Spring 2021

A Comparison of the Effectiveness and Integration Capability of Personal Aerial Vehicles (PAV) into the Existing Transportation Network of the City of Los Angeles

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Abstract

Traffic demands on the current infrastructure network is becoming more strained as populations migrate and increase, particularly in large cities. Therefore, city officials, transportation and traffic authorities and researchers, and city inhabitants themselves are always striving to find faster and more efficient means of transportation. With the rise of new technologies such as autonomous vehicles and drones, the applications for transportation are endless. Therefore, this paper will describe and explore the operations, and consequently the efficacy, of Personal Aerial Vehicles (PAV), also known as Urban Air Mobility (UAM). The machines, while still hypothetical, are being researched extensively by some of the most powerful and influential scientific and technological organizations today. This paper will not only describe PAVs and their operations, but also their ability to be operational in the complex world of a modern transportation network of a large city. The city chosen for this paper to study is Los Angeles, California. The overall conclusion is that, given a limited scope, PAVs could be very effective in decreasing travel times, traffic congestion, and air pollution, while not overwhelming the existing transportation network and air traffic control systems.

Glossary

PAV: Personal Aerial Vehicle

UAM: Urban Air Mobility

LA: Los Angeles

LAX: Los Angeles International Airport

FAA: Federal Aviation Administration

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1. Introduction

As long as there have been cities, they have been associated with traffic and congestion. With the rise of vast supercities in the 19th century, places like New York, Los Angeles, Chicago, London, Paris, Sao Paolo, Tokyo, and Shanghai are home to tens of millions of people, often in a very confined land area. The rise of vehicles, beginning with the railroad, then moving on to trolleys, interurbans, and finally cars and buses, has made the issue of navigating cities very difficult.

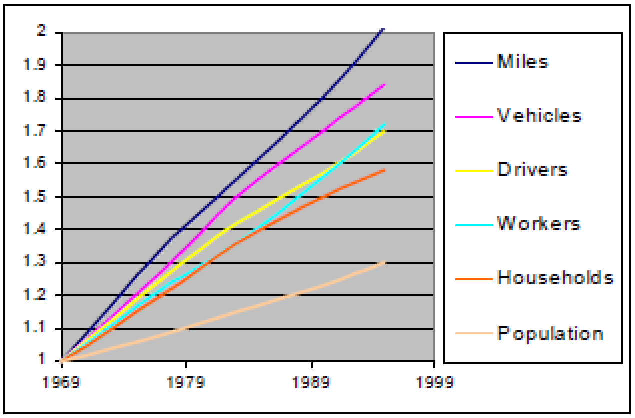


Figure 1: Personal travel trends in the U.S. [14]

Figure 1 describes the rise in population in the US, and the consequent growth in households, workers, drivers, vehicles, and miles traveled. In Los Angeles alone, the city has grown in population from 1,970,358 in 1950 to 3,979,576 in 2019 [19]. The growth of cities out into the suburbs has also lengthened commute times dramatically, increasing in LA alone from 54 minutes /day in 1980 to 66 minutes/day as of 2019 [20, 21]. Therefore, various options outside of cars have been explored for some time, particularly public transportation options like buses, trolleys, subways, and light rail. However, these options, although well established in LA, are not heavily utilized and do little to reduce travel times. In fact, as of 2000, the average commute time of a solo driver versus the average commute time of a city bus passenger was 11% shorter [20]. Therefore, a new method and mode of transportation should be discussed and analyzed. One proposed system is Urban Air Mobility (UAM), as defined by the National Aeronautics and Space Administration (NASA). UAM and its associated subcategories, sub-Urban Air Mobility (sUAM) and Regional Air Mobility (RAM) (as defined below by Figure 2), are a promising way to utilize new technologies in electric vehicles, lightweight materials, and autonomous operations to produce a new means of transportations in crowded urban cities.

Figure 2: The three parts of comprehensive air mobility [10]

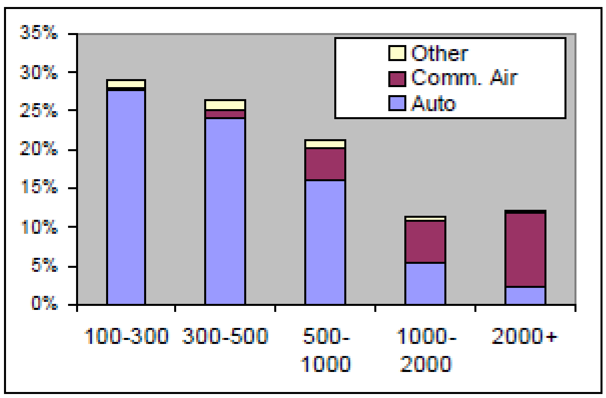


Figure 3: Current mode choice based on distances greater than 100 miles [14]

Figure 3 demonstrates that for distances less than or equal to 300 miles, commercial airliners and other means of transportation (other than cars) make up approximately only 2-3% of personal trips. Therefore, there is certainly a market for additional means of transportation, as the existing options are usually excessively confined and expensive. UAM holds great promise as an affordable, safe, time-saving, and environmentally friendly mass transportation option for the City of Los Angeles.

2. Current and Proposed PAV Technology

a. Description

A visualization of a current PAV prototype is shown in Figure 5, with its typical dimensions and performance qualities being described in Table 1. Additionally, Figure 4 provides a flow chart of the historical development of PAVs. PAVs are not currently envisioned as being like a "flying car", as is often depicted in science fiction and movies. A true "flying car" configuration would be fully operational driving and flying virtually any payload in any conditions. This scenario is currently out of the scope of nearly all models of PAVs, as it would make handling and operating these vehicles inordinately difficult, both at personal and traffic control levels. Therefore, the best and most efficient model for optimal operations that is being considered is a ride-serving mode that would function like an on-demand service like Uber™ or Lyft™. Using an app, passengers would reserve seats on an available vehicle at a specific time. Then the passenger would transport themselves to a vertiport, the designated takeoff and landing location for that particular craft. After a short boarding process (including a security screening), the passenger can board the vehicle and begin their journey. This entire process is illustrated by Figures 6-10.

Issue	Specification
Dimension	"Garageable": size of a large/mid-size car
Max. take-off mass (MTOM)	450 kg ("microlight / ultralight")
Number of seats	1 + 1
Take-off capability	VTOL required
Total range	100 km
Cruising speed	150 - 200 km/h
Average cruising altitude	< 500 m above ground level
Propulsion technology	Preferable electric
Maneuverability on ground	Yes, short distances, no "roadable aircraft"
Usability over the year	90%
Ability to fly under Instrument Meteorological Conditions (IMC)	Yes
Ability to fly in darkness	Yes
Ability to fly in clouded environment	In degraded visual environment, not into clouds
Level of automation	Two levels ("fully autonomous" and "augmented flight")[a]
Automatic collision avoidance	Yes
Automatic landing/start	Yes
Ability to come autonomously to the user	Included in the "full level of automation"

Table 1: Specification for a reference UAM vehicle [13]

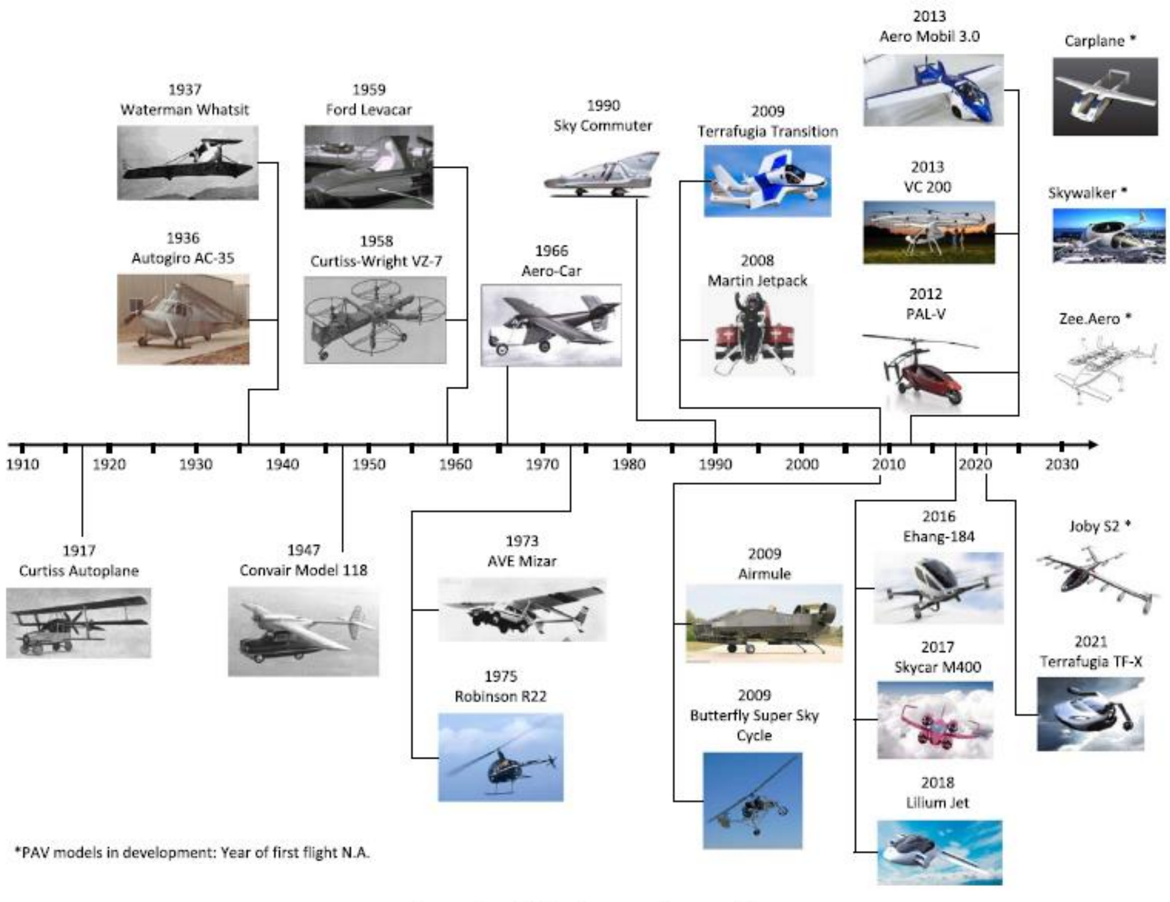


Figure 4: Chronological development of PAV vehicles [11]

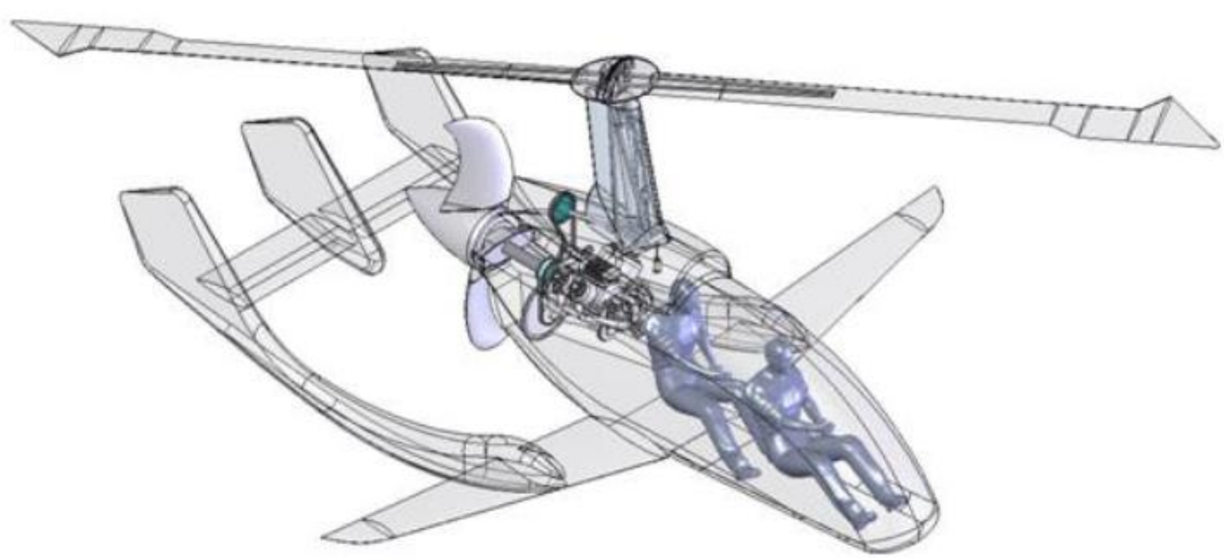


Figure 5: Proposed model of a PAV (the Carter Slowed Rotor Compound Aerial Vehicle) [9]

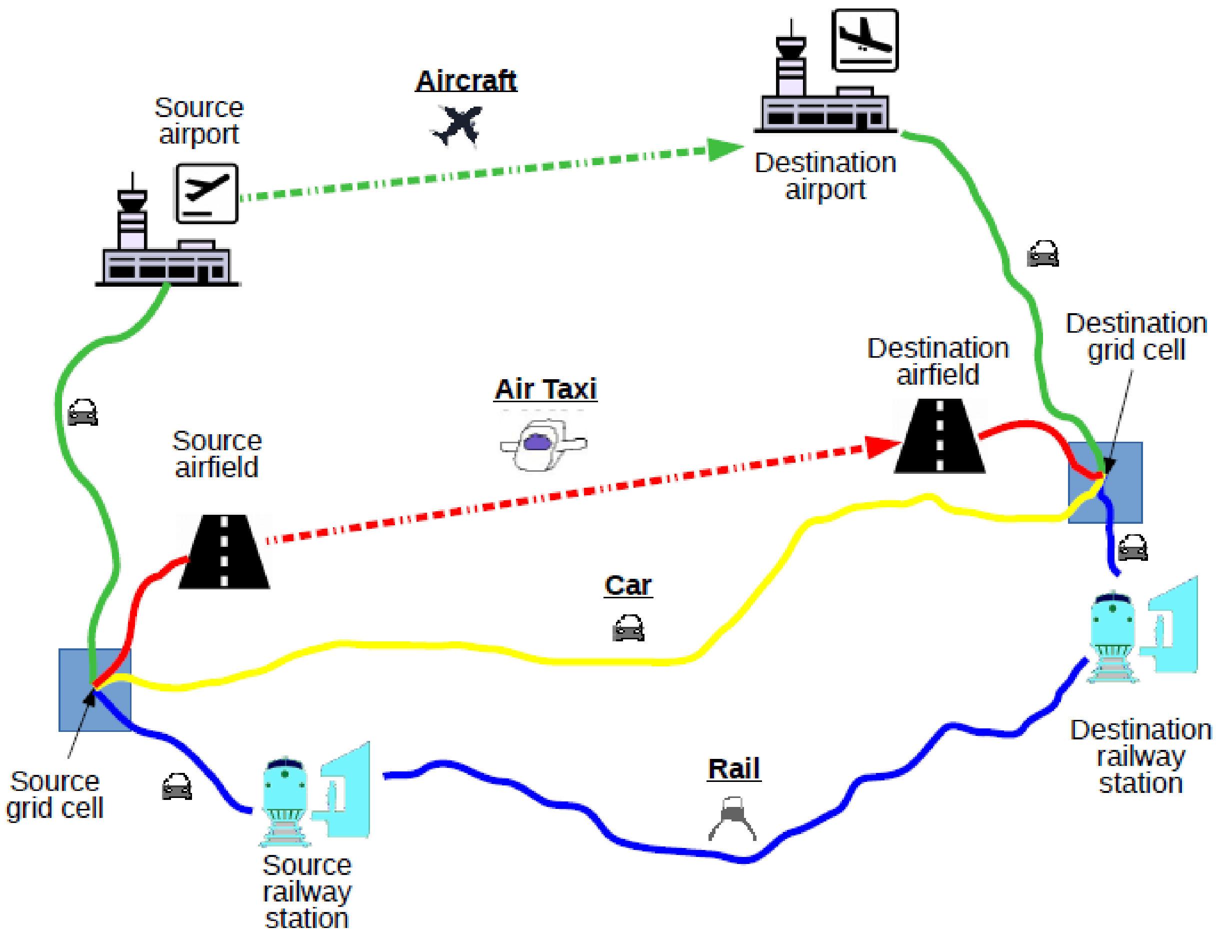


Figure 6: Visual diagram of the competing transportation systems in Los Angeles [4]

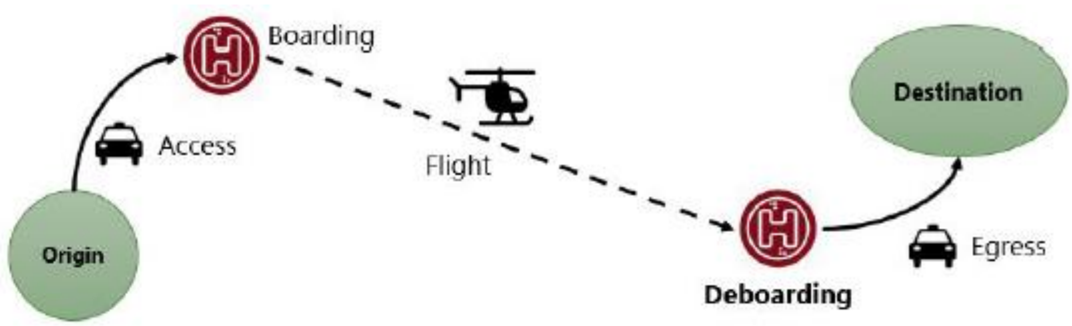


Figure 7: General diagram of day-to-day operation [1]

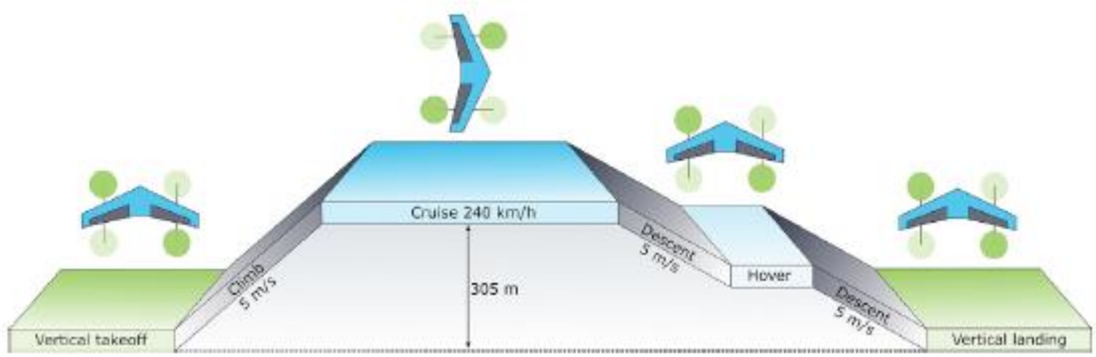


Figure 8: Operation schematic of a typical PAV flight [6]

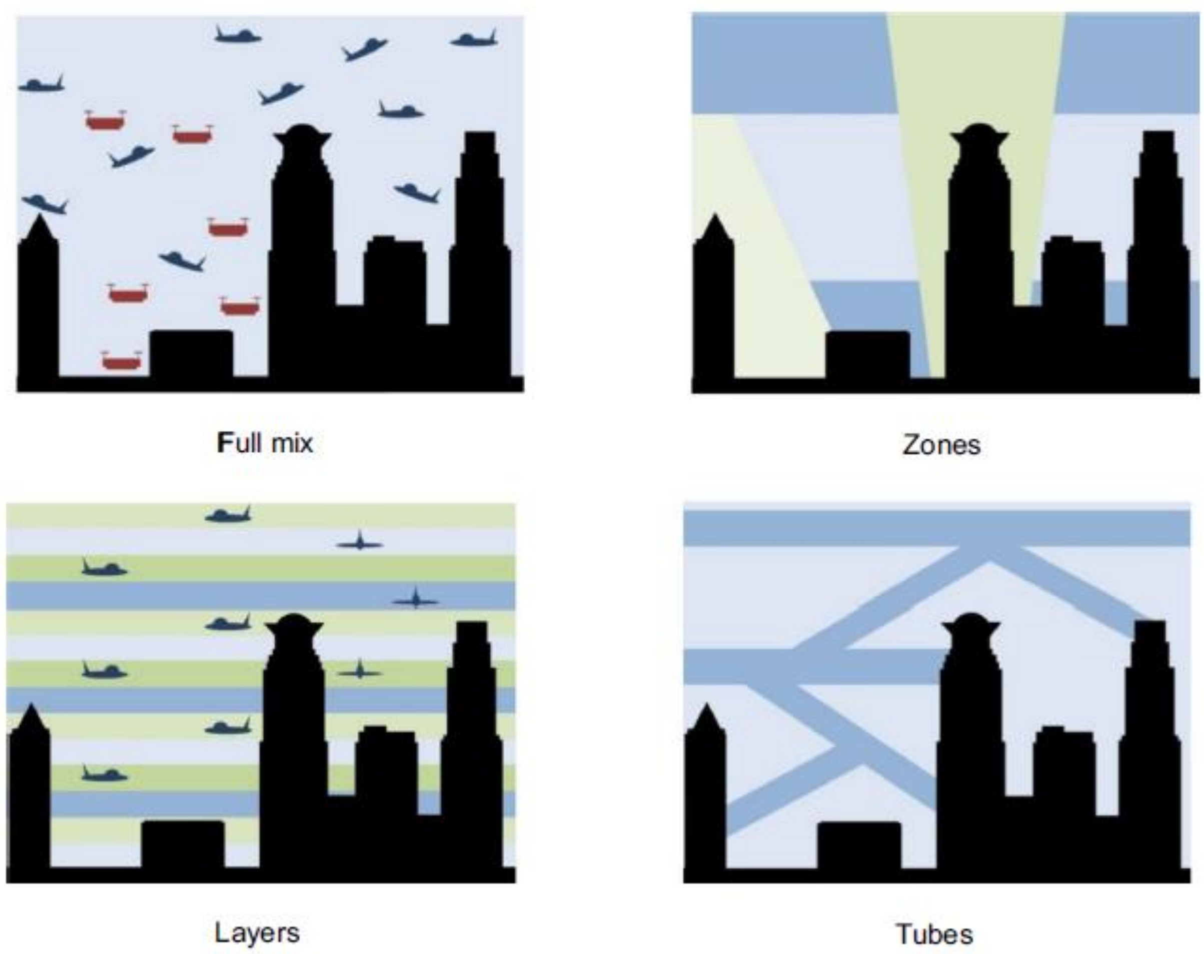


Figure 9: Visualization of the various UAM operating configurations [11]

Figure 10: Conceptual rendering of a UAM vertiport [17]

Table 2 describes the various components of a UAM network and how they are categorized. It can be seen that the first steps in designing a viable network are determining the vertiport capacity, the vertiport locations, and the vertiport operational constraints. After these results have been determined, then more ambitious goals can be obtained, such as fleet size and the basic UAM route network. Lastly, a comprehensive fleet management policy must be developed to ensure smooth operations.

Design Variable	Variable Type	Variable Frozen
Vertiport Capacity	Long-Term Strategic	Varied
Vertiport Locations	Long-Term Strategic	Frozen
Vertiport Ops Constraints	Long-Term Strategic	Frozen
Fleet Size	Short-Term Strategic	Varied
UAM Route Network	Short-Term Strategic	Frozen
Fleet Management Policy	Tactical	Varied

Table 2: UAM system design variables and types [3]

One important aspect that undoubtedly make UAM operations especially attractive to traffic planning and air traffic control authorities is its potential for autonomous flight and handling. Currently, most research anticipates that fully autonomous UAM operations are quite some time from happening, but will continue to explored. Figure 11 provides some visualization for the process necessary for autonomous UAM operations to be realized. However, for the forseeable future, a human pilot will be needed to ensure a safe and secure flight.

Figure 11: Visual diagram of the progress of autonomous PAVs [12]

Table 3 provides a very comprehensive look into the resources, operations, policies, and economics (ROPE) needed in a UAM network, both for the vertiports and the vehicles themselves. The Greek letters α, β, γ, and δ represent the consecutive levels of development needed for a fully operational UAM system.

	Resources		Operations		Policies		Economics	
	UAM-Port	Aircraft	UAM-Port	Aircraft	UAM-Port	Aircraft	UAM-Port	Aircraft
α	UAM-Port subsystems (e.g., runway, helipad, taxiway, terminal, landing zone, security screening, etc.)	Aircraft subsystems (e.g., avionics, propulsion system, energy system, etc.)	Operations of UAM-Port Subsystems (e.g., runway operations, helipad operations, terminal operations, etc.)	Operations of Aircraft Subsystems (e.g., avionics operation, propulsion system operation, etc.)	Regulations of Subsystems (e.g. runway design guideline, etc.)	Regulation related to vehicle subsystems (e.g., battery handling regulations, petrol fuel regulations, energy system regulations, etc.)	Cost and/or Value of UAM-Port subsystems (e.g., cost of developing infrastructure, revenue options at the UAM-Port, energy replenishing costs, etc.)	Cost and/or Value of Aircraft subsystems (e.g., total operating costs of distributed electric propulsion system, etc.)
β	UAM-Port	Vehicle (e.g. Wisk Cora, Joby S4, Pipistrel 801, etc.)	Operation of a UAM-Port (e.g., UAM-Port slot management, passenger embarkation / debarkation, etc.)	Operation of a vehicle (e.g., VTOL/CTOL operations, etc.)	Regulations of UAM-Port operations (e.g., UAM ground vehicle/staff maneuvers regulations, minimum clearance between buildings and vehicles, etc.)	Vehicle certification regulations (e.g., safety, energy replenishment procedures, etc.)	Cost and/or Value of UAM-Port (e.g., impact of placing UAM-Port at a specific location, etc.)	Vehicle acquisition, operation, maintenance and other supply chain costs
γ	Collection of serviceable ports by a transportation service provider	Omnigenous fleet of a transportation service provider	Operation of a collection of serviceable ports by a transportation service provider	Operation of omnigenous fleet of vehicles of a transportation service provider	Requirements of a collection of serviceable ports	Omnigenous Fleet/network policies and requirements	Costs and/or Value of a Transportation Service Provider (e.g. cost of crew, ride-sharing costs/benefits, service provider's business model)	Fleet operation and maintenance costs of a transportation service provider
δ	Omnigenous collection of serviceable ports by all transportation service providers	Omnigenous fleet of all transportation service providers	Operation of omnigenous collection of serviceable ports by all trasnportation service providers	Operation of omnigenous fleet of vehicles of all transportation service providers	Requirements of omnigenous collection of all serviceable ports (e.g., slot assignment between service providers from other UAM-Ports)	National level guidelines / regulations to regulate design / operation of vehicles	Cost and/or Value of all transportation service providers (e.g., competition / coopetition between transportation service providers)	Fleet operation and maintenance costs of all transportation service proviers

Table 3: A Resource, Operation, Policy, and Economic (ROPE) table for UAM [7]

b. Operational Capabilities

The operational capabilities of any UAM network are determined first by the demand, and then by the number of vehicles purchased and made operational at any given time. Figure 12 gives a schematic of a typical cycle of operation for a single PAV.

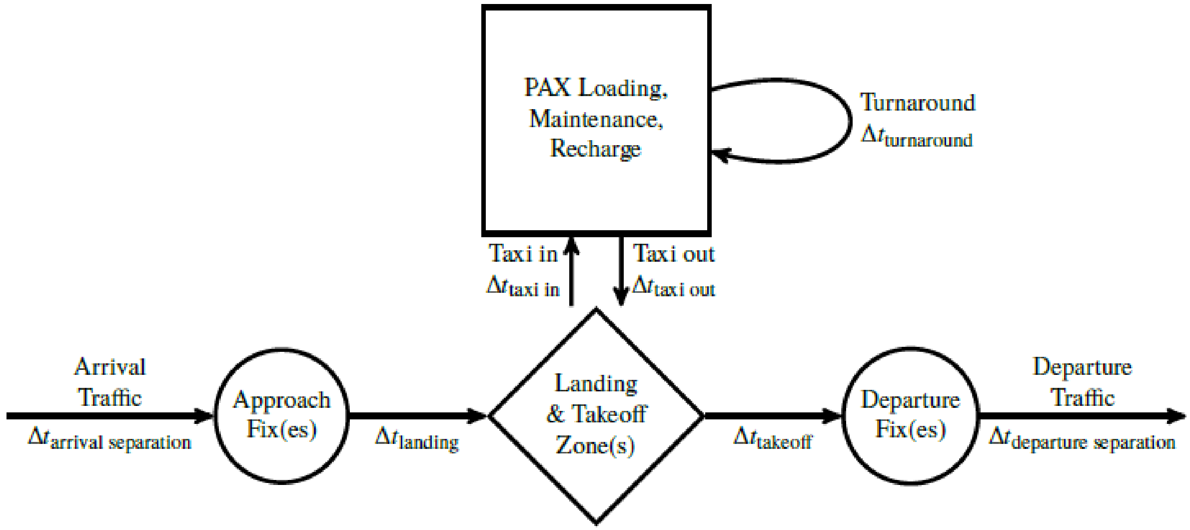
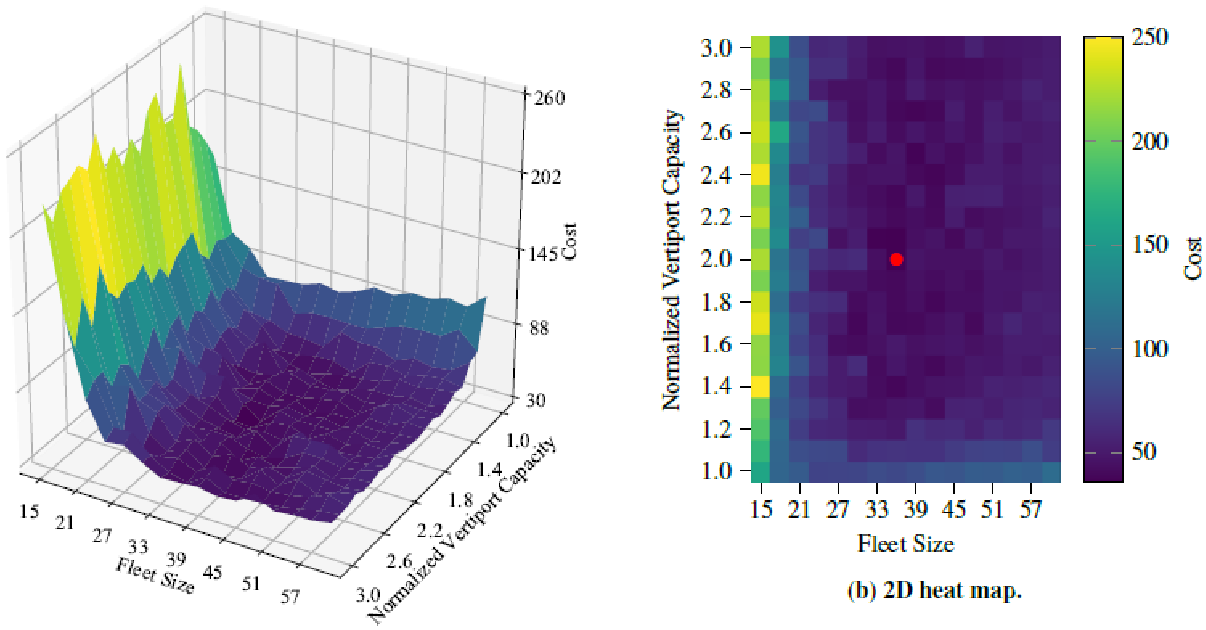


Figure 12: Vertiport structure and operational flow [3]

Figure 13 presents a fascinating model that predicts the optimal UAM fleet size, using the Bay Area as a case study. Although the results cannot be directly carried over to Los Angeles, it is nonetheless a good starting point for estimation purposes. The model also gives an estimation for minimizing cost, although the numbers associated with Figure 13 are reflected not just in personal transportation cost, but all of the associated spending required to install and maintain the required UAM infrastructure.



(a) 3D surface plot. **(b) 2D heat map.**

Figure 13: 3-D model optimization graph, with the optimal operating point shown in red [3]

Figure 14 shows the percentages of UAM flights that can be handled by existing air traffic control systems and personnel. With modifications to the UAM network routes, virtually all UAM flights (95-99%), even at a high volume, can be handled with the existing air traffic control infrastructure, although these percentages drop significantly if the proper modifications are not taken.

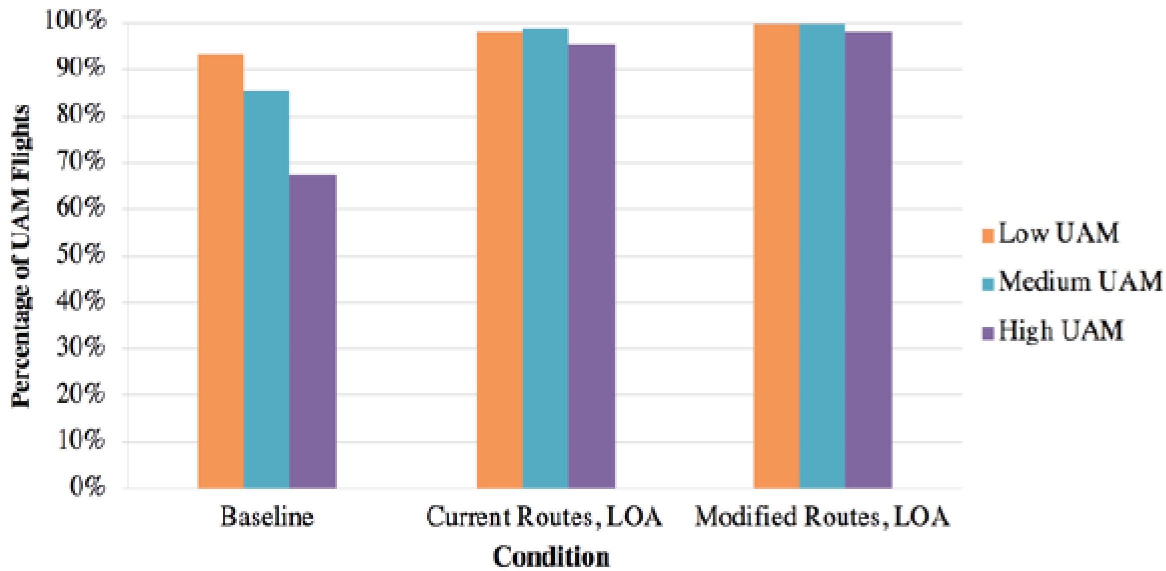


Figure 14: Effects of modification of UAM operations and expectations [5]

Figure 15 describes the Small Air Transport System (SATS) model, a European-led semi-autonomous network that would allow for unprecedented levels of efficiency and speed in air traffic control.

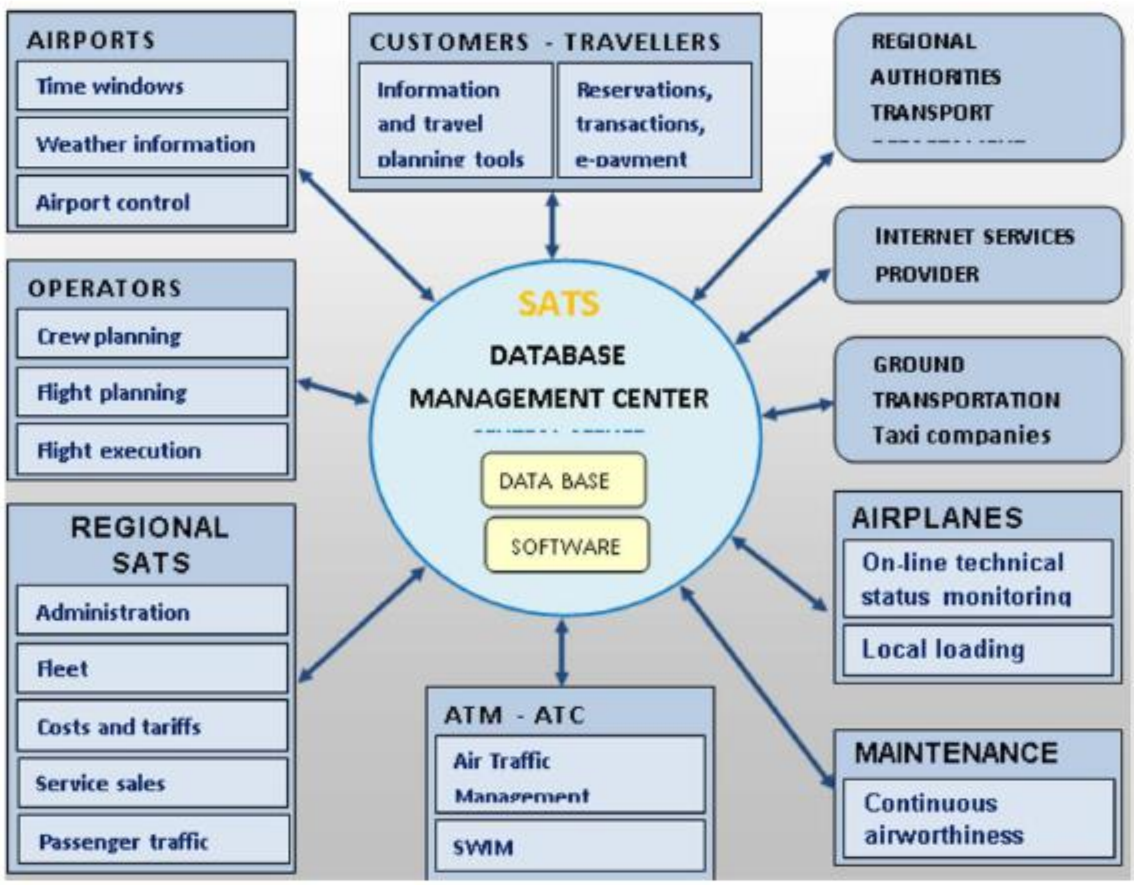


Figure 15: Diagram showing the air traffic control process for UAM operations [11]

Figure 16 shows a collection of useful ideas, technologies, and hypotheses for PAVs that are being currently considered, as well as their application to a UAM scenario. Although not all of these aspects could or even should be implemented in the near future, it is beneficial to consider them as areas to research and consider in the future.

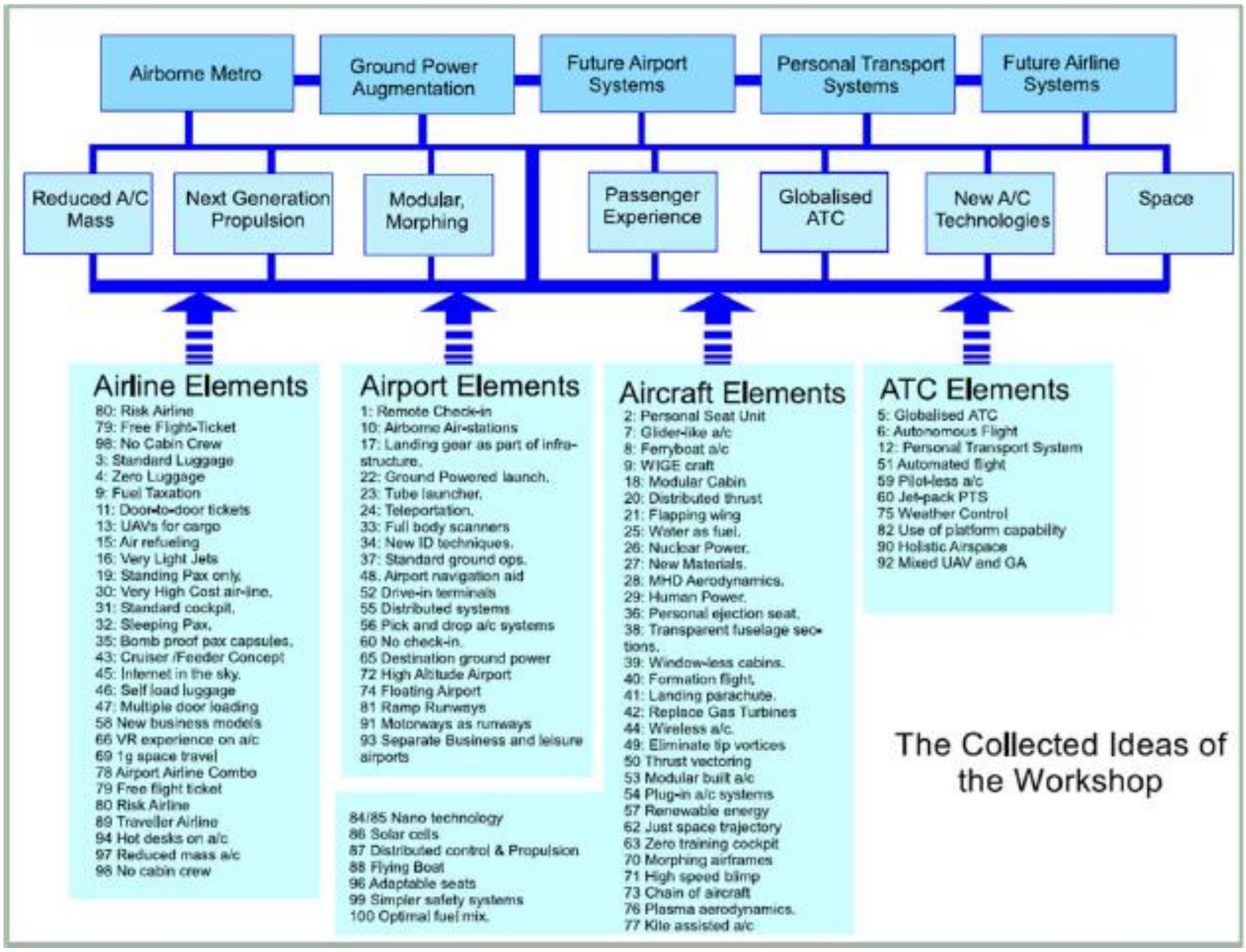


Figure 16: Summary of elements involved in UAM operation [11]

Last, but certainly not least, safety considerations must be analyzed. Safety is one of the biggest concerns that prospective passengers of PAVs have. Table 4 breaks down their top concerns, with 84% concerned about equipment and safety failure, and 82% concerned about accidents in the air. Security issues are also important to prospective passengers, with 70% concerned about security against hackers or terrorists, and 67% concerned about personal information privacy. These concerns are very valid, and have not been fully addressed in any of the current research. However, as a general rule, commercial aviation is the safest form of mass transportation available today. Figure 17 shows that an individual is 104 times safer in an airplane than a car, 3 timer safer in an airplane than urban mass transit rail, and twice as safe in an airplane then a bus. Although these figures for aviation safety might be lowered slightly for UAM operations, it will be still be substantially safer than all existing terrestrial transportation.

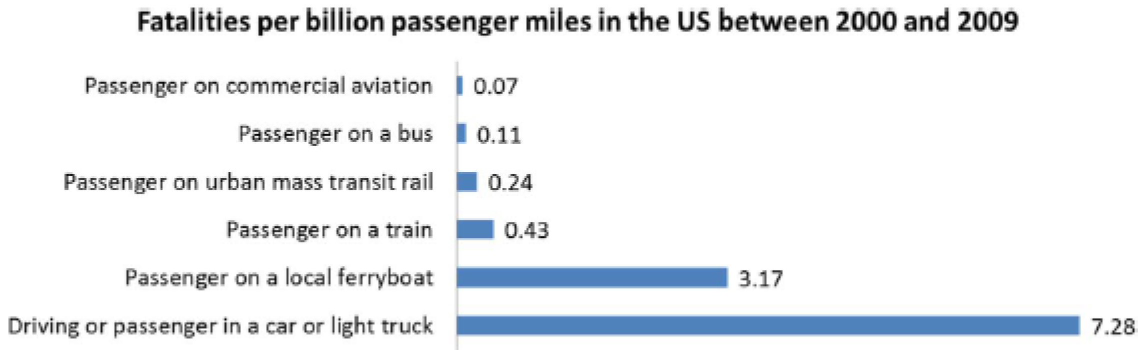


Figure 17: Comparison of passenger fatality rates between various modes of transportation [11]

	Very unlikely	Somewhat unlikely	**Overall unlikely**	Somewhat likely	Very likely	**Overall likely**
Safety Benefits						
Fewer crashes on the roadway	12.03%	21.99%	**34.02%**	41.54%	24.44%	**65.98%**
Less severe crashes on the roadway	17.67%	25.00%	**42.67%**	38.16%	19.17%	**57.33%**
Security Measures						
Use existing FAA regulations for air traffic control	16.76%	22.22%	**38.98%**	41.62%	19.40%	**61.02%**
Establish air-road police enforcement (with flying police cars)	10.17%	19.21%	**29.38%**	42.56%	28.06%	**70.62%**
Detailed profiling and background checking of flying car owners/operators	9.57%	15.20%	**24.77%**	39.59%	35.65%	**75.23%**
Establish no-fly zones for flying cars near sensitive locations (military bases, power/energy plants, governmental buildings, major transportation hubs, etc.)	7.49%	13.48%	**20.97%**	30.71%	48.31%	**79.03%**
	Not at all concerned	Slightly concerned	**Overall unconcerned**	Moderately concerned	Very concerned	**Overall concerned**
Safety Concerns						
Safety consequences of equipment/system failure	4.13%	11.44%	**15.57%**	25.14%	59.29%	**84.43%**
Accidents on the airway	4.32%	13.51%	**17.82%**	25.89%	56.29%	**82.18%**
Security Concerns						
Security against hackers/terrorists	6.75%	23.26%	**30.02%**	27.95%	42.03%	**69.98%**
Personal information privacy (location/destination monitoring)	10.38%	22.64%	**33.02%**	30.94%	36.04%	**66.98%**

Table 4: Survey results about safety- and security-related benefits and concerns [2]

c. Limitations

Although UAM seems like a viable and attractive option for public transportation in Los Angeles, there are drawbacks to their implementation. These drawbacks are summarized below in Table 5.

Category	Barriers to a Viable UAM Market	Critical Events or Tipping Points Indicating Viability
Safety and Security	Detect-and-avoid capability GPS-denied technology Weather mitigation Unmanned Traffic Management (UTM) Regulatory requirements UTM certification Flight above people Weight and altitude restrictions Beyond visual line of sight Operator certification Environmental restrictions Emergency procedures Data security	Comprehensive regulatory climate in place UTM technology matured Cybersecurity standards established
Economics	Battery technology Vehicle performance and reliability Autonomous flight technology Electric propulsion efficiency Vertiport/Vertistop Infrastructure	Annual reduction in cost per trip Introduction of autonomous operations Initial investments in infrastructure Annual growth of infrastructure
Demand	Competing modes (train, bus, bike, ride-share)	Annual growth in number of urban passenger trips Annual growth in air market share as percent of all urban passenger trips
Public Acceptance	Proven safety record Pilot training Privacy Job security Environmental threats Noise and visual disruption	Proven safety record better than ground mode travel Number and severity of local operational restrictions

Table 5: A compiled list of barriers to entry along with scenarios enabling viability [1]

Another criticism of UAM is the potential for inefficient use of time. Although on-demand scheduling of UAM flights seeks to mitigate this problem, it would be very difficult and expensive to adopt a fully on-demand service without a predictable and extensive flow of passengers. Therefore, some combination of on-demand scheduling and pre-defined scheduling would most likely be adopted. Figure 18 gives a breakdown of the typical time spent on a commercial airline flight. UAM flights would seek to minimize terminal and wait times, but access and egress times (the time spent coming to and from the flight access point) might be increased based on the number of vertiports constructed and their location.

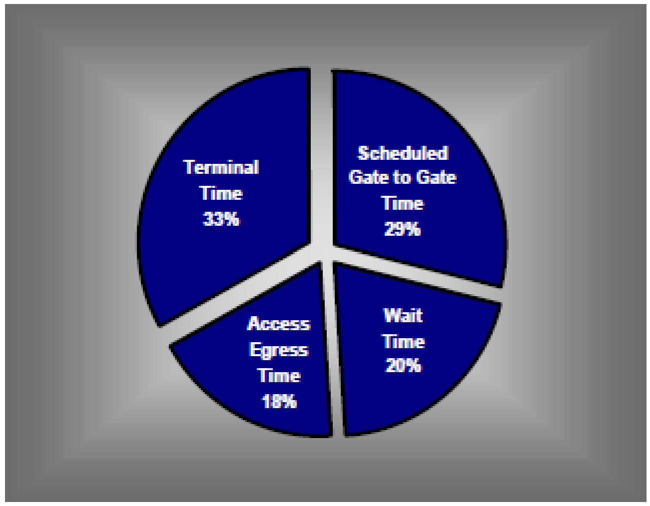


Figure 18: Average commercial airliner door-to-door time breakdown [14]

The final drawback to implementing UAM is the potential for increased day-to-day costs for the average passenger, especially compared with existing ground-based ride-sharing services. These concerns are reflected in preliminary studies, as shown in Figure 19. However, over 60% of passengers would see a daily cost increase of only up to $1 and just under 40% would see an increase of up to $3, which even taken annually are not significant cost increases. This study, however, does not take into consideration the large capital costs that would be needed to install and maintain the initial UAM network; therefore, the average cost to the consumer might rise somewhat, but that rise is difficult to quantify as of now.

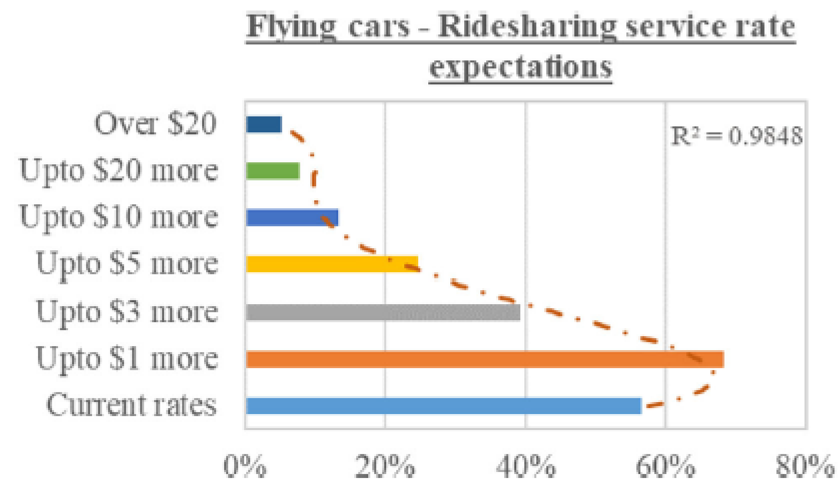


Figure 19: Expected consumer cost increases for PAVs compared to traditional ride-sharing services [16]

3. Existing Conditions

a. Selection Reasons

Los Angeles was chosen to as the ideal location for studying UAM operations for this paper. The first reason was size. Any potential UAM market would require a significant amount of potential users, and therefore the larger the market, there would be a theoretically larger demand. Numerous studies have estimated the future market share of PAVs at 4% [7], which when taken with the existing LA commuter population of over 800,000 [22], could lead to a demand of over 32,000 passengers per day.

The second reason was congestion. LA is the most congested city in the U.S., according to Figure 20, with a Roadway Congestion Index (RCI) value of almost 1.6, significantly above the maximum preferred RCI value of 1.0. Figure 21 shows the increasing rate of annual LA delay per commuter; the current data (as of 2017) shows that the average LA commuter endures over 119 annual hours of traffic delay, over 6.1 hours of congested weekday hours, over $2,676 annually in costs related to congestion, and wastes over 35 gallons of gasoline annually. This accumulates to totals of 971,478,000 of annual delay, $19,490,000,000 of annual congestion cost, and 256,931,000 gallons of fuel wasted annually [23].

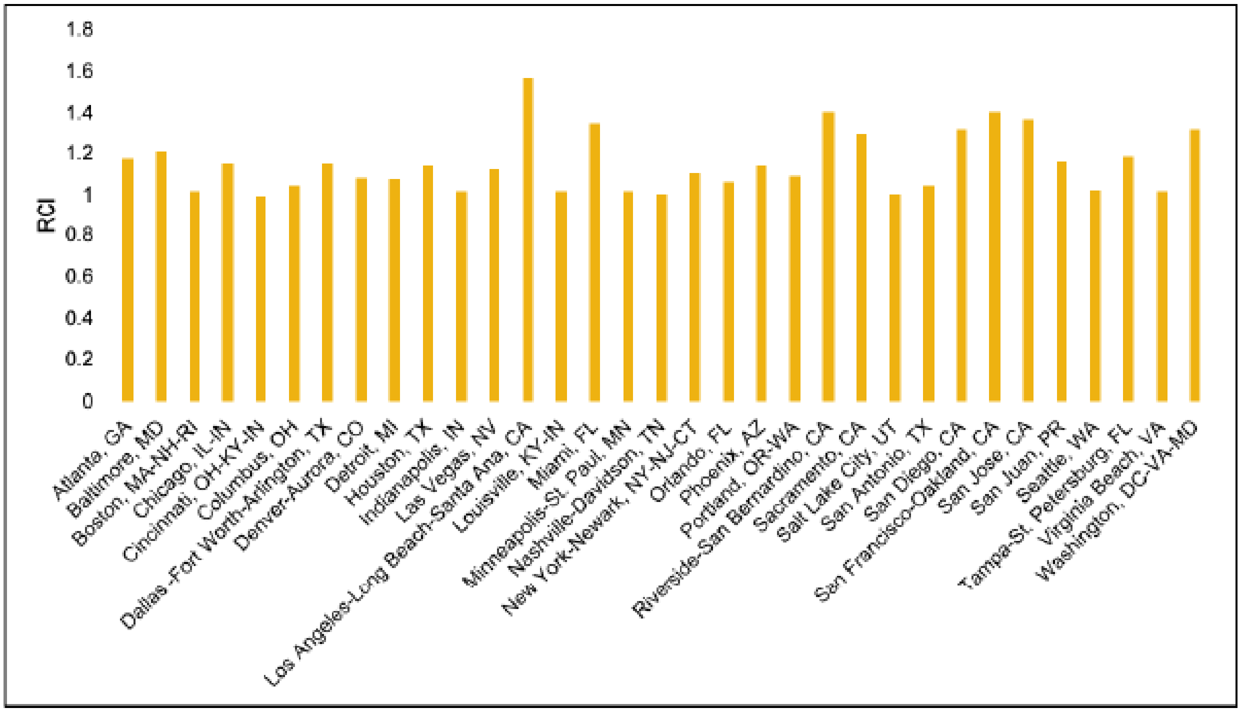


Figure 20: Roadway Congestion Index (RCI) across major American cities [10]

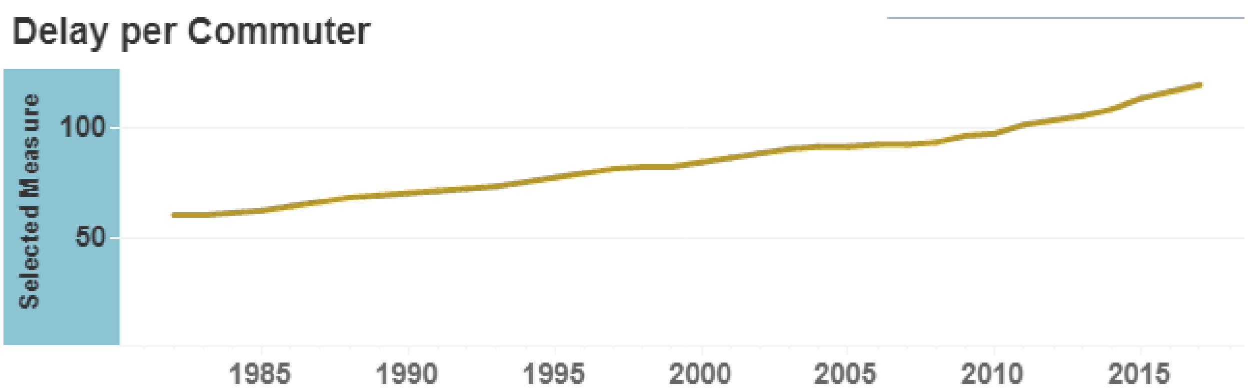


Figure 21: Average annual delay per commuter in Los Angles [23]

The third reason was commute times. LA is notorious for its commute times, which are directly tied not only to its congestion, but the sprawling geographical layout of the city and its suburbs. Figure 22 gives a visual representation of the average commute times in discrete sections of the LA metro area. It is important to note, however, that these times are average commute times in general, not average commute times to the Central Business District (CBD) or other high-traffic areas.

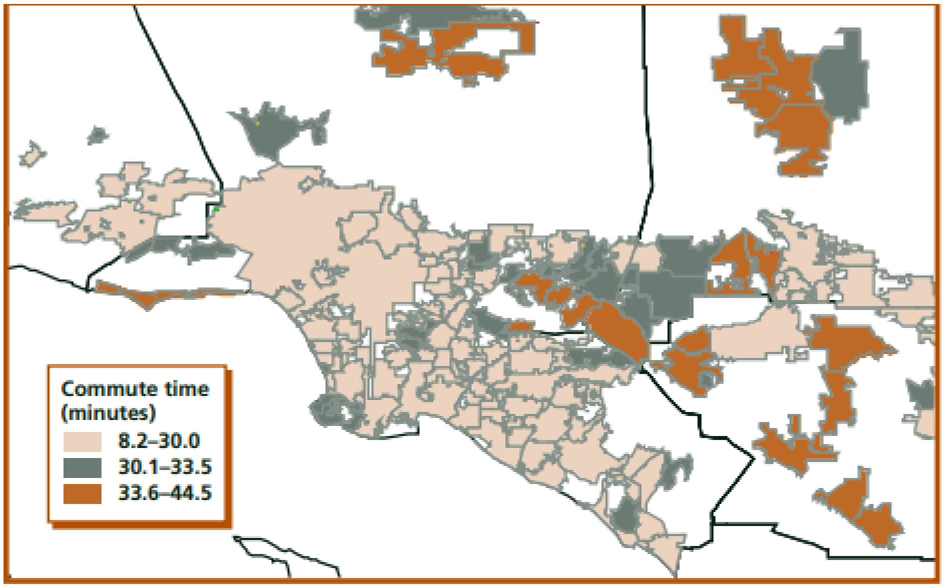


Figure 22: Average commute times in Los Angeles area cities [20]

The fourth reason is a robust and diverse public transportation system already in existence. Although most people drive alone in their cars to work, almost 10% of the city's commuter population uses public transit, according to Figure 23. Both this population and extra-long commuters might be very interested in a faster and more streamlined method transportation.

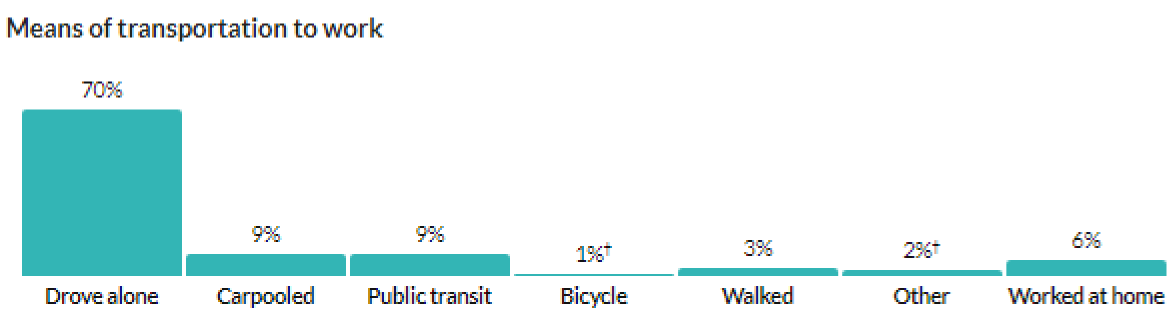


Figure 23: Means of work-related transportation in the City of Los Angeles [20]

The fifth reason is environmental factors. LA is famous for its mild, dry, and sunny climate year-round, which would significantly reduce complications with air travel. Figure 24 presents typical weather data for Downtown LA.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Record high °F (°C)	95 (35)	95 (35)	99 (37)	106 (41)	103 (39)	112 (44)	109 (43)	106 (41)	113 (45)	108 (42)	100 (38)	92 (33)	113 (45)
Mean maximum °F (°C)	83.3 (28.5)	84.3 (29.1)	85.8 (29.9)	91.2 (32.9)	89.7 (32.1)	90.2 (32.3)	94.1 (34.5)	95.3 (35.2)	98.9 (37.2)	95.5 (35.3)	88.0 (31.1)	81.4 (27.4)	102.7 (39.3)
Average high °F (°C)	68.2 (20.1)	68.6 (20.3)	70.2 (21.2)	72.7 (22.6)	74.5 (23.6)	78.1 (25.6)	83.1 (28.4)	84.4 (29.1)	83.1 (28.4)	78.5 (25.8)	72.8 (22.7)	67.7 (19.8)	75.2 (24.0)
Daily mean °F (°C)	58.0 (14.4)	58.9 (14.9)	60.6 (15.9)	63.1 (17.3)	65.8 (18.8)	69.2 (20.7)	73.3 (22.9)	74.3 (23.5)	73.1 (22.8)	68.6 (20.3)	62.4 (16.9)	57.6 (14.2)	65.4 (18.6)
Average low °F (°C)	47.8 (8.8)	49.3 (9.6)	51.0 (10.6)	53.5 (11.9)	57.1 (13.9)	60.3 (15.7)	63.6 (17.6)	64.1 (17.8)	63.1 (17.3)	58.7 (14.8)	52.0 (11.1)	47.5 (8.6)	55.7 (13.2)
Mean minimum °F (°C)	41.3 (5.2)	42.9 (6.1)	44.9 (7.2)	48.4 (9.1)	53.6 (12.0)	57.2 (14.0)	61.2 (16.2)	61.8 (16.6)	59.2 (15.1)	54.1 (12.3)	45.0 (7.2)	40.8 (4.9)	39.1 (3.9)
Record low °F (°C)	28 (−2)	28 (−2)	31 (−1)	36 (2)	40 (4)	46 (8)	49 (9)	49 (9)	44 (7)	40 (4)	34 (1)	30 (−1)	28 (−2)
Average rainfall inches (mm)	3.12 (79)	3.80 (97)	2.43 (62)	0.91 (23)	0.26 (6.6)	0.09 (2.3)	0.01 (0.25)	0.04 (1.0)	0.24 (6.1)	0.66 (17)	1.04 (26)	2.33 (59)	14.93 (379)
Average rainy days (≥ 0.01 in)	6.1	6.4	5.5	3.2	1.3	0.6	0.3	0.3	1.0	2.5	3.3	5.2	35.7
Mean monthly sunshine hours	225.3	222.5	267.0	303.5	276.2	275.8	364.1	349.5	278.5	255.1	217.3	219.4	3,254.2
Percent possible sunshine	71	72	72	78	64	64	83	84	75	73	70	71	73

Figure 24: Downtown Los Angeles climate data [24]

Figure 25 shows that the greatest concern that potential users have is encountering inclement weather while using a PAV. The relatively placid climate of LA would certainly mitigate those fears, and would help with attracting investors.

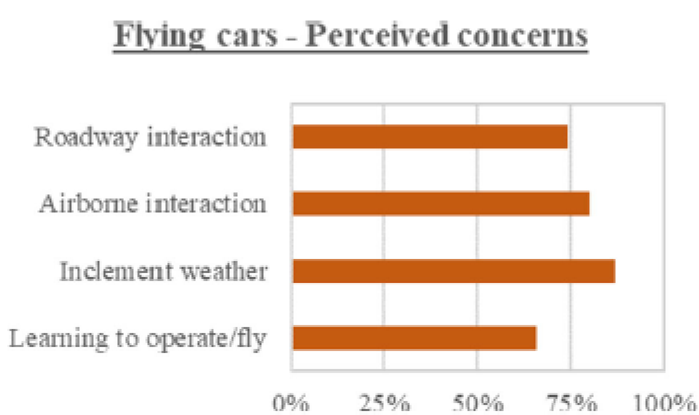


Figure 25: Perceived concerns with PAVs [16]

The sixth and final main reason for choosing LA as the ideal site for implementing UAM as a viable public transportation option is environmental pollution and climate change. LA is rated is one of the worst emission source areas in the U.S., producing nearly 13.5 million tons of CO_2 gas per person per year, with almost one-third of those emissions coming from transportation uses [25]. UAM has the potential to reduce those emissions by relying on electric power. PAVs have the potential to reduce greenhouse gas emissions by 52% relative to internal combustion engine vehicles and 6% relative to ground-based electric vehicles [6].

b. Current Capabilities and Constraints

Figure 26 describes the restricted airspace in Los Angeles, particularly around Los Angeles International Airport (LAX). Figures 27 and 28 describe the high and low altitude-permitted air sector areas as well. Figure 29 combines the information from Figures 27 and 28 to produce a visual representation of the air traffic around LA.

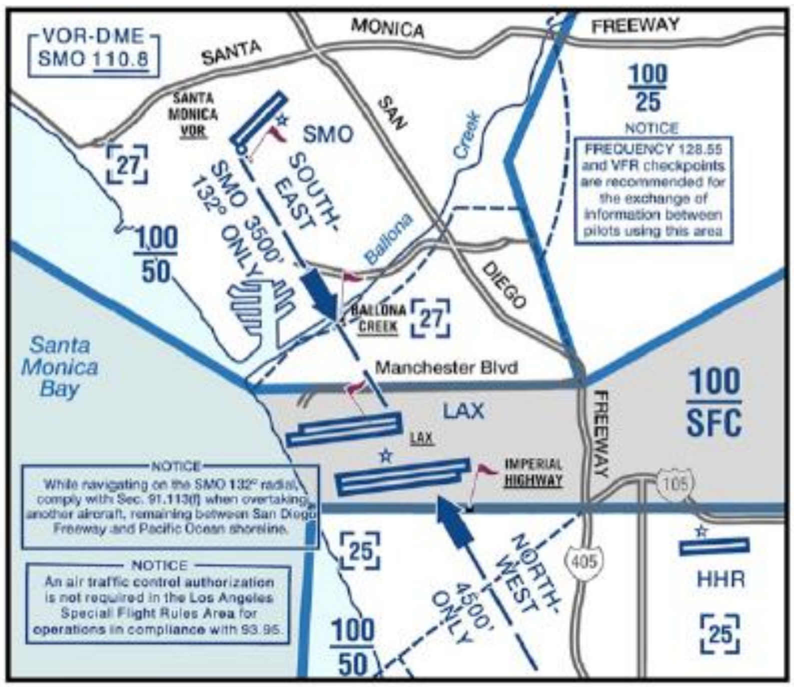


Figure 26: LA restricted airspace map [18]

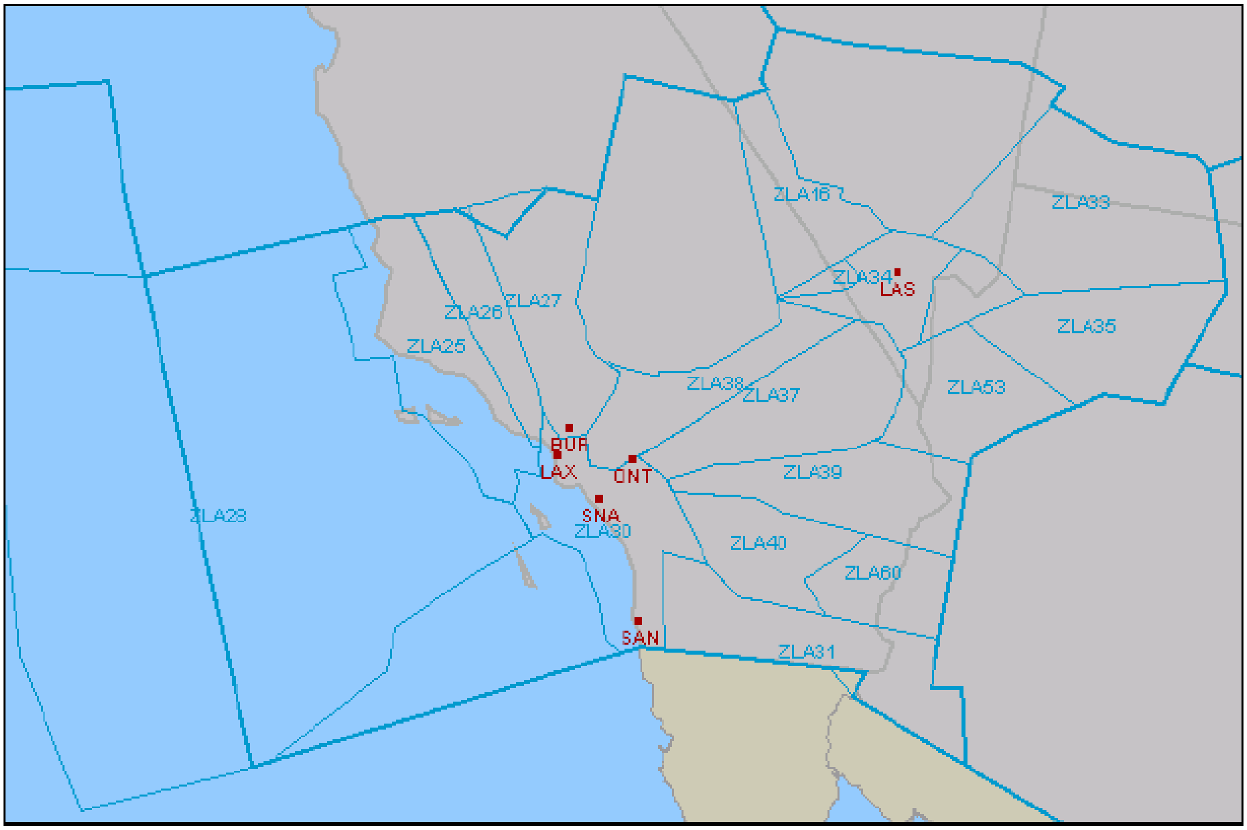


Figure 27: LA high-altitude airspace map [27]

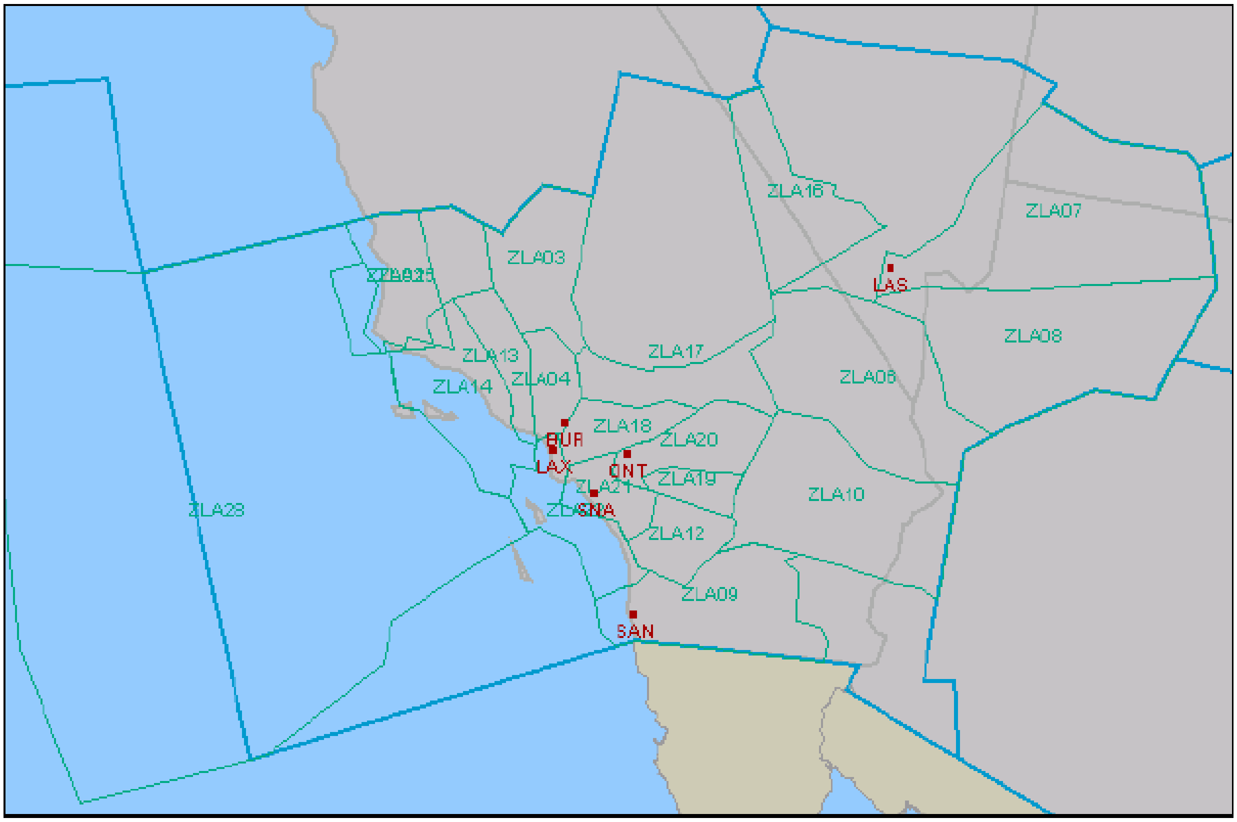


Figure 28: LA low-altitude airspace map [27]

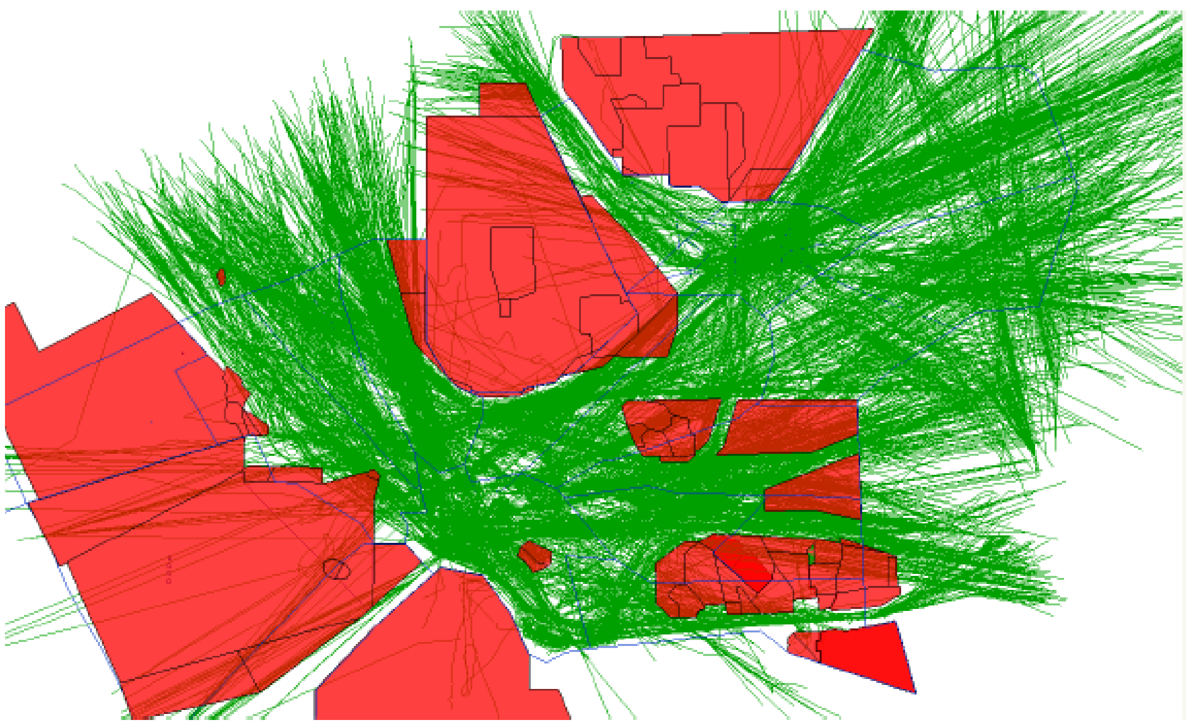


Figure 29: Air traffic flow around restricted areas in LA [27]

4. Analysis

Figures 30 and 31 show how transportation nodes, existing points of interest, and existing airports, airfields, and helipads influence the placement of PAV stations and the subsequent UAM networks in a hypothetical model.

Figure 30: Hypothetical map showing the influence of existing infrastructure on vertiport placement [8]

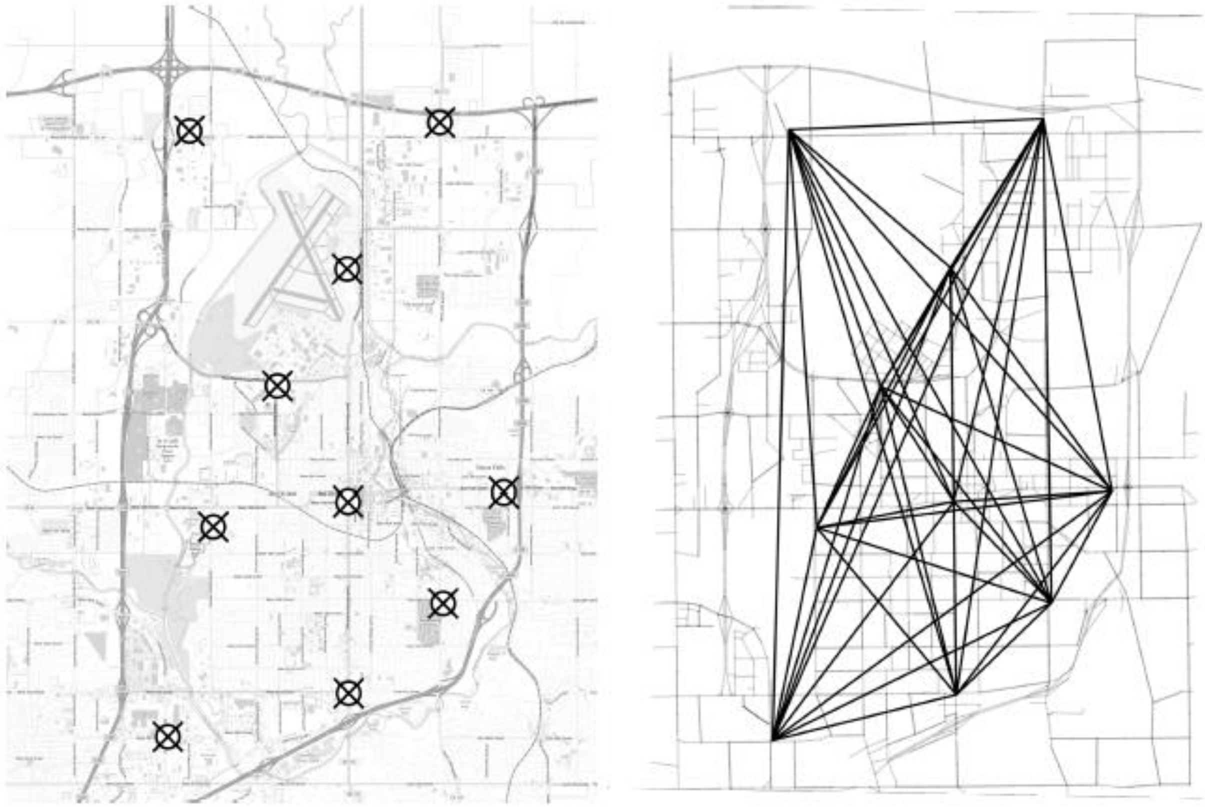


Figure 31: Hypothetical map showing the visualization of a UAM network structure based off of UAM station placement [8]

One case study in 2017 sought to realistically model UAM demand and networks based on the population distribution and socioeconomic factors present in the LA metro area. Their findings are presented below in Figures 32 and 33.

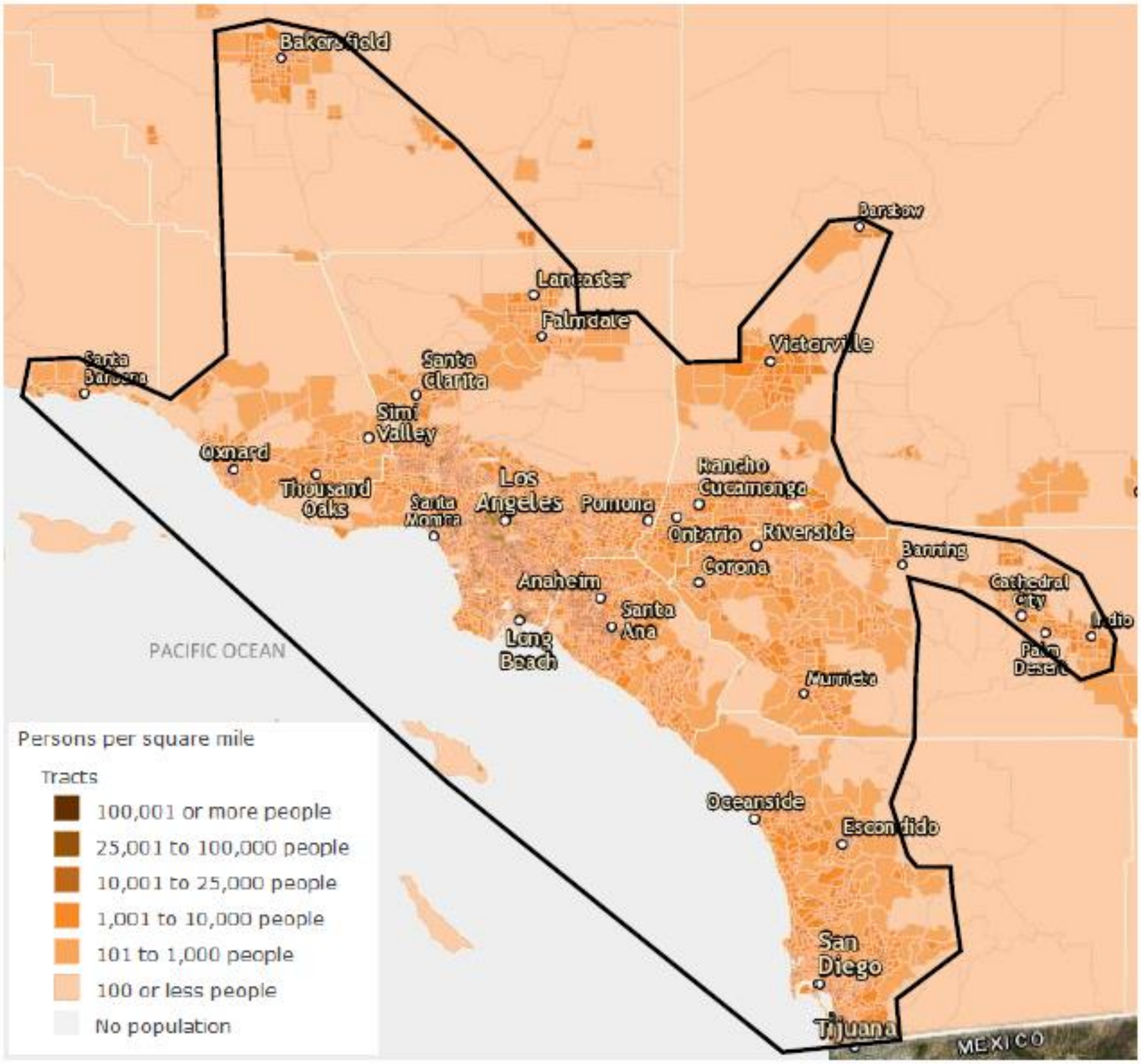


Figure 32: Population distribution in LA [26]

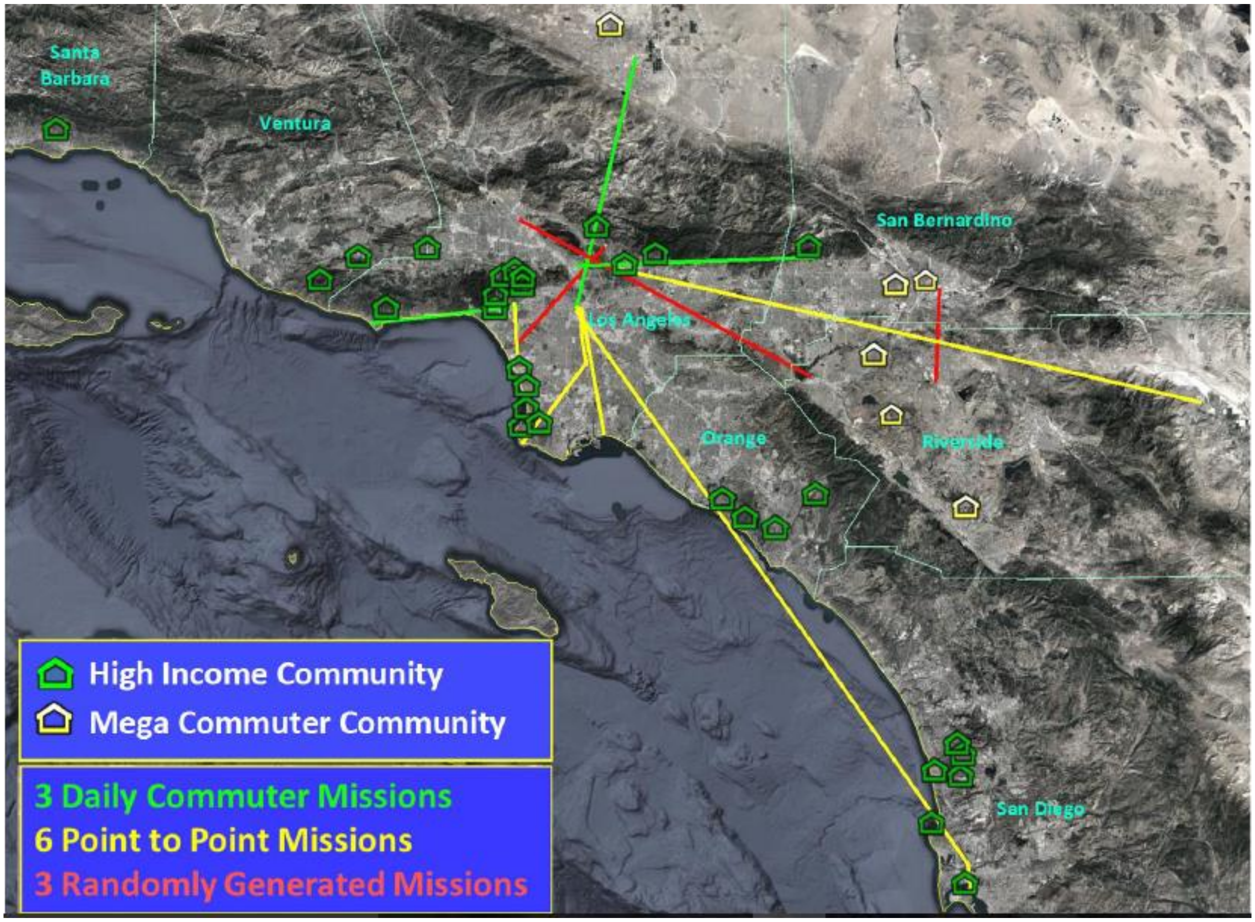


Figure 33: UAM model results in LA [26]

	Reference Mission	Demand Opportunity	Ground Distance	Off-Peak Ground Time	Peak Ground Time
Daily Commute	Malibu to Century City	High Income Severe Congestion	27.5 mi	60 min	110 min
	San Bernardino to Glendale	High Income Severe Congestion	44.0 mi	60 min	160 min
	Antelope Valley to L.A. City Center	Long Distance	61.5 mi	80 min	130 min
Non-Commute Point to Point	San Diego to L.A. City Center	Long Distance	122 mi	140 min	195 min
	L.A. City Center to Long Beach	Severe Congestion	26.5 mi	43 min	100 min
	Beverly Hills Hotel to LAX	High Income Severe Congestion Arrival Deadline	13.0 mi	42 min	90 min
	Redondo Beach to Dodger Stadium	High Income Severe Congestion Arrival Deadline	22.7 mi	55 min	130 min*
	Rancho Palos Verdes to Hospital	High Income Arrival Deadline	8.5 mi	21 min	23 min
	San Marino to Palm Springs	High Income Long Distance	116 mi	125 min	185 min
Random	San Bernardino to Perris	-	26 mi	34 min	70 min
	Arleta to Corona	-	71 mi	92 min	190 min
	Altadena to Culver City	-	30 mi	58 min	130 min

Table 6: Summary of the UAM model flights shown in Figure 33 [26]

Based off of Table 6 (which lists the most probable production and attraction zones for UAM operations), the optimal locations for potential vertiports can be assumed.

5. Conclusion

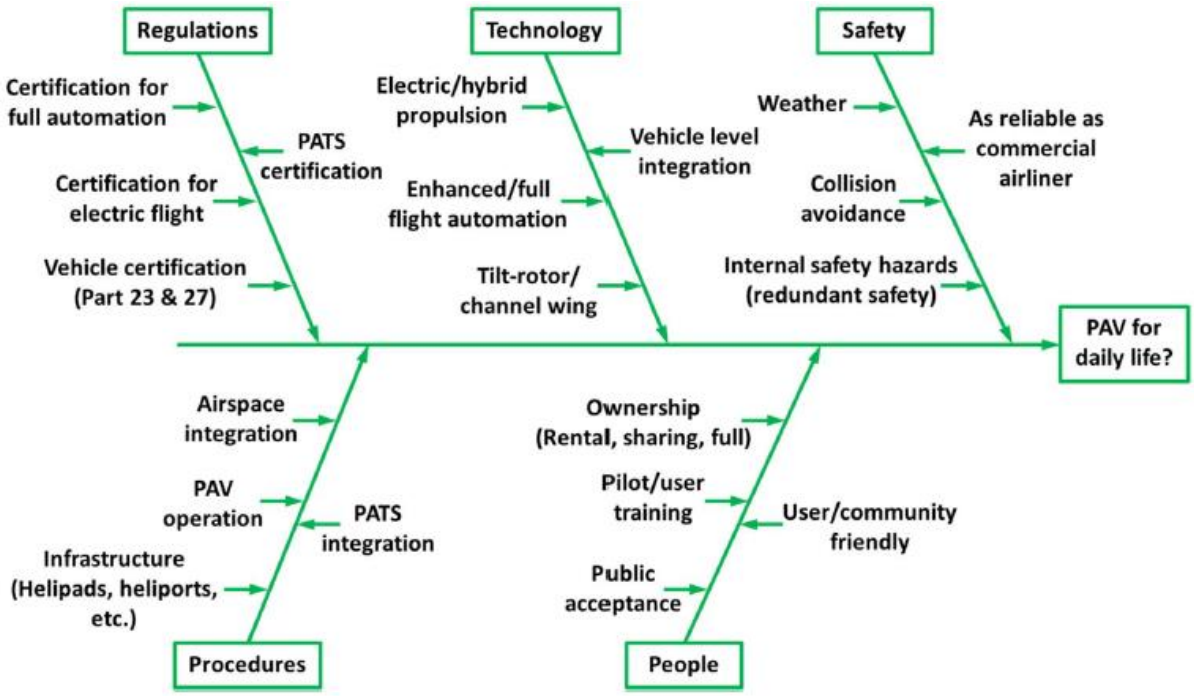


Figure 34: An Ishiwaka diagram for UAM vehicle development [11]

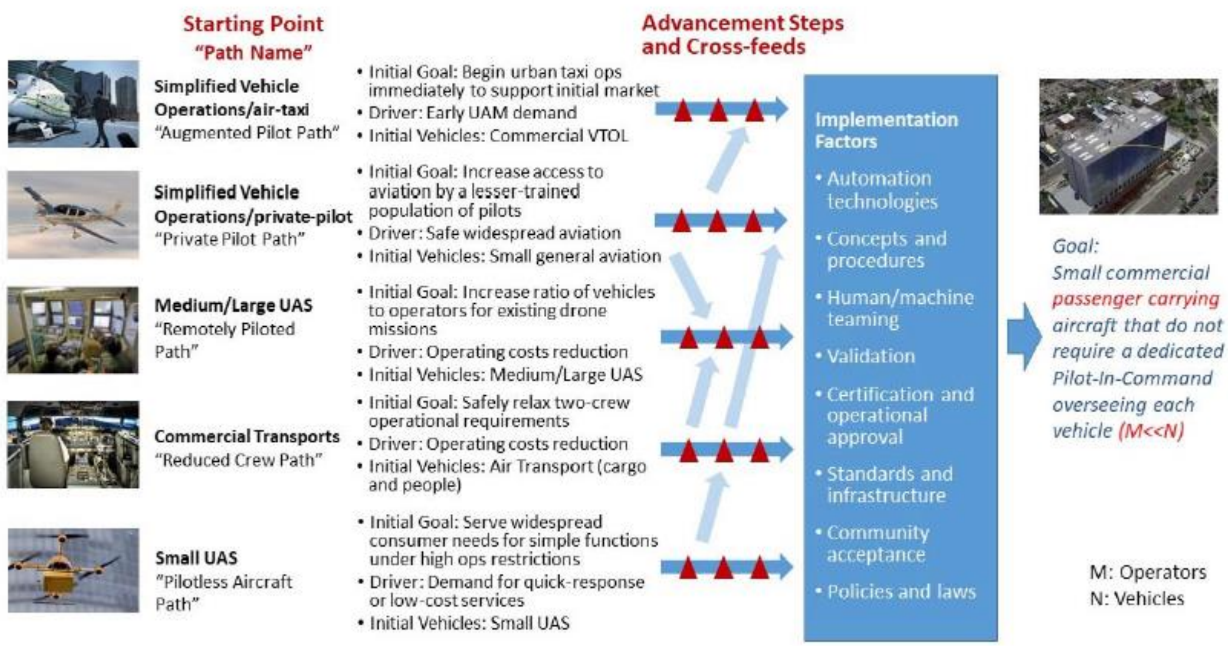


Figure 35: Steps to development for UAM operations [12]

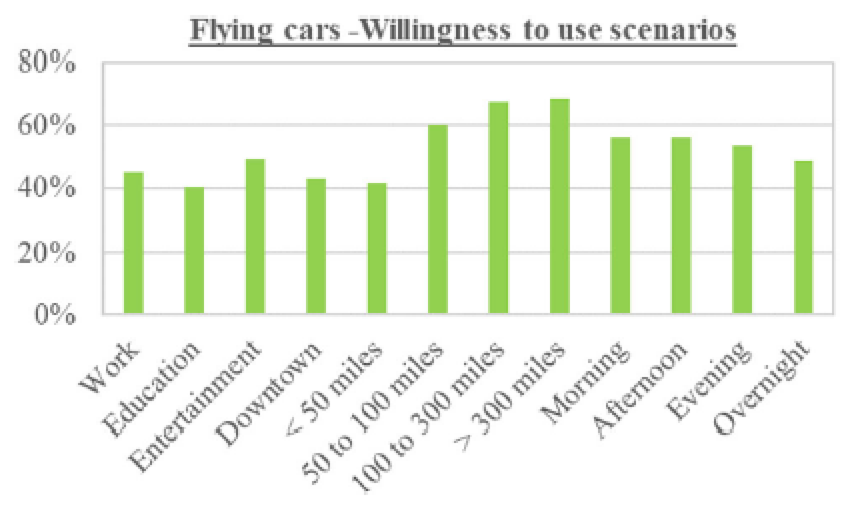


FIGURE 5 | Flying car use case scenarios.

Figure 36: Various scenarios in which individuals would be willing to use PAVs [16]

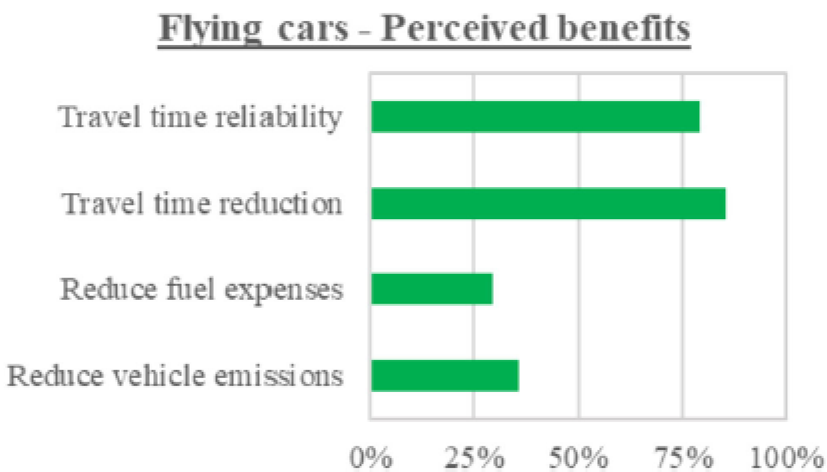


Figure 37: Perceived benefits of PAVs [16]

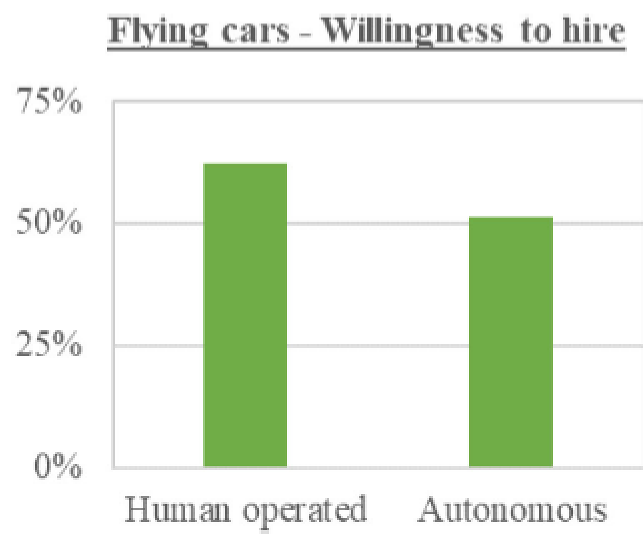


Figure 38: Contrast in preferences between piloted and autonomous PAVs [16]

6. References

1. Mayakonda, M., Justin, C., Anand, A., Weit, C., Wen, J., Zaidi, T., Mavris, D. "A Top-Down Methodology for Global Urban Air Mobility Demand Estimation". American Institute of Aeronautics and Astronautics Aviation Forum, June 15-19, 2020.
2. Eker, U., Ahmed, S., Fountas, G., Anastasopoulos, P. "An Exploratory Investigation of Public Perceptions towards Safety and Security from the Future Use of Flying Cars in the United States". *Analytic Methods in Accident Research*. July 12, 2019.
3. Li, S., Egorov, M., Kochenderfer, M. "Analysis of Fleet Management and Network Design for On-Demand Urban Air Mobility Operations". American Institute of Aeronautics and Astronautics Aviation Forum, June 15-19, 2020.
4. Sun, X., Wandelt, S., Stumpf, E. "Competitiveness of On-Demand Air Taxis Regarding Door-to-Door Travel Time - A Race Through Europe". *Transportation Research Part E: Logistics and Transportation Review*. September 18, 2018.
5. Verma, S., Keeler, J., Edwards, T., Dulchinos, V. "Exploration of Near-term Potential Routes and Procedures for Urban Air Mobility". American Institute of Aeronautics and Astronautics Aviation Forum, June 17-21, 2019.
6. Sutherland, B. "Flying Cars for Green Transportation". *Joule,* Cell Press, 50th Hampshire Street, 5th floor, Cambridge, MA 02139, USA.

7. Maheshwari, A., Mudumba, S., Sells, B., DeLaurentis, D., Crossley, W. “Identifying and Analyzing Operational Limits for Passenger-Carrying Urban Air Mobility Missions”. American Institute of Aeronautics and Astronautics Aviation Forum, June 15-19, 2020.
8. Rothfeld, R., Balac, M., Ploetner, K., Antoniou, C. “Initial Analysis of Urban Air Mobility’s Transport Performance in Sioux Falls”.
9. Schrage, D. “KISS Principle Required for Rotorcraft to Become Personal Air Vehicles (PAVs)”. American Helicopter Society (AHS) 64th Forum, April 28, 2008.
10. Venkatesh, N., Payan, A., Justin, C., Kee, E., Mavris, D. “Optimal Siting of Sub-Urban Air Mobility (sUAM) Ground Architectures Using Network Flow Formulation”. American Institute of Aeronautics and Astronautics Aviation Forum, June 15-19, 2020.
11. Liu, Y., Kreimeier, M., Stumpf, E., Zhou, Y., Liu, H. “Overview of Recent Endeavors on Personal Aerial Vehicles - A Focus on the US and Europe Led Research Activities”. *Progress in Aerospace Sciences*. March 31, 2017.
12. Mathur, A., Panesar, K., Kim, J., Atkins, E., Sarter, N. “Paths to Autonomous Vehicle Operations for Urban Air Mobility”. American Institute of Aeronautics and Astronautics Aviation Forum, June 17-21, 2019.
13. Fleischer, T., Meyer-Soylu, S., Schippl, J., Decker, M. “Personal Aerial Transportation Systems – A Potential Solution for the Urban Mobility Challenges”. *Futures*. March 28, 2019.
14. Moore, M. “Personal Air Vehicles - A Rural-Regional and Intra-Urban On-Demand Transportation System”. American Institute of Aeronautics and Astronautics Paper 2003-2646.
15. Decker, M., Fleischer, T., Meyer-Soylu, S., Schippl, J. “Personal Air Vehicles As a New Option for Commuting in Europe - Vision or Illusion”. European Transport Conference, 2013.
16. Ahmed, A., Hulme, K., Fountas, G., Eker, U., Benedyk, I., Still, S., Anastasopoulos, P. “The Flying Car - Challenges and Strategies toward Future Adoption”. *Frontiers in Built Environment*. July 16, 2020.

17. Hulme, K., Anastasopoulos, P., Still, S., Fountas, G., Pantangi, S., Ahmed, S., Eker, U. "The Flying Car - Emergent Modeling & Simulation". Interservice/Industry Training, Simulation, and Education Conference, 2019.
18. Thipphavong, D., Apaza, R., Barmore, B., Battiste, V., Belcastro, C., Burian, B., Dao, Q., Feary, M., Go, S., Goodrich, K., Homola, J., Idris, H., Kopardeker, P., Lachter, J., Neogi, N., Ng, H., Oseguera-Lohr, R., Patterson, M., Verma, S. "Urban Air Mobility Airspace Integration Concepts and Considerations". American Institute of Aeronautics and Astronautics Aviation Forum, June 25-29, 2018.
19. https://www.census.gov/prod/www/decennial.html
20. https://www.ppic.org/content/pubs/cacounts/CC_206EBCC.pdf
21. https://censusreporter.org/profiles/16000US0644000-los-angeles-ca/
22. https://www.census.gov/newsroom/press-releases/2013/cb13-r13.html
23. https://mobility.tamu.edu/umr/congestion-data/
24. https://w2.weather.gov/climate/xmacis.php?wfo=lox
25. "California Greenhouse Gas Emissions from 2000 to 2007 – Trends of Emissions and Other Indicators". California Air Resources Board. 2019.
26. Vascik, P., Hansman, J. "Constraint Identification in On-Demand Mobility for Aviation through an Exploratory Case Study of Los Angeles". American Institute of Aeronautics and Astronautics Aviation Technology, Integrity, and Operations Conference, June 2017.
27. https://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/air_traffic_services/artcc/media/ZLA-ARTCC.pdf