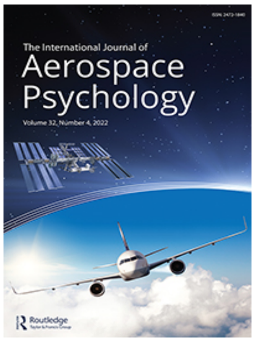

The International Journal of Aerospace Psychology

Routledge Taylor & Francis Group

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/hiap21

Technology Adoption and Acceptance of Urban Air Mobility Systems: Identifying Public Perceptions and Integration Factors

Ricole A. Johnson, Erika E. Miller & Steven Conrad

To cite this article: Ricole A. Johnson, Erika E. Miller & Steven Conrad (2022) Technology Adoption and Acceptance of Urban Air Mobility Systems: Identifying Public Perceptions and Integration Factors, The International Journal of Aerospace Psychology, 32:4, 240-253, DOI: 10.1080/24721840.2022.2100394

To link to this article: https://doi.org/10.1080/24721840.2022.2100394

Published online: 12 Jul 2022.

THE INTERNATIONAL JOURNAL OF AEROSPACE PSYCHOLOGY
2022, VOL. 32, NO. 4, 240–253
https://doi.org/10.1080/24721840.2022.2100394

Routledge
Taylor & Francis Group

Check for updates

TRUE EXPERIMENTS

Technology Adoption and Acceptance of Urban Air Mobility Systems: Identifying Public Perceptions and Integration Factors

Ricole A. Johnson, Erika E. Miller, and Steven Conrad

Department of Systems Engineering, Colorado State University, Fort Collins, Colorado, USA

ABSTRACT

Objective: This study aims to identify expectations and perceptions of Passenger Air Vehicles (PAVs). Specifically, (1) what are the initial perceptions of PAVs by the public, and (2) what are the differences between early and laggard adopters of PAVs.
Background: The emergence of Urban Air Mobility presents an opportunity to increase transportation capacity in densely populated metropolitan areas. However, successful integration is largely dependent on adoption and acceptance from communities.
Method: A survey of 407 respondents across the United States provides insights from potential users. The Technology Adoption Life Cycle and Technology Acceptance Model are used to characterize adopter profiles and rates of adoption.
Results: Respondents not only expect the same level of safety standards as conventional aircraft (i.e., seatbelts, air quality), but even more feedback (i.e., displays on current and projected flight operations). PAVs are not an immediate replacement for daily trips once available. In-cabin noise is not a crucial deterrent to ridership. Earlier PAV adopters are trusting of the technology, willing to pay more to ride, and exhibit overall riskier behaviors. Later PAV adopters need more feedback in-flight and a pilot on-board.
Conclusion: PAV manufacturers, operators, and policymakers can utilize these findings to incorporate crucial design elements needed for PAVs to satisfy user expectations. These findings identify priorities that should be targeted in relative timeframes to satisfy near-term and long-term PAV users appropriately.

KEYWORDS
Urban Air Mobility; Passenger Air Vehicles; Autonomous Technology Adoption; Human Systems Integration

Introduction

The next frontier in aviation innovation is approaching. Rapid development, testing, and certification of Passenger Air Vehicles (PAVs) is underway to address the need for alternative transportation in densely populated cities, giving rise to the concept of Urban Air Mobility (UAM). NASA defines UAM as a safe, efficient, and highly automated aircraft used at lower altitudes to transport passengers or cargo in and around metropolitan areas (Price et al., 2020). The US Federal Aviation Administration (FAA) is working in collaboration with NASA to develop regulatory rules and standards for autonomous air vehicle integration into the national airspace. The industry envisions the first PAV entry into service as soon as 2025, with a US potential market valuation of $115 billion USD by 2035 and global market potential of $318 billion USD by 2040 (Goyal et al., 2021).

CONTACT Erika E. Miller erika.miller@colostate.edu 6029 Campus Delivery, Colorado State University, Fort Collins CO 80523-1301, USA

The US Department of Transportation's Beyond Traffic 2045 Report offers a comprehensive assessment on how population growth will influence future transportation system needs and priorities. It projects that by 2045, the US population will increase by 70 million, to a total of 390 million people (Barami & Merrefield, 2016). Furthermore, growth trends and population shift from rural areas to urban centers are expected to continue in the years ahead. According to the United Nations World Urbanization Report, globally there are more people living in urban areas (currently 55% of the world's population), with expected growth to 68% by 2050 (United Nations [UN], 2019). North America is the most urbanized region of the world, with 82% of its population living in urban areas (UN, 2019). This population growth will lead to corresponding growth in travel demand on already capacity-strained transportation systems. Currently, it is estimated that on average, US commuters spend over 42 hours each year stuck in traffic, with an annual cost of congestion in delays and lost fuel totaling $160 billion (Barami & Merrefield, 2016).

Three primary use cases are being explored for relatively near-term UAM deployment: cargo transport, air metro (i.e., scheduled routes), and air taxi (i.e., on demand; Hasan, 2019). In this study, we examine the latter, the air taxi use case – as primary enabler of passenger mobility. The service vision for air taxis includes short-duration, on-demand intra- and inter-city trips aboard a PAV. The initial functional requirements for PAVs proposed by NASA include vertical takeoff and landing (VTOL) capability (to enable runway independence), short duration hover capability, 60-hour battery life, 7-minute battery charging, payload capacity for four passengers and one pilot [and luggage], and a maximum payload weight not to exceed 980 pounds (Johnson & Silva, 2018). A PAV would operate at cruise speeds of 150 miles per hour and altitudes 1,500 feet above ground level (Price et al., 2020). PAVs can either be operated by an onboard pilot, a remote pilot, or be fully-autonomously piloted (Mathur et al., 2019). Additionally, PAVs would be designed to be energy efficient and eco-friendly – by having reduced or zero emissions as compared to conventional, petroleum-fueled, ground-based modes of transport – and to operate at reduced noise output around 70 decibels, which is significantly quieter than a traditional helicopter that produces noise output 85 decibels (Moore, 2003). It is important to note that PAVs are still early in development and their designs will likely be modified before deployment. Advancements in enabling technologies (i.e., distributed electrical propulsion systems, long-life lithium energy, advanced structural materials, and autonomous flight operation systems) have accelerated the development of PAVs and their progress toward full-scale implementation and commercialization (Goyal et al., 2018). An array of aircraft design configurations is in development by numerous PAV manufacturers. Globally, there are approximately 100 aircraft designs for PAV air taxi projects (Goyal et al., 2018). Proposed PAV design configurations include, but are not limited to, vectored thrust (fixed-wing), lift + cruise, and multi-rotor (wingless; Johnson & Silva, 2018; Goyal et al., 2018). Given the growing interest and development investment in PAVs, there is a need to study consumer acceptance of the technology.

Furthermore, while interest and building momentum are creating numerous pathways for prototype development, there are still significant challenges and barriers to overcome before PAVs are widely utilized in transportation systems. NASA identified five key areas for a successful UAM framework: *(i)* vehicle development & production, *(ii)* individual vehicle management & operations, *(iii)* airspace system design & implementation, *(iv)* airspace & fleet operations management, and *(v)* community integration (Hasan, 2019; Price et al., 2020). This paper aims to focus on the challenge of community integration, a crucial component of public acceptance and adoption.

Two sociological models serve as frameworks to ascertain individual behaviors for community integration of PAVs, which drive acceptance and adoption of new innovation and technology. Rogers's (2003) *Technology Adoption Life Cycle* model proposes that the rate of adoption of any new innovation is normally distributed along a bell-shaped curve, segmented by standard deviations from the mean. A normalized adoption curve would present five groups characterized as Innovators (2.5%), Early Adopters (13.5%), Early Majority (34%), Late Majority (34%), and Laggards (16%), where innovators and early adopters are often grouped together to represent early market. Innovators are the first to adopt new technology, knowingly accepting risk with perceived reward. Early Adopters adopt new technology fairly early albeit carefully in order to balance risk. Early and Late Majority adopt new technology after most people have tried it, and do so with a bit of skepticism. Laggards may adopt technology, if at all, only after the technology has been well established. The *Technology Acceptance Model* (Davis, 1989) suggests that perceived usefulness and perceived ease of use are two key determinants that drive individual behavior intentions to use a new system or technology. Perceived usefulness describes how an individual believes technology would enhance job performance or life, while perceived ease of use describes the degree to which an individual believes using the technology requires effort (Venkatesh & Davis, 2000).

In this paper, we demonstrate and discuss the use of a quantitative survey designed to gain insights and general perceptions of PAVs as an alternative aviation transportation system. The two research questions are as follows: *(i)* what are the initial perceptions of PAVs by the general public; and *(ii)* what are the differences between early, moderate, late, and laggard adopters of PAV technology. A survey was conducted to examine respondent's technology adoption profiles and adoption time horizons relative to full-scale PAV entry into service. Findings from this study inform community acceptance and integration of PAV revolutionary technology.

Materials and Methods

A survey study was conducted to evaluate the research questions. The survey gained approval from the Colorado State University Institutional Review Board (IRB), protocol 20-10371H.

Passenger Air Vehicle (PAV) Description

The first page of the survey provided a description of PAVs and a conceptual image to familiarize participants with the concept. The image depicted a fixed wing, small aircraft flying relatively low within a metropolitan area, with four other PAVs flying in the background. Aircraft design configurations vary among PAV manufacturers, and while the PAV concept introduced in the survey was a fixed wing, the questions were structured to be agnostic to the type of PAV design. The definition provided to participants followed NASA's typical definition of PAVs; they were informed that "Passenger Air Vehicles are on-demand, auto-piloted, electric aircraft that transport 1 to 4 passengers at low altitudes within urban and suburban areas. These air vehicles, or air taxis, are capable of vertical take-off and landing, thereby requiring no traditional runway, and offer a safe, quiet and eco-friendly alternative to road traffic emissions and congestion."

Participants

There were a total of 470 responses to the survey. After data cleaning, a total of 407 survey responses were usable. The respondents were sampled through Pollfish, an online survey platform. We paid Pollfish $0.95 for each completed survey and respondents were compensated through Pollfish. Data was collected from February 14, 2021 through March 4, 2021. Only respondents who lived in the United States were included, which was determined by a survey question that asked participants to provide their residential zip code.

Survey Design

There were a total of 70 questions. Many of the questions used a 5-point Likert scale. Similar questions were grouped together into matrices to alleviate workload (e.g., "To what extent do you agree or disagree with the following statements . . ."). Hence, while there were 70 different questions many were very similar to adjacent questions and quick to answer (e.g., How important is *(i)* comfortable seats, *(ii)* ample legroom, *(iii)* large windows, etc.). The questions were developed to capture respondent's feedback on PAV systems (i.e., trust, safety, ease of use, usefulness, and interior and interface design requirements) and their general affinity to technological innovation and rate of technology adoption. Questions were developed to follow the Technology Acceptance Model (Davis, 1989). There were nine questions related to participant demographics. The survey took approximately 15 minutes to complete.

PAV Adopter Groups

Participants were asked how soon after being available to the public they would be willing to ride a PAV. This information was used to group participants into four PAV adopter groups: Early (0–6 months); Moderate (6 months–1 year); Late (1–5 years); and Laggard (5 or more years).

Data Analysis

Data were cleaned and analyzed using R (version 4.1.0). Chi-square tests were used to test for independence between the different PAV adopter groups and their various perceptions. Ordered logistic regression models were used for multivariate analysis of the different PAV adopter groups. Statistical significance was evaluated at $\alpha = 0.05$.

Results

Demographics

A total of 470 survey responses were collected. After removing incomplete responses and cross-referencing participant residential zip codes with known US zip codes, 407 responses provided data for our analyses. Respondents represent a broad spectrum of education, employment and income statuses, and residential locations (Table 1). Comparative demographics from 2020 US Census data for individuals 18 and over are provided as appropriate. Participant ages range from 18 to 74 years old (Avg = 39.3; SD = 12.6 years).

Table 1. Participant demographics with comparable US demographics.

Variable	Group	N Responses	% of Total	US Total (%)
Gender	Male	223	54.5	49.2
	Female	181	44.5	50.8
Education	Some HS	26	6.4	6.5
	HS Diploma	74	18.2	27.8
	Some College	81	19.9	17.5
	Associates	35	8.6	10.1
	Bachelors	76	18.7	22.1
	Postgraduate	115	23.6	11.4
Household Income ($)	<25k	79	19.4	18.1
	25–50k	95	23.3	19.7
	50–100k	95	23.3	28.6
	100–150k	66	16.2	15.3
	150–250k	64	15.7	8.0
	>250k	6	1.5	10.3
Employment Status	Student	11	2.7	9.9
	Employed	300	73.7	59.6
	Retired	37	9.1	–
	Unemployed	59	14.5	3.9
Residential Location	Rural	63	15.5	19.3
	Unincorporated	2	0.5	–
	Small Town	50	12.3	–
	Suburban	110	27.0	–
	Urban Core	118	29.0	71.2
	Urban Non-Core	60	14.7	9.5
	Unsure	4	1.0	–

Respondents were also asked: prior to COVID-19, what was their primary mode of transport for their work commute. Most of the respondents (50.1%) drive alone, followed by personal vehicle with 2 or more passengers (20.9%), then no commute (10.6%), public transport (5.4%), on-demand car service (3.4%), walk (3.2%), motorcycle (2.7%), vanpool (1.5%), bicycle (1.2%), and lastly other (1.0%).

General Perceptions

Just over half of the respondents (50.8%) are not familiar with PAVs, while 21.1% and 11.1% are extremely familiar and very familiar with PAVs, respectively. Of the respondents who are at least slightly familiar with PAVs, 55.5% are willing to ride a PAV within the first year they become available to the public, while 34.5% are willing to ride between 1 and 5 years after availability. The remaining 6.5% said they will wait at least 5 years to ride.

PAV Cabin Design

Respondents were asked to conceptually consider the interior of a PAV and rate the extent to which each feature was important to them. These are provided in descending order of importance (Figure 1), wherein importance ratings were captured using a 5-point Likert scale: Not at all important, Slightly important, Moderately important, Very important, and Extremely important. Figure 1 illustrates total percentage distribution, where the left value reflects the combined percentage of respondents who indicate *Not at All* and *Slightly* important, the center value reflects percentage of respondents who indicate *Moderately* important, and the right value reflects the combined percentage of respondents who indicate *Very and Extremely* important. A majority of respondents (>64%) rank each of

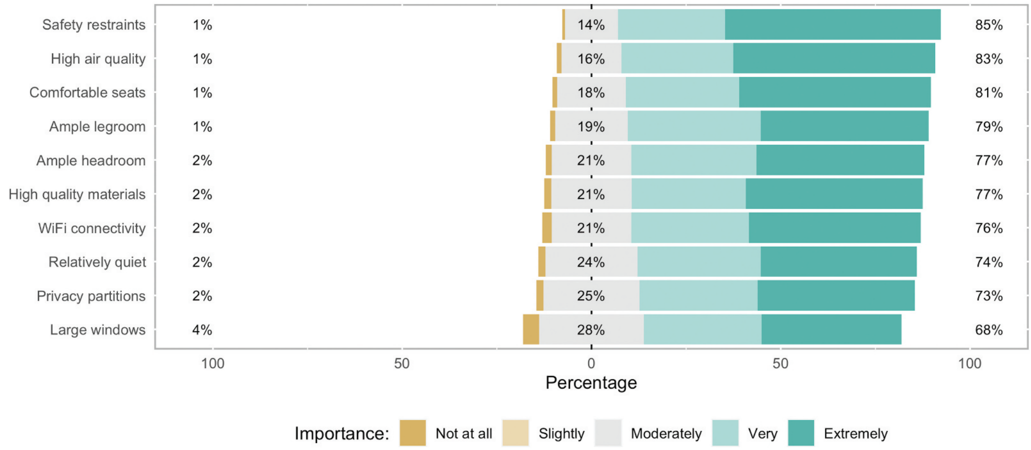

Figure 1. Perceived importance of various PAV cabin interior features.

the cabin interior features listed as either very important or extremely important. Participants were not asked to rank order the features, and future research could explore using best-worst scaling to parse out the most important features. Safety, vis-à-vis, safety restraints is of paramount importance to respondents, garnering the highest rating among all cabin features. The second highest is high air quality (83%), which the authors believe could be influenced by conducting the study during the COVID-19 pandemic. Comfortable cabin seating (81%), with ample leg room (79%) and ample headroom (77%), is rated as very and/or extremely important by respondents. Respondents also rate large windows as the PAV interior cabin feature of moderate importance (28%). Regarding interior cabin noise, respondent's perceptions of relatively quiet cabins are moderately (24%) to less important (2%) as a feature.

Similarly, participants were asked about their perceived importance of information presented on interior display screens within the PAV cabin (Figure 2), also on a 5-point Likert scale of importance. Participants rate weather condition information as the most

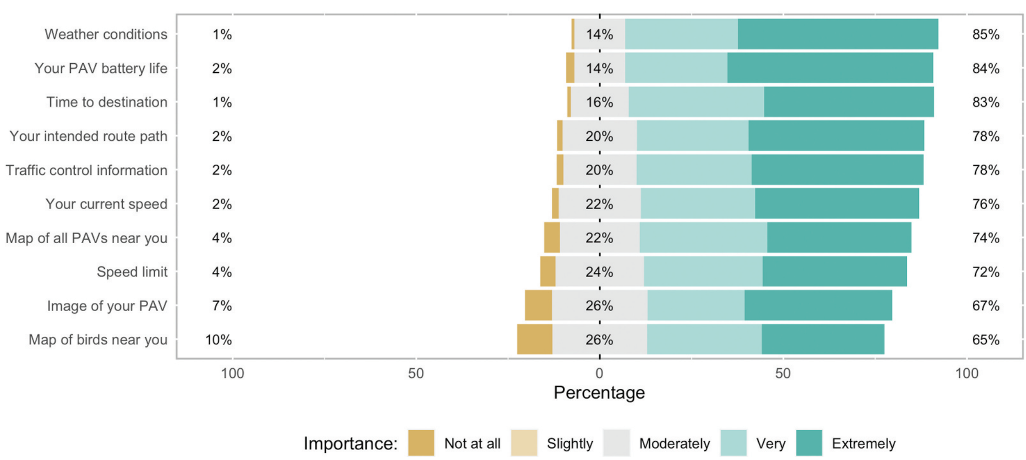

Figure 2. Perceived importance of various information on PAV passenger interior display screen.

Table 2. PAV adopter group demographics.

Demographic Variable	PAV Adopter Group Early (0–6 mo)	Moderate (6 mo–1 yr)	Late (1–5 yrs)	Laggard (5+ yrs)
Total, *N (%)*	102 (28.0)	107 (29.6)	126 (34.9)	26 (7.2)
Age, *Average (SD)*	41.5 (13.7)	37.7 (11.5)	36.4 (11.5)	40.0 (10.7)
Male, *N (%)*	63 (61.8)	58 (54.2)	69 (54.8)	18 (69.2)
Live in Urban Area, *%*	40.2	52.3	46.8	30.8
At least Bachelor's degree, *%*	37.2	54.2	53.2	42.3

important, with 83% rating it as very important or extremely important, whereas participants rate a map of birds near the PAV presented on a display screen as least important, with respondents finding the information moderately (23%) or less (20%) important. Interestingly, aircraft battery life, which is information unique to PAV displays compared to conventional aircraft passenger displays, is the second highest (82% rate as very important or extremely important) on the list of important information to view on a display screen within the cabin. Typical information one would perceive to be important to view in a conventional aircraft, such as time to destination, route path, and travel speed, are also rated as very/extremely important to respondents at 81%, 75%, and 71%, respectively.

Participants were grouped according to how soon they would be willing to ride a PAV once available to the public, from early to moderate to late to laggard. Participants who responded as "not sure" (N = 44) were removed from this subsequent analysis, resulting in 361 responses. Table 2 provides demographic information for these four PAV adopter groups.

Chi-square tests of independence were performed to determine if there is a relationship between the PAV adopter groups and more broad concepts not directly related to PAV design and functionality. Participants were asked, when it comes to technology, what best describes them: wanting to be first to try new technology, waiting awhile before trying new technology, usually being the last to try new technology, and preferring to stick with what they know. These definitions correspond to Rogers (2003) general technology adoption life cycle groups. There is a significant relationship between these self-reported general technology adoption groups and the PAV adopter groups, χ^2 (9, N = 359) = 41.3, $p < .001$, where PAV adopter groups correspond to general technology adoption groups. There is also a relationship between PAV adopter groups and willingness to ride in a driverless [automated] car, χ^2 (6, N = 359) = 23.732, $p = .0006$, where earlier PAV adopters are more willing to ride in an automated vehicle. There is also a relationship between PAV adopter group and the influence of airplane crashes, χ^2 (12, N = 333) = 21.184, $p = .048$, where earlier PAV adopters are less likely to let reports of airplane crashes influence their decision to ride in an airplane. A chi-square test also indicates no significant relationship ($p = .53$) between PAV adopter group and household income level.

Trips with PAVs

An ordered logistic regression model (Table 3) was used to evaluate differences between likely PAV trip purposes for the different PAV adopter groups. Ordered logistic regression was used because this model provides estimates (coefficient column in table) for the effect of each independent variable (first column) on the likelihood (specifically log odds) of increasing levels of the dependent variable. The dependent variable in this case has discrete

Table 3. Ordered logistic regression for PAV adopter group by PAV trip type.

Variable: Likely to use PAVs for . . .	Coefficient	Odds Ratio	SE	t-value	*p*-value
Daily commute to/from work	−0.175	0.805	0.161	−1.09	ns
Occasional commute to/from work	−0.335	0.729	0.159	−2.10	.04
Personal, non-business travel	−0.430	0.751	0.159	−2.70	.01
Entertainment/sight-seeing	−0.028	0.916	0.161	−0.17	ns
Early | Moderate	1.090	-	0.129	8.26	<.01
Moderate | Late	0.206	-	0.106	1.94	.05
Late | Laggard	2.531	-	0.208	12.19	<.01

ordered levels, that is, PAV adopter group from early to laggard, with four levels. A negative coefficient or odds ratio less than 1, with p-value less than 0.05, indicates that variable significantly reduces the likelihood of a later adopter. A positive coefficient or odds ratio greater than 1, with *p*-value <.05, represents a variable that is associated with an earlier adopter preference. As can be seen in Table 3, there is no significant difference between adopter groups and their intent to use PAVs for daily work commute and entertainment-related trips, but later PAV adopters are less likely to use PAVs for occasional work commute and personal travel.

Data on work commute times were additionally analyzed, where commute time was binned into no commute, <15 minutes, 15–30 minutes, 30–45 minutes, 45–60 minutes, or greater than 60 minutes. A chi-square test shows that respondents with shorter work commute times are more likely to be early and moderate PAV adopters, χ^2 (15, N = 357) = 27.32, $p = .026$.

Technology Acceptance Model Attributes

Participants were asked about their perceived usefulness (Figure 3) and perceived ease of use (Figure 4) of PAVs. Similar to the model structure for the ordered logistic regression above, two ordered logistic regression models were conducted with the dependent variable PAV adopter group with *(i)* the six variables relating to perceived usefulness, with somewhat and strongly agree ratings grouped together, as well as somewhat and strongly disagree ratings grouped together; and *(ii)* the five variables relating to perceived ease of use, also with somewhat and strongly ratings for agree and disagree grouped together, respectively. For perceived usefulness, earlier adopters are statistically more likely to agree that PAVs are safe (Coefficient = −0.434, OR = 0.65, $p = .02$) and more reliable (Coefficient = −0.612, OR = .54, $p < .01$), but not cost less per mile (Coefficient = 0.366, OR = 1.44, $p = .03$). For perceived ease of use, the only statistical correlation is that participants in the earlier adopter groups are more likely to agree that riding in PAVs would reduce stress (Coefficient = −0.633, OR = 0.531, $p < .01$).

Trust in PAVs

An ordered logistic regression model with dependent variable PAV adopter group and independent variables as various PAV trust concepts was used to identify differences in PAV trust that might lead to different PAV adoption times (Table 4). The model shows that trust in later adopters improves with visual indicators providing feedback to passengers inside the PAV (Coeff. 0.720); that early adopters are more likely to trust PAVs operated by an established brand (Coeff −0.708) and PAVs autonomously piloted (Coeff −0.364); and that trust in on-board piloted PAVs is not predictive of PAV adopter group ($p > .05$).

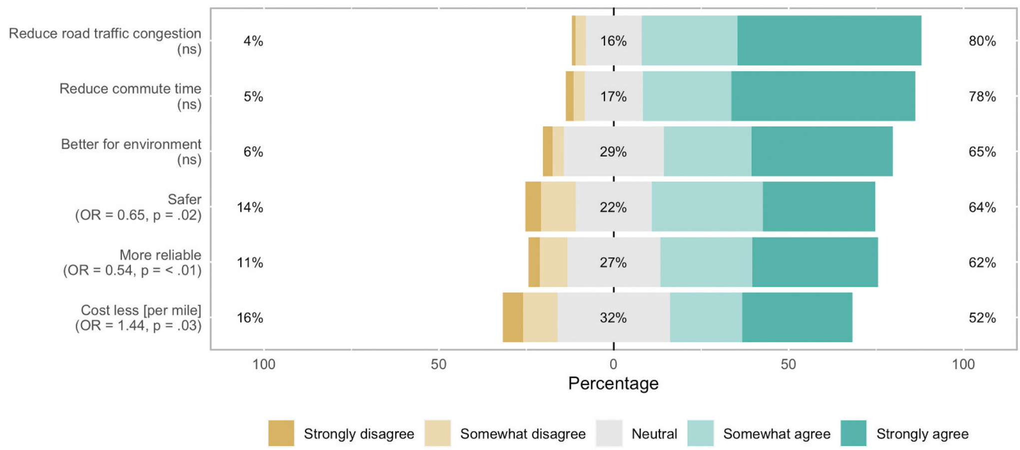

Figure 3. Perceived PAV usefulness with ordered logistic regression odds ratios and p-values.

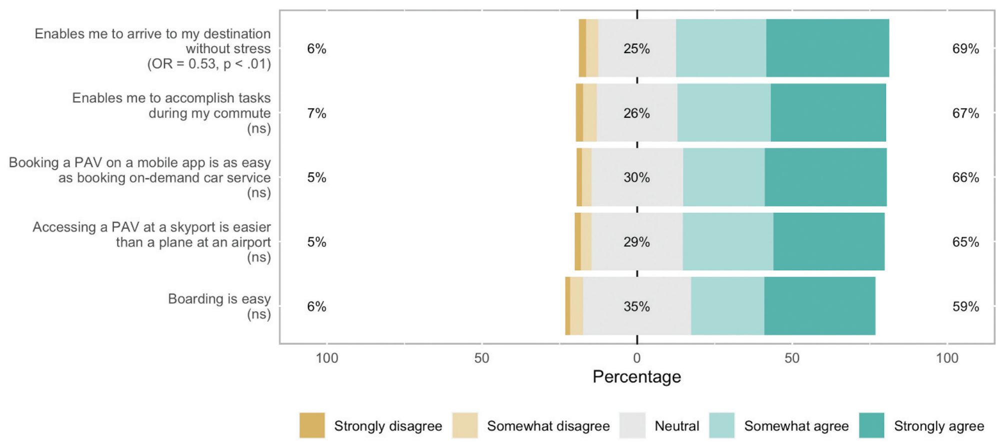

Figure 4. Perceived PAV ease of use with ordered logistic regression odds ratios and p-values.

Table 4. Ordered logistic regression for PAV adopter group by trust in PAVs.

Variable	Coeff.	Odds Ratio	SE	t-value	*p*-value
Need visual indicators inside PAV to trust flight is operating safely *(agree)*	0.720	2.054	0.331	2.18	.03
Trust riding in a PAV operated by an established brand *(agree)*	−0.708	0.492	0.344	−2.06	.04
Trust riding in a PAV with a pilot on-board *(agree)*	−0.213	0.808	0.335	−0.64	ns
Trust riding a PAV that is autonomously piloted *(agree)*	−0.364	0.695	0.176	−2.07	.04
Early | Moderate	1.257	-	0.331	3.80	<.01
Moderate | Late	0.019	-	0.327	0.06	ns
Late | Laggard	2.380	-	0.361	6.39	<.01

Discussion

Capacity constrained roadways and developments in autonomous technology have made PAVs a viable option for urban mobility. However, successful integration and implementation of PAVs depends on both technological advancements and societal adoption and acceptance. This study aimed to gain insights and understand perceptions of emerging

PAV technology systems from potential users. Since this technology is not yet available to riders in the US, we surveyed a broad spectrum of people to gain insight on expectations to encourage ridership. This study found that half of the respondents are not familiar with PAVs prior to participating in the survey, and as such, these findings represent general public perceptions and potential PAV community users. In doing so, this study builds on previous studies that have focused on PAV subject matter experts and stakeholders.

As is the case with conventional airplane passengers, safety is of prime importance for future PAV passengers (Cohen et al., 2021). Potential users perceive PAV cabins equipped with safety restraints as the most important feature, even more than cabin comfort (i.e., ample legroom and headroom). Safely and properly securing PAV passengers during take-off and landing appears to be an expectation, similar to conventional aircraft. Safety restraints are likely to be federally required on PAVs per existing FAA Code of Federal Regulations, 14 CFR 91.107 ("Use of Safety Belts, Shoulder Harnesses and Child Restraint Systems," 1999). Haddad et al. (2020) also performed a survey study on factors impacting adoption of PAVs with 221 responses across the world, with a majority of the respondents from Germany, and similarly reported safety regulations and automation reliability as key elements in improving users' trust in PAVs.

Perhaps owing to the heightened awareness of airborne pathogen transmission during the COVID-19 pandemic (Wise et al., 2020), respondents rated PAV cabin air quality as of extremely high importance (80%). The small cabin interior envisioned for PAVs creates a confined space of circulated air shared by passengers, where clean cabin air likely translates to perceived health safety. Literature on perceptions of COVID-19 shows that airplanes are viewed as the riskiest mode of transport in terms of potential virus spread (Barbieri et al., 2021). Similarly, respondents correspondingly view PAV air quality as an important cabin feature necessary to minimize health safety risks.

Interestingly, respondents indicate having a relatively quiet PAV cabin as a less important feature. NASA and other UAM stakeholders have found that PAV noise is a key barrier to public acceptance of UAM (Price et al., 2020). The distinction noted is noise level experienced within a PAV (as surveyed in this study) versus PAV noise level experienced outside of a PAV cabin while on the ground within a city (as evaluated in the above mentioned research). Moore (2003) predicted that PAVs flying within a typical city would emit a noise level of 65 decibels, comparable to a city bus or motorcycle noise level, which may be perceived as noise annoyance. Future research should investigate whether respondents who rated internal PAV noise as less important, would have the same or different rating for externally emitted PAV noise.

Unlike jet-fuel powered airplanes, PAVs are electrically powered, deriving energy from lithium-ion batteries. Participants perceive PAV battery life status as highly important information to display on a cabin human-machine interface (HMI) panel. PAV battery life information may convey a sense of safety to potential passengers, now armed with the knowledge that there is ample power for the range and duration of their trip. Conversely, HMI panels in traditional aircraft typically do not display jet-fuel reserve status, nor do passengers expect to see such information displayed. However, the prevalence of electric vehicles (EVs) on the road, which are equipped with HMI displays of the EVs battery life, may influence the expectation and priority of visualizing real-time battery power consumption.

Respondents perceive weather conditions as the most important information to display on a PAV HMI. This perception agrees with studies that show PAVs are more susceptible to weather hazards based on their diminutive size, as well as their operation at lower altitude versus traditional airplanes, which are larger and fly at much higher altitudes, above conventional weather patterns (Steiner, 2019). Inclement weather is a challenge for any transit mode and PAVs are no exception, and in fact may experience more unique challenges. In addition to inclement conditions such as rainstorms, snow, ice, and fog, PAVs flying through high-rise building-dense cities may experience exceptionally high gusty wind conditions and urban canyon effects. Potential PAV passengers need reassurance of reliable and safe flight through real-time accurate weather reporting through an in-cabin HMI display. PAV manufactures implementation of various weather-mitigating technologies such as AI-based prediction systems, rapid deicing systems, and enhanced vision systems (Steiner, 2019), will enable safe and reliable PAV flight operation, and assure trust. Furthermore, to support community acceptance efforts, targeted campaigns educating the public about PAVs robust capability to safely and reliably withstand extreme weather should be considered.

Based on self-reported time to adopt PAVs, the respondents group as early adopters (28%), moderate adopters (29.6%), late adopters (34.9%), and laggard adopters (7.2%). The Technology Adoption Life Cycle distribution generally characterizes adopters as early (16%), early majority (34%), late majority (34%), and laggards (16%; Rogers, 2003). Relative to this Technology Adoption Life Cycle curve, our respondents were slightly skewed more toward early adopters than laggards, but otherwise representative across groups.

Early PAV adopters tend to be a slightly older average age (41 years old) as compared to the other adopter groups and who have attained the least percentage of college education (37.2% hold bachelor's degree). Research in autonomous vehicle adoption has also indicated older populations to be in favor of such innovative transport modes (Rahman et al., 2019). Haddad et al. (2020) also evaluated the characteristics of potential riders relative to their stated time horizon of PAV adoption, and found that full-time workers tended to be the earlier adopters compared to part-time workers and students. We also found that laggard adopters live in rural areas (smallest % of urban dwellers) compared to all the adopter groups. There is also a correlation between commute time and residential location, where urban core residents have longer commute times than urban non-core and suburban dwellers. This is not surprising, as a key value proposition that the PAV market offers is adding transport capacity within already constrained cities and reducing commute time. Hence, the laggards, who are likely less prone to the effects of congestion due to more rural household locations, are more likely to either never use a PAV or wait to ride PAVs until their safety has been established. Similarly, this study revealed that respondents who have relatively short commute time to work (30 minutes or less) are characterized as early adopters, while respondents who have relatively long commute time to work (greater than 30 minutes) are characterized as later adopters. These findings perhaps indicate that respondents do not immediately perceive PAVs as a suitable alternate transportation solution. Otherwise, one might conclude that lengthy commute times would be undesirable and lead to adoption of alternative transportation, which has been seen with ride-hailing adoption and autonomous vehicle interest, where these modes allow riders to use long commute times more productively (Lavieri & Bhat, 2019; Moore et al., 2020). These previous findings do not immediately seem to transfer to PAVs.

Overall, early PAV adopters tend to have higher trust in riskier situations beyond the scope of PAVs, exhibited by being most likely to ride in driverless cars and least likely to be influenced by airplane crashes on their decision to fly. Autonomously piloted PAVs represent an aspect of trust in the system. Early PAV adopters' high propensity to take (perceived) risks likely explains their willingness to embark into an unfamiliar experience of riding an air or land vehicle that is autonomously operated. In contrast, laggards' response is an indication of their propensity to be risk averse. Findings reveal differentiation between adopter groups relative to PAVs operated with or without a pilot on board. Early adopters indicate a willingness to trust PAVs that are autonomously operated, essentially indicating a willingness to be first to ride a PAV regardless of whether there is a pilot on board or not. The same is not observed for laggard adopters; results indicate that laggards are less prone to trust PAVs that are autonomously operated. Potentially explaining their rationale to defer adoption of PAV technology to beyond a five-year time horizon post-market introduction.

Both late and laggard adopters indicate that to trust PAV flight is operating safely, they need visual indicators inside the PAV, whereas early adopters do not need such visual indicators. This finding coincides with previous research that shows how late and laggard adopters by nature are experiential and evidence-driven (Dedehayir et al., 2017). In their view, a technology has to be proven, through prolonged use (evidenced by successful use by earlier adopters), in order for trust in the technology to be established. Having visual indicators in the PAV is a prime example of an evidenced-based system that needs to be in place to earn later adopters' trust. Conversely, the experience-driven nature of an early adopter, trust is more freely and immediately granted to the system, in exchange for the opportunity to be the first to try a new technology.

Limitations and Future Research

PAVs are conceptual technologies and may pose limitations to survey respondents' full comprehension of the transport mode. Future research asking these or similar questions once PAVs become more commonly recognized could provide insight on how perceptions change with advertising and exposure. Also noted are limitations in extrapolating the sample size to the entire US adult population. However, this study aimed to capture representation of the general public and is comparable in sample size to similar studies that gauged passenger perceptions and willingness to try new technology for emerging autonomous road vehicles (McLeay et al., 2021; Smith et al., 2017). The study was conducted at the onset of the global pandemic, a time when normal daily commutes were halted, which may have impacted perceptions around emerging transportation options. Further research could include segmentation and modeling of gender, age, and income demographic dynamics. There is additional interest in further study of PAV acceptance between individuals on the ground (i.e., community) versus individuals in the air (i.e., passengers).

Conclusions

The study provides keen insights about PAV adopters and what drives their human behavior and intention to adopt new technology. Utilizing the Technology Acceptance Model as a contextual framework, PAV usefulness, and PAV ease of use were examined.

There is concurrence across all PAV adopters of the usefulness of PAVs in reducing road congestion and commute time. Early adopters translate PAVs' usefulness into perceived value by indicating their willingness to pay more money to use PAV technology, i.e., early adopters do not perceive the cost per mile of PAV to have less value than alternative transportation modes. While later adopters perceive PAVs as useful, results indicate less willingness to pay a premium to ride. There appears to be a lack of concurrence across all PAV adopters, with respect to the ease of use, otherwise described as a convenience factor. Early adopters perceive PAVs as a stress-free, convenient mode of transport, while late and laggards perceive PAVs as a stressful, less-convenient mode of transport. The Technology Adoption Model posits that the usefulness and ease of use of a new technology as perceived by potential users are strong influencers to intention to adopt and use newly introduced technologies (Davis, 1989).

Overall, PAV manufacturers, PAV operators, jurisdictions, and both local and federal policymakers will need to consider public acceptance and adoption to achieve successful PAV integration into the transportation network. To satisfy the expectations of all potential users, this study identified safety (i.e., seat belts, air quality, visual in-cabin feedback of safe trajectory) as a crucial element of PAVs. This study further identified PAV priorities that should be targeted in relative timeframes in order to satisfy near-term and long-term PAV users appropriately.

Acknowledgments

Funding support for this study was provided by the Systems Engineering Department at Colorado State University.

Disclosure Statement

No potential conflict of interest was reported by the author(s).

ORCID

Ricole A. Johnson http://orcid.org/0000-0002-8961-699X

References

Barami, B., & Merrefield, C. (2016). *Beyond traffic 2045 reimagining transportation: Technology, disruptive innovation, and the future of transportation* (Report No. DOT-VNTC-16-0). John A. Volpe National Transportation Systems Center.

Barbieri, D. M., Lou, B., Passavanti, M., Hui, C., Hoff, I., Lessa, D. A., Sikka, G., Chang, K., Gupta, A., Fang, K., Banerjee, A., Maharaj, B., Lam, L., Ghasemi, N., Naik, B., Wang, F., Mirhosseini, A. F., Naseri, S., Liu, Z., & Rashidi, T. H. (2021). Impact of COVID-19 pandemic on mobility in ten countries and associated perceived risk for all transport modes. *PLoS ONE*, *16*(2), e0245886. https://doi.org/10.1371/journal.pone.0245886

Cohen, A. P., Shaheen, S. A., & Farrar, E. M. (2021). Urban air mobility: History, ecosystem, market potential, and challenges. *IEEE Transactions on Intelligent Transportation Systems*, *22*(9), 6074–6087. https://doi.org/10.1109/TITS.2021.3082767

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly*, *13*(3), 319–340. https://doi.org/10.2307/249008

Dedehayir, O., Ortt, R. J., Riverola, C., & Miralles, F. (2017). Innovators and early adopters in the diffusion of innovations: A literature review. *International Journal of Innovation Management*, *21*(8), 1740011. https://doi.org/10.1142/S1363919617400102

Goyal, R., Reiche, C., Fernando, C., Serrao, J., Kimmel, S., Cohen, A., & Shaheen, S. (2018). *Urban air mobility market study* (Report No. HQ-E-DAA-TN63717). National Aeronautics and Space Administration (NASA).

Goyal, R., Reiche, C., Fernando, C., & Cohen, A. (2021). Advanced air mobility: Demand analysis and market potential of the airport shuttle and air taxi markets. *Sustainability*, *13*(13), 7421. https://doi.org/10.3390/su13137421

Haddad, C. A., Chaniotakis, E., Straubinger, A., Plotner, K., & Antoniou, C. (2020). Factors affecting the adoption and use of urban air mobility. *Transportation Research Part A: Policy and Practice*, *132*, 696–712. https://doi.org/10.1016/j.tra.2019.12.020

Hasan, S. (2019). *Urban air mobility (uam) market study* (Report No. HQ-E-DAA-TN70296). National Aeronautics and Space Administration (NASA).

Johnson, W. R., & Silva, C. (2018). *Observations from exploration of VTOL urban air mobility designs*. National Aeronautics and Space Administration (NASA).

Lavieri, P. S., & Bhat, C. R. (2019). Modeling individuals' willingness to share trips with strangers in an autonomous vehicle future. *Transportation Research Part A: Policy and Practice*, *124*, 242–261. https://doi.org/10.1016/j.tra.2019.03.009

Mathur, A., Panesar, K., Kim, J., Atkins, E. M., & Sarter, N. (2019). Paths to autonomous vehicle operations for urban air mobility. In *Proceedings of the AIAA aviation 2019 forum*. American Institute of Aeronautics and Astronautics. https://doi.org/10.2514/6.2019-3255

McLeay, F., Olya, H., Liu, H., Jayawardhena, C., & Dennis, C. (2021). A multi-analytical approach to studying customers motivations to use innovative totally autonomous vehicles. *Technological Forecasting and Social Change*, *174*, 121252. https://doi.org/10.1016/j.techfore.2021.121252

Moore, M. (2003). Personal air vehicles: A rural/regional and intra-urban on-demand transposition system. In *Proceedings of the AIAA international air and space symposium and exposition: The next 100 years*. American Institute of Aeronautics and Astronautics. https://doi.org/10.2514/6.2003-2646

Moore, M. A., Lavieri, P. S., Dias, F. F., & Bhat, C. R. (2020). On investigating the potential effects of private autonomous vehicle use on home/work relocations and commute times. *Transportation Research Part C: Emerging Technologies*, *110*, 166–185. https://doi.org/10.1016/j.trc.2019.11.013

Price, G., Helton, D., Jenkins, K., Kvicala, M., Parker, S., & Wolfe, R. (2020). *Urban air mobility operational concept (OpsCon) passenger-carrying operations* (Report No. NASA/CR-2020-5001587). National Aeronautics and Space Administration (NASA).

Rahman, M. M., Deb, S., Strawderman, L., Burch, R., & Smith, B. (2019). How the older population perceives self-driving vehicles. *Transportation Research Part F: Traffic Psychology and Behaviour*, *65*, 242–257. https://doi.org/10.1016/j.trf.2019.08.002

Rogers, E. M. (2003). *Diffusion of innovations* (5th ed.). Free Press.

Smith, B., Olaru, D., Jabeen, F., & Greaves, S. (2017). Electric vehicles adoption: Environmental enthusiast bias in discrete choice models. *Transportation Research Part D: Transport and Environment*, *51*, 290–303. https://doi.org/10.1016/j.trd.2017.01.008

Steiner, M. (2019). Urban air mobility: Opportunities for the weather community. *Bulletin of the American Meteorological Society*, *100*(11), 2131–2133. https://doi.org/10.1175/BAMS-D-19-0148.1

United Nations. (2019). *World urbanization prospects: The 2018 revision* (Report No. ST/ESA/SER.A/420).

Use of safety belts, shoulder harnesses, and child restraint systems, 14 CFR § 91.107. (1999).

Venkatesh, V., & Davis, F. D. (2000). A theoretical extension of the technology acceptance model: Four longitudinal field studies. *Management Science*, *46*(2), 186–204. https://doi.org/10.1287/mnsc.46.2.186.11926

Wise, T., Zbozinek, T. D., Michelini, G., Hagan, C. C., & Mobbs, D. (2020). Changes in risk perception and self-reported protective behaviour during the first week of the COVID-19 pandemic in the United States. *Royal Society Open Science*, *7*(9), 200742. https://doi.org/10.1098/rsos.200742