City Archetypes

Cluster 1 (Addis Abeba)	**Cluster 2 (Johannesburg)**	**Cluster 3 (Mumbai)**	**Cluster 4 (Warschau)**	**Cluster 5 (München)**	**Cluster 6 (Tokyo)**
Kabul	Aracaju	Dhaka	Edmonton	Adelaide	Tokyo
El Djazair (Algiers)	Baixada Santista	Sao Paulo	Ottawa-Gatineau	Brisbane	
Luanda	Belem	Beijing	Taibei	Melbourne	
Buenos Aires	Belo Horizonte	Shanghai	Praha (Prague)	Perth	
Cordoba AR	Brasilia	Al-Qahirah (Cairo)	Lille	Sydney	
Mendoza	Campinas	Delhi	Marseille-Aix-en-Provence	Wien (Vienna)	
Rosario	Curitiba	Mumbai (Bombay)	Paris	Antwerpen	

Yerevan	Florianopolis	Ciudad de Mexico (Mexico City)	Toulouse	Bruxelles-Brussel	
Baku	Fortaleza		Köln (Cologne)	Calgary	
Chittagong	Goiania		Athinai (Athens)	Montreal	
Minsk	Grande Sao Luis		Budapest	Toronto	
Abomey-Calavi	Grande Vitoria		Hefa (Haifa)	Vancouver	
Cochabamba	Joao Pessoa		Milano (Milan)	Hong Kong	
La Paz	Joinville		Napoli (Naples)	Kobenhavn (Copenhagen)	
Santa Cruz	Maceio		Roma (Rome)	Helsinki	
Rio de Janeiro	Manaus		Torino (Turin)	Lyon	
Sofia	Natal		Chukyo M.M.A. (Nagoya)	Berlin	
Ouagadougou	Porto Alegre		Hiroshima	Hamburg	
Bujumbura	Recife		Kinki M.M.A. (Osaka)	München (Munich)	
Phnum Penh (Phnom Penh)	Salvador		Kitakyushu-Fukuoka M.M.A.	Dublin	
Douala	Teresina		Sapporo	Tel Aviv-Yafo (Tel Aviv-Jaffa)	
Yaounde	Barranquilla		Sendai	Amsterdam	
N'Djamena	Bucaramanga		Shizuoka-Hamamatsu M.M.A.	Rotterdam	
Santiago CL	Cali		Warszawa (Warsaw)	Auckland	
Anshan	Cartagena		Lisboa (Lisbon)	Oslo	
Anyang CN	Medellin		Porto	Singapore	
Baoding	Tegucigalpa		Busan	Stockholm	
Baoji	Al Kuwayt (Kuwait City)		Changwon	Zürich (Zurich)	
Baotou	Tarabulus (Tripoli)		Daegu	Abu Zaby (Abu Dhabi)	
Benxi	Maputo		Daejon	Dubayy (Dubai)	
Binzhou	Matola		Goyang	Birmingham (West Midlands)	
Changchun	Ciudad de Panama (Panama City)		Gwangju	Manchester	
Changsha	Ar-Riyadh (Riyadh)		Incheon	Atlanta	
Changzhou, Jiangsu	Jiddah		Seoul	Austin	
Chaozhou	Cape Town		Suweon	Baltimore	
Chengdu	Durban (Ethekwini)		Yongin	Boston	
Chifeng	Ekurhuleni		Bucuresti (Bucharest)	Charlotte	

Chongqing	Johannesburg		Barcelona	Chicago	
Cixi	Port Elizabeth (Nelson Mandela Bay)		Madrid	Cincinnati	
Dalian	Pretoria		Ash-Shariqah (Sharjah)	Cleveland	
Daqing	Caracas		Glasgow	Columbus, Ohio	
Datong	Valencia		London UK	Dallas-Fort Worth	
Dongguan	Lusaka		West Yorkshire	Denver-Aurora	
Dongying			Montevideo	Detroit	
Foshan				Houston	
Fushun, Liaoning				Indianapolis	
Fuyang				Jacksonville, Florida	
Fuzhou, Fujian				Kansas City	
Ganzhou				Las Vegas	
Guangzhou, Guangdong				Los Angeles-Long Beach-Santa Ana	
Guilin				Louisville	
Guiyang				McAllen	
Haerbin				Memphis	
Haikou				Miami	
Handan				Milwaukee	
Hangzhou				Minneapolis-St. Paul	
Hefei				Nashville-Davidson	
Hengyang				New York-Newark	
Hohhot				Orlando	
Huai'an				Philadelphia	
Huaibei				Phoenix-Mesa	
Huainan				Pittsburgh	
Huizhou				Portland	
Jiangmen				Providence	
Jiaxing				Raleigh	
Jieyang				Richmond	
Jilin				Riverside-San Bernardino	
Ji'nan, Shandong				Sacramento	
Jingzhou, Hubei				Salt Lake City	
Jinhua				San Antonio	

Jining, Shandong				San Diego	
Jinzhou				San Francisco-Oakland	
Kaifeng				San Jose	
Kunming				Seattle	
Lanzhou				St. Louis	
Lianyungang				Tampa-St. Petersburg	
Linyi, Shandong				Virginia Beach	
Liuan				Washington, D.C.	

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