ICAS 2021 SHANGHAI
International Council of the Aeronautical Sciences
32nd Congress of the International Council of the Aeronautical Sciences
September 6-10, 2021
Pudong Shangri-La, Shanghai, China

# VERTIPORT PLACEMENT METHOD BASED ON MOBILITY SURVEY DATA

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## Abstract

Accessibility, network capacity and connectivity are crucial key factors when planning infrastructure elements for transportation systems. Determining the right network size to handle the expected amount of passengers with a profitable utilization rate can secure a sustainable operation. This present work proposes a method based on Germany-wide travel survey data for locating infrastructural elements in the context ofUrban Air Mobility (UAM), in the following named vertiports. An interface to parallel ongoing research is presented at the end of the paper, where recommendations for vertiport layout design are derived from a given surface area, including a calculation of the possible throuhgput.

**Keywords:** Vertiport Placement, UAM, Travel Survey Data

## 1. Abbreviations

**FLP** Facility Location Problem

**GIS** Geographic Information System

**MiD** Mobilitaet in Deutschland (Mobility in Germany)

**UAM** Urban Air Mobility

**eVTOL** electric Vertical Take-Off and Landing vehicles

**VST** Vertiport Sizing Tool

## 2. Introduction

UAM describes a novel concept of air travel where at least one end of the trip inside urban areas. Facilitating electric Vertical Take-Off and Landing vehicles (eVTOL), which may fly fully autonomous in the future, the hope is to mitigate inner-city congestion. In general UAM includes both cargo and passenger transport in a fast and efficient way. In the following the passenger transport will be the focus.

Making UAM a reality and including this new mode of transport into an urban environment, a range of stakeholders need to be involved. Crucial factors which are often mentioned in literature are regulations, esp. the vehicle certification, security and safety as well as infrastructure availability [1], [2], [3]. In order to plan and setup a scalable network the selection of the first locations is crucial. The adoption rate of the new mode of transport is depends in particular on costs and the trip duration [4]. Therefore, the inital offered connections must be frequented enough to allow for a profitable business cases. The present work contributes to the question of where vertiports should best be located from a traffic demand perspective. It gives a brief outlook on which design concept can be applied to the available space and which capacity can be achieved with the chosen design. This study is a methodical approach and sets the base for detailed future research.

## 3. Literature Review

Many aspects such as regulations, public acceptance, air traffic control, environmental impacts and infrastructure availability are constraining the introduction and the proposed operations of UAM [1]. Key constraints for the success of UAM as a new concept of mobility are beside safety and costs [4]. Further constraints are the accessibility of start and landing locations, their number and distribution as well as the value of time savings for the future passengers [5]. The two factors of availability and accessibility are closely related as the choice of suitable locations is crucial for both. There are various approaches for finding suitable vertiport locations, for example Wei et al. conducted a case study for South Florida using a set of given airpark locations. The original number was reduced based on the available space for certain sizes of runways and a sensitivity study for several origin and destination (O and D) pairs within an urban and suburban environment was performed [6]. A different approach was chosen by Holden and Goel who selected a subset of hubs that maximize the spatial coverage of potential demand [2]. In a first step, a k-means clustering algorithm was applied to the set of long-distance UBER trips performed in the study area. Next to further reduce the number of results in a second step, a large-scale optimization model was applied for maximum accessibility. Wei et al. developed another approach providing solutions for uncapacitated and capacitated cases. Here the overall service region was partitioned into multiple facility catchment areas to minimize the demand-weighted distance of customers to each supporting facility [7]. Rath and Chow [8] focused on the use case 'airport shuttle' and distributed the vertiports in a given city so that the travel time was optimal. To reduce complexity of calculating door-to-door in an urban traffic model, a variant of the Hub Location Problem to solve a generalization of the Vertiport Location Problem was applied.

All previously discussed examples are based on the same mathematical problem, known as a Facility Location Problem (FLP). A FLP is an optimization problem with the aim to select a subset of locations from a list of possible locations that are optimally placed under a set of boundary conditions. FLPs are well known and have been extensively studied in the past. A first attempt to formulate a general location theory was done by Alfred Weber beginning of the 20th century in his work 'Theory of the Location of Industries' [9]. Another well-known and often cited researcher in this area is Mark S. Daskin. With his work on discrete network and discrete location models [10] as well as with his summary of different taxonomies on how to solve facility location problems [11] he set the foundation for this research field.

The presented examples answer the question of vertiport location, but fail to account for important factors such as regulations, environmental impact and public acceptance. In his master's thesis, Fadhil uses a GIS-based approach to analyze suitable areas for vertiport locations and define factors influencing vertiport placements. He divides these into two categories: supply and demand and assigns them corresponding factors such as population density, median income, office rental rates or existing infrastructure and existing noise. Using an analytical hierarchical process and the Delphi method, he weights these factors and enriches them with the help of two expert interviews [12]. In addition to the factors and assumptions mentioned so far, it is necessary for the further investigations to make basic assumptions for the operation in order to define the model limits. For this purpose, it is obvious to orientate on the existing. As of today Helicopter services such as Uber Copter [13] and Voom are operating or have been operating in cities. The operation of Voom had to be deceased in March 2020 due to the Corona pandemic but before they operated for four years in three major metropolitan areas: Sao Paulo, Mexico City and the San Francisco Bay Area [14]. With the collected usage and customer data, both companies gained a lot of experience which can be used for the operation of UAM services. Due to the similarities of the use cases, most of the operational requirements for a vertiport can be obtained from helicopter services.

One significant difference between todays helicopter operations an envisioned UAM is the mission range. In different studies an approximated distance between 10 and 30km seems to be the minimum reasonable operating distance for the future UAM mode of transport [2],[15],[16] while the maximum range depends on the operating vehicle. Shamiyeh et al. published an overview of current VTOL concepts and technical demonstrators with a range variation for electric VTOLs between 27 km and 370 km [17]. Various approaches have been implemented such as Grandl et al. who analyzed travel time savings for car trips in Munich below 40 km and 45 min compared to potential VTOL trips, Holden and Goel conducted a sensitivity study for Los Angeles and London on Uber long-haul data with a variying number of vertiports [15],[2]. The results showed advantageous travel time savings for Munich for distances longer than 20 km and using UAM instead of a car, while the calculated route average of about 50 km (30.4 miles) for Los Angeles and 42 km (26.0 miles) for London were identified as time advantageous routes. The range depends on various factors, such as the urban structure, the distribution of places of residence and work, the availability of public transport, and the average commuting time for an area. UAM can therefore be a complementary service for all trips above a certain city- or region-specific range. This ranges from 20 km to 50 km in the studies mentioned above. This leads to the conclusion that in addition to the limited range, a minimum distance should also be taken into account in order to be able to draw conclusions about relevant UAM routes based on the existing demand. The next section describes the steps and methods used in this work to identify possible locations and networks based on empirical data.

| Symbol | Name | Description |
|---|---|---|
| **S** | Trip | Each trip from the mobility survey data was assigned a unique trip ID before the data was aggregated. The information which IDs have been used for what level of aggregation was kept to be later able to use the information on the 500m or 1km grid cells where applicable. |
| $\chi$ | Extrapolation Value | Each trip in the data set is representative for a number of trips undertaken by the entire German population. The extrapolation value expresses this relation and is part of the data set. |
| **G** | Origin and destination grid cells | For each trip the origin and destination is given in the form of a 5x5 km grid cell. For some origins and destinations a higher resolution of 1x1 km or 500x500 m grid cells are given. The grid cells are based on standard reference grids. [18] |
| **x,y** | Latitude and Longitude | These values are the centers of each grid cell and are used to calculate the beeline distances |

Table 1 – Variables Used

## 4. Methodology

The Federal Ministry of Transport and Digital Infrastructure in Germany conducts the survey Mobilitaet in Deutschland (Mobility in Germany) (MiD) on a regular base. The data used for this study was collected between May 2016 and September 2017 and provides insights into mobility patterns and transport mode choices of more than 156,000 German households [19]. Each respondent was asked to answer a questionnaire which consisted of three parts. In the first part the participants had to answer questions about their general mode of transport. The second as well as the third part concentrated on the trips done on the day the questionnaire was answered. A trip is defined as 'all distances covered on foot or by any means of transport on public roads' [20]. The way to and from a destination is counted as two trips. When the mode of transport was changed during one trip, it was still counted as one trip as the trip was not interrupted for an extended period of time. The result is a list of more than 960,000 trips including household information, geographical references, trip purposes, mode of transport and many more variables. From the list of trips the datapoints shown in table 1 where selected. In a first step a frequency value for each grid cell was calculated.

## 4.1 Frequency Value

Using the MiD data as a basis, the following section analyzes areas and routes that highly frequented and present promising locations for the introduction of a new mode of transport. As discussed earlier, the use of UAM under distances of 10km-30km does not appear resonable, and technical restrictions of current design models limit the maximum operating distance to values between 27km and 370km. For the purpose of this paper, the following assumptions were made and all data sets were removed which do not meet the assumptions.

1. Following the analysis of Grandl et al. showing that UAM trips below an airline distance of 20 km are likely to be too short to provide value to the traveler [15].
2. Round trips as they do not add value to the identification of Vertiport locations and networks in the first step.
3. The chosen means of transportation was neglected for the first study. In subsequent studies, the mode of transport choice will considered to account for travel time advantages.
4. The direction of travel is irrelevant to the frequency value because only the magnitude of demand is relevant for an unidirected network.
5. Some of the reported trips had no connection to the rest of the network and have been eliminated from the future network.

With the remaining trip data, the frequency value, per grid cell was calculated as follows: The value for each grid cell $\chi_\mathrm{G}$ results as the sum of the extrapolation values (given in the data set) $\chi_\mathrm{i}$ for all incoming or outgoing trips $S$ divided by 2 as expressed in Equation 2. With this the value of incoming and /or outgoing trips has been averaged between the participating grid cells.

$$\chi_1 = S_1(A,B); \chi_2 = S_2(B,A) \tag{1}$$

$$\chi_\mathrm{G} = \sum_{i=1}^{n} \frac{\chi_\mathrm{i}}{2} \tag{2}$$

With the knowledge of which grid cells are highly frequented, to question of vertiport location can now be approached. For the location it is irrelevant if the frequency is based on incoming or outgoing traffic as stated in assumption 4. In a next step with the help of the clustering method *Natural Breaks* from *Jenks* provided as a basic function of *ArcGIS*, the grid cells are divided into 5 classes based on their frequency value. Figure 1 shows the 5 classes from lowest (class 1) to highest (class 5) grid cell frequency value. Based on this classification different scaled networks are constructed which will be described in the next paragraph in more detail.

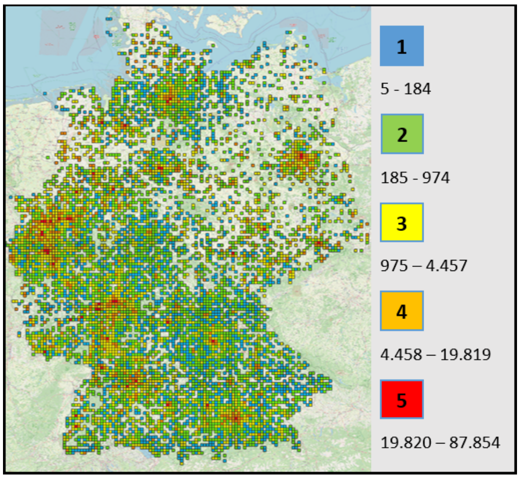


Figure 1 – Grid Cell Values for Germany

### 4.2 Network(s)

For the visualization, *ArcMap 10.6*, a Geographic Information System (GIS) software from *ESRI*, was used. Using Open Street Map as the base map and the projected coordinate reference system *WSG 1984* (Web Mercator Auxiliary Sphere), the underlying grid cells for 5km, 1km, and 500m cells were imported into *'ArcMap 10.6'* and visualized [21]. As identifier the unique grid cell names were used and each grid cell was assigned the calculated frequency value accordingly. As expected figure 1 shows that the high-frequency (red) areas are located within and around major cities. Since in this work the focus was on designing a network of vertiports for eVTOLS that have constraints on the possible mission distance, only connections with less than 120 km beeline distance were considered for the network creation. This limit was chosen because the beeline distance in our model is the distance between the centroid of the origin and destination grid cells, not the actual distance between the reported origin and destination. Each grid cell has the dimension of 5km x 5km, i.e. the real distance between origin and destination address can be +/- the diagonal dimension of a grid cell (7.1km). This restriction is only applied for the creation of the networks. For the calculation of the frequency values, all relevant data sets were considered as described in chapter 2. Since all trips less than 20km were removed from the dataset at the beginning, the trip distance of our dataset can now vary between a theoretical minimum airline distance of 13km and a maximum beeline distance of 127km, depending on where the trip started or ended within the grid cell. These approximations have been chosen in order to compare the work of this paper with other studies such as those in the OBUAM project [22]. Analogue to the described steps, two more networks were created including frequency classes 3 and 4 as can be seen in figure 2. The results obtained so far will be presented in the chapter 5.

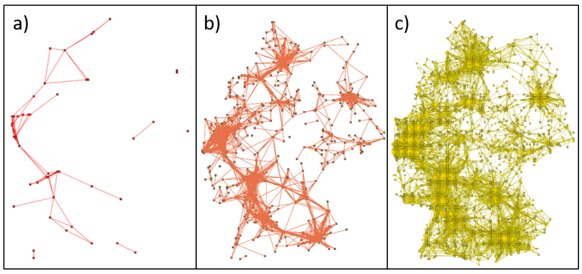


Figure 2 – Networks based on frequency values and respective connections

## 5. Results

In the previous sections it was described how frequency values were calculated, assigned, clustered and visualized from the trips data set. It was further explained how networks of highly frequented locations can be created. The different networks are constructed from the different classes of the frequency value. Starting with the network of grid cells of class 5, for each additional network the grid cells of the lower class are added. Thus the network grows with decreasing frequency values as visualized in figure 2 a, 2 b and 2 c. For some of the trips, the origin and/or destination was reported with a high accuracy; at street level or sometimes even at house number level. Therefore it was possible to determine the geographical location of the demand more precisely. The following example shows how the additional information from smaller grid cells of 1x1 km and 500x500 m can help to identify possible locations for vertiports. For the example in figure 3 a highly frequented network in the west of Germany was selected. Within the network the grid cell around Cologne was chosen as the center of this network. With the help of the detailed information for the 1km and 500m grid cells concrete physical location of a vertiport was chosen semi-quantitative as input for a method to estimate size and throughput of vertiports, which will be described in more detail in the next chapter.

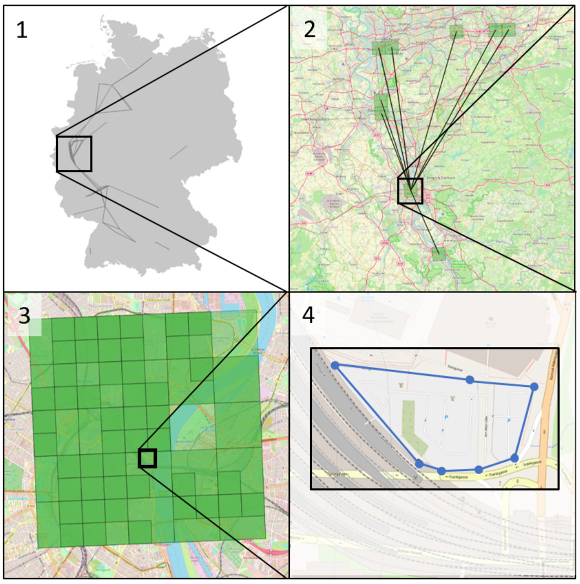


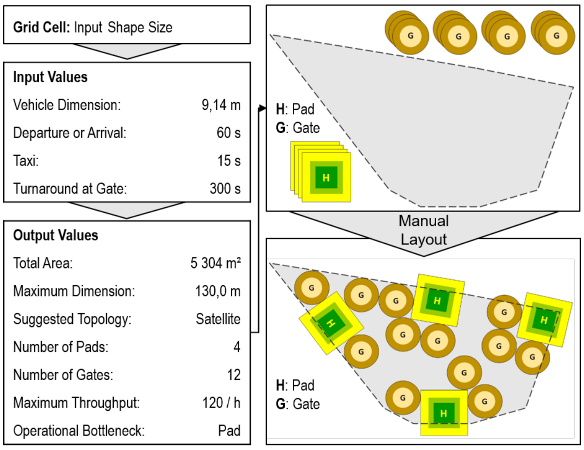
Figure 3 – Detailed analysis per Grid Cell

## 6. Vertiport Sizing and Layout Design

So far this paper introduced a method with which transportation networks can be derived from mobility survey data in Germany. A network of highly frequented origins, destinations and their respective connections gives indications for promising vertiport locations. Once a grid cell is identified, a concrete location can be selected on the basis of semi-quantitative expert judgement. Factors influencing this selection encompass among others the following: proximity to transportation hubs for multimodal transport, distance to living quarters to reduce noise impact, free space for construction, direct accessibility of train tracks or highways to avoid flying over pedestrians at low altitude, etc. The method of choosing concrete vertiport locations, estimating throuhgput capability and designing surface layouts is presented in detail by Preis [23].

To illustrate the capability of the vertiport sizing method, a car parking area near Cologne main train station was selected as use case (see figure 3).

The selected coordinates were exported from GIS and passed on to *MATLAB*. The maximum possible throughput for various different layouts is calculated and design recommendation are given. Among these recommendations are the suggested topology, number of pads and gates; further an estimation of maximum possible throughput and the excepted operational bottleneck. This information is the loaded into a GUI to create an optimal and concrete vertiport layout. This process is visualized in figure 4.



**Grid Cell:** Input Shape Size

| **Input Values** | |
|---|---|
| Vehicle Dimension: | 9,14 m |
| Departure or Arrival: | 60 s |
| Taxi: | 15 s |
| Turnaround at Gate: | 300 s |

| **Output Values** | |
|---|---|
| Total Area: | 5 304 m² |
| Maximum Dimension: | 130,0 m |
| Suggested Topology: | Satellite |
| Number of Pads: | 4 |
| Number of Gates: | 12 |
| Maximum Throughput: | 120 / h |
| Operational Bottleneck: | Pad |

Figure 4 – Steps of vertiport sizing and layout design as presented by Preis [23]

## 7. Weakness and Future Research Ideas

One of the weaknesses of the proposed GIS-based approach is the use of pre-processed mobility survey data, i.e. the lack of raw data and consequently the lack of detailed origin and destination information. There is no way for the authors to verify that the reported trip origins and destinations are correctly applied to the grid cells. For privacy reasons, the raw data had to be geographically aggregated so that no inference could be made about the individual respondant. In addition, there was no requirement for survey participants to provide exact origin and/or destination addresses, so only rough information on spatial distribution is available. In further studies, these inaccuracies must be taken into account accordingly and, if necessary, compensated for by enriching them with additional information. It would be conceivable to include additional information such as the spatial distribution of inhabitants, households or workplaces. Another weakness is the lack of evaluation of the identified sites with respect to building, environmental, or legal regulations. This will be considered in subsequent studies.

In the next step, it is planned to consider the previously hidden driving directions in the networks. For all networks, the directional information for the aggregated trips was kept, which allows to draw conclusions about imbalances or equilibria. In addition, it will be investigated where network support points are located, which on one hand allows for further routes with intermediate stops and on the other hand provides the basis for an evolutionary network. Another idea is to analyze competing modes based on travel time and evaluate travel time savings. The idea is to identify areas where travel times will be significantly shorter with UAM than with conventional modes of transport, similar to the analyses of Al Haddad et al. [4] or Rothfeld et al.[24]. The UAM network connections should be compared with the existing road and public transport networks, and arrival and departure times must be considered, as well as the corresponding timetables and routes.

## 8. Acknoledgement

The author wants to thank the Federal Ministry of Transport and Digital Infrastructure for the provision of the data source: MID 2017 B3 local ways and the opportunity to work with these.

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## 10. Copyright Statement

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