Scenario-Based Urban Air Mobility Demand Forecast

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Increased roadway congestion and urbanization have led to renewed interest in exploring more efficient modes of transport, particularly in urban air mobility (UAM) concepts which can attenuate congestion effects. A precise understanding of UAM demand is crucial for stakeholders, public planning agencies, and manufacturers to facilitate the services and infrastructure required for UAM's entrance into the market. In a previous study, the authors developed a top-down methodology for global UAM demand estimation. The current study extends the methodology further to forecast UAM demand at the geographic region level and city level in specified future scenarios from 2035 to 2050. UAM forecast results are presented for six geographic regions around the world and the top five cities with the highest demand in each region are identified. Given the nature of future uncertainties in regards to consumer preferences, this work presents forecast results across three consumer adoption scenarios to better reflect the bounds of UAM demand under varying projected circumstances.

I. Introduction

URBAN Air Mobility (UAM) is a progressively developing concept that has the capability to transport passengers and goods in urban areas. UAM employs the concept of vertical take-off and landing (VTOL) or short take-off and landing (STOL) to operate and contributes towards reducing some percentage of roadway congestion. An accumulation of

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economic potential and population in the urban or metropolitan areas results in the occurrence of extensive transportation requirements in spatially limited areas. When these requirements are encountered at the same time, congestion manifests itself. In a disaster or crisis, congestion is a major bottleneck that could restrict the enactment of the crisis or disaster response [1].

The intensity of traffic congestion has become a severe issue in many global cities [2]. A progressive reduction in traffic speeds results in a surge in trip times, fuel consumption other operating expenses, and environmental pollution in comparison with an uninterrupted traffic flow [3]. In 2017, roadway congestion around urban areas in the United States caused 8.8 billion hours of travel time delays and 3.3 billion gallons of wasted fuel, leading to a congestion cost of $166 billion. The congestion cost in the United States is expected to grow by 20% by 2025 from the 2017 congestion value [4]. INRIX trip analytics state that the most congested 25 cities of the United States may cause the commuters or drivers a cost of ~ $480 billion due to wasted fuel, time lost, and carbon emissions during congestion. This dispossession is significantly affecting the global economy. To address the serious issues related to the congestion and its associated pollution which causes a sudden growth in carbon emissions, the transportation industry must develop and switch to novel modes of transportation, including UAM at a faster pace than ever before.

UAM concepts have been pursued in literature since the 1950s but previous UAM endeavours focused on helicopter-based passenger services that did not achieve long-term viability due to fatal accidents, economic challenges, and noise restrictions. However, with the advancement in technologies during the past few decades, UAM services can be a potential commuting option for inter and intra-city trips. Certain aspects of eVTOL design and their requirements have become more concrete in recent years [5, 6]. The newly developed UAM technologies can bring fast, secure, and more comfortable trips from origin to destination. In 2016, Uber proposed the use of distributed electronic VTOL concepts UAM vehicle flying in major urban areas [7]. The recent market report by Booz Allen Hamilton (BAH) suggests that more than 70 investors, manufactures, suppliers, operators, and government have invested over $1 billion in UAM technologies and have a vision of competing in the potential multi-billion-dollar market [8, 9]. The industry needs to understand the potential demand to enable data-driven decisions concerning investment transcendence. On the other hand, governments must evaluate the environmental impact of potential UAM operations and check their compliance with the emission standards. Consequently, a precise understanding of UAM demand is foremost to empower economic growth.

In a previous study by authors [10], a top-down methodology was developed and implemented to forecast the global demand for UAM services for a set of 542 global cities viable for UAM operations during the 2035 to 2050 time period. The population of a city and its economic indicators were considered as the most relevant factors to identify cities viable for UAM operations. The global-level results of that implementation suggested that a strong market demand exists for a range of UAM ticket prices and vertiport network density for each forecast year between the 2035 to 2050 time period. The current research aims to improve the granularity of the previous study by forecasting the demand for UAM services on a region and city level. Three different scenarios with more representative consumer-based assumptions are employed to forecast the UAM demand from the 2035 to 2050 time frame. The first scenario is named as Early Adopters; this scenario presumes to offer the UAM services to ultra-high net worth (UHNW) individuals or those individuals who value their time more than cost, the value of travel time savings (VTTS) for both personal and business trips are considered higher for Early Adopters scenario. The second scenario called Mainstream Adopters aims to offer services to a middle-class population who does not value their travel time savings as high as the Early Adopters scenario. Furthermore, the mainstream scenario assumes a degree of technological advancement in the UAM vehicles, the scenario assumes a matured infrastructure and market conditions. While the first two scenarios' ideals are inclined towards technical advancement and social acceptance of a novel class of services, the third scenario emphasizes reducing global carbon emissions on the environment. A set of different assumptions are carried out in each scenario to determine their outcomes in the future time frame. Detailed scenario definition and assumptions are provided in section IV.

II. Background

There are many technical and non-technical challenges to successful UAM operations. Non-technical challenges correspond to the regulatory and certification issues, competition from existing modes of transportation, infrastructure needs, viable business case, and social acceptance. On the other hand, technical improvements include improvement of battery technology, safety and security, weather concerns, environmental impacts, cruise speeds, range, payload, and more. A lot of technological advancements have been made in the past few years to address some of these hurdles [11]. The design requirements and constraints for the UAM services are widely explored in the literature. Based on the seating capacity and speed of UAM vehicles a general overview of UAM vehicle configuration is provided by [12] and [13]. Other work provides system-level modeling of the viable UAM network and investigates constraints related to energy, for instance, battery life of eVTOL aircraft along with charging stations which are a part of infrastructure [14]. A conceptual explanation of methodologies for enabling the integration of on-demand operations with existing commercial transportation is presented in [15].

Some market consulting companies have provided limited context and estimation for the size of UAM globally. Their estimates are subjected to varying assumptions and different methodologies. However, the market reports do not reflect their methodologies transparently hindering third-party validation of their salient outcomes. Additionally, the scope of implementations is restricted to a small set of cities [16, 17]. A NASA funded market study by Booz Allen Hamilton (BAH) evaluated the demand by calculating the total number of trips that can be captured by UAM. The first step involved the identification of total trips in each urban area that is further categorized based on trip type and mode type. Then, existing infrastructure is outlined, and a gravity model of origin-destination trips is generated to identify the percentage of trips that provide travel time savings. In the end, willingness to pay, infrastructure capacity, time of day, and weather constraints are applied [8]. A paper by [18, 19] recommends that the hourly demand of passengers carrying

UAM vehicles could be around 2,500 by the year 2035 for a city like Paris.

Recently, a handful of other literature employed an agent-based simulation to forecast the demand of UAM for the year 2030 for one or two cities [20–22]. All these research findings suggest that kilometer based price of UAM services have a substantial impact on the growth of UAM services.

The existing literature and market reports by consulting companies suggest that there is abundant demand for UAM services. An accurate estimation of demand at the individual city level is crucial for the city planners, policymakers, regulators, and manufacturers. This study aims to evaluate the demand for UAM services at a city and region level for a set of 542 global cities. This list of 542 cities viable for UAM operation represents 83 countries globally. For ease of implementation, the 83 countries are categorized into six geographical regions. Based on each geographical region annual UAM passenger trips, annual UAM passenger kilometers (PKM), annual UAM utilization, and annual UAM vehicle trips are computed. Furthermore, the top-five cities based on annual UAM PKM are identified, and an explanation of results for each region is provided.

A. Consumer Adoption of Novel Technologies

The adoption of a novel technology implies a condition in which society integrates, accepts, and initiates the use of a new technology concept. It is natural that not every individual will adapt to new or disruptive ideas despite potential benefits. UAM is a progressively developing concept, and large-scale consumer acceptance of UAM is important to the future of urban air mobility services. Technology adoption follows various stages which are generally categorized by the group of people who use that technology [23]. Rogers identified some interesting personality traits which facilitate an understanding of the adoption of new technology [24, 25]. Five segments of technology adoption in society are proposed following a normal distribution as shown in Figure 1. It should be noted that the numerical values associated with this normal distribution are not directly employed in this implementation. However, the identified adoption segments are utilized to cast more representative scenarios that better reflect consumer attitudes towards UAM services in the future.

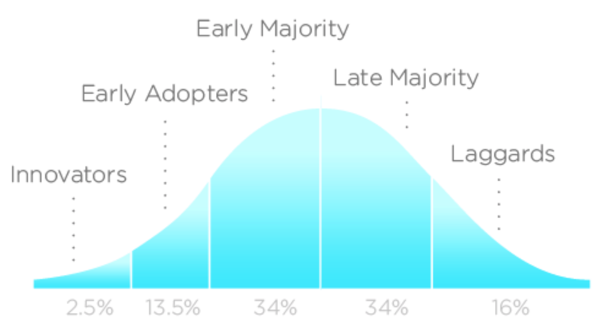


Fig. 1 Technology Adoption Life Cycle [26]

Technology Enthusiasts or Innovators are the first individuals to embrace innovative technologies, and they typically occupy a higher social class and possess financial strength. This category of individuals usually represents a population segment willing to take risks. The second segment of technology adoption is termed, Early Adopters. This segment of individuals is usually young possess financial stability and standard education. These categories of individuals are more discrete in adoption choices relative to Technology Enthusiasts. The third segment of technology adoption is called the Early Majority or pragmatists. This pragmatist section of the market adopts innovation as the technology starts to reach a stable phase. These individuals possess above-average social and income standards, they are exposed to the opinions of Early Adopters and most likely to follow their lead. The Early Majority contributes around 1/3rd of total market share. The Late Majority or conservatives comprise individuals who wish to adapt to innovation after the average member of society. These individuals approach innovation with a degree of skepticism and reach acceptance after the majority of society has adopted the innovation. The late majority are typically skeptical about innovation and may have below-average social and financial status. Laggards or Skeptics in the last category of individuals among the technology adoption phases. Individuals in this category show almost no preference to adapt to novel technological changes. This category of individuals is usually very older individuals who tend to be focused on traditional paradigms.

III. Methodology

A. Traditional Traffic Forecasting Approach

The Traditional Traffic Forecasting Approach employs a four-step traffic forecasting transportation model [27–29]. An illustration of four-step transportation model is shown in Figure 2.

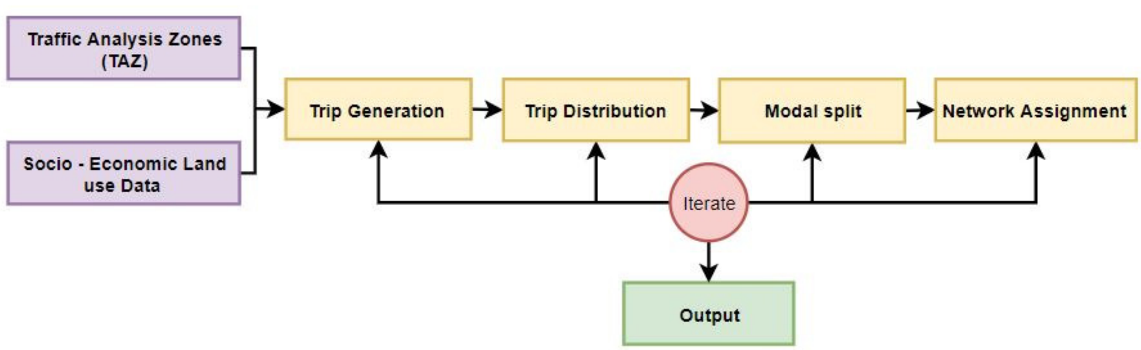
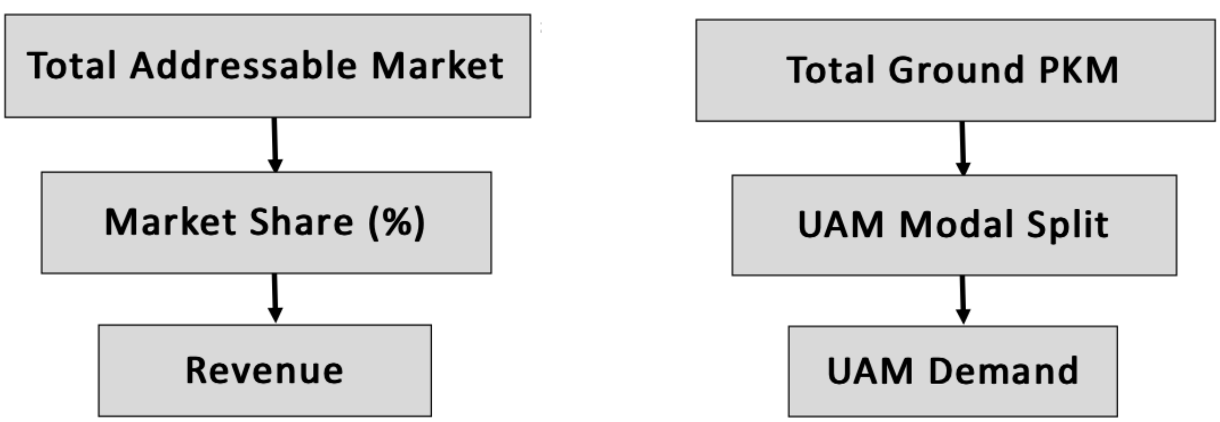


Fig. 2 Traditional Four-Step Transportation Forecasting Model

A prior understanding of traffic movement within the city boundaries enables city planners and public planning agencies to make informed decisions and keep the traffic flow in their control. The traditional four-step transportation model starts with segmenting into discrete traffic analysis zones (TAZ). Once the traffic analysis zone is created the land use and socio-economic data are needed. This demographics data helps to identify the number of trips originating i.e (origins) and the number of attractions i.e. (destinations) in any region. A gravity choice model is used to match trip origin and distribution. An extensive explanation of the four-steps transportation model is presented in previous work by the authors [30]. The traditional four-step transportation model cannot be implemented for the current research as the model requires comprehensive demographic data, calibrated equations, and a framework capable of evaluating the trip counts and modal splits. When addressing a global set of 542 cities in this implementation, there persist issues regarding the availability of data, budget, and resource constraints. For these reasons, a small number of cities were removed from consideration when accurate economic or transportation data was not available to avoid misleading results. However, the traditional four-step transportation model is used as a road map in developing a new approach.

B. UAM Demand Estimation Methodology

The authors have developed a generic top-down approach to estimate UAM demand for a global set of 542 cities. Top-down forecasting for a business traditionally begins with an estimation of the total addressable market (TAM). Then the market share, or percentage of the TAM which the business expects to capture, is estimated. By multiplying the TAM with the expected market share, a company or a service provider can calculate their expected revenue. A similar approach can be followed to estimate the demand for UAM. The total addressable market is the volume of traffic by ground-based transport that serves routes with ranges within the expected economic range envelope of UAM operations. Market share can be considered as a switching percentage; a certain percentage of the population will choose to use UAM as the mode of transport for a given trip instead of conventional ground-based transport. By applying this switching percentage to the TAM, the UAM traffic can be estimated. Figure 3 depicts an overview of the generic top-down demand forecasting approach for UAM.



(a) Generic Top-Down Approach **(b) Top-Down Approach Applied for UAM**

Fig. 3 Generic Top-Down Approach and Applied for UAM Demand Estimation

A key potential advantage of UAM services is the time savings achieved by UAM trips over conventional modes of transport. The authors devised an approach considering the inherent benefits of UAM without the need for traveler's behavior data [10]. A paper by Sirirojvisuth et al. suggests that if the traveler's willingness to pay (WTP) is greater than the price of the UAM trip, then the traveler will select UAM as their mode choice [31]. The willingness to pay can be evaluated as the total value of time saved during a trip plus the price of an alternate mode of transport. Mathematically, the WTP equation is computed as Equation 1.

$$WTP = VTTS(income, purpose) * Trip\ Time\ Saved + Trip\ Price\ of\ Alternate\ Mode \tag{1}$$

1. Urban Air Mobility Market Share Estimation

The evaluation of willingness to pay (WTP) for UAM services of a traveler to evaluate their mode choice decision is a credible and affirmative approach [31]. It is a function of the value of travel time savings (VTTS) an individual may place per unit time saved, the time savings of UAM by adopting UAM instead of alternate mode, and the cost of the trip using the conventional or alternate mode. VTTS is defined as a function of income level and the trip purpose. US Department of Transportation recommends that VTTS for personal trip ranges between 35% and 60% per unit time saved and for the range for business trips lies between 80% and 120%. Personal trips can be further segregated as trips for shopping, leisure, vacation, education, and others. Figure 4 demonstrates a notional illustration of VTTS.

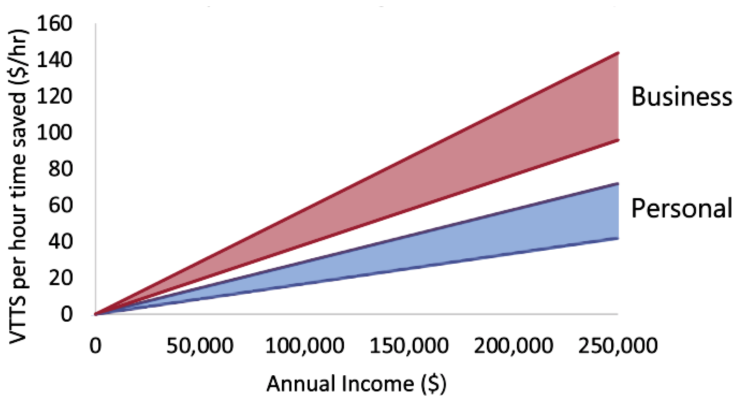


Fig. 4 Notional Illustration of VTTS

Equation 2 characterizes the decisive conditions for an individual to select UAM as their mode of transport instead of conventional or alternate modes.

$$Price_{UAM}(d) \leq WTP = Price_m(d) + VTTS(income, purpose) * (Time_m(d) - Time_{UAM}(d)) \tag{2}$$

On evaluating this function across the entire range and values for distance, income and trip purpose, a set that enables UAM travel is identifiable.

$Price_{UAM}(d)$: The trip price for UAM is the summation of the prices associated with access trip, actual flight, and egress trip distances. Mathematically, UAM ticket price is written as shown in Equation 3

$$Price_{UAM} = Price_{access} + Price_{flight} + Price_{egress} \tag{3}$$

$Price_m(d)$: The current cost of operating a personal vehicle in the US is assumed as \$0.37/km [32]. The inter and intra-city price of an alternate mode using bus or metro for a global set of 542 cities is very challenging. To reduce the dimensionality, the intra-city ticket price for all the countries in a region is gathered and an averaging is performed over those costs to account for intra-city trip prices. A detailed explanation of estimating the alternate mode trip prices for both inter and intra-city is discussed by authors in prior works [10]. The global averaged inter and intra-city bus ticket costs are considered as \$22.70 and \$1.20 respectively. To account for the parking costs for a personal vehicle a global averaged four-hour parking cost is considered. The parking cost for all the capital cities for 83 countries is gathered from Parkopedia [33]. An averaging is performed on the global parking charges and a further four-hour parking cost is added to support accounting of total trip cost by alternate modes of transportation. The selection of four-hour parking cost is incorporated via the suggestions from the subject matter expert's from German Aerospace Center (DLR). The four-hour global averaged parking cost is \$7.48.

$Time_m(d)$: This is the time of a trip of distance 'd' using an alternate mode 'm'. The trip time for each mode (personal vehicle and public transit) is estimated as a function of distance by using either an assumed average speed or a speed curve which varies with distance. The time of the day impacts, for instance, rush hour traffic vs free-flow traffic adds up a significant complexity and is not considered in the research. As a substitute average speed across the entire day is considered. The speed regression model is built to fit the data to enable the analysis.

$Time_{UAM}(d)$: The concept of operation for current research assumes UAM as a multi-mode travel option. A traveler must take some secondary mode of transport (ride-share) to arrive and depart from the origin and destination vertiports. The entire journey time from UAM is aggregated as the time to access, time to board, time for actual flight, time to de-board, and time to egress. Mathematically, Equation 4 can be written as following.

$$T_{UAM} = T_{access} + T_{board} + T_{flight} + T_{de-board} + T_{egress} \tag{4}$$

Several other metrics as such household income distribution which acts as important economic indicators of individuals within each city, modal split, purpose split are elaborated in detail in the previous work by the authors [10, 30].

2. Urban Air Mobility Total Addressable Market

The total UAM PKM is estimated as a function of individuals income, trip distances, trip purposes, and trip modes, as shown in Equation 5.

$$PKM_{UAM} = PKM_{tot} * s_m * s_p * (CDF_{TD}(d_2) - CDF_{TD}(d_1)) * (CDF_{inc}(inc_2) - CDF_{inc}(inc_1)) \tag{5}$$

In Equation 5, s_m is the share of trips associated with mode m; s_p is the share of trips associated with purpose p; CDF_{TD} is the cumulative distribution function (CDF) of trip distance; and CDF_{inc} is the CDF of household income [30].

To bring together each of these data sets, each set is considered as independent of the other i.e. to say trip distribution, modal split, trip purpose split, and income distribution do not vary w.r.t each other.

C. City Identification for UAM Viability

Since the focus of the study is to forecast the UAM demand from the 2035 to 2050 time period; population and economic indicators of cities during the above-mentioned time interval are used as a filtering parameter to select more than 500 global cities viable for UAM operation. Publicly available city-level population data is sourced from Demographia [34]. The source provides a ranking of 1,073 cities globally based on the population of the year 2019. A population growth percentage is employed to forecast the population data for 2019 until 2050. The gross domestic product (GDP) of a city is considered as the second parameter to select cities viable for UAM operation. A proprietary data source 'IHS Markit's Global Insight' is used for economic data [35]. A population filter of 1 million and a GDP filter of 5 billion for 2019 (current year) and 100 billion for 2050 (forecast year) is applied which in-turns to have 535 global cities viable for UAM operation. Additionally, seven cities are added to incorporate the subject matter expert's suggestion of the German Aerospace Center (DLR) as those cities represent sizeable touristic attractions. The selected 542 cities represent 83 countries globally, and the 83 countries are categorized into six geographical reasons to execute region-level demand estimation for UAM services from 2035 to 2050. Table 1 represents the distribution of countries for six different geographical regions.

Table 1 Regional Distribution of Countries

Asia	Europe	North America	South America	Africa	Pacific
Azerbaijan	Austria	Canada	Argentina	Algeria	Australia
Bangladesh	Belarus	Chile	Brazil	Egypt	New Zealand
Cambodia	Belgium	Costa Rica	Colombia	Ghana	
China	Bulgaria	Cuba	Ecuador	Morocco	
India	Croatia	Dominican Republic	Praguay	Nigeria	
Indonesia	Czech Republic	El Salvador	Peru	South Africa	
Iran	Denmark	Guatemala	Uruguay	Tunisia	
Iraq	Finland	Mexico			
Israel	France	Panama			
Japan	Germany	United States of America			
Jordon	Greece				
Kazakhstan	Hungary				
Kenya	Italy				
Kuwait	Ireland				
Lebanon	Luxembourg				
Malaysia	Netherlands				
Myanmar	Norway				
Oman	Poland				
Pakistan	Portugal				
Qatar	Romania				
Republic Of Korea	Russia				
Saudi Arabia	Serbia				
Singapore	Spain				
Sri Lanka	Sweden				
Syria	Switzerland				
Thailand	Ukraine				
Turkey	United Kingdom				
United Arab Emirates					
Vietnam					
334 Cities	77 Cities	83 Cities	30 Cities	12 Cities	6 Cities

1. Clustering Procedure

After the set of 542 cities viable for UAM operation during the forecast timeline is identified, the next step is to merge cities with similar characteristics. Several clustering approaches are studied during the research and the K-means clustering algorithm is selected to enable some dimensionality reduction so that just a handful of cities require to analyze. An exhaustive description of the various clustering approach is discussed by the authors in prior works [10]. K-means algorithm is one of the most prominent and popular unsupervised machine learning algorithms to solve clustering problems [36]. Land area, population density, GDP of the city for the current year (2019), and GDP of the city for the forecast year (2050) are the four descriptors selected to cluster the city-data. The clustering is performed using a statistical software program JMP. This tool facilitates ease in data visualization, data filtering, simulation, and statistical modeling. Furthermore, JMP aided the authors to select the optimal number of clusters needed to merge cities with congruent attributes. The statistical tool JMP suggested 22 as the optimal number of clusters, subsequently, a representative city in each cluster is selected. For a single city cluster, the city itself is considered a representative city while for a multi-city cluster the representative city is the city with metrics that are closest to the statistical centroid of the cluster (assuming equal weighting of all attributes). For the cases where a representative city is numerically indistinguishable, the subject matter experts' suggestions from DLR and Georgia Tech were incorporated to select the representative city in each cluster.

IV. Implementation

In this section, three different scenarios considered for the implementation are defined and their related assumptions are explained. Additionally, a summary of the concept of operation (CONOPS) is also provided in section IV.B. Please refer to previous work by authors [30] for detailed explanation of CONOPS.

A. Scenarios for UAM Forecast

Scenarios planning is a flexible approach to make long-term plans. Airbus and a German car manufacturer Audi have formalized a partnership to develop an on-demand helicopter service (Voom) in cities like São Paulo (Brazil), Mexico City (Mexico), and San Francisco (USA). These cities typically have a higher congestion level index and the public transportation system is execrable. An introduction of a novel class of transportation service via UAM can be an enormous step towards suppressing the problems related to congestion. Nevertheless, social acceptance of UAM services is very crucial for its long-term success. A large number of uncertainties exist while introducing an unconventional mode of transport into the market. To address the uncertainties related to the future market prospects of UAM services, three different kinds of scenarios are considered in this research to forecast the regional and city level UAM demand from 2035 to 2050 period over an interval of five years. Each of the scenarios is defined in the following section and assumptions for each scenario are also explained.

As discussed in section II.A, the adaptation of a novel technology follows five major phases i.e. Innovators, Early Adopters, Pragmatists, Conservatives, and Skeptics. Having the technology adaptation pattern in mind current research proposes three distinct scenarios to capture the entire phase of adaptation and uncertainties related to the introduction of UAM services. The three scenarios are named Early Adopters, Mainstream Adopters, and Green 2050. All three scenarios and their assumptions are considered for the forecast years from 2035 to 2050 at an interval of five years. It should be noted that the use of these scenario names is not intended to reflect a specific timeline for the adoption of UAM scenarios. Rather it indicates the attitudes of the consumers assumed to be utilizing UAM services in the given scenario, and this consumer mindset is then used to characterize the scenario assumptions in Table 2.

1. Early Adopters

Early Adopters scenario considers the availability of UAM services mostly for ultra-high net worth individual (UHNW) individuals or those individuals who value their time more than income. The value of travel time saving (VTTS) is estimated as a function of an individual's income and trip purpose. Trips for the business place a much higher value on time-saving than personal trips. As per the guidance of the US department of transportation, [37] VTTS for personal trips can vary in a range of 35 to 60% while for business trips VTTS varies in a range of 80 to 120%. This scenario assumes a VTTS of 60% for personal trips and 120% for business trips. The scenario assumes non-robust technical specifications of UAM vehicles and a non-matured infrastructure to facilitate the demand for UAM services. Owing to these assumptions the Early Adopters scenario may only attract a small percentage of the population having greater financial strength. The numerical values considered to execute all three scenarios are presented in Table 2.

2. Mainstream Adopters

The Mainstream Adopters scenario assumes an advancement in the technical specifications of UAM vehicles. As the vehicle level specifications are improved UAM can offer services to longer distances at higher cruise speeds, the advancement in technology would enable the UAM service to attract greater percentages of populations to avail its services. Once a higher percentage of the population are attracted to UAM services, UAM would start to compete with traditional modes of transportation. Individuals would be willing to utilize the UAM services even if the UAM service offers the slightest VTTS than the traditional modes of transport. Thereby, a VTTS of 40% for personal trips and 100% business trips is considered in the Mainstream Adopters scenario. This scenario assumes that the city infrastructure such as the optimal location of vertiports, battery charging facilities, and many more are well established to facilitate the demand arising in this scenario. Compared to the Early Adopters scenario a larger number of vertiports are considered in this scenario.

3. Green 2050

As the name suggests, the Green 2050 scenario emphasizes a strong focus on the environment. During the past few decades, there has been significant growth in the aviation industry the growth in aviation is linked with the increasing percentage of CO_2 emissions. Globally many countries have signed environmental agreements including a treaty to reduce the CO_2 emissions by 50% by the year 2050 [38]. A report by the EU transport emission department demonstrates that over $\sim$ 70% of carbon emission is directly produced by roadway vehicles [39]. To achieve a significant reduction in CO_2 emissions individuals switch to UAM transportation services.

In this scenario, city-planners or the government should encourage the population to utilize UAM services and provide some subsidy on the ticket prices for UAM services due to their low environmental footprint. A positive step by the government and city planning agencies can augment the demand for services significantly. To facilitate the demand having a better infrastructure than Early Adopters scenarios is a prerequisite for the Green 2050 scenario. The optical placement of vertiports within city boundaries is crucial so that the services are better realizable to city populations.

The Green 2050 scenario assumes better infrastructure for the vertiports and as well as its optimal utilization. The creation of more than the required number of vertiport is not a plausible option for this scenario, as the development of vertiports usually requires some sort of degradation of natural resources. The key emphasis of this scenario is to have a minimum carbon footprint in the environment and optimize the use of available infrastructure. From a technical perspective, it is assumed that UAM will operate at a very high load factor. The boarding time in this scenario is considered slightly higher than the other two scenarios as the pilot may have to wait for more passengers to embark inside the UAM vehicle before take-off. The VTTS is considered as 35% for personal trips and 80% for business trips. Technological advancement such as speed, range, and seating capacity is also assumed to be in improved conditions than the Early Adopters scenario. In this scenario, the UAM ticket price matrix is evaluated on a range of $0.1 per pax km to $5 per pax km.

Table 2 Scenario Assumptions for UAM Demand Estimation

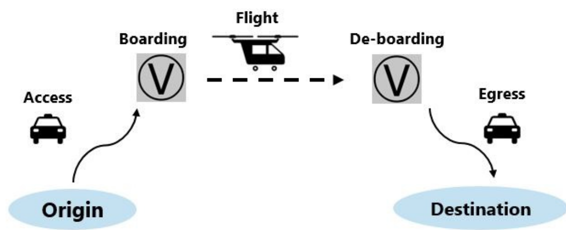
UAM Demand Drivers	Early Adopters	Mainstream Adopters	Green 2050
Average speed of UAM vehicle (km/hr)	80	150	110
Range (km)	60	80	120
Seating capacity	2	3	5
Boarding time	5	8	10
De-boarding time	2	4	4
VTTS (Personal, business)	60%, 120%	40%, 100%	35%, 80%
Vertiport network density	300	120	200
Base fare ($ per trip)	10	5	0
UAM ticket price ($ per pax per km)	2.5 to 10	0.5 to 7.5	0.1 to 5

B. Urban Air Mobility Concept of Operations

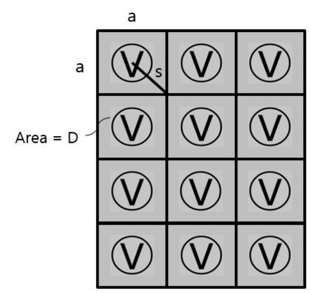
UAM is a multi-mode travel option where an individual or traveler has to use a secondary mode of transport to start his trip and reach to the nearest vertiport. The distance from the origin to the nearest vertiport location is termed as access trip distance. A ride-share option is considered for the access trip distance. As the potential user or traveler reaches the vertiport, the traveler passes through the security check and boards the air taxi. The UAM is expected to fly at a constant cruise speed of 80 km/hr in the Early Adopters scenario, 150 km/hr for the Mainstream Adopters scenario, and 110 km/hr for the Green 2050 scenario. Once the air taxi reaches the destination vertiport, the traveler de-boards and exits the station. Further, the traveler uses another ride-share option to reach their final destination. The distance from destination vertiport and traveler actual destination is termed as egress trip distance. Both the access and egress trip distances (d_v) are calculated as a function of vertiport network density. Assuming a grid-like distribution of vertiports, average access, and egress distance is considered as 2/3rd of the maximum distance to a vertiport. The total UAM trip distance (d_t) is calculated as twice the d_v i.e. access and egress distance to vertiport plus UAM actual flight distance (d_{flight}). Mathematically, it can be written as Equation 6.

$$d_t = 2 * d_v + d_{flight} \tag{6}$$

Early Adopters scenario assumes one vertiport every 300 sq. km of city boundaries, equating to roughly six vertiports within a city like London that has a land area of roughly 1800 sq. km. The CONOPS for the current research is depicted in Figure 5a.



(a) Concept of Operation for UAM



(b) Grid Like Distribution of Vertiport

Fig. 5 Concept of Operation for UAM & Grid Like Distribution of Vertiport

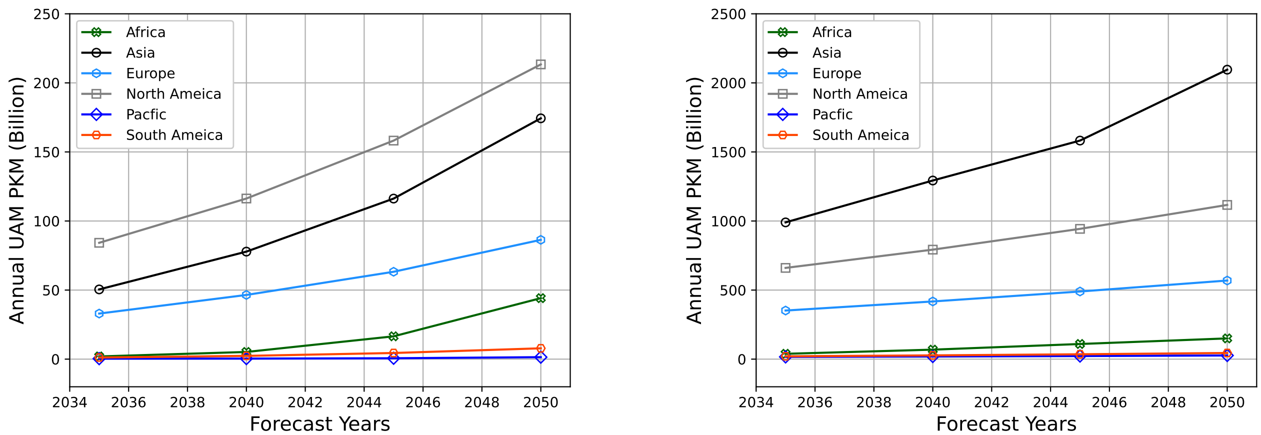
V. Results

This section presents the results of the implementation of a geographical region and city-level. First, the implementation outcomes at the region-level for the Early Adopters and Green 2050 scenario are presented. The outcomes for the Mainstream Adopters scenario are omitted for brevity as the demand estimates follow a similar trend as the Green 2050 and Early Adopters scenario. A table is presented to demonstrate the UAM demand outcomes for all three scenarios for all the forecast years.

Next, the top-five cities in each region are identified based on UAM demand estimates in terms of annual UAM PKM. Several tables are presented for each scenario to display the demand in terms of UAM passenger trips and UAM PKM. The annual UAM utilization and annual UAM vehicle trips follow a similar trend as UAM passenger trips.

A. Region Level Results for All Scenarios

The results of implementation in terms of annual UAM PKM for all the six geographical regions for Early Adopters and Green 2050 is shown in Figure 6a and Figure 6b respectively. The outcomes are plotted at the minimum ticket price considered in each scenario. Early Adopters scenario outcomes are plotted for a ticker price of \$2.5 per pax km while Green 2050 scenario outcomes are plotted for \$0.1 per pax km. BAH report found that ~ 55% of a price for a four-seat eVTOL are made up of indirect operating costs, infrastructure cost, crew costs, route cost, profit structure, and taxes, while the remaining 45% is made up of capital cost, insurance cost, battery reserve, maintenance, and energy costs [8]. The current study assumes only the first group of costs (indirect operating costs, infrastructure cost, etc.) that may be adjusted by the cost-of-living, while the remaining costs will be fixed across all markets. For simplicity, 50% of the UAM ticket cost respective to the US will be adjusted by the cost-of-living (COL) across other markets.



(a) Early Adopters Scenario

(b) Green 2050 Scenario

Fig. 6 Top-Five Cities With Highest UAM Demand in North America and Asia

The Early Adopters scenario assumes pre-mature market conditions, the UAM services in this scenario could only persist if UAM services can have the potential to provide substantial time savings i.e. VTTS is considered sufficiently higher. Considering that, only a small percentage of the population could afford UAM services. This phenomenon is well reflected in Figure 6a. A total of 334 and 83 cities are considered for analysis in Asia and North America geographical regions respectively. Even though the number of the city for analysis in Asia is approximately four times higher than in North America the demand estimates in terms of regional annual UAM passenger trips in greater in North America compared to Asia. This phenomenon is expected because cities in the North American region possess a much higher GDP than cities in Asia. Asia is ranked second in the Early Adopters scenario in terms of annual passenger trips and this ranking is influenced by a larger number of cities viable for UAM in Asia compared to any other geographical region. Europe carries the third-ranking after Asia and North America; Europe is the third region with a higher number of cities considered for analysis and also the economic indicators of Europe are better than the rest of the other three regions. Africa is ranked fourth followed by South America as fifth and the Pacific holds the last (sixth) ranking. Only six cities in the pacific regions are considered for analysis. In the Mainstream Adopters and Green 2050 scenario annual UAM PKM for Asia is ranked first followed by North America, Europe, Africa, South America, and the Pacific. This trend is expected as Mainstream Adopters and Green 2050 scenario assumptions are inclined towards matured market conditions. In addition to that, the VTTS which is a function of trip purpose and individual's income is considered lower in these two scenarios compared to the Early Adopters scenario. An improved vertiport network densities are considered in Mainstream Adopters and Green 2050 scenario to facilitate the progressive demand for UAM services.

The annual UAM PKM for all the six geographical regions considered in research is presented in Table 3. The table depicts that the Early Adopters scenario which considers the scenario assumptions on the lower end but the higher value of travel time savings (VTTS) may have a lesser number of potential users. As the VTTS is considered significantly higher in this scenario compared to the other two scenarios, higher VTTS enables the UAM service to be affordable to only a smaller population having a higher income. This class of individuals is typically the go-to choice for ultra-high-net-worth (UHNW) individuals and executives of large companies, who are typically time-constrained and not money-constrained when traveling. The Green 2050 scenario assumes the lowest value for VTTS as the key objective of this scenario is to reduce the level of carbon footprint in the environment. The green scenario assumes an optimal utilization of infrastructures as a consequence of that maximum demand estimates are observed in this scenario. Additionally, the base fare is assumed as 'zero' in the Green 2050 scenario while for Early Adopters and Mainstream Adopters scenarios the base fare is assumed as \$10 and \$5 per passenger trip. This reduction in base fare for the Green 2050 scenario enables a higher percentage of the potential users which is well reflected in Table 3. The letter "B" in table heading represent regional UAM PKM in billion for aforementioned three scenarios.

Table 3 Region Level Annual UAM PKM Estimates for Three Different Scenarios

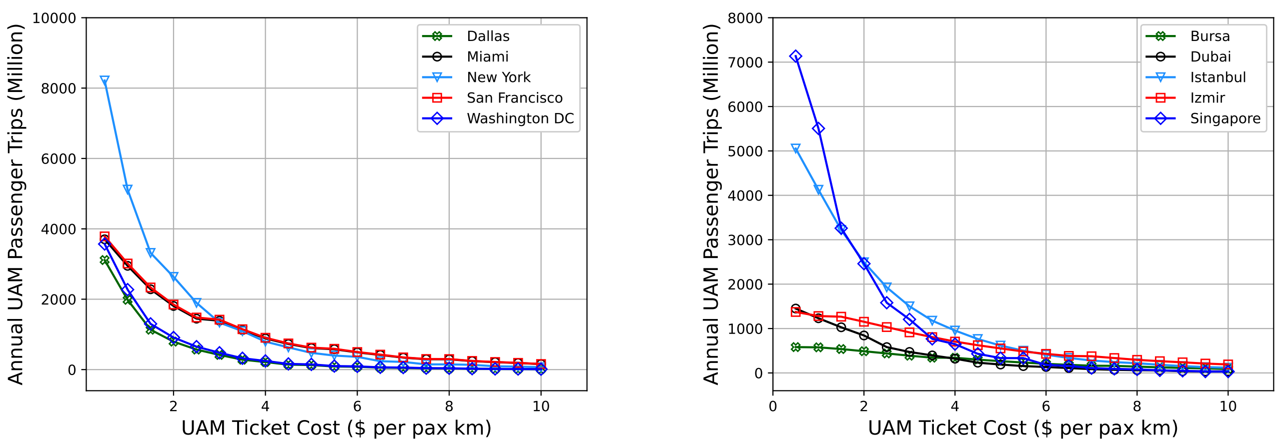
Scenarios	Regions	UAM PKM(B)$_{2035}$	UAM PKM(B)$_{2040}$	UAM PKM(B)$_{2045}$	UAM PKM(B)$_{2050}$
	Africa	1.95	5.19	16.52	44.15
	Asia	50.48	77.84	116.23	174.33
	Europe	32.99	46.47	63.25	86.36
Early Adopters	North America	84.22	116.27	158.20	213.37
	Pacific	0.36	0.41	0.65	1.43
	South America	1.18	2.36	4.45	7.84
	Africa	15.69	38.33	71.76	113.03
	Asia	444.86	626.34	737.93	960.60
	Europe	197.20	245.79	301.28	366.04
Mainstream Adopters	North America	308.74	395.90	499.45	625.15
	Pacific	4.55	5.96	8.05	10.73
	South America	7.28	11.53	17.23	24.52
	Africa	38.63	68.68	109.68	150.10
	Asia	990.02	1293.12	1582.21	2095.57
	Europe	351.82	417.59	489.68	569.04
Green 2050	North America	660.49	792.98	943.18	1116.39
	Pacific	16.29	19.15	22.49	26.57
	South America	20.56	27.30	35.26	44.52

B. City Level Results for Green 2050 Scenarios

The region-level results demonstrated that the UAM services will have the highest demand in the Green 2050 scenario for the forecast year 2050. The authors investigated the top-five cities with the highest demand for UAM services in terms of annual UAM passenger trips for each geographical region. The results for each geographical region are plotted and logical reasoning is provided. The results are plotted for a UAM ticket price ranging from \$0.5 per passenger-km to \$10 per passenger-km.

1. North America and Asia

The results for the top-five North American and Asian cities are shown in Figure 7a and 7b respectively. As per the results, New York is expected to have the highest demand for UAM services for the Green 2050 scenario in terms of annual UAM passenger demand. San Francisco is ranked as the second city in North America to have the highest demand, Miami carries the third-ranking followed by Washington D.C and Dallas as the fourth and fifth city respectively. All the above-mentioned cities in North America falls under the list of the largest urban agglomerations in North America and are the richest cities in terms of their economy (GDP). The average income per person is higher than most of the cities in the world. In the United States, most of the cities are facing an immense problem of traffic congestion that results in a higher amount of wasted fuel. Due to higher individual incomes in the United States, individuals from this region will likely be more willing to adopt UAM. Strong demand is noticed at a lower ticket price while the demand drops when prices are higher.



(a) Green 2050 Scenario (North America) **(b) Green 2050 Scenario (Asia)**

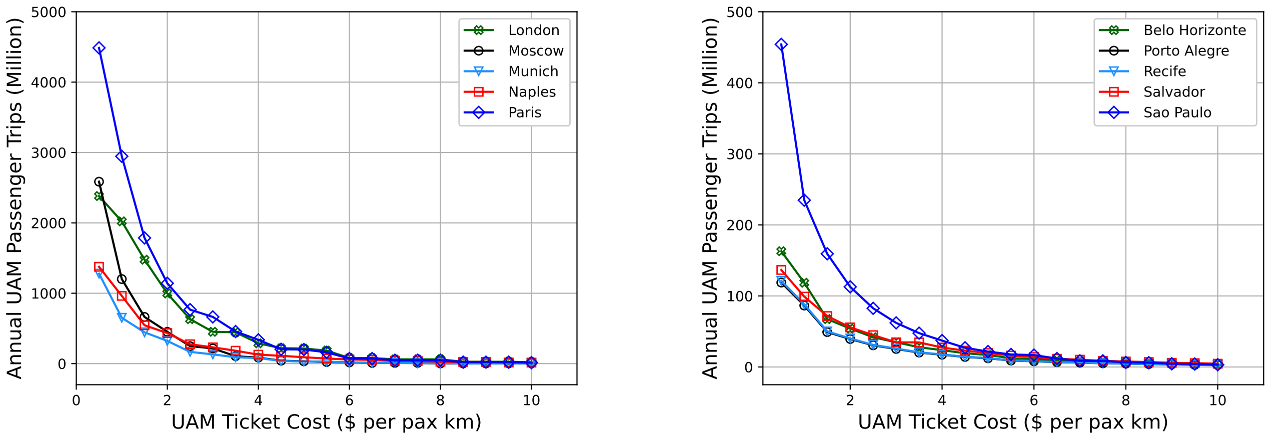
Fig. 7 Top-Five Cities With Highest UAM Demand in North America and Asia

The top-five cities in Asia that may have the highest demand for UAM services are shown in figure 7b. The results exhibit that Singapore may have the highest demands in terms of annual UAM passenger trips for the Green 2050 scenario. Singapore is one of the world's most prosperous cities, with a business-friendly regulatory environment and a very low unemployment rate. The outcomes show that Singapore has the highest number of UAM passenger trips for a ticket price ranging from $ 0.1 per passenger-km to $2.0 per passenger-km. After $2.0 per passenger-km Istanbul takes over the first ranking of Singapore. Istanbul is one of the world's largest cities by population and is one of the most important tourism spots in Turkey. There are thousands of hotels and other tourist-oriented industries in the city, catering to both vacationers and visiting professionals. Historically, Istanbul has been the center of the country's economic life because of its location as an international junction of land and sea trade routes. Izmir is the third most populous city in Turkey, after Istanbul, and the second-largest urban agglomeration on the Aegean Sea after Athens, Greece. Izmir is located in one of Turkey's most densely populated areas. Dubai and Bursa are ranked as fourth and fifth cities in Asia for the Green 2050 scenario that may have the highest demand. The land area and population density for Dubai are greater than Bursa that justifies to results for Dubai being the fourth and Bursa being the fifth city. The authors acknowledge that in the top-five cities, the cities from China and Japan are absent, the potential reason for this could be non-proprietary data sources for the household income matrix.

2. Europe and South America

Paris is ranked first to have the highest demand for UAM services in terms of annual UAM passenger trips in the Green 2050 scenario for the forecast year 2050, shown in Figure 8a. Paris and London are the most populous cities in Europe. The city of London has a developed network for bus and train lines than Paris that is still catching up. In terms of prices of alternate modes (bus, tram, metro), Paris is quite cheaper than in London. The alternate modes of transport in Paris is still in the developing phase and, if UAM services are introduced in Paris, it is expected that Paris may have a slightly higher demand for UAM than in London. Moscow has a higher population density than Naples which relates to the fact that the necessity for UAM services will be more for Moscow than Naples. However, at a ticket price of $2.0 per passenger-km, demand for UAM services is higher in Naples than in Moscow. This implies the fact that if UAM service providers, manufacturers, operators can work together and keep the UAM ticket price below $2.0 per passenger-km in Naples, the demand for UAM would be substantial. A large number of researchers have estimated the demand for UAM services in the city of Munich in Germany [20]. The cost-of-living of Munich is higher than in the capital city i.e. Berlin. The average per capita income of individuals in Munich is slightly higher than in Berlin. These factors provide legitimate reasoning to have Munich among the top five cities in Europe to have higher annual UAM passenger trips.

In some cities in South America, a company called Voom is already providing helicopter services. The Voom helicopter taxi service charges according to the distance and weight of the passenger. São Paulo is among one of the largest cities in Brazil and is one of the most congested cities in Brazil. The higher level of congestion in São Paulo enables the city to be ranked as the first city in South America that have the highest demand for UAM services. The other top-four cities Belo Horizonte, Salvador, Recife, and Porto Alegre are ranked as second, third, fourth, and fifth city respectively, to have a higher demand for UAM services in South America for the Green 2050 scenario. These four cities can accommodate the similar size of the population and follow similar trends in terms of demands i.e. to say at a ticket price below \$3.00 per passenger-km, an exponential jump is noticed for the UAM demand. The results of implementation for South America are shown in Figure 8b.



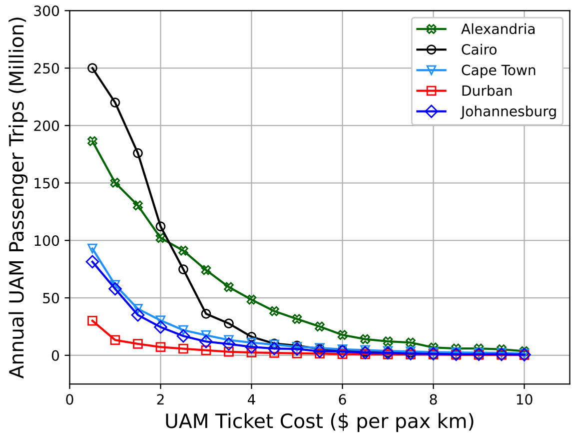
(a) Green 2050 Scenario (Europe) **(b) Green 2050 Scenario (South America)**

Fig. 8 Top-Five Cities With Highest UAM Demand in Europe and South America

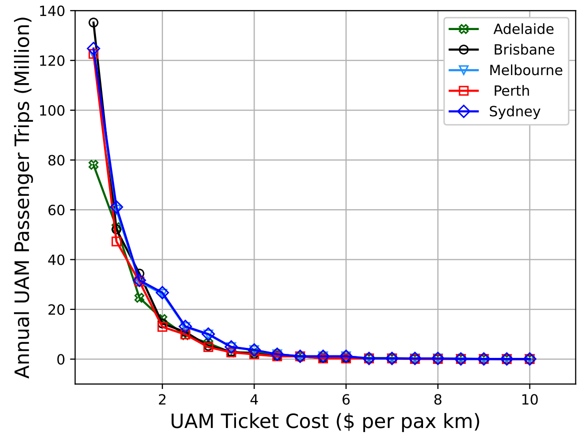
3. Africa and Pacific

In Africa, the city of Cairo in Egypt is expected to be the first city to have the highest demand for UAM services during the Green 2050 scenario for the forecast year 2050. Egypt is known for its tourist attractions, especially the Pyramids. Additionally, the transport system in Cairo comprises an extensive road network, rail system, subway system, and maritime services. Its metro network has been ranked as one of the fifteenth busiest in the world and to avoid congestion time, people will be more willing to pay to avail of UAM services. However, when the UAM ticket prices are higher i.e. more than \$3.0 per passenger-km, the demand drops for Cairo, and Alexandria may have to have greater demand. Alexandria (a city in Egypt) is a great center of trade and commerce in Africa. Alexandria being the second-largest city in Egypt and a major economic center validates its ranking amongst the top. Alexandria is a popular touristic destination; therefore, it does not make a strident decline in its demand for a UAM ticket cost from \$2 per pax km until \$6 per pax km, as tourists will be keen to pay for its services. The cities from South Africa, Cape Town and Johannesburg have population and GDP comparable to each other. Therefore, the demand is these cities are contiguous to each other. Durban is ranked as the fifth city in Africa to have the highest demand for UAM services. The outcome of implementation is shown in Figure 9a.

Six cities are identified in the pacific region to be viable for UAM operation. These six cities represent two nations, namely Australia and New-Zealand. Out of six cities in the pacific region, five of them belong to Australia and the



(a) Green 2050 Scenario (Africa)



(b) Green 2050 Scenario (Pacific)

Fig. 9 Top-Five Cities With Highest UAM Demand in Africa and Pacific

remaining one from New-Zealand. The average income in New-Zealand is significantly lower compared to Australia. Only one city in New-Zealand, namely Auckland, has a population greater than 1 million and GDP greater than 5 billion in 2019 and 100 billion in 2050, which are the filter parameter set to identify cities viable for UAM operations globally.

Brisbane is ranked as the first city in the pacific region to have the highest UAM demand. Only 12% of Brisbane homes have access to a bus or train stop with services running at least every half hour - the worst of all Australian cities. Sydney is ranked as the second city to offer the highest demand for UAM services in the Green 2050 scenario for the forecast year 2050. Perth and Melbourne are ranked as the third and fourth cities to have higher demand estimates, however, when visualizing the demand estimates in terms of number, the difference in demand for UAM service is almost negligible. Adelaide is ranked as the fifth city in Australia to offer higher UAM services. The results for the Pacific region are shown in Figure 9b. The results demonstrate that an exponential increase in demand upon decreasing the UAM ticket price.

Table 4 shows the annual UAM passenger trips for Early Adopters scenario for the forecast years from 2035 to 2050 for all the geographical regions. The results are shown for a UAM ticket price of $3 per passenger-km. In Africa, the city of Alexandria in Egypt shows an year-over-year evolving growth for UAM demand during the forecast years. The Turkish capital Istanbul in the Asia region may have a higher percentage of demand growth than Singapore, enabling Istanbul to be ranked as the first city in 2050 to have the highest demand for UAM services in the Asia region at a UAM ticket price of $3.00 per passenger-km. In Europe, Paris and London will always remain amongst the top two-cities to have the highest UAM demand at all the ticket prices. However, at a higher ticket price greater than $3.00 per passenger-km, Moscow may have a higher demand than Naples in the forecast year 2050. Moscow in Russia is among one of the most congested cities across the globe. Also, the population density of Moscow is higher than in Naples. Therefore, Moscow taking over Naples in the forecast year 2050 is reasonable. In the North America region, during all the forecast years, all the five-cities remain the same for each forecast year, however, their ranking is slightly changed upon year-over-year demand growth. The Pacific region shows a constant growth of UAM demand for all the forecast years the ranking of the top five cities in the pacific region is not affected at all. In South America, the top-three cities have shown a constant year-over-year growth for UAM demand, and a slight change is noticed in the fourth and fifth-ranked city for the year 2035. The city Belem in Brazil cannot maintain its demand growth for the future forecast years.

Table 4 Top-Five Cities in Each Region for Early Adopters Scenario

Regions	UAM Pax Trips (M)$_{2035}$	UAM Pax Trips (M)$_{2040}$	UAM Pax Trips (M)$_{2045}$	UAM Pax Trips (M)$_{2050}$
	Cairo (14.623)	Cairo (18.28)	Alexandria (34.99)	Alexandria (91.91)
	Algiers (5.37)	Algiers (9.21)	Cairo (20.42)	Johannesburg (22.95)
Africa	Cape Town (4.16)	Alexandria (8.86)	Cape Town (13.24)	Cairo (22.30)
	Johannesburg (3.98)	Cape Town (7.61)	Johannesburg (12.65)	Cape Town (22.06)
	Alexandria (3.78)	Johannesburg (6.59)	Durban (3.16)	Durban (5.42)
	Singapore (637.54)	Singapore (864.05)	Singapore (1141.96)	Istanbul (1939.94)
	Dubai (167.02)	Istanbul (409.14)	Istanbul (972.57)	Singapore (1494.85)
Asia	Izmir (152.34)	Izmir (330.86)	Izmir (598.16)	Izmir (924.00)
	Istanbul (142.29)	Dubai (265.45)	Dubai (400.01)	Dubai (576.02)
	Nagoya (140.40)	Nagoya (188.14)	Bursa (302.48)	Bursa (438.51)
	Paris (465.94)	Paris (635.62)	Paris (854.74)	Paris (1137.52)
	London (343.15)	London (489.75)	London (679.96)	London (924.68)
Europe	Naples (128.63)	Naples (167.39)	Naples (216.57)	Moscow (313.99)
	Vienna (66.76)	Dublin (79.21)	Moscow (193.50)	Naples (277.19)
	Dublin (55.34)	Munich (71.65)	Munich (111.05)	Munich (167.76)
	San Francisco (849.06)	San Francisco (1108.90)	New York(1518.39)	New York (2127.07)
	Miami (829.77)	Miami (1080.17)	San Francisco (1419.45)	San Francisco (1793.91)
North America	New York (732.61)	New York (1061.33)	Miami (1385.65)	Miami (1754.74)
	Washington DC (320.81)	Washington DC (474.77)	Washington DC (696.35)	Washington DC (998.13)
	Dallas (279.42)	Dallas (412.93)	Dallas (607.63)	Dallas (870.71)
	Brisbane (2.30)	Brisbane (5.65)	Brisbane (9.30)	Brisbane (10.99)
	Sydney (2.12)	Sydney (5.19)	Sydney (8.58)	Sydney (10.12)
Pacific	Perth (2.09)	Perth (5.12)	Perth (8.44)	Perth (9.97)
	Melbourne (2.09)	Melbourne (5.12)	Melbourne (8.41)	Melbourne (9.93)
	Adelaide (1.68)	Adelaide (4.44)	Adelaide (6.90)	Adelaide (8.10)
	Sao Paulo (12.26)	Sao Paulo (20.78)	Sao Paulo (45.74)	Sao Paulo (94.04)
	Salvador (6.75)	Salvador (13.44)	Salvador (24.75)	Salvador (42.72)
South America	Belo Horizonte (5.57)	Belo Horizonte (11.62)	Belo Horizonte (22.35)	Belo Horizonte (40.20)
	Belem (4.18)	Recife (8.64)	Recife (16.62)	Recife (29.90)
	Recife (4.15)	Porto Alegre (8.47)	Porto Alegre (16.30)	Porto Alegre (29.31)

In Table 5 annual UAM pax trips for Mainstream Adopters scenario for the forecast years, 2035 to 2050 for all the regions, are represented for a UAM ticket price of $3 per pax-km. The regional UAM demand in the Mainstream

Adopters scenario has grown tremendously compared to the Early Adopters scenario for all the regions and all the forecast years, discussed in Table 3. However, while comparing the results at the city level for the Early Adopters and Mainstream Adopters scenario, there are some cities where the UAM demand is higher in the Early Adopters scenario despite more realistic scenario assumptions for the Mainstream Adopters scenario. This phenomenon depicts the sensitivity of assumptions considered in the research. The methodology computes a viable space for UAM. There might be some cases where UAM can be a viable option in the Early Adopters scenario but may not be viable in the Mainstream scenario.

Table 5 Top-Five Cities in Each Region for Mainstream Adopters Scenario

Regions	UAM Pax Trips $(M)_{2035}$	UAM Pax Trips $(M)_{2040}$	UAM Pax Trips $(M)_{2045}$	UAM Pax Trips $(M)_{2050}$
	Cairo (15.93)	Cairo (21.85)	Alexandria (49.49)	Alexandria (110.57)
	Cape Town (6.47)	Alexandria (15.61)	Cairo (26.97)	Cairo (31.05)
Africa	Alexandria (5.71)	Cape Town (11.33)	Cape Town (18.87)	Cape Town (30.26)
	Algiers (5.47)	Algiers (8.67)	Algiers (9.21)	Algiers (22.38)
	Durban (1.60)	Durban (2.84)	Johannesburg (6.22)	Johannesburg (11.93)
	Singapore (1607.77)	Singapore (2060.01)	Singapore (2592.44)	Singapore (3239.23)
	Dubai (321.24)	Izmir (558.83)	Istanbul (965.13)	Istanbul (1922.84)
Asia	Izmir (311.74)	Dubai (462.08)	Izmir (852.23)	Izmir (1145.23)
	Manila (177.64)	Istanbul (406.60)	Dubai (637.70)	Dubai (847.80)
	Nagoya (175.01)	Bursa (237.64)	Bursa (362.52)	Bursa (487.17)
	Paris (452.20)	Paris (617.43)	Paris (831.08)	Paris (1107.19)
	London (268.27)	London (374.12)	London (512.16)	London (692.13)
Europe	Naples (212.76)	Naples (271.94)	Naples (344.66)	Naples (433.07)
	Dublin (139.02)	Dublin (187.71)	Dublin (250.65)	Dublin (329.71)
	Munich (101.23)	Munich (152.42)	Munich (224.45)	Munich (322.31)
	New York (1266.92)	New York (1768.30)	New York (2432.82)	New York (3287.70)
	San Francisco (673.32)	San Francisco (886.25)	San Francisco (1146.40)	San Francisco (1466.25)
North America	Miami (658.02)	Miami (863.29)	Miami (1119.10)	Miami (1434.24)
	Chicago (302.87)	Chicago (413.39)	Chicago (555.50)	Chicago (736.62)
	Boston (264.20)	Boston (357.25)	Boston (474.32)	Boston (620.94)
	Sydney (8.20)	Sydney (9.63)	Sydney (14.59)	Sydney (31.54)
	Adelaide (8.16)	Melbourne (9.49)	Melbourne (14.31)	Melbourne (30.98)
Pacific	Melbourne (8.08)	Adelaide (9.00)	Adelaide (12.90)	Adelaide (18.41)
	Auckland (2.29)	Auckland (5.02)	Auckland (6.94)	Auckland (9.53)
	Brisbane (1.69)	Brisbane (2.19)	Brisbane (3.61)	Brisbane (5.34)
	Belo Horizonte (12.44)	Belo Horizonte (23.32)	Belo Horizonte (40.65)	Sao Paulo (82.40)
	Salvador (10.36)	Salvador (19.40)	Sao Paulo (39.59)	Belo Horizonte (66.74)
South America	Recife (9.25)	Sao Paulo (17.84)	Salvador (33.84)	Salvador (55.57)
	Porto Alegre (9.07)	Recife (17.34)	Recife (30.23)	Recife (49.63)
	Fortaleza (9.02)	Porto Alegre (17.00)	Porto Alegre (29.64)	Porto Alegre (48.66)

Table 6 visualizes the annual UAM passenger trips for the Green 2050 scenario for the forecast years from 2035 to 2050 for all the geographical regions. The results for the top-five cities in each geographical region are shown for a UAM ticket price of $3 per passenger-km. The demand estimates for Green 2050 is highest among the three scenarios considered in the research. Higher demand estimates for Green 2050 scenarios is influenced by the scenario assumptions, a minimal VTTS is considered for this scenario compared to the other two scenarios. Optimal utilization of infrastructure and technology is the focus of this scenario. The optimal use of resources would enable some percentage reduction in the carbon footprint in the environment.

Table 6 Top-Five Cities in Each Region for Green 2050 Scenario

Regions	UAM Pax Trips (M)$_{2035}$	UAM Pax Trips (M)$_{2040}$	UAM Pax Trips (M)$_{2045}$	UAM Pax Trips (M)$_{2050}$
Africa	Cairo (16.12)	Cairo (23.08)	Cairo (30.21)	Alexandria (74.21)
	Algiers (5.38)	Algiers (9.21)	Alexandria (25.79)	Cairo (36.72)
	Cape Town (3.13)	Alexandria (8.82)	Cape Town (10.33)	Cape Town (17.50)
	Johannesburg (1.56)	Cape Town (5.84)	Johannesburg (6.24)	Johannesburg (11.96)
	Alexandria (1.24)	Johannesburg (2.63)	Durban (2.51)	Durban (4.38)
Asia	Singapore (507.46)	Singapore (689.83)	Singapore (915.83)	Istanbul (1501.05)
	Izmir (150.79)	Izmir (327.08)	Istanbul (695.64)	Singapore (1206.60)
	Nagoya (134.03)	Istanbul (269.34)	Izmir (590.99)	Izmir (913.52)
	Dubai (128.74)	Dubai (208.05)	Dubai (320.51)	Dubai (472.68)
	Istanbul (85.45)	Nagoya (179.85)	Bursa (251.43)	Bursa (388.55)
Europe	Paris (236.06)	Paris (338.79)	Paris (477.76)	Paris (663.57)
	London (154.16)	London (225.00)	London (321.68)	London (452.22)
	Naples (106.14)	Naples (138.53)	Naples (180.38)	Naples (231.44)
	Munich (45.06)	Munich (71.19)	Munich (87.02)	Moscow (216.84)
	Turin (26.95)	Vienna (42.83)	Dublin (67.87)	Munich (131.21)
North America	San Francisco (631.84)	San Francisco (841.95)	San Francisco (1100.42)	San Francisco (1419.41)
	Miami (617.48)	Miami (820.14)	Miami (1074.22)	Miami (1388.42)
	New York (436.88)	New York (640.67)	New York (935.45)	New York (1334.74)
	Washington DC (158.31)	Washington DC (239.45)	Washington DC (322.95)	Washington DC (478.38)
	Chicago (139.64)	Dallas (208.26)	Chicago (283.02)	Dallas (417.31)
Pacific	Sydney (2.11)	Sydney (2.97)	Sydney (4.71)	Sydney (10.07)
	Melbourne (2.08)	Melbourne (2.92)	Melbourne (4.61)	Melbourne (9.89)
	Brisbane (1.65)	Adelaide (1.95)	Adelaide (2.95)	Adelaide (6.39)
	Adelaide (1.66)	Brisbane (1.69)	Brisbane (2.59)	Brisbane (5.34)
	Perth (1.49)	Perth (1.54)	Perth (2.35)	Perth (4.84)
South America	Sao Paulo (5.51)	Sao Paulo (14.14)	Sao Paulo (28.69)	Sao Paulo (62.07)
	Salvador (5.10)	Salvador (10.39)	Salvador (19.59)	Belo Horizonte (34.78)
	Belo Horizonte (4.89)	Belo Horizonte (10.09)	Belo Horizonte (19.28)	Salvador (34.68)
	Recife (3.64)	Recife (7.50)	Recife (14.34)	Recife (25.87)
	Porto Alegre (3.57)	Porto Alegre (7.36)	Porto Alegre (14.06)	Porto Alegre (25.36)

VI. Conclusion and Future work

A. Conclusion

This work presents a generic top-down approach to estimate the demand of UAM for a global set of 542 cities viable for UAM operations at their geographical region and the city-level from 2035 to 2050 time frame. A transparent methodology is devised in the research which is capable of considering the inherent benefits of UAM without the need for traveler's behavior data. The willingness to pay (WTP) function suggests that if the traveler's willingness to pay is greater than the price of the UAM trip, then the traveler will select UAM as their mode choice. In the previous work by authors, the results of implementation for a global set of 542 was presented. Low and High demand scenarios were defined in which Low demand scenario assumed pre-matured market conditions and High demand scenarios assumed a matured market conditions. Arbitrary technical improvements were considered to execute the scenario outcomes.

Current research identifies a novel approach to define the scenarios. The consumer adoption of a novel technology is studied to better define the scenario and more realistic assumptions are considered for all three scenarios in the work. As of now, the UAM ticket price is uncertain due to this each scenario is evaluated for a range of ticket prices, and the results at each ticket price are recorded. A strong demand exists for a range of UAM ticket prices for all three scenarios. The demand for UAM services augments exponentially with a decrease in the ticket price and vertiport network density. In the Mainstream Adopters scenario, better infrastructure is considered compared to the Early Adopters scenario i.e to say vertiport network density in this scenario is considered at every 120 sq. km of city boundaries, and as a consequence, a higher value of annual UAM PKM is noticed in Mainstream Adopters scenario for each geographical regions compared to Early Adopters scenario. In the Green 2050 scenario, the vertiport network density is considered at each 200 sq. km of city boundaries but the value of travel time savings (VTTS) is considered significantly lower than the Mainstream Adopters scenario which results in a significantly higher demand for UAM services compared to the Mainstream scenario in all the geographical regions. From these observations, it is worth mentioning that demand estimates are highly sensitive to the assumptions made during the research.

B. Future work

The three scenarios considered in the research capture a particle perspective or mind-set of a potential UAM service user however in practice considering a hybrid scenario that considers certain percentages of all the different scenarios assumed in this research would be an added benefit to the current research. This would enable a mixture of different attitudes of potential UAM users. Another potential improvement in the developed model would be the consideration of qualitative choice attributes such as traveler's convenience, comfort, and perception of waiting times. The addition of both cognitive components which are related to the physical feature of the destination and the affective components which are related to the traveler's values and motives would be a plus to the developed model. To better understand the optimal location for placements of vertiports within city boundaries a more sophisticated city map illustrating the land area and population distributions of cities which is available by an isochrone map would be relevant. Transportation costs, household incomes in the current research relies on current market estimates and do not ameliorate for future years. To improve the rigor of economic analysis for each city this could be augmented with additional data or forecasts.

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