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USABILITY OF URBAN AIR MOBILITY: QUANTITATIVE AND QUALITATIVE ASSESSMENTS OF USAGE IN EMERGENCY SITUATIONS

Final Report

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16. Abstract

The purpose of these four studies was to determine participants' willingness to support the use of urban air mobility (UAM) in response to natural disasters, along with the preferred locations to establish vertiports. Study 1 assessed the willingness to support using a mixed factorial design. The findings demonstrated strong, robust support for the use of UAM when responding to natural disasters. Study 2 worked to create and validate a scale that could assess vertiports' current and proposed locations. The Vertiport Usability Scale was developed and shown to have strong psychometric properties to validly assess vertiport locations through a multi-stage process. Study 3 used the Vertiport Usability Scale to understand the most highly preferred locations for vertiports in three conditions from a multi-stage process: temporary disaster locations, permanent disaster locations, and permanent consumer locations. Study 4 was conducted using qualitative methods to complement the earlier quantitative approaches. Through an initial survey and follow-on interview, three themes emerged related to UAM in response to natural disasters and vertiports: 1) human involvement in UAM operations, 2) scenarios for usage, and 3) setup and deployment of vehicles.

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EXECUTIVE SUMMARY

This project aimed to assess the use of urban air mobility in response to natural disasters. Four studies were conducted in conjunction with the center's theme 2, optimizing mobility in emergency situations. These studies provided quantitative and qualitative assessments of participants willingness to support the use of UAM in response to natural disasters, the creation of a valid scale to measure vertiport usability, the evaluation of the ideal locations for vertiports in various scenarios, and finally, a qualitative analysis of perceptions related to vertiport locations.

In Study 1, a mixed factorial design assessed participants' willingness to support the use of UAM in response to natural disasters based on the type of operation, the type of natural disaster, and the type of mission. Five hundred and seventy-eight participants were used in Study 1. The findings from the study indicate robust support for the use of UAM in response to natural disasters. Participants showed no significant difference in willingness to support based on the type of operation, either human-operated or fully autonomous. Nor were the significant differences based on the type of natural disaster. While the delivery of news information was rated significantly less than all other missions, there was generally robust support for the use of UAM.

In Study 2, a valid instrument was created to assess Vertiport Usability. The literature review revealed lacking research into methods of determining proposed and current vertiport sites. Through a four-stage process that involved participants at each stage, a total of 1,328 participants were used to validate the scale. A seven-item Likert scale was created that can be used by researchers to assess vertiport usability. The Vertiport Usability Scale can be used in several types of research designs, and it provides a tool from this research that can be beneficial to future studies investigating vertiports.

Study 3 had the goal of identifying the ideal locations for the placement of vertiports in several different categories: temporary disaster locations, permanent disaster locations, and permanent consumer locations. As with Study 2, a multi-stage process involving 1,178 participants generated the list of possible places and paired the listings down to find the highest-rated sites. The significant locations for the temporary disaster location were open fields, military bases, and fairgrounds. For permanent disaster locations, the significant

locations were military bases and airports. For permanent consumer locations, the significant locations were open fields, hospitals, and airports.

While studies 1-3 were quantitative, Study 4 used a qualitative interview method to collect data on UAM usage in response to natural disasters and locations of vertiports. A survey was administered to 45 students in a 100-level course at the subject university. From these responses, purposeful sampling was conducted to gather a broad sample of majors and aviation experience in the participants. Ten participants were invited to complete an interview to gather more specifics and information. From the analysis of the transcribed interview files, three themes emerged: (1) Human Involvement in UAM Operations, (2) Scenarios for Usage, and (3) Setup and Deployment of Vehicles.

DESCRIPTION OF PROBLEM

Background Of Urban Air Mobility

Urban Air Mobility (UAM) can be thought of simply as enhancing an urban population's mobility through air transportation methods. The National Aeronautics and Space Administration (NASA) defines Urban Air Mobility (UAM) as "safe and efficient air traffic operations in a metropolitan area for manned aircraft and unmanned aircraft systems" (Thipphavong et al., 2018, p. 1). These craft range from a passenger service (i.e., taxi) to delivery services (i.e., Amazon) and can be deployed for vast spectrum operations for civilians and government agencies. This technology was once only in science fiction but is now slated to become part of many people's daily life. Another term often used with UAM is Advanced Air Mobility (AAM). This term expands on the "urban" portion of UAM and extends it beyond the urban population. According to recent NASA-commissioned market studies, by 2030, as many as 500 million flights a year for package delivery services and 750 million flights a year for air metro services could make UAM a profitable, relevant enterprise (Gipson, 2019).

Why do we need it?

As urban areas such as New York City, Los Angeles, and Miami develop, populations become denser. This growth, in turn, creates increased traffic density in these urban environments. TomTom's (2020) Traffic Index for 2020 shows New York City, Los Angeles, and Miami to have a 27%, 26%, and 23% traffic index, respectively. This index means a 30-minute drive in New York City; it would take approximately 27% longer to travel due to the traffic congestion. These numbers are slightly deceptive, as the COVID-19 pandemic created reduced traffic patterns as many places were shut down. In 2019, the traffic indexes for Los Angeles, New York City, and San Frisco were 42%, 37%, and 36%, respectively (TomTom, 2020). As ground space is finite, the next logical step would be to take to the air to help reduce the congested areas below.

Proposed and Current Uses

Shaheen et al. (2018) describe UAM as a "revolutionized way to move people within and around cities by shortening commute times, bypassing ground congestion, and enabling point-to-point flights across cities" (p. 6). To make this idea possible, innovators globally have developed prototypes that can take off and land vertically (Shaheen et al., 2018), allowing aerial crafts to operate without a runway. These crafts are referred to as vertical takeoff and landing (VTOL) aircraft.

Companies worldwide are currently developing and testing advanced aviation systems such as the German aircraft manufacturer Volocopter or electric VTOL (eVTOL) vehicles, which are UAMs that take off and land vertically with a carrying capacity of two people (Volocopter, n.d). These autonomous vehicles are the leading way to build an ecosystem surrounding UAM. Another technological advancement in UAM is Joby Aviation, which recently acquired Uber Elevate, and plans to provide air transportation between suburbs and cities as soon as 2023 (Khalili, 2020). Similarly, Kitty Hawk's Cora is another autonomous vehicle that focuses on time the public could save flying over ground traffic. Also, Cora's UAM design allows individuals to utilize these transportation methods in spaces like airports, rooftops, and parking lots (Kitty Hawk, 2019). Furthermore, Airbus' Voom Urban Mobility seeks to progress in the same magnitude offering safety and convenience for those who live far away from their families (Airbus Aerospace Company, 2019).

Interestingly, several cities globally are currently on the way to developing UAM. Leading in Singapore and Dubai, the Volocopter vehicle made its first successful flight over Dubai in September 2017. Following this flight, the German aircraft manufacturer announced a partnership with the United Kingdom-based vertiport owner with a collaborative plan to complete the first Volo-Port in Singapore by the end of 2019 (Loh, 2019). The next plan of action for Volocopter is to include the public within the demonstration flights. Moreover, Airbus’ Voom is already operating in São Paulo and Mexico City. One customer of Airbus, Joerg Mueller, the Head of Programs and Strategy for UAM, had firsthand experience with the helicopter booking platform and the convenience of urban air travel (Airbus Aerospace Company, 2019). He expressed that upon arrival in São Paulo, he used Voom to take him to his hotel. He noted that his flight was during rush hour and that the journey usually takes 2-hours; however, with the convenient use of urban air travel, the journey only took 11 minutes (Airbus Aerospace Company, 2019). Kitty Hawk's Cora has also teamed up with New Zealand to set up air taxi services with self-flying aircraft. New Zealand's new prime minister has been on board with the project and is working towards the certification process (Werwitzke, 2018).

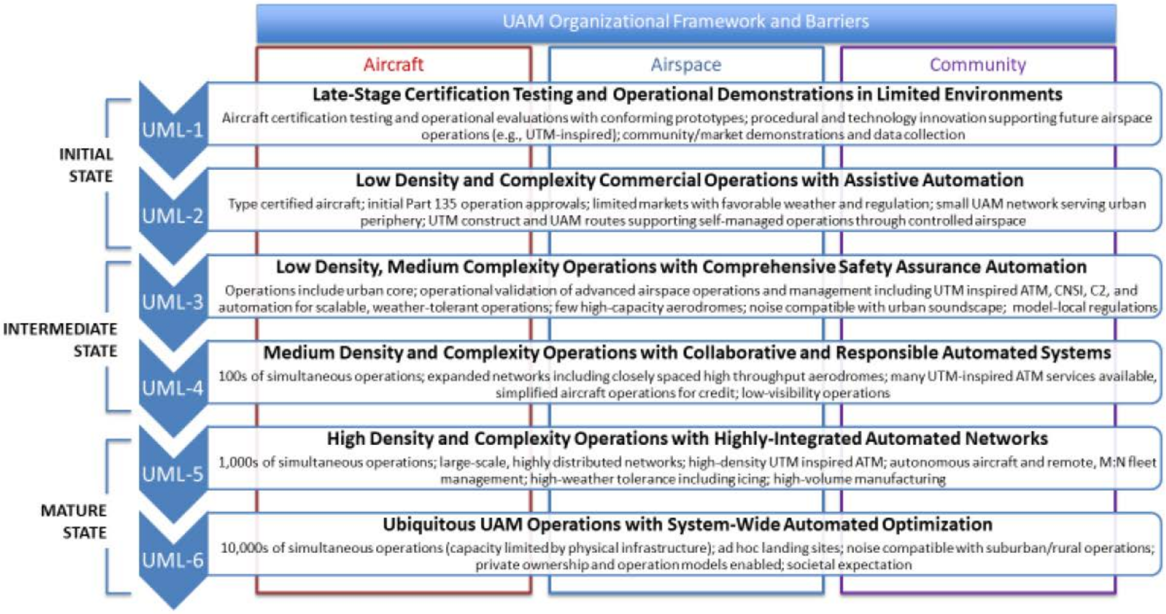
Major manufacturers such as Airbus, Lilium, Kitty Hawk, Bell, Embraer, Hyundai, Rolls-Royce, and Toyota are working in the Air Taxis Services market (Rajendran & Srinivas, 2020). Additionally, numerous startups are developing technology to support UAM for passenger transport. These startups include Joby Aviation who received $100 million in venture funding in 2018 to create a flying eVTOL prototype to carry five passengers up to 150 miles on a single charge (Downing, 2019).

Automation

According to NASA (2021), UAM is accomplished by maturing technology capabilities and developing on-demand urban air travel (i.e., helicopter services in New York City). Currently, the technology is not at a high enough maturity for full automation. Figure 1 provides a detailed look at the six UAM Maturity Levels (UMLs) and details about each level.

Figure 1

In-Depth Description of the Various UAM UMLs



Note. In the public domain, from the UAM Vision ConOps/UAM Maturity Level 4 (NASA, 2021).

Due to the current lack of maturity in UAM, the present study used two different approaches when discussing UAM. The first described UAM as using autonomous air vehicles with a remote human pilot or operator. The second described UAM as using autonomous air vehicles without a human pilot or operator. This allowed the current study to address mature and immature UMLs to gain a better overall perspective of consumer preferences.

UAM Requirements

Technology Requirements

With the emergence of UAM technologies and the possibility of implementing these autonomous vehicles, several requirements need to be met to develop a sustainable UAM market and meet the increasing UAM demand. When analyzing requirements, one element that must be considered is an individual's willingness to utilize the vehicle, which can be positively influenced by understanding and providing solutions to concerns. Personal willingness would seem to fluctuate based on additional factors, including familiarity with the system, value, fun factor, happiness, fear, and wariness of technology. Winter and Rice (2019, 2020) understood that the previous elements are the most significant determinants for consumer willingness to fly. Additional consumer perceptions would influence these factors, such as culture, gender, and risk acceptance.

Energy Usage. A significant concern with implementing urban air mobility vehicles would be the energy consumed to power the machines. Despite the vehicles being smaller and lighter than modern commercial aircraft, as mentioned by Reiche et al. (2021), the development and use of UAM in urban environments would increase a city's need for additional sources of fuel and power. One approach would be to reduce the energy consumed by the actual vehicle, which was partly examined by Niklaß (2020) and associates from Hamburg, Germany. Their "Remote Component Environment" (RCE) workflow engine incorporates physical analysis components such as demand forecasting, trajectory, capacity management, and energy demand to "quickly identify physical effects and cross-disciplinary influences of UAM" (Niklaß, 2020, p. 28). Considering that the planned system did not already exist, they needed to identify and define the primary requirements of the system, which would be prioritizing cause-effect relationships, modeling the overall system, and the utilization and linkage of existing models. For "cause-effect relationships," they understood that various disciplines would need to be linked in a closely-knit cooperative effort. The RCE framework would eventually be developed to support the German Aerospace Center's (DLR's) interdisciplinary and distributed work and would include an initial architecture referring to each component in the original physical analysis. As the second to last component to the architecture design, energy demand would assess the overall energy consumption of the urban air mobility vehicle, which was supported by other parts earlier in that process in additional optimized flight patterns, which will require high effort.

Additionally, the organization of urban air spaces would have significant impacts on energy usage. One option discussed in the previous literature was a "Free-Flight-inspired concept" that allows for free flight velocity, altitude, and flight track "to reduce energy consumption due to optimized tracks" (Niklaß, 2020, p. 14). Even if we lower the energy consumption of UAM vehicles, other factors will require more in-depth analysis to ensure that energy consumption is minimal. This would include modifying approach surfaces and optimizing landing performance (Kleinbekman, 2018; German, 2019). Despite the substantial difference between eVTOL designed for UAM and the currently utilized helicopters, Dr. German (2019) emphasizes that examining the latter design and its flight performance theories would assist with understanding what types of factors should be considered when analyzing and developing new approach surfaces. Despite the 2019 publication focusing on landing accuracy, energy consumption would be accounted for during all conducted analyses, particularly with the performance analysis where they saw reduced energy consumption.

Accuracy. Even as better technology is developed, there are lingering concerns about the accuracy of certain pieces of technology based on previous records of failed testing and general unease with driverless vehicles. Notable mentions include the “272 failures and 13 near misses” of Google’s autonomous vehicles between November 2014 and November 2015 and Uber’s first recorded pedestrian fatality in 2018 when conducting real-world testing (Harris, 2016; Schmelzer, 2019). In the latter incident, the self-driving vehicle struck the pedestrian when they walked their bike across the road at night without utilizing a crosswalk. This would be another critical variable to consider with the future implementation of UAM systems in public spaces.

Daskilewicz et al. (2019) indicate that descent angles can meet minimum energy requirements without compromising any of their determined constraints, including accuracy. Additional research conducted by Pu et al. (2020) investigates how to improve the navigational abilities of unmanned surface vehicles (USV) using a variety of onboard sensors. Understanding that the scenario needs to have a complex navigational environment and special mission requirements, they chose to simulate the “Sanchi Oil Spill” that transpired in the middle of the Yellow Sea. The toxic pollutant covered a vast distance and posed a severe threat to all humans within a certain vicinity, which led to immediate emergency evacuation efforts being pushed by several Chinese government maritime institutions. Their final design would be an unmanned boat equipped with a standard radar, Light Detection, and Ranging (LiDAR) device, and an innovative Launch and Recovery System (LARS) unique to the USV. By utilizing the equipment onboard this USV, these scientists from Shanghai University improved path following and collision avoidance algorithms, developed a new sampling system unique to the vehicle, and enhanced deployment and recovery systems to perform faster.

Similar research by Kyrkou and Theocharides (2021) recognizes the usefulness of implementing image sensors to improve remote sensing capabilities so that drones can operate in disaster zones and other hazardous locations. These sensor systems contribute to the overall body of unmanned systems research and may prove viable for developing UAM vehicles that can operate in these dangerous environments.

Customer Privacy. A massive hurdle to overcome with the implementation of UAM in any functional area would be privacy considerations for all users. For nearly the last two decades, the utilization of drones in private spaces has raised many issues regarding privacy laws that protect law-abiding people from peering criminals or unlawful observation. Despite the differences between drones and the proposed UAM vehicles, these computers are similar technologically since they require various sensors and camera systems to operate efficiently. Considering these technological similarities, considerations should still be made when implementing the technology into the public space.

We attempt to account for these concerns by exploring several risk perceptions studies that examine the public acceptance of drones and unmanned aerial vehicles. In a piece of multi-staged research, the primary objective was to assess risk perception and public acceptance of drones amongst an Australian population (Clothier, 2015). The first study was divided into three sections. The first section would introduce images of established technology and ask participants to respond to a series of Likert-type and open-ended questions related to the images. This action was meant to capture four primary qualitative elements; an immediate emotional response, specific terminology utilized to represent the technology, perceptions of risk and acceptability, and concerns associated with each piece of technology. The following sections would examine images of drones with similar follow-up questions and a section designed to collect demographic information. Similar studies and analyses assessed public concerns about drone usage (Marte et al., 2019). Despite the differing objectives from these studies, the results would be relevant since they noticed that a lack of understanding or negative usage perceptions would hinder the implementation of these devices in a public landscape.

Infrastructure Challenges

Several studies have explored infrastructure requirements of UAM (Batty et al., 2012; Caragliu et al., 2011; Niklaß et al., 2020; Preis, 2021; Rothfeld et al., 2018; Straubinger et al., 2020; Taylor et al., 2020). Due to the rapid growth of UAM within recent years, considerations for dedicated takeoff and landing locations would need to be accounted for to reduce potential airspace conflicts that would inevitably arise. As a part of the current research, we seek to understand ideal vertiport locations and therefore look to previous research to assist researchers in developing a user scale. Niklaß et al. (2020) dedicate an entire section of their publication to vertiport design and integrating such structures. It views this as an equally integral part of UAM implementation amongst other factors, including demand predictions and noise evaluation. In their explanation, they utilize pre-existing helicopter landing pads as a basis for the design of vertiports, which is a helpful approach since previous publications (German, 2018; Kleinbekman, 2018) utilize helicopter standards for their approaches that revolve around accuracy and energy demands.

Despite this, Niklaß et al. (2020) does emphasize that using existing launching pads would "not provide the capacities necessary to meet the traffic numbers envisioned for UAM" due to the limitation on parking positions, which conflicts with current helicopter regulations (p. 12). Additionally, the researchers for this study discuss how mid-route conflicts and vertiport vicinity conflicts would need to be minimized by implementing special procedures. Understanding that landing pad requirements for vertiports have been developed according to previously established standards, the researchers created two study models they describe as "Level 0" and "Level 1" approaches. The "Level 0" model, also mentioned as a simple approach, shows vertiports "as a single point with defined capacity," meaning that a vertiport would cover a city district or significant space over an urban population with the infrastructure itself being in a centralized location. The "Level 1" model incorporates two sub-models described as the vertiport design and the vertiport allocation components. Respectively, the vertiport design component accounts for the available capacities of differing vertiport designs, spacing requirements, and takeoff positions. In contrast, the vertiport allocation component deals with the distribution of vertiports within different districts.

One study explores the latter concept for on-demand mobility (ODM) in the capital city of Seoul in South Korea (Lim & Hwang, 2019). As noted by Goyal et al. (2018), vertiport locations for usage with air taxi services should "enable 10-minute door-to-door trips" for optimal flight time, meaning that vertiports must be both abundant and established in frequently traveled locations. Using a similar approach to other studies (Reiche, 2021), Lim and Hwang (2019) collected data from a 2015 census report about commuters within different districts and developed cluster groups using a MatLab program and k-means to find ideal vertiport locations and installations. The group found 18 cases and created three line graphs based on vertiport locations and numbers to display travel time. Based on that data, it was found that about ten to twelve vertiport locations would create the ideal travel time when combined with short-distance travel in personal vehicles.

Additionally, the FAA established vertiport location and design criteria that include the development form of the surrounding areas (i.e., the alterations to the surrounding landscape), weather conditions, land transport accessibility, and economics. Additional requirements are taken from the ICAO-published heliport manual that describes how heliport locations should allow for accessible land transport, parking options, and considerations toward avoiding noise-sensitive areas (Have to pay to see additional materials). These noise-sensitive locations include schools, hospitals, industrial complexes, and certain types of business facilities. Though several studies investigate implementing vertiports in urban environments, vertiports could ideally be developed in various locations to ensure security and rapid response to mid-to-post disaster scenarios.

Smart Cities

An ideal environment for UAM vehicles would incorporate these machines and develop other major facilities that could better support these technologies and other future tech. Based on the major technological criteria required for sustaining continually healthy UAM performance, smart cities would seem to be the optimal choice given the rise of autonomous technologies in our daily life. International researchers examined the efficiency and usability of smart cities and artificial intelligence (AI) (Yigitcanlar et al., 2020). They ask whether the utilization of AI in cities would ensure the safety of humans in the event of natural disasters, pandemics, and emerging catastrophes and start answering these questions by exploring the background of AI applications in the modern-day and the same technology itself. The researchers define AI as *machines or computers that mimic cognitive functions humans associate with the human mind*, which is achieved using rule-based and deep learning systems (Yigitcanlar, 2020).

Following this determination, they understand that artificially intelligent cities, and therefore smart cities, would be areas with robust systems that can manage economic, environmental, governmental, and societal activities using AI algorithms. The researchers provide examples of AI solutions in Australia, including trial autonomous vehicle trials and image capturing to identify drivers utilizing mobile devices while driving. Nonetheless, there are also highlighted cases where AI was improperly used, such as automatically detecting debts and issuing infringement notices without human intervention, and facial recognition software systems for crime prevention, which lead to unfair discrimination of many Aboriginal and Torres Strait Islanders. Despite these issues, though, the combination of AI with already present technologies would provide opportunities to tackle more complex challenges in urban environments. Implementing specific AI components into a smart city may prove beneficial in many regards, especially regarding disaster cases and UAM implementation, where efficiency and safety are critical factors in averting further harm to inhabitants.

Based on a summarization described by Caragliu et al. (2011), as well as a thorough discussion provided by Hollands (2008), it can be surmised that the purpose of a smart city is to improve upon the current city infrastructure by incorporating advanced technologies that emphasize environmental improvement efforts, the resolution of economic issues, and better social inclusivity to enhance the quality of life. Though the level of technology is not defined explicitly for smart cities, the types of technologies proposed and currently being implemented for these future cities include drone services and, most notably, incorporated artificial intelligence. AI has already been utilized in many applications as recent as the development models that can respectively determine the spread of COVID-19 and show measures that can limit transmission rates (Yigitcanlar, 2020). Additionally, these scientists determined that based on the level of the AI that is incorporated into these smart cities, these programs can be applied in specified application areas to address planetary challenges that range from climate change to weather and disaster resilience (i.e., weather prediction and infrastructure management). Suppose this artificial intelligence is integrated alongside autonomous urban air transport. In that case, we could see improved systems that could assist human operators with overcoming some of the potential challenges of UAM implementation.

Challenges to Implement Urban Air Mobility

As the number of UAM requirements may indicate, numerous challenges would come with the implementation of UAM in public settings. These challenges are further emphasized if we attempt to incorporate them into environments such as on-demand transport (i.e., taxi servicing and public transportation), medical transportation, or general emergency response scenarios. The following looks at a few key areas that are vital to implementing UAM.

Weather

Reiche et al. (2021) presented a comprehensive seasonal and diurnal climatology analysis of ten metropolitan areas in the United States that experience natural disasters and weather conditions that vary. This was followed up with a five-city general population survey. Their initial analyses utilize historical meteorology data of weather at the anticipated operational altitude of UAM vehicles gathered as part of a broader UAM market study guided by NASA and a 30-person strategic advisory group that included experts from the FAA, NTSB, and ICAO. Their proposal for countering these weather challenges consists of the incorporation of meteorological sensors along with artificial intelligence and machine learning onto these autonomous vehicles to ensure adaptation is possible.

Another research group (Adkins et al., 2020) proposed that combined network architecture and crowdsensing application would be ideal for real-time urban meteorological observation supporting UAM. To create the ideal dense meteorological networks, researchers need to develop an incentive-based application that rewards human operators for completing tasks within the program. As proposed by the ICAO, vertiports should follow similar criteria to their heliport manual. They would have to consider more variables for implementing UAM Vertiports and develop countermeasures to ensure that the facilities and autonomous vehicles do not cause further damage due to harsh weather conditions.

Collision Avoidance

Due to the significant push for more public automated vehicles, whether through air taxis or PAV's, these vehicles could pose an equally significant risk for injury if they are poorly engineered and improperly regulated. Collision avoidance should be a prioritized requirement for implementing UAM vehicles. Several collision studies and analyses (Fleetwood, 2017; Thipphavong, 2018; Pu et al., 2020) have examined the importance of these autonomous systems and systems and regulates that could be instated to emphasize consumer safety. Pu's (2020) USV design incorporates elements of the collision avoidance capabilities that we would need to include during the development of these UAM vehicles.

Noise Pollution

Various researchers identified noise pollution (Eißfeldt, 2020, Niklaß et al., 2020; Vascik et al., 2018; Vascik & Hansman, 2017) as a prominent factor in implementing UAM in public areas. Researchers from DLR and the Technical Institute of Hamburg investigated the potential of noise pollution. They realized that implementing UAM in Hamburg airports, public facilities, and sports areas would create more significant noise pollution and endanger the public (Niklaß et al., 2020). Similarly, cities with higher noise pollution and higher population densities such as New York City, Miami, and Atlanta may pose more significant implementation challenges for Urban Air Mobility. According to Hammer et al. (2013), they estimated that approximately 104 million individuals were at risk of noise-induced hearing loss as of 2013. Additionally, this increase in noise will affect various aspects of an individual's health, including sleep quality, heart health, and stress levels. Though not many studies have identified permanent solutions to this factor, they have emphasized that these issues need to be addressed with the community transparently.

Policy Issues

From the article discussing how artificially intelligent cities could safeguard humanity, these international researchers highlighted that the policy framework revisions for cities would be required to begin implementing newer policies aimed toward more AI applications within civilization (Yigitcanlar et al., 2020). In research conducted by (researchers of European origin), they attempted to quantify factors that would impede the utilization of UAM and understood that certain policy level insights and recommendations would be necessary. These suggestions would be marketed toward industrial stakeholders and policymakers to ensure that more stringent regulations would be maintained using these technologies (Al Haddad et al., 2020). Further studies that explore policy revision and implementations include an article conducted by Embry-Riddle students and faculty that explore the positive and negative information on WTF for driverless vehicles (Anania et al., 2018).

Airspace Congestion

Many groups, such as NASA and Volocopter, have proposed new ways to implement UAM technologies into the public medium, most commonly through autonomous air taxi services. The idea of these air taxis would be to take people from one location to another and potentially reduce road congestion in major cities with greater population densities. Although these UAM systems may be operating at lower altitudes than commercial aircraft, the vehicles would be flying in airspaces commonly utilized by helicopters. Given that this may impact later operational efforts of UAM, understanding and designing new methods to reduce airspace congestion is imperative.

Vascik et al. (2018) discussed the operational constraints that would impact the implementation of UAM services by conducting exploratory system-level analyses in Los Angles, Boston, and Dallas. A total of thirty-two reference missions, also described as “daily commute missions,” would be conducted to represent system-level requirements that may emerge from each city concerning mission range, ATC interactions, and consumer groups that this system would be serving. Most of these reference missions experienced “a congestion penalty greater than 100%,” which the researchers described as surface travel during rush hour periods that required more than double the free-flow travel time (Vascik et al., 2018). Accounting for factors such as air congestion, passenger volume, and market type, they identified eight operational constraints where community acceptance of aircraft noise, takeoff and landing area availability, and air traffic control (ATC) scalability were the most critical and prevalent constraints among all missions. ATC scalability is best described as the number of air traffic controllers to UAM operational flights.

One way of eliminating this demand on air traffic controllers would be programming optimized landing algorithms into UAM vehicles like drones. Zhou et al. (2020) worked with a fleet of eighteen drones and developed a software solution using mixed-integer programming techniques. The results would allow drones on the same altitude to complete "routing and trajectory computations in less than 5 seconds as well as land in three pre-determined landing spots within an allotted three minutes (Zhou et al., 2020).

Perceptions of UAM

Many papers have explored consumer perceptions of UAM (Al Haddad et al., 2020; Anania et al., 2018; Asgari & Jin, 2019; Clothier et al., 2015; Haboucha et al., 2017; Holmes, 2016; Hughes et al., 2009; Marte et al., 2018; Ragbir et al., 2018; Ragbir et al., 2020; Rice et al., 2014; Rice et al., 2016; Rice et al., 2019; Rice & Winter, 2019; Shaheen et al., 2018; Winter et al., 2020). Several willingness studies have examined the effect of weather on a participant's inclination toward boarding various autonomous air vehicles. Two of these studies (Ragbir et al., 2018; Ragbir et al., 2020) revolved around autonomous airplanes and air taxis associated with UAM vehicles, given the types of services they could provide when implemented. In the 2018 study, results showed that both Indian and United States participants showed common apprehension toward boarding autonomous flights when weather conditions were severe (Ragibr et al.).

Studies that public perceptions of usage would heavily reflect the utilization of other modern and future technologies such as UAM, especially considering that the vehicles are fully autonomous in this context. In an article published by Asgari and Jin (2019), they mention in their results how individuals who show more trust concern would be more willing to pay for autonomous features and adopt autonomous vehicles. The researchers sought to explore potential reasons for willingness and adoption in their study, including looking into *ride-sourcing* and private ownership. One of the factors of concern when probing *ride-sourcing* that participants commonly mentioned was the ability to trust strangers leading to an inverse relationship to private ownership where privacy was a notable advantage. This finding is further exemplified when looking at the impacts of attitudes on adoption and willingness to pay for autonomous vehicles, which shows that participants would be more willing to pay based on preconceived trust issues.

Given that one of the primary stakeholders of these vehicles will be consumers themselves, it would be essential to examine the different factors that would impact consumers' overall perceptions. As mentioned previously, several positive and negative factors are associated with a consumer's thoughts and emotions toward technology, including familiarity, fun factor, wariness, and fear (Ragbir, 2018; Rice, 2014; Rice, 2019; Winter, 2020). In addition to fear and value, those factors were previously determined by researchers to impact the actual adoption of these technologies into daily activities. One way that fear and unfamiliarity with these vehicles could be reduced is to increase consumers' comfort aboard the flight. One study carried out by Reiche (2018) found that respondents were more comfortable flying if they were on the same flight as individuals familiar to them. Additional analyses (Asgari & Jin, 2019) found that participants used taxi services less due to determined untrustworthiness toward strangers.

Cultural Considerations

In addition to individual emotional and knowledge factors, cultural differences may also encourage or discourage the adoption of UAM vehicles for future initiatives. Several studies have examined how nationality and ethnicity affect perceptions of autonomous flight systems (Ragbir et al., 2018; Rice et al., 2019; Winter et al., 2020). Ragbir et al. (2018) found that American participants were more negative toward using these technologies unless weather conditions were perfect. In contrast, Indian participants were more open apart from severe weather cases. Additionally, Rice et al. (2019) identified that ethnicity and the appropriate social norms accompanying each group significantly predict willingness to fly. The researchers extrapolate this information from additional papers that focus on social behaviors and consumer habits, which leads to a further understanding of how these UAM systems can be advertised to each group (Marin et al., 1991; Phinney, 1996).

Gender Considerations

Just as cultural differences impact usage and trust of UAM systems, gender could also play a significant role in these decisions. Rice and Winter (2019) found that women were less willing to fly in driverless vehicles where fear was the most observed mediator in that decision. As explored earlier (Ragbir et al., 2018; Rice et al., 2014; Rice & Winter, 2019; Rice et al., 2019; Winter et al., 2020), greater fear would typically be seen when relating to an individual's unfamiliarity with the system and value. These findings correspond with similar discoveries from additional researchers (Clothier et al., 2015; Reiche et al., 2018), where they collected participant responses showing unfamiliarity with the UAM systems present. Like the findings on unfamiliarity and fear acting as negative mediators of willingness, they also identified that variables such as happiness and fun factors were positive mediators, which could encourage unmanned vehicle usage despite unfamiliarity. Understanding how these factors impact the adoption and usability of unfamiliar systems could ensure that these systems could be fully trusted in dangerous scenarios. Although efficiency and time are critical factors in UAM usage in disaster scenarios, accounting for and improving mistrust or uncomfortableness by emphasizing safety features could reassure victims that the machines will not further endanger them.

The Emergency Usability of Urban Air Mobility

While the primary purpose of UAM may be urban mobility, there is the possibility for their usage in the emergency response following natural disasters. For example, UAM could transport survivors as a medivac vehicle or deliver supplies and emergency needs. In the aftermath of natural disasters, many necessary responses must be completed. Survivors may need medical transportation to the hospital or evacuation from hazardous areas. Mobility may be significantly compromised or impossible for those who can remain in place due to downed trees, powerlines, or washed away roads. UAM offers some possible responses that could significantly increase the response, assistance, and mobility in the aftermath of natural disasters.

Given the ability of most UAM vehicles to take off and land vertically, they may reach stranded persons when ground access is not possible. Unlike helicopters, which require 2-3 crewmembers, UAM vehicles are primarily designed to operate autonomously or via remote pilot controls. Therefore, they are not limited by the number of flight crewmembers available or fatigue/tiredness, and aside from charging (for electric vehicles) or refueling, they could operate non-stop. These vehicles could remove stranded persons from hazardous areas due to collapsed buildings or flooding. Injured persons could be airlifted to the hospital, and supplies could be delivered to those in need.

The purpose of the first study in the current project was to assess consumers' willingness to support the use of urban air mobility in response to natural disasters based on the type of UAM operation, the type of natural disaster, and the type of mission. While many studies have explored consumer perceptions of UAM (Al Haddad et al., 2020; Anania et al., 2018; Asgari & Jin, 2019; Clothier et al., 2015; Haboucha et al., 2017; Holmes, 2016; Hughes et al., 2009; Marte et al., 2018; Ragbir et al., 2018; Ragbir et al., 2020; Rice et al., 2014; Rice et al., 2016; Rice et al., 2019; Rice & Winter, 2019; Shaheen et al., 2018; Winter et al., 2020) and infrastructure requirements (Batty et al., 2012; Caragliu et al., 2011; Preis, 2021; Rothfeld et al., 2018; Straubinger et al., 2020; Taylor et al., 2020), few have looked into support for UAM in response to natural disasters. Some proposed uses for UAMs in response to emergencies include search and rescue (Boukerche & Coutinho, 2018; Lygouras et al., 2019; Tariq et al., 2018), disaster recovery (Almeida et al., 2017; Kyrkou & Theocharides, 2020; Mohammed et al., 2014), and maritime uses (Pu et al., 2020; Bayirhan & Gazioğlu, 2020). While these uses are still in their infancy, the advantages of using UAM in a natural disaster will continue to drive this emerging technology.

Search and Rescue

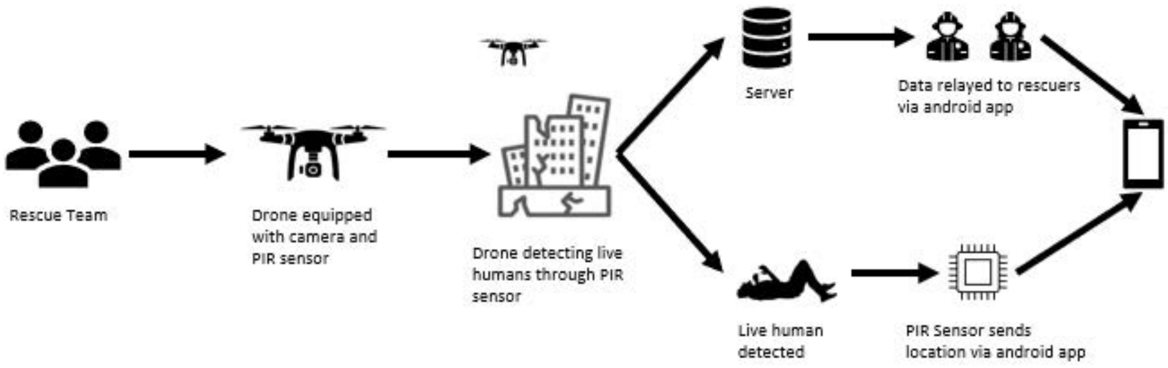
In a disaster situation like a tornado or earthquake, one of the major challenges for the rescue and search teams is locating and finding victims at soon as humanly possible (Viswan & Madhav, 2013). The use of unmanned aerial vehicles (UAVs) for search and rescue has been a popular topic among researchers and organizations worldwide (Boukerche & Coutinho, 2018; Lygouras et al., 2019; McClure, 2019; Tariq et al., 2018; Thipphavong et al., 2018). During times of disaster, one of the most critical things agencies can do is locate survivors facing danger. Removing an individual from a dangerous situation can increase their chance of survival. Lygouras et al. (2019) explain that while providing emergency services during an event, aerial robots can contribute by providing data to both distressed humans and rescue teams. Further, deep learning techniques are applied to the UAVs to increase their detecting capabilities and reduce response time (Lygouras et al., 2019).

The UAS technology known as “DronAID” can detect humans in disastrous conditions, providing exact locations to rescuers. Rescue teams may be unable to reach areas during search and rescue operations immediately after a disaster. This limitation could be due to a myriad of reasons, including dangerous conditions for rescuers, location of the disaster, or debris fields (Tariq et al., 2018). DronAID can search for people trapped under debris, tag their location for rescuers, and send alerts to them. The platform uses a passive infrared (PIR) sensor that detects infrared radiation (IR), which human bodies emit.

The use of an aerial platform can provide a better vantage point for teams who would otherwise have a limited vision of the entire disaster area. The use of DronAID would offer a low-risk option to rescuers to begin search and rescue operations immediately following the onset of a disaster. Figure 2 details the workflow of the DronAID system. The rescue team would deploy a drone with the PIR sensor to the disaster area. The drone would then relay its findings to the ground relay station. The image would then be projected to rescuers equipped with a mobile android application that superimposes the victim's location on the app for rescuers to locate the victim more efficiently.

Figure 2

Workflow Diagram of DronAID System



Note: Data flow as described by Tariq et al. (2018).

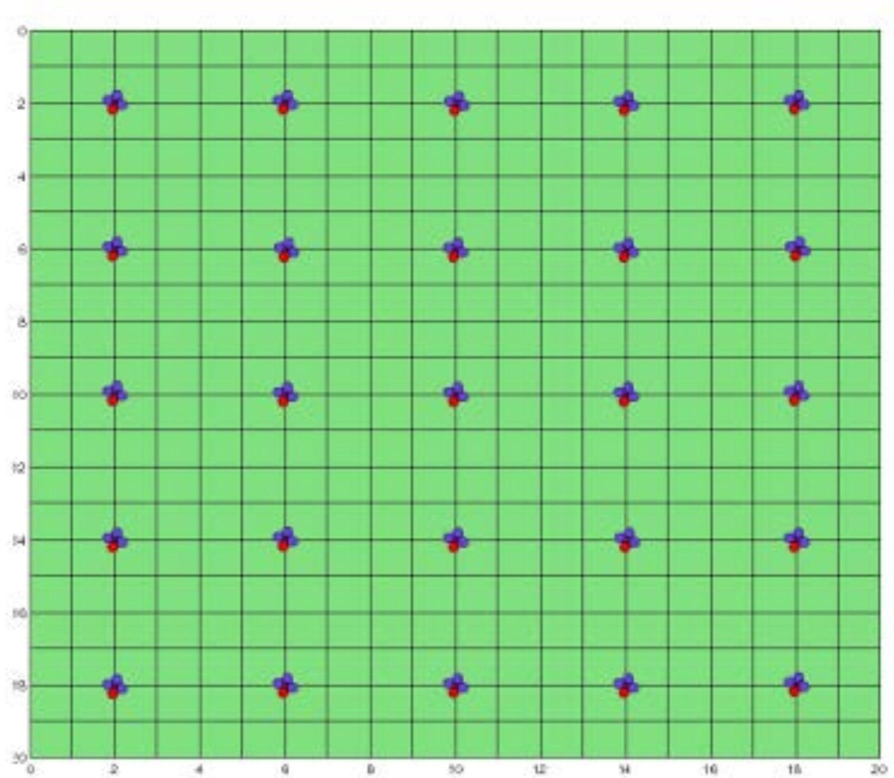
Disaster Recovery

According to Almedia et al. (2017), UAVs have become a universal product, available and affordable for the general public due to the massive reduction in cost and size. This availability increases the uses in disaster recovery, environmental mapping, protection, firefighting, and emergency response. Almedia et al.’s (2017) research develop an approach to use a “swarm technique” to deploy a series of drones that provide area coverage for a large-scale area. This technique offers real-time data for emergency planners who must react to the situation at hand. It would also provide the capability to see the entire region from a single platform and monitor its progression.

Figure 3 shows how 25 drones could be deployed to provide coverage for a 20x20 location using the swarm technique. The 20x20 distance would be subjective to the range of the drones in use. Therefore, the hypothetical model does not account for the actual coverage in a quantifiable way. This deployment method would allow rescue workers to gain awareness of large areas that could be subject to a natural disaster. Using this technique after a flood would allow rescue workers on the ground a near-real-time aerial view of the entire flooded area. This information could enable rescue workers to locate survivors, monitor flood levels, and help people on the ground navigate through challenging terrain.

Figure 3

Hypothetical Swarm of 25 UAVs Used Over a 20x20 Grid (400 Grid Locations)



Note. From Almeida et al. (2017), licensed under CC BY 4.0.

Maritime Uses

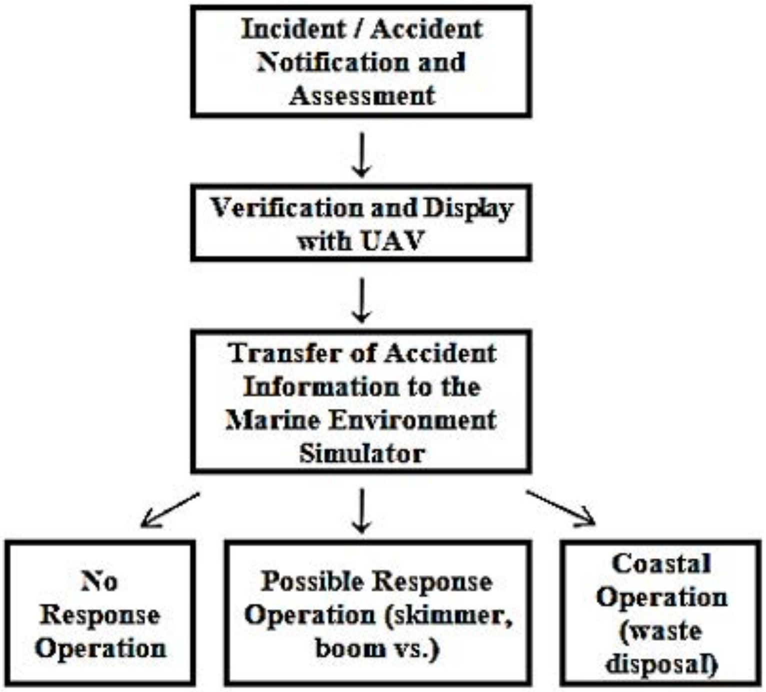
Researchers have proposed many uses of unmanned technology in marine scenarios. Pu et al. (2020) explored using unmanned surface vehicles (USV) for real-time scanning and water sampling in emergency response to a shipwreck. The researchers responded to the

Sanchi oil taker collision and explosion to analyze the efficacy of the USV. This vehicle was the first USV to have improved navigation control algorithms, an improved launch, and recovery system (LARS), and a new sampling system was specially designed for the USV. The USV craft was deployed and collected five water samples from five locations, providing rescue workers with detailed information of the surrounding areas. Pu et al. (2020) stated that there were numerous issues with the successful mission: stability of the craft in rough seas, long mission times due to limited speeds and payloads along with a single USV, and that when it broke down, it stopped the entire mission and removed rescuers from the primary mission.

Bayirhan and Gazioğlu (2020) used a prototype integrated response to the Orcun C ship being stranded near the shores of Kilyos, Istanbul. This incident also marked Turkey's first use of UAV technology to identify the crash site before response operations. This UAV response helped first responders identify the exact location within 15 minutes and deploy a team of 200 individuals, which further helped prevent the spread and impact of the accident (Bayirhan & Gazioğlu, 2020). Figure 4 describes the model used for the integrated UAV and Marine Environment Simulators (MES) prototype.

Figure 4

Combination Model of UAV and MES

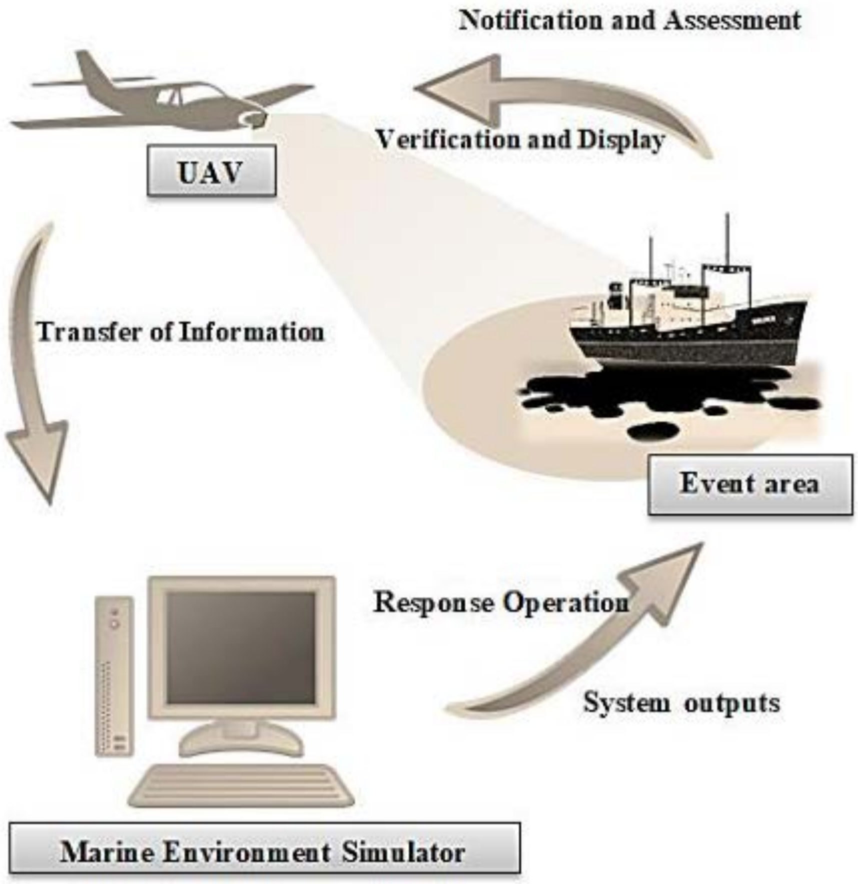


Note: From Bayirhan and Gazioğlu (2020), in the Public Domain, (CC0 1.0).

Figure 5 details the cyclic nature of the integrated UAS-MES system. The event area would be reported, and a UAV would be deployed to verify the accident and to be displaying the event area. Next, the UAV would transfer information to the MES. For the Orcun C ship incident, the software used weather and sea report information to create a scenario to determine if there was indeed a spill of oil in a sea accident at that time. This scenario makes a three-dimensional oil distribution model instead of typical surface-only models that enable greater support for decision-makers in the disaster area (Bayirhan & Gazioğlu, 2020).

Figure 5

Cyclic Working Principal of UAV and MES



Note: From Bayirhan and Gazioğlu (2020), in the Public Domain (CC0 1.0).

Natural Disasters

This section will provide an overview of the natural disasters that are the focus of the first study. The International Federation of Red Cross identifies five categories of natural disasters: (1) geophysical, (2) hydrological, (3) climatological, (4) meteorological, and (5) biological (IFRC, 2016). Of these categories, the first four were explored in the current study. From these four categories, we selected five types of natural disasters. Those five types are earthquakes, hurricanes, tornados, floods, and wildfires. These types of natural disasters are discussed below, including a definition, agencies involved, issues caused by the disaster, traditional approaches to rescue and recovery, and current uses of UAM in each disaster.

Earthquakes

The United States Geological Survey (USGS) provides science about natural hazards for American citizens. Their mission statement is “The USGS mission is to monitor, analyze, and predict current and evolving dynamics of complex human and natural Earth-system interactions and to deliver actionable intelligence at scales and timeframes relevant to decision makers” (USGS, n.d. -c). They are the only US Federal agency responsible for recording and reporting earthquake activity nationwide (USGS, n.d. -a). Earthquakes are measured using the magnitude of an earthquake in the Richter Scale. The scale is logarithmic so that a recording of 5, for example, indicates a disturbance with ground motion ten times as large as a recording of 4 (Shedlock & Pakiser, 2016). Table 1 describes the magnitude, effect, class, and estimated number of each magnitude per year.

Table 1

Earthquake Magnitude Scale

Magnitude	Earthquake Effects	Class	Estimated Number Each Year
2.5 or less	Usually not felt but can be recorded by a seismograph.	n/a	900,000
2.5 to 5.4	Often felt, but only causes minor damage.	Minor	30,000
5.5 to 6.0	Slight damage to buildings and other structures.	Moderate	500
6.1 to 6.9	May cause a lot of damage in very populated areas.	Strong	100
7.0 to 7.9	Major earthquake. Serious damage.	Major	20
8.0 or greater	Great earthquake. Can completely destroy communities near the epicenter.	Great	One every 5 to 10 years

Note. Adapted from Endsley (n.d.).

Issues caused by Earthquakes

Earthquakes threaten well over 143 million Americans (USGS, n.d. -a). These individuals rely on the USGS to provide accurate and timely information on every earthquake detected. This information includes where the earthquake occurred, the possible economic and/or human impacts, and the likelihood of future tremors. While an earthquake alone poses a minimal threat to a person, the resulting impacts can cause catastrophic effects widely seen on infrastructure. The associated phenomenon related to an earthquake creates extreme economic consequences and causalities (Kossobokov et al., 2018). Common phenomena of an earthquake are surface faulting, ground shaking, ground failure, and tsunamis.

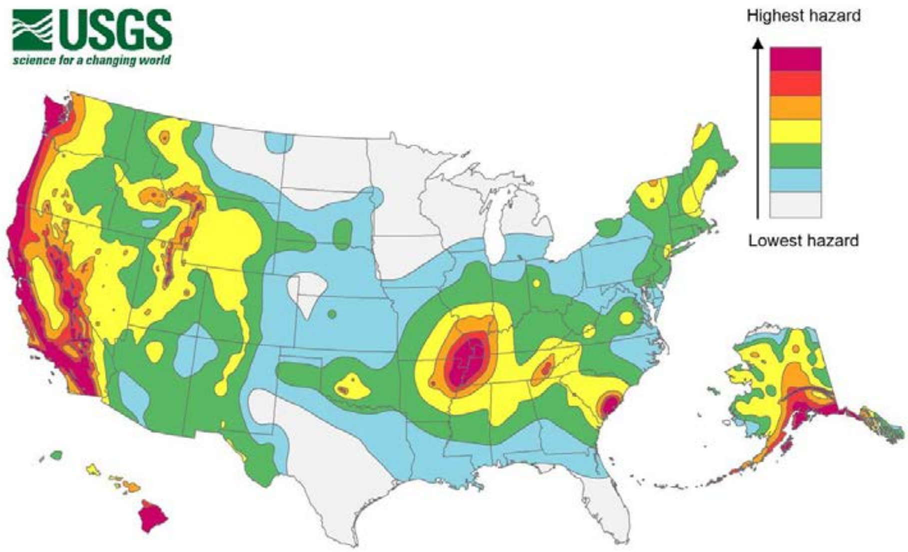
Surface faulting occurs when the earthquake tears apart the ground at the surface resulting in a rupture. According to the Southern California Earthquake Data Center at Caltech (n.d.), the Landers earthquake in 1992 resulted in a 53-mile-long surface rupture. Ground shaking occurs from the vibration of the ground during an earthquake. Most damages from an earthquake result from these strong vibrations and their effects on infrastructure (e.g., roads and buildings) (Shedlock & Pakiser, 2016).

Traditional Approaches and Risks Associated

The USGS conducts field, laboratory, and theoretical investigations and supporting research to determine the likelihood of future earthquakes (Shedlock & Pakiser, 2016). Due to the unpredictability of earthquakes, limited approaches are available for emergency response. The Occupational Safety and Health Administration (OSHA) (n.d. -a) describes that collapsed structures constitute most of the emergency response to an earthquake. This damage puts first responders in perilous conditions, entering collapsed structures to locate casualties. The USGS is deploying the Advanced National Seismic Systems (ANSS) to provide real-time information, providing situational awareness for emergency-response personnel (Wolfe, n.d.). Figure 6 shows a recent earthquake hazard map for the United States.

Figure 6

Earthquake Hazard Map, 2018



Note. The map is based on the most recent USGS models for the conterminous U.S. (2018), Hawaii (1998), and Alaska (2007). From USGS (2018), in the public domain.

How the use of UAM Mitigate Risks. UAM could limit a first responder's exposure to dangerous situations. Accurate readings from sensors could be deployed in UAM vehicles to relay important information to these rescue workers, preventing unnecessary risks. Xiong et al. (2020) developed a UAS to detect seismic damage to buildings before first responders move into the affected areas. The researchers used UAV technology and a convolutional neural network (CNN) to train the system to detect buildings damaged in the aftermath of an earthquake with an accuracy of 89.39% (Xiong et al., 2020). This technology could prove advantageous to rescue workers to notify them of builds that may no longer be structurally sound following a seismic event.

Hurricanes

Belonging to the National Centers for Environmental Protection (NCEP), The National Hurricane Center (NHC) is an agency that specializes in hurricane responses for the United States. The NHC mission statement is to save lives, mitigate property loss, and improve economic efficiency by issuing the best watches, warnings, forecasts, and analyses of hazardous tropical weather and increasing understanding of these hazards (NHC Public Affairs Officer (PAO), 2020). The Saffir-Simpson Hurricane Wind Scale measures a hurricane's strength and typical damage associated with the category, as shown in Table 2.

Table 2

Saffir-Simpson Hurricane Wind Scale

Category	Sustained Winds	Types of Damage Due to Hurricane Winds
1	74-95 mph 64-82 kt 119-153 km/h	Very dangerous winds will produce some damage: Well-constructed frame homes could have damage to roof, shingles, vinyl siding and gutters. Large branches of trees will snap and shallowly rooted trees may be toppled. Extensive damage to power lines and poles likely will result in power outages that could last a few to several days.
2	96-110 mph 83-95 kt 154-177 km/h	Extremely dangerous winds will cause extensive damage: Well-constructed frame homes could sustain major roof and siding damage. Many shallowly rooted trees will be snapped or uprooted and block numerous roads. Near-total power loss is expected with outages that could last from several days to weeks.
3 (major)	111-129 mph 96-112 kt 178-208 km/h	Devastating damage will occur: Well-built framed homes may incur major damage or removal of roof decking and gable ends. Many trees will be snapped or uprooted, blocking numerous roads. Electricity and water will be unavailable for several days to weeks after the storm passes.
4 (major)	130-156 mph 113-136 kt 209-251 km/h	Catastrophic damage will occur: Well-built framed homes can sustain severe damage with loss of most of the roof structure and/or some exterior walls. Most trees will be snapped or uprooted, and power poles downed. Fallen trees and power poles will isolate residential areas. Power outages will last weeks to possibly months. Most of the area will be uninhabitable for weeks or months.
5 (major)	157 mph or higher 137 kt or higher 252 km/h or higher	Catastrophic damage will occur: A high percentage of framed homes will be destroyed, with total roof failure and wall collapse. Fallen trees and power poles will isolate residential areas. Power outages will last for weeks to possibly months. Most of the area will be uninhabitable for weeks or months.

Note. Created from NHC (n.d.). In the public domain.

Issues caused by Hurricanes

OSHA (n.d. -c) has recognized several general hazards encountered during a typical hurricane response. The hazards include downed power lines, live electrical equipment, structural instability, falling through openings, open gas lines, flying objects, flooding, and possible contact with unknown chemicals. The Center for Disease Control (CDC) has issued safety guidelines to response workers that include five hazards: sharp jagged debris, floodwater exposure, electrical hazards, contact with blood/body fluids from animal or human remains, and slick/unstable surfaces. Many of these hazards stay for several days after the hurricane, increasing the risk of exposure.

Traditional Approaches

Hurricanes are one of the most predictable natural disasters, allowing for weeks of advanced notice to a population before landfall. This notice enables a coordinated emergency response that allows for proper preparation and evacuation. Despite these advanced warning and evacuation orders, many choose to remain in high-risk areas during the storm. According to Florido (2018), most people who stay behind have sound, rational decisions. He says that many reasons can influence people's decisions: expense, pets, elderly neighbors, fear, or no way to evacuate due to lack of transportation. Since people will stay in these disaster areas, it creates additional, and sometimes unnecessary, risks for rescue workers who must stay behind to ensure the public's safety.

The National Oceanic and Atmospheric Administration provides several recovery missions after a hurricane. The National Geodetic Survey will begin aerial survey missions as soon as weather permits flying (NOAA, 2021). The survey missions are rapidly processed and available to anyone through open-source means. This survey helps facilitate emergency strategies, search and rescue, hazard identification, HAZMAT concerns, and comparative images for damage assessments (NOAA, 2021).

How the use of UAM Mitigate Risks. Successful use of UAM in response to a hurricane would depend on the weather stabilizing to allow for flight and assist in recovery efforts. However, due to the unmanned nature of the craft, it would not put a human pilot in jeopardy. This could allow missions to launch sooner than human-piloted craft. UAM could provide detailed renderings of flooded and damaged areas to rescuers before arrival and enable planners to prioritize locations based upon imaging. It could also be deployed for search and rescue operations to identify victims signaling for help. Supplies could also be delivered using unmanned vehicles to individuals inaccessible to rescuers.

Many people can recognize photographs from the aftermath of a hurricane, much like the one seen in Figure 7. The Stage 4 storm, Katrina, caused the levee system of New Orleans to fail, which resulted in widespread flooding. This flooding caused further damage to the already battered area. Individuals were forced to flee to their roofs while awaiting rescue. The implementation of UAM in this situation could have provided rescue workers with precise locations and a detailed map which could have assisted in the extraction of the victims.

Figure 7

People on a Roof Waiting to be Rescued After Hurricane Katrina, August 30, 2005.

Note: From Augustino (2005), in the public domain.

Tornados

The National Weather Service (NWS) is responsible for tornado forecasts in the United States. Tornados are highly unpredictable and can occur from severe thunderstorms but are most common in the Central Plains and the southeastern United States (NWS, n.d. -b). Most of the reporting mechanisms rely on doppler radar and storm spotters in the local area. Tornados are measured through the Enhanced Fujita Scale, as shown in Table 3.

Table 3

The Enhanced Fujita Scale

EF Rating	3 Second Gust (mph)	Typical Damage
0	65-85	Light damage. Some damage to chimneys; branches broken off trees; shallow-rooted trees pushed over; sign boards damaged.
1	86-110	Moderate damage. Peels surface off roofs; mobile homes pushed off foundations or overturned; moving autos blown off roads.
2	111-135	Considerable damage. Roofs torn off frame houses; mobile homes demolished; boxcars overturned; large trees snapped or uprooted; light-object missiles generated; cars lifted off ground.
3	136-165	Severe damage. Roofs and some walls torn off well-constructed houses; trains overturned; most trees in forest uprooted; heavy cars lifted off the ground and thrown.
4	166-200	Devastating damage. Well-constructed houses leveled; structures with weak foundations blown away some distance; cars thrown, and large missiles generated.
5	Over 200	Incredible damage. Strong frame houses leveled off foundations and swept away; automobile-sized missiles fly in excess of 100 meters (109 yds); trees debarked; incredible phenomena will occur.

Note. Adapted from the National Weather Service (n.d. -a). In the public domain.

Issues caused by Tornados

Tornados can damage power lines, gas lines, electrical systems, create debris fields, damage buildings, and injure or kill people (CDC, 2012). Table 4 shows all F5 and EF5 tornados on record in Oklahoma, resulting in 520 deaths and 2,848 injuries. Keep in mind, this death toll only includes the 15 F5 and EF5 tornados on record. This amount of destruction shows the devastating effects tornados can have. OSHA (n.d. -d) identifies hazardous driving conditions due to slippery and/or blocked roadways as a potential hazard that could be mitigated using UAM.

Table 4

List of F-5 Tornados recorded in Oklahoma History and Summary Statistics

Date	Width (yds)	F-Scale	Deaths	Injuries	Counties
5/10/1905	880	F5	97	58	Jackson/ Kiowa
4/14/1939	1000	F5	7	19	Dewey/ Major/ Woodward/ Major/ Woods
4/12/1945	880	F5	69	353	Pushmataha
4/9/1947	3200	F5	184	980	Hemphill, TX/ Lipscomb, TX/ Ellis/ Woodward/ Woods
5/31/1947	800	F5	7	15	Roger Mills/Dewey
5/25/1955	1320	F5	80	273	Kay/ Sumner KS/ Cowley KS
5/5/1960	800	F5	5	81	Pottawatomie/ Lincoln/ Okfuskee/ Creek
3/26/1976	440	F5	2	64	Le Flore
4/2/1982	500	F5	0	29	Choctaw/ McCurtain
5/3/1999	1760	F5	36	583	Grady/ McClain/ Cleveland/ Oklahoma
5/24/2011	1760	EF5	9	181	Canadian/ Kingfisher/ Logan
5/20/2013	1900	EF5	24	212	McClain/ Cleveland

Note: Created from National Weather Service (n.d.), in the public domain.

Traditional Approaches

Most rescue operations can occur immediately following a tornado. However, some major storm systems could result in multiple tornados, delaying recovery efforts. During a major storm, rescue workers could be subject to another tornado while attempting a rescue or providing aid. Emergency responders typically arrive at a scene that could include fallen debris, live electrical wires, chemical spills, and flying debris. Rescue workers are required to dig through the rubble to locate those in need. UAM may be able to help rescuers find those individuals sooner.

How the use of UAM Mitigate Risks. The use of UAM in response to tornados could provide rescuers with aerial footage to locate casualties and damaged infrastructure. Infrared sensors could help rescue workers find casualties buried in debris and pinpoint locations to rescuers to expedite recovery efforts. This could expedite search and rescue efforts to enable workers to see a much more accurate picture of the ground. Platforms such as DronAID (Tariq et al., 2018) would be ideal for a situation where victim extraction from the rubble was necessary.

Flood

The USGS collects flood data to assist Federal, State, and local agencies, decision-makers, and the public before, during, and after a flood (Fitzpatrick et al., n.d.) in addition to their collection of earthquake data. According to the USGS, there are two flood categories: river floods and flash floods. River floods occur with large rivers in wetter climates. Excessive runoff from prolonged rainstorms and melting snow causes a slow water-level increase over a large area. On the other hand, flash floods occur when excessive rainfall causes a rapid rise in the water of a stream or otherwise dry channel (USGS, n.d. -b).

Issues caused by Floods

OSHA (n.d. -b) identifies several hazards associated with flooding: electrical, tree and debris, carbon monoxide, mold, chemical, and biological hazards, fire, drowning, and hypothermia. These hazards pose a severe risk to rescue workers and individuals experiencing flooding. Flooding can also cause areas to become inaccessible due to standing water or washed-out roads. This creates additional issues for rescue workers trying to reach those in need.

Traditional Approaches

Like hurricanes, a typical response to flooded areas involves the National Geodetic Survey conducting aerial survey missions as soon as weather permits flying (NOAA, 2021). River floods are more predictable and allow evacuations to occur in populated areas. Flash flooding, on the other hand, is highly unpredictable and represents a more significant threat. The threats remain the same between hurricanes and flooding since many hurricanes result in massive flooding.

How the use of UAM Mitigate Risks. UAM could assist rescue workers using surveillance to identify the affected areas. Supplies would be delivered without restrictions from blocked or submerged roadways. Additionally, rescue operations could be conducted for perilous situations such as experiencing hypothermia or in rushing waters of a flash flood.

Wildfire

According to the Government Accountability Office (n.d.), five federal agencies are responsible for wildland fire management. Those agencies are USDA's Forest Service and the Department of the Interior's Bureau of Indian Affairs, Bureau of Land Management, Fish and Wildlife Service, and National Park Service. The leadership which enables interoperability with wildland fire operations comes through the National Wildfire Coordinating Group (NWCG) (n.d. -a). Table 5 provides an overview of the class and size of wildfires.

Table 5

Size and Classes of Fire

Class	Size
A	one-fourth acre or less
B	more than one-fourth acre, but less than 10 acres
C	10 acres or more, but less than 100 acres
D	100 acres or more, but less than 300 acres
E	300 acres or more, but less than 1,000 acres
F	1,000 acres or more, but less than 5,000 acres
G	5,000 acres or more

Note. Adapted from NWCG (n.d. -b). In the public domain.

Issues caused by Wildfire

There have been 15 forest fires since 2000 that have each caused at least $1 billion in damages (Center for Climate and Energy Solutions (C2ES, n.d.). There is an extensive list of hazards associated with wildfire response: electrical, carbon monoxide poisoning, extreme heat, unusable structures, fire, fatigue, respiratory issues, downed electrical wires, and chemical exposure (OSHA, n.d. -e; C2ES, n.d.). These hazards pose large risks for rescue workers and individuals in the way of the fires. Wildfire smoke can also irritate eyes, noses, throats, and lungs, resulting in labored breathing or coughing (CDC, 2021).

Traditional Approaches

Fighting wildfires is a dangerous job. The CDC (2020) reports that between 2000-2019, there were over 400 on-duty fatalities from battling forest fires. Many threats face first responders: burnovers, entrapments, heat-related illnesses and injuries, and smoke inhalation. Additionally, the responders are at risk for sudden cardiac deaths due to intense physical exertion (CDC, 2020). While many of these are uncontrollable, some use of UAM could help mitigate the risks and possibly decrease the death toll.

How the use of UAM Mitigate Risks. UAM could assist in wildfire response teams in a variety of ways. First, aerial surveillance could prove advantageous in determining a plan to combat the fire. The aerial vision could also help those on the ground avoid areas and determine escape routes when visibility is reduced. The use of UAM technology would prevent pilots from flying in dangerous conditions where excessive smoke could cause issues to visibility. Next, it could deliver supplies to front-line workers or those trapped by the fires who may be inaccessible otherwise. Finally, the use of UAM could allow for the rescue of individuals in perilous situations where smoke would hinder the view of a piloted craft for rescue or create conditions not favorable for piloted operations.

APPROACH AND METHODOLOGY

The current project was conducted over a series of four separate research studies. In Study 1, the participants reported their willingness to support the use of urban air mobility vehicles in response to natural disasters. Specifically, we assessed willingness to support based on whether or not the UAM was human-operated or remotely operated, the type of mission, and the type of natural disaster. After learning the perceptions of using UAM in response to natural disasters, Study 2 created a Vertiport Usability Scale. Built over a series of several stages, the Vertiport Usability Scale presents a valid tool that can be used to gather information on the current and future proposed locations of vertiports. After validation, this scale was used in Study 3, which determined participants' preferred locations for vertiports in three conditions: temporary disaster locations, permanent disaster locations, and permanent consumer locations. Finally, in Study 4, the research team conducted a qualitative analysis of participants' perceptions on the use of UAM in response to natural disasters. The themes from Study 4 were compared to the results from the previous three quantitative studies.

Study 1 – Methods

Participants

Six hundred and thirteen (278 males, 330 females, 3 nonbinaries, 2 no response) individuals participated in the study. The average age of participants was 40.29 (*SD* = 13.25) years old, and 79% reported as Caucasian, 9% Asian descent, 6% African descent, 4% Hispanic descent, and 2% Other. Participants were recruited using Amazon's ® Mechanical Turk ® (MTurk). MTurk is a worldwide platform of individuals willing to complete online human intelligence tasks (HITs) in exchange for monetary compensation. Prior studies (Buhrmester, Kwang, & Gosling, 2011; Germine et al., 2012; Rice, Winter, Doherty & Milner, 2017) have demonstrated that the data collected via MTurk is as reliable as traditional laboratory studies. In addition, the researcher can set qualifying parameters to ensure quality responses further. In the current study, participants needed to be residents of the United States, have completed at least 100 prior tasks on MTurk, and maintained an overall worker approval rating of 98% or greater.

Materials, Stimuli, and Procedure

Participants were first presented with the consent form, which they had to digitally sign to continue with the study. Those who disagreed were exited from the study. Next, participants were presented with the following instructions, "*Instructions - You will be presented with some scenarios and you will then be asked some questions about those scenarios. Following that, you will be asked some demographics questions. The data collection process is anonymous and your responses will remain confidential."* Following the instructions, participants were randomly assigned into one of the two between-participant conditions, based on the type of UAM operations, either remotely human operated or fully autonomous. In the remotely human operated condition, participants were presented with the following, *"In this case, Urban Air Mobility (UAM) refers to the use of autonomous air vehicles (with a remote human pilot or operator) to deliver people or goods from one location to another, when ground transportation is less practical or feasible. Some examples include air taxis for people or drones to deliver packages. These are typically initially expensive to operate due to the costs of the technology and resources needed. The government would fund these operations using public tax dollars."* In the case of the fully autonomous condition, participants read, *"In this case, Urban Air Mobility (UAM) refers to the use of autonomous air vehicles (without a human pilot or operator) to deliver people or goods from one location to another, when ground transportation is less practical or feasible. Some examples include air taxis for people or drones to deliver packages. These are typically initially expensive to operate due to the costs of the technology and resources needed. The government would fund these operations using public tax dollars."* In either condition, they were then presented with *"In each of the following scenarios, we would like you to rate how willing or unwilling you would be to support the following missions using federal tax dollars."* Following this, participants responded to each of the 25 conditions on a seven-point scale from either extremely unwilling to extremely willing. All 25 conditions were randomized to prevent order effects, and the cases are presented in Appendix A. Participants then completed several demographic questions, were debriefed, compensated, and dismissed.

Design and Statistical Analysis

Study 1 used a quantitative experimental design. The three independent variables were the type of UAM operation (between-participants, 2 levels: remote human operated or fully autonomous), type of natural disaster (within-participants, 5 levels; earthquake, hurricane, tornado, flood, and wildfire), and the type of mission provided (within-participants, 5 levels; food and water delivery, medicine, delivery, delivery of survival equipment, delivery of news, rescue of victims). The resulting analysis was conducted using a 2x5x5 mixed analysis of variance (ANOVA).

Ethics

The study was approved by the research university's institutional review board (IRB) before the solicitation of participants. All researchers on the project received training in the proper treatment of human participants and held current certification through the Collaborative Institutional Training Initiative (CITI) program.

Hypotheses

The following hypotheses were proposed for Study 1:

H_{a1}: Participants would be significantly more willing to support UAM when it was human-operated.

H_{a2}: There would be significant differences in willingness to support UAM based on the type of natural disaster.

H_{a3}: There would be significant differences in willingness to support UAM based on the type of mission.

H_{a4}: There will be significant interactions in the data; however, this hypothesis was non-directional.

Study 1 - Results

Initial Data Analysis

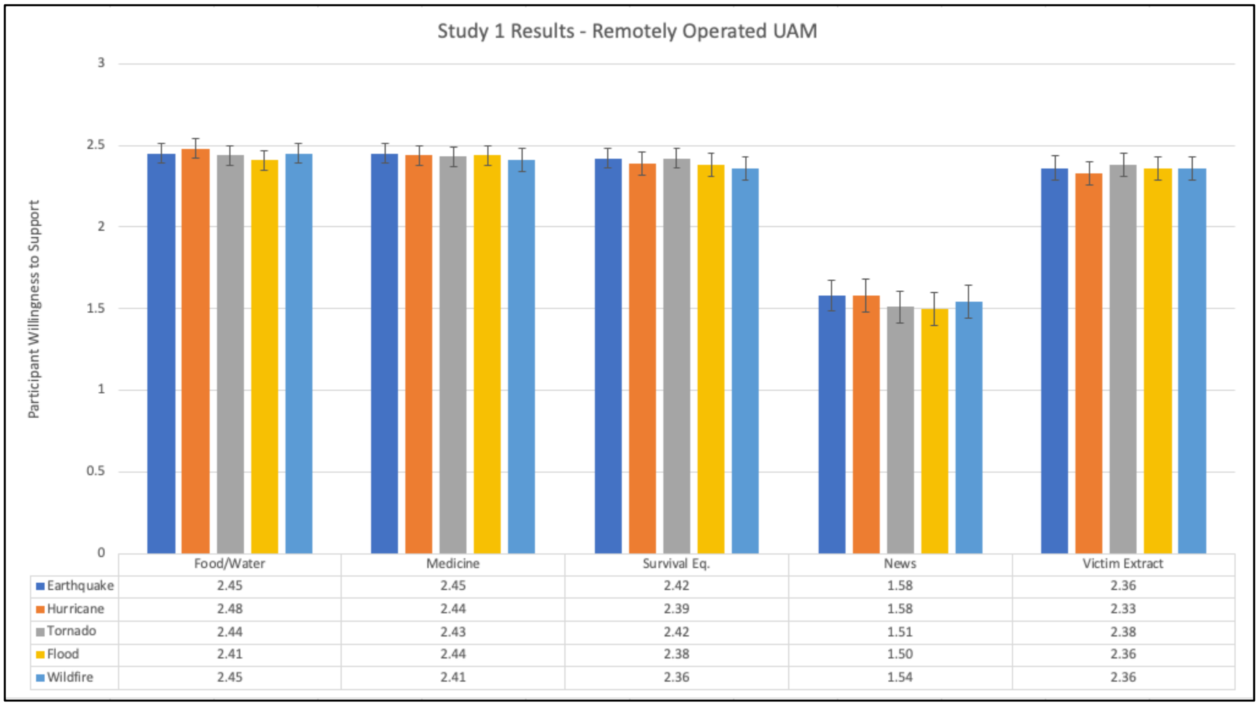
Initial data analysis found 35 cases where participants failed to respond to all 25 cases. These participants were removed listwise from the data set, resulting in 578 total participants for the data analysis, with 272 in the remote human operated condition and 306 in the fully autonomous condition. The data were assessed for outliers. While several cases were identified as possible outliers, given the seven-point scale, it is unlikely that these cases could be justified as outliers. Thus, they were retained for data analysis. Normality was assessed through a visual assessment of histograms. The data did display a negative skew; however, this was somewhat expected due to participants favoring the use of UAM in response to emergency scenarios. Additionally, the large sample size was viewed as potentially offsetting this skew to the data, along with the robustness of the ANOVA statistic. Mauchly's Test of Sphericity was violated with the data ($p < .001$), and therefore, a Greenhouse-Geisser correction was applied to interpret the results.

Main Data Analysis

A 2x5x5 mixed factorial ANOVA was conducted to analyze the data between the Type of Operation, the Type of Natural Disaster, the Type of Mission, and the interaction terms. A significant main effect was found based on the Type of Mission, $F(1.583, 911.823) = 186.987$, $p < .001$, *partial eta squared* = .245. No significant main effects were found for the Type of Natural Disaster, $F(3.449, 1986.844) = 1.368$, $p = .247$, *partial eta squared* = .002, or Type of Operation, $F(1, 576) = 0.645$, $p = .422$, *partial eta squared* = .001. Additionally, no significant interactions were found between the Type of Disaster and the Type of Group, $F(3.449, 1986.844) = 1.751$, $p = .146$, *partial eta squared* = .003, the Type of Mission and the Type of Operation, $F(1.583, 911.823) = 0.447$, $p = .594$, *partial eta squared* = .001, the Type of Natural Disaster and the Type of Mission, $F(12.702, 7316.439) = 0.804$, $p = .653$, *partial eta squared* = .001, or the Type of Natural Disaster, the Type of Mission, and the Type of Operation, $F(12.702, 7316.439) = 1.052$, $p = .397$, *partial eta squared* = .002. Figures 8 and 9 present the significant findings for the main effect of the Type of Mission based on remotely operated or fully autonomous UAM operations, respectively.

Figure 8

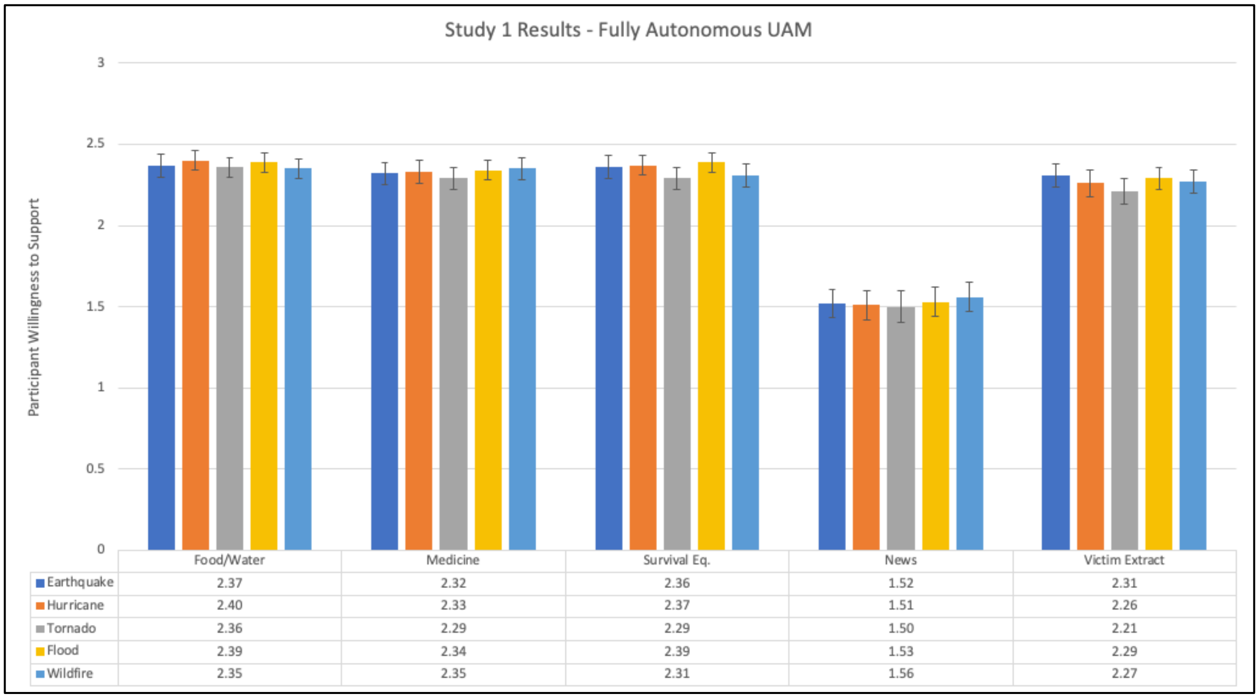
The Significant Main Effect of Type of Mission when the UAM was Remotely Operated



	Food/Water	Medicine	Survival Eq.	News	Victim Extract
Earthquake	2.45	2.45	2.42	1.58	2.36
Hurricane	2.48	2.44	2.39	1.58	2.33
Tornado	2.44	2.43	2.42	1.51	2.38
Flood	2.41	2.44	2.38	1.50	2.36
Wildfire	2.45	2.41	2.36	1.54	2.36

Figure 9

The Significant Main Effect of Type of Mission when the UAM Was Autonomously Operated



	Food/Water	Medicine	Survival Eq.	News	Victim Extract
■ Earthquake	2.37	2.32	2.36	1.52	2.31
■ Hurricane	2.40	2.33	2.37	1.51	2.26
■ Tornado	2.36	2.29	2.29	1.50	2.21
■ Flood	2.39	2.34	2.39	1.53	2.29
■ Wildfire	2.35	2.35	2.31	1.56	2.27

Study 1 – Discussion

The findings from Study 1 provide some interesting findings. First, participants did not have any difference in willingness to support the use of UAM based on whether the vehicle was remotely or autonomously operated. There was also no significant difference based on the natural disaster type nor any significant interactions between variables. However, participants were less willing to support the delivery of news to individuals compared to the other four mission types. Participants may feel the news does not need to be delivered urgently, or perhaps there are other methods from which victims could obtain current news.

Study 2 – Introduction

The purpose of Study 2 was to develop and validate a scale that could be used to assess participants' perspectives on the viability of a location to host a vertiport. The scale development followed a multi-stage process utilized in several prior studies (Rice, Mehta, Steelman & Winter, 2014; Rice, Mehta, Winter, & Oyman, 2015; Rice et al., 2020), and the original framework was developed by Hinkin (1998).

Study 2 - Methods

Stage 1: Item Generation

The purpose of stage 1 is to generate as many words as possible that relate to the overall topic of the scale. In the current study, words were solicited in three main ways. First, consumers were asked to complete a short questionnaire listing five words or phrases that they felt related to where a vertiport should be built. Second, the research team thoroughly reviewed the literature related to vertiports to determine if any additional words should be added. Lastly, two subject matter experts on unmanned aerial vehicles and urban air mobility were asked to review the word list and determine if any additional words should be added.

Participants

Participants in stage 1 were run in two parts. First, two hundred and fifty-seven (127 males; 127 females; 3 no response) completed the instrument via a convenience sample using Amazon's Mechanical Turk (MTurk). The average age of participants was 41.48 (*SD* = 13.41) years old, and 76% reported as Caucasian, 8% African descent, 9% Asian descent, 4% Hispanic descent, and 3% Other. Participants were limited to those who reside in the United States, had completed at least 500 prior tasks on MTurk, and had ratings of 98% or better. While these participants provided good words, there was some concern that several terms were not specific to the location aspect of the vertiport. Therefore, a second set of 50 participants (22 females) was run with a focus to clarify words were related to location, as noted below using the same participant requirements. The average age of participants was 39.08 (*SD* = 10.90) years old, and 82% reported as Caucasian, 10% Asian descent, 6% African descent, and 2% Hispanic descent.

Procedure, Materials, and Stimuli

Participants in the first run were directed to Google Forms to complete the instrument. They were first presented with an electronic consent form, brief instructions, and the following information on vertiports: *A vertiport is the proposed takeoff and landing site for urban air mobility (UAM) aircraft. The UAM aircraft can be either remotely operated or a fully automated aerial vehicle, such as an air taxi.* They were then instructed: *In the context of usability related to a vertiport, please enter 5 words or phrases that you feel are strongly relevant to the concept of vertiport usability. In other words, what items or phrases would* *make the vertiport more accessible and user friendly? For example, a vertiport should be convenient, accessible, safe, etc. Each answer should include only a one word or one sentence phrase*. After providing their list of words or phrases, they answered some demographic questions, were debriefed, compensated, and dismissed. The process in the second run of participants was identical to the first run with the exception that the final instructions were changed to the following to focus on the location aspect of the vertiport: *In the context of LOCATION related to where a vertiport should be built, what are the most important issues you can think of when deciding on a LOCATION for a new vertiport? Each answer should include only a one word or one sentence phrase.*

Results

After stage 1, 49 unique words or terms were collected (e.g., accessible, convenient, safe, secure). All the terms were reviewed for spelling and lowercase font before being used in stage 2.

Stage 2: Nominal Paring

The purpose of stage 2 in the instrument development is to begin paring down the initial list of words to find those most focused and relevant to the topic of "vertiport location." In this stage, each participant was asked to read each item and assess the item's relevance to the construct of "vertiport location."

Participants

Two hundred and fifty-five individuals completed the study. Three participants were removed due to failure to agree to the consent form, resulting in 252 participants (139 males; 111 females; 2 no response). Participants were again selected from MTurk, and those who completed stage 1 were not available to complete stage 2 due to a user-specified restriction. The average age of participants was 40.24 (*SD* = 12.11) years old, and 76% reported as Caucasian, 8% African descent, 8% Asian descent, 6% Hispanic descent, and 2% Other.

Procedure, Materials, and Stimuli

Participants read and digitally indicated their agreement to the electronic consent form. Following this, participants read brief instructions: *Instructions - You will be presented with some terms and asked to rate how relevant or irrelevant those terms are to where a vertiport should be LOCATED. The data collection process is anonymous, and your responses will* *remain confidential*, and provided with the following contextual information on urban air mobility: *In this case, Urban Air Mobility (UAM) refers to the use of autonomous air vehicles (with a remote human pilot or operator) to deliver people or goods from one location to another, when ground transportation is less practical or feasible. Some examples include air taxis for people or drones to deliver packages. These are typically initially expensive to operate due to the costs of the technology and resources needed. The government would fund these operations using public tax dollars*. They were then presented with the list of 49 unique words identified in stage 2, administered randomly across two pages and instructed: *In the context of determining where a new vertiport should be LOCATED, please review each term or phrase below and determine whether it is relevant or not relevant to determining where a new vertiport should be LOCATED*. Participants selected one of these response options: Relevant, Not Relevant, or Don't Know. Lastly, they provided demographics, were debriefed, compensated, and dismissed.

Results

An a priori cutoff determination was established that at least 75% or more of the participants had to agree that a word was relevant to vertiport location to be included in the following stage of the scale development. After completion of the data analysis, 20 words met these criteria. These words are listed in Table 6.

Table 6

Words and Phrases receiving 75% Relevance or Higher to Advance to Stage 3

Accessible	Beneficial	Clear area	Clear directions	Convenient
Economical	Emergency-prepared	Follows safety precautions	Functional	Good location
Location	Monitored by air traffic control	Practical	Reachable	Safe
Secure	Serviceable	Viable	Weather protected	Well maintained

Stage 3: Likert-scale Paring

The purpose of stage 3 was to create a more sensitive measure of each item's relevancy to the concept of "vertiport location." The participants read through the 20 items identified in stage 2 and provided a rating on a scale from 'Not at all related to location' (0) to 'Extremely related to location' (4). The a priori determination was made that an item must obtain a score of 3.0 or higher to be selected for inclusion in the following stage.

Participants

Two hundred and fifty-two (120 males; 129 females; 3 no response) participants completed the study, and they were selected via a convenience sample from MTurk. The average age of participants was 40.29 (*SD* = 11.71) years old, and 80% reported as Caucasian, 9% African descent, 5% Asian descent, 5% Hispanic descent, and 1% Other.

Procedure, Materials, and Stimuli

Participants began by indicating their agreement with the terms of the electronic consent form. They were then provided with the same instructions and descriptions as in the stage 2 instrument; however, in this stage, participants responded to the 20 terms on a rating scale from 'Not at all related to location' (0) to 'Extremely related to location' (4). Lastly, they provided demographics, were debriefed, compensated, and dismissed.

Results

The findings indicated that nine words met the a priori baseline averaging 3 or higher. Two words, good location and location, were merged to be used in the scale as good location. Also, the phrase 'monitored by air traffic control' was determined that it could be confusing as participants may or may not be aware of this aspect given various scenarios, so it was not included in the final scale. The final scale for vertiport location consisted of the following 7 items: convenient, good location, reachable, accessible, secure, safe, and clear area. These terms were converted into statements and used as the scale for factor analysis and sensitivity testing in stage 4.

Stage 4: Factor Analysis and Sensitivity Testing

In stage 4, the vertiport location scale, consisting of the seven items from stage 3, was tested for validity, consistency, reliability, and sensitivity. The participants were presented with figures of four possible vertiport location sites, and they used the scale to respond to these scenarios.

Participants

Five hundred and fourteen individuals completed the study as part of stage 4. Two cases were removed due to failure to agree to the terms of consent, and two additional cases were removed due to failure to complete an entire scale (seven items) on the instrument. The final usable dataset consisted of 225 males, 280 females, 3 no response, 2 nonbinaries/other. The average age of participants was 40.78 (*SD* = 12.38) years old, and 73% reported as Caucasian, 13% African descent, 8% Asian descent, 4% Hispanic descent, and 2% Other. As with the earlier stages, participants were recruited from MTurk, and those participants who completed in the earlier stages were excluded from participating in stage 4.

Procedure, Materials, and Stimuli

Participants were first presented with a consent form. Following this, they were presented with the following instructions, "*Instructions - You will be presented with some figures and asked to rate how suitable those locations are for the use of a vertiport for urban air mobility. The data collection process is anonymous and your responses will remain confidential*" and brief information on urban air mobility, "*In this case, Urban Air Mobility (UAM) refers to the use of autonomous air vehicles (with a remote human pilot or operator) to deliver people or goods from one location to another, when ground transportation is less practical or feasible. Some examples include air taxis for people or drones to deliver packages. These are typically initially expensive to operate due to the costs of the technology and resources needed. The government would fund these operations using public tax dollars.*" Participants were then presented four figures, shown in Appendix B, depicting four different proposed locations for the vertiport and asked to respond to the proposed seven-items of the vertiport location scale anchored from strongly disagree (-2) to strongly agree (2). The four locations and items on each scale were all randomized in presentation to avoid order effects. Participants then provided demographic information, were debriefed, and dismissed.

Results For Factor Analysis

For each of the four location scenarios, a principal components analysis using a varimax rotation was used to determine the factor structure of the proposed scale. Table 7 depicts the results for each location, along with the metrics to assess validity, consistency, and reliability. Across all scenarios, the scale had high Kaiser-Meyer-Olkin (KMO) values and significant *p*-values for Barlett's sphericity test, suggesting the data's factorizability. Each scale loaded onto 1 factor and explained more than 50% of the variance in the data. Cronbach's alpha values were above the minimum suggested thresholds of 0.7, indicated high internal consistency across the items, and finally, Guttman's split-half test for reliability produced values above .8. The scree plots for each analysis can be found in Appendix C.

Table 7

Validity, Consistency, and Reliability Metrics for the Vertiport Location Scale

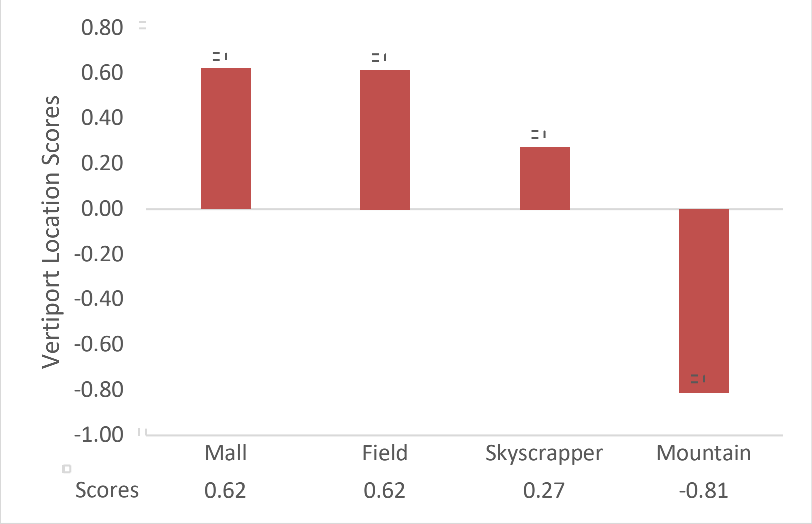
	Mall	Field	Skyscraper	Mountain
KMO Value	.910	.822	.887	.894
Bartlett's	< .001	< .001	< .001	< .001
Variance Explained	66.29%	54.02%	64.50%	67.40%
Number of Factors (Validity)	1	1	1	1
Cronbach's Alpha (Consistency)	.914	.856	.907	.914
Guttman's Split-Half (Reliability)	.905	.860	.924	.890

Results for Sensitivity

Normality was assessed through a visual assessment of histograms, and for all conditions appeared to satisfy this assumption. Skewness and kurtosis values were also within acceptable ranges. Mauchly's Test of Sphericity was violated with the data ($p < .001$), and therefore, a Greenhouse-Geisser correction was applied to interpret the results. A one-way within-participants ANOVA was conducted to analyze the data between the Type of Vertiport Location. A significant main effect was found based on the Type of Vertiport Location, $F(2.69, 1370.04) = 357.70$, $p < .001$, *partial eta squared* = .413. A post hoc comparison with a Bonferroni adjustment indicated that there were no significant differences between the mall and field locations, but there was a significant decrease in location scores for the skyscraper and another significant decrease in scores for the mountain location. These results are summarized in Figure 10.

Figure 10

The scores from the vertiport location scale by type of vertiport location.



Study 2 – Discussion

The purpose of study 2 was to create a vertiport usability scale. This scale was conducted using a multi-stage process. These multiple stages allowed the users to generate and rate the ideal terms to assess vertiport location. After using the first stages to generate, rate, and parse the list of descriptive terms, the later stages assessed the scale through factor analysis and sensitivity to demonstrate the detection of variance among several different types of locations. The final scale was shown to be a unidimensional construct consisting of seven items.

Study 3 – Methods

The purpose of Study 3 was to determine the preferred locations for the placement of vertiports in response to natural disasters. Three conditions were established as scenarios in which vertiports would be necessary: a temporary disaster location, a permanent disaster location, and lastly, we produced a condition to assess permanent consumer locations for vertiports. Study 3 was conducted in three stages. In stage 1, locations were solicited from participants to help generate the top proposed locations for vertiports. In stage 2, participants rated their preference for these locations to pare down the list, and in stage 3, participants used the Vertiport Usability Scale developed in Study 2 to assess and compare the conditions. Due to the locations likely varying based on the type of scenario, comparisons were not made across the scenarios but rather within each scenario.

Stage 1: Location Generation

Participants

Fifty-one individuals completed stage 1 and consisted of 28 males and 23 females. The average age of participants was 40.92 (*SD* = 14.01) years old. Participants self-reported their ethnicities as 76% Caucasian, 6% African descent, 8% Asian descent, 4% Hispanic descent, and 6% Other. As in studies 1 and 2, Amazon's Mechanical Turk was used for participant selection. Eligibility criteria were set to only residents of the United States, at least 500 prior approved tasks, and 98% or better approval rating.

Procedure, Materials, and Stimuli

Participants were first presented with a digital consent form. Following this, they were presented with the following instructions, *"You will be presented with some scenarios and you will then be asked some questions about them. Following that, you will be asked some demographics questions. The data collection process is anonymous and your responses will remain confidential."* For context, a brief description on urban air mobility and vertiports was provided, *"A vertiport is the proposed takeoff and landing site for urban air mobility (UAM) aircraft. The UAM aircraft can be either remotely operated or a fully automated aerial vehicle, such as an air taxi."* Participants then each reviewed three scenarios and were asked to provide 5 words or phrases to identify locations for vertiports. In the temporary disaster location they read, "*In the context of LOCATION related to where a vertiport should be built, what are some of the LOCATIONS you can think of to place a temporary vertiport in response to a disaster? This location will be temporary until the disaster response is completed, primarily for first responder use (e.g., a closed interstate or football field). Each answer should include only a one word or one sentence phrase."* In the permanent disaster location they read, "*In the context of LOCATION related to where a vertiport should be built, what are some of the LOCATIONS you can think of to place a* *permanent vertiport in response to a disaster? This location will be permanent, similar to a fire or police station, primarily for first responder use (e.g., on top of a parking garage or open field). Each answer should include only a one word or one sentence phrase."* In the permanent consumer location, they read, *"In the context of LOCATION related to where a vertiport should be built, what are some of the LOCATIONS you can think of to place a permanent vertiport for use in consumer transportation? This location will be permanent, similar to a heliport or airport, and primarily for consumer use (e.g., near a shopping center or on top of a skyscraper). Each answer should include only a one word or one sentence phrase."* Lastly, participants were asked for demographic information, were debriefed, and dismissed.

Results

The compiled list of words, after removing duplicates, resulted in 30 possible locations temporary disaster locations, 22 for permanent disaster locations, and 23 for permanent consumer locations. These words were used in stage 2 where participants were asked to rate their support for each location. The complete list of words is presented in Appendix D.

Stage 2: Location Rating

Participants

One hundred and two participants completed stage 2. The average age was 40.51 (*SD* = 12.49) years old, and 74% reported as Caucasian, 9% African descent, 8% Asian descent, 7% Hispanic descent, and 2% Other. Participants were recruited using MTurk and the same eligibility criteria as in stage 1. Participants who completed stage 1 were excluded from participating in stage 2.

Procedure, Materials, and Stimuli

Participants began with a digital consent form, followed by the same instructions and UAM/vertiport introduction in stage 1. For each location, they were presented with the list of words in Appendix D in a randomized format and asked to state their level of agreement from Strongly Disagree (1) to Strongly Agree (5), with a neutral option of Neither disagree nor agree in support of the location being used as a vertiport in that scenario. For the temporary disaster location, they were presented with, *"In response to a natural disaster* *such as a hurricane, tornado, or wildfire, the proposed location will be a temporary location establishing a base of operations for UAM operations to support first responders until the disaster response is completed. This could include areas such as a closed interstate, local military base, or a football field."* For permanent disaster location, *"In response to a natural disaster, such as a hurricane, tornado, or wildfire, the proposed location will be a PERMANANT location establishing a base of operations for UAM operations to support first responders, much like a fire department or police station. This could include areas such as the top of a police station or a local military base."* For permanent consumer location, "*To facilitate the use of UAM, the proposed location would be a PERMANANT location establishing a hub for consumers, similar to a heliport or airport, and primarily for consumer use. This could include areas such as near the local airport or at a mall."* Participants then answered demographics, were debriefed, and dismissed.

Results

The average score for each location was calculated, and the top 5 locations were assessed. Data were examined with participants who occasionally missed some items and with only participants who only provided answers to all questions. For the temporary disaster location, there were no changes to the top five words. For permanent disaster location and permanent consumer location, there was no change to 4 of the 5 top locations. The additional item from these two scenarios was included in stage 3, resulting in the top 5 locations for temporary disaster location and the top 6 preferred locations for the permanent disaster and permanent consumer locations. The top locations are shown in Table 8.

Table 8

The List of Top-Rated Locations from Stage 2

Temporary Disaster	Permanent Disaster	Permanent Consumer
Professional Sports Stadium	Top of police station	Near Airport
Large parking lot	Areas with open fields	Hospitals
In an open field	Federally owned land	Shopping Malls
Military base	Top of Firehouse	Near Sport Stadiums
Local Fair Ground	At the local airport	Parking garages
--	Military bases/airfields	Open areas (fields)

Stage 3: Location Comparison

Participants

One thousand and twenty-five (483 males, 534 females, 2 nonbinaries, 6 no response) participants completed stage 3. The average age was 41.93 (*SD* = 12.94) years old, and 77% reported as Caucasian, 8% African descent, 6% Asian descent, 6% Hispanic descent, 2% Other, and 1% Indian descent. Participants were recruited using MTurk and the same eligibility criteria as in stages 1 and 2. Participants who completed stage 1 or stage 2 were excluded from stage 3.

Procedure, Materials, and Stimuli

Participants began by digitally agreeing to the consent form. They were then presented with the same instructions and UAM/vertiport introduction in the earlier stages of study 3. Each participant was then randomly assigned to one of the 3 scenarios where they read the scenario description as in stage 2. Participants were then presented with a randomized order of the locations listed in Table 8. For each location, they responded with the vertiport usability scale to assess the use of that location in the scenario. After rating each location, participants completed demographics, were debriefed, and dismissed.

Results

Initial data analysis revealed that 4 cases had excessive missing data (defined as a participant missing one entire scale or more), and 1 participant failed to agree to the consent form terms. Three hundred and eighty-six participants were randomly assigned to the temporary disaster location, 315 to the permanent disaster location, and 319 to the permanent consumer location. A review of each condition identified 23 unengaged responses in the temporary disaster location, 13 in the permanent disaster location, and 11 in the permanent consumer location. These values were determined by having standard deviations of 0 across all scale responses. In other words, these participants provided the exact same response for each scale item response. After removal, there were 363 usable responses within the temporary disaster location, 302 in the permanent disaster location, and 308 in the permanent consumer location. Due to various locations for each specific condition, a comparison between conditions was not conducted, only an examination within each of the three conditions.

Temporary Disaster Location. A one-way within-participants ANOVA was conducted on the five locations presented in this scenario. The statistical assumptions were assessed and determined to be met. Normality was reviewed by assessing kurtosis and skewness values and a visual inspection of histograms. Mauchly's Test of Sphericity indicated a violation of this assumption ($p < .05$), and therefore, a Greenhouse-Geisser correction was applied to the reporting of the ANOVA statistics. The results of the ANOVA indicated a significant difference based on the type of location, $F(3.59, 1299.37) = 10.47$, $p < .001$, *partial eta squared* = .028, indicating that there was a difference in ratings based on the type of location. An examination of the post hoc tests was completed using the Bonferroni correction. In general, open fields, military bases, and fairgrounds were the preferred locations for temporary vertiports in response to natural disasters. Figure 11 shows the average ratings by condition, while Figure 12 shows the mean difference between locations.

Figure 11

The Average Results by Type of Location for Temporary Disaster Location

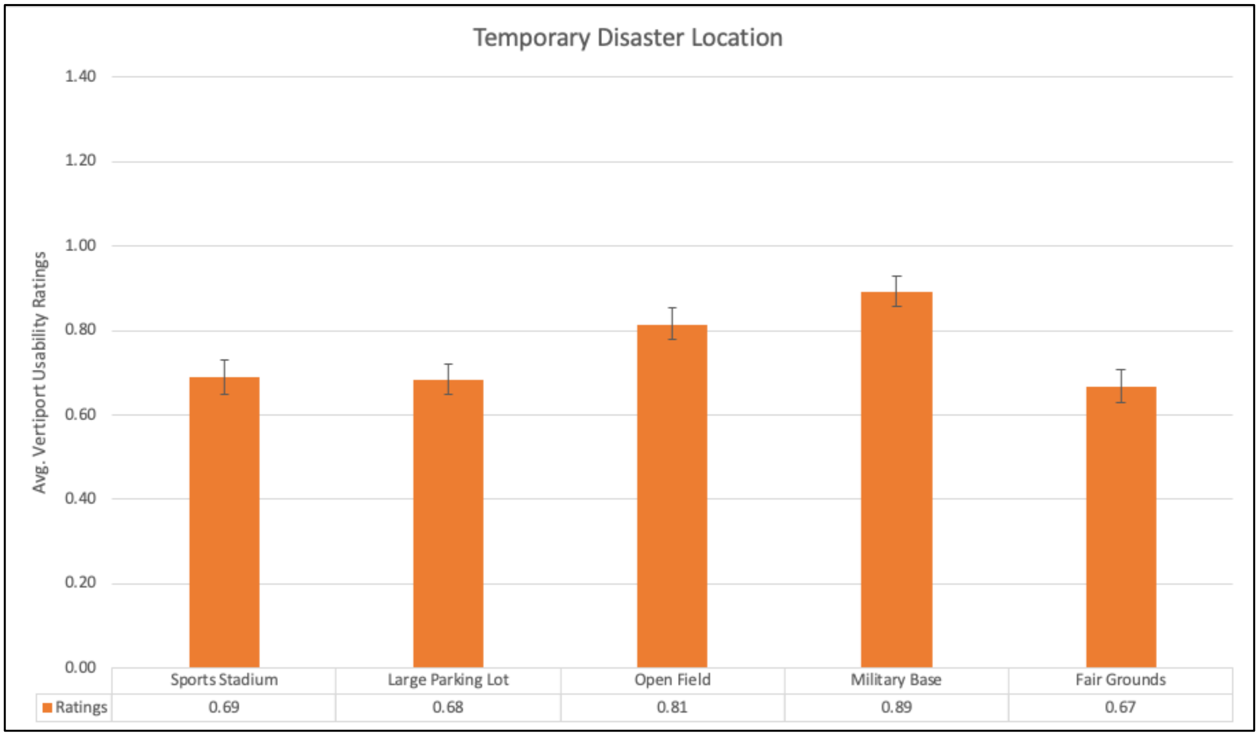
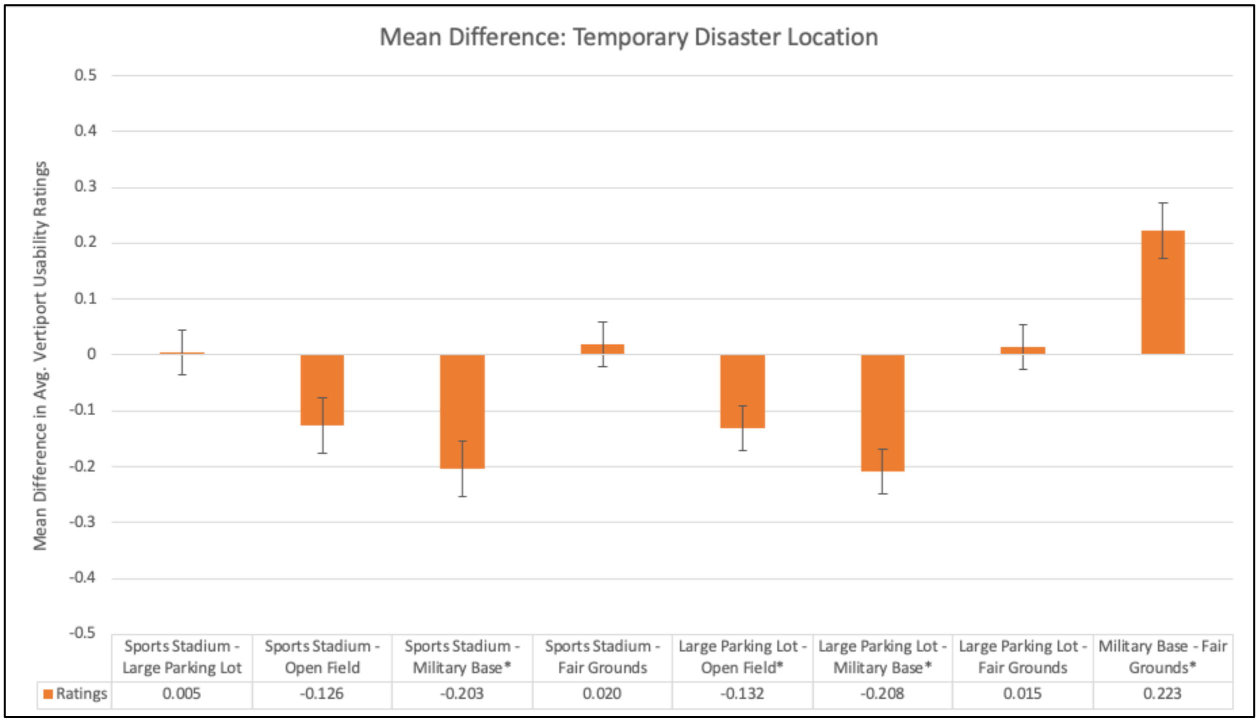


Figure 12

The Mean Difference in Scores Across Locations for Temporary Location Scenario



Note: An * indicates a significant difference using the Bonferroni correction.

Permanent Disaster Location. A one-way within-participants ANOVA was conducted on the six locations presented in this scenario. The statistical assumptions were assessed and determined to be met. Normality was reviewed by assessing kurtosis and skewness values and a visual inspection of histograms. Mauchly's Test of Sphericity indicated a violation of this assumption ($p < .05$), and therefore, a Greenhouse-Geisser correction was applied to the reporting of the ANOVA statistics. The results of the ANOVA indicated a significant difference based on the type of location, $F(3.99, 1201.03) = 11.46$, $p < .001$, *partial eta squared* = .037, indicating that there was a difference in ratings based on the type of location. An examination of the post hoc tests was completed using the Bonferroni correction. In general, military bases and airports were the preferred locations for permanent vertiports in response to natural disasters. Figure 13 shows the average ratings by condition, while Figure 14 shows the mean difference between locations.

Figure 13

The Average Results by Type of Location for Permanent Disaster Location

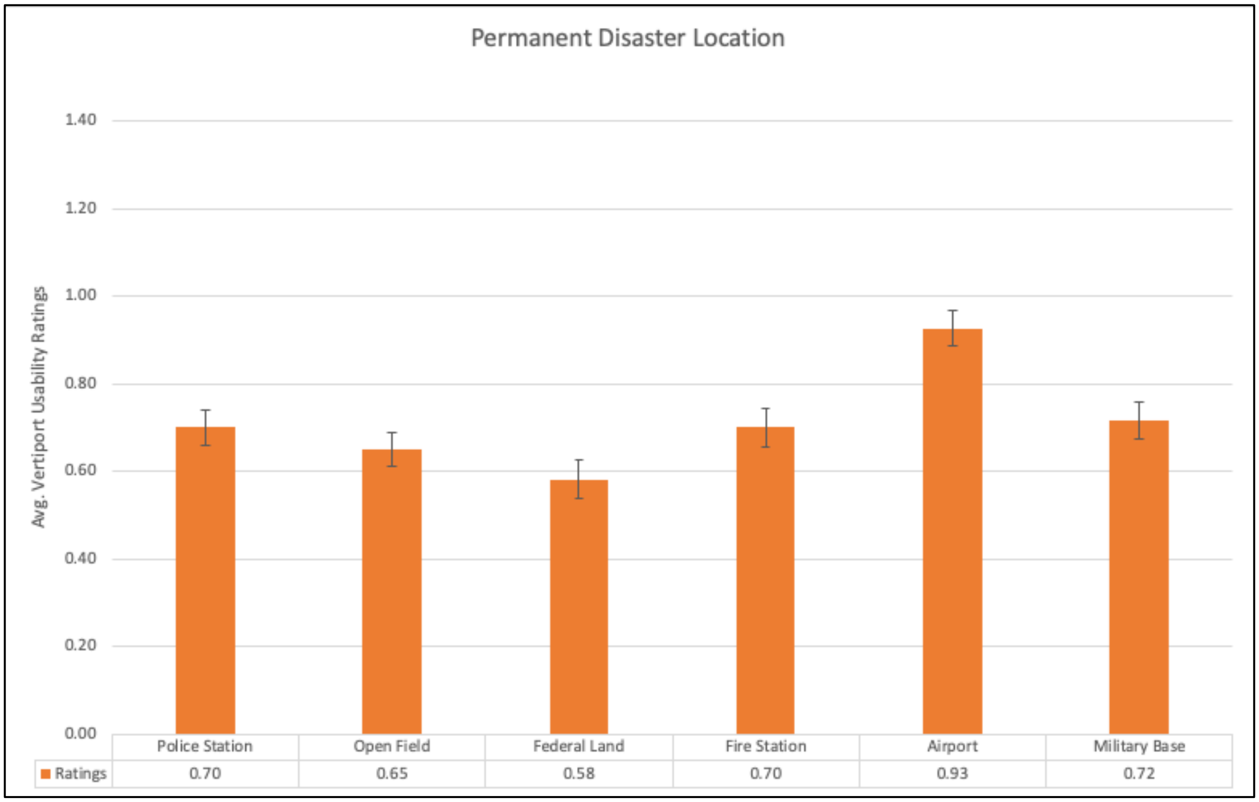
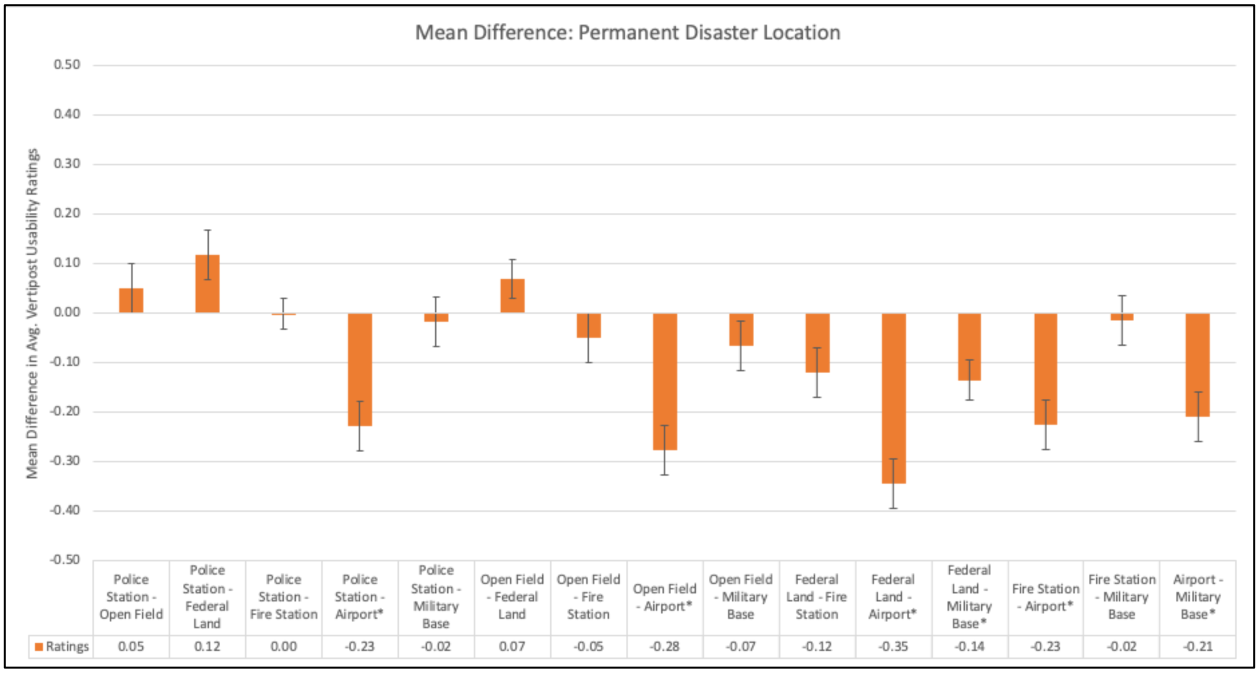


Figure 14

The Mean Difference in Scores Across Locations within the Permanent Location Scenario



Note: An * indicates a significant difference using the Bonferroni correction.

Permanent Consumer Location. A one-way within-participants ANOVA was conducted on the six locations presented in this scenario. The statistical assumptions were assessed and determined to be met. Normality was reviewed through the assessment of kurtosis and skewness values and a visual inspection of histograms. Mauchly's Test of Sphericity indicated a violation of this assumption ($p < .05$), and therefore, a Greenhouse-Geisser correction was applied to the reporting of the ANOVA statistics. The results of the ANOVA indicated a significant difference based on the type of location, $F(4.34, 1332.27) = 29.75$, $p < .001$, *partial eta squared* = .088, indicating that there was a difference in ratings based on the type of location. An examination of the post hoc tests was completed using the Bonferroni correction. In general, open fields, hospitals, and airports were the preferred locations for permanent consumer vertiports. Figure 15 shows the average ratings by condition, while Figure 16 shows the mean difference between locations.

Figure 15

The Average Results by Type of Location for Permanent Consumer Location

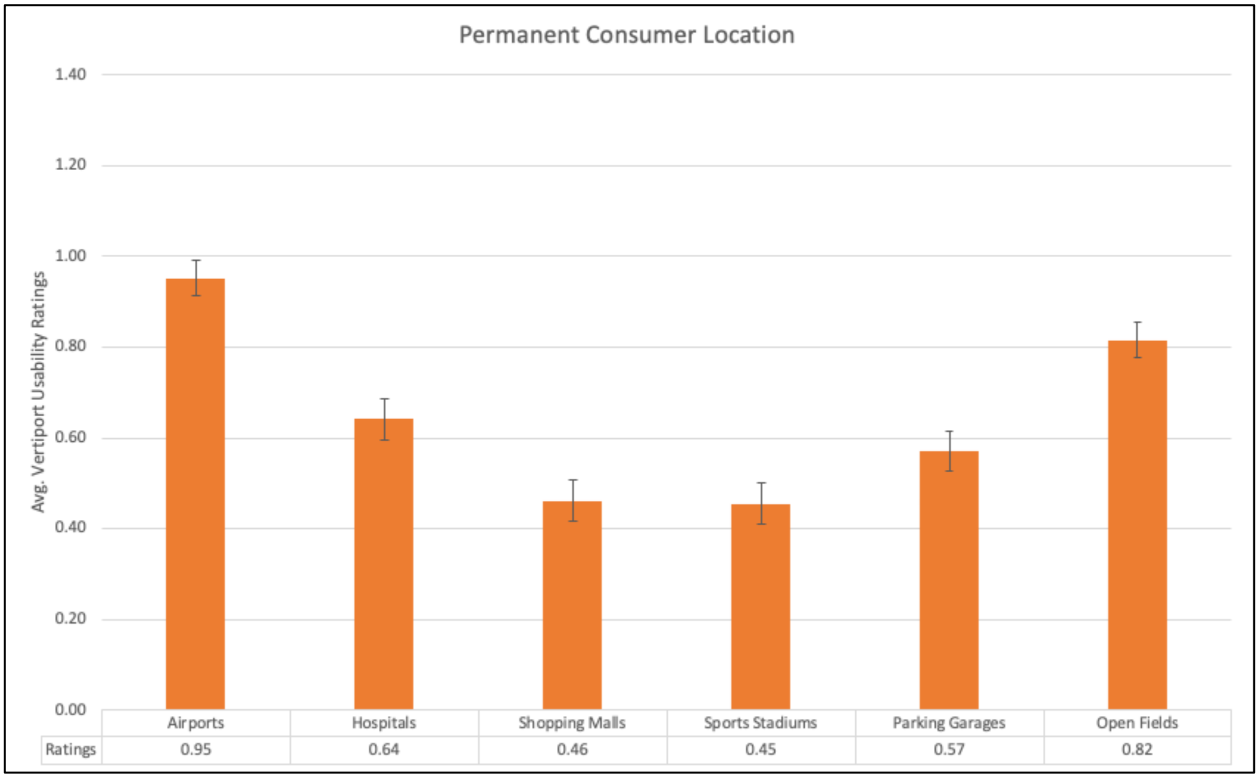
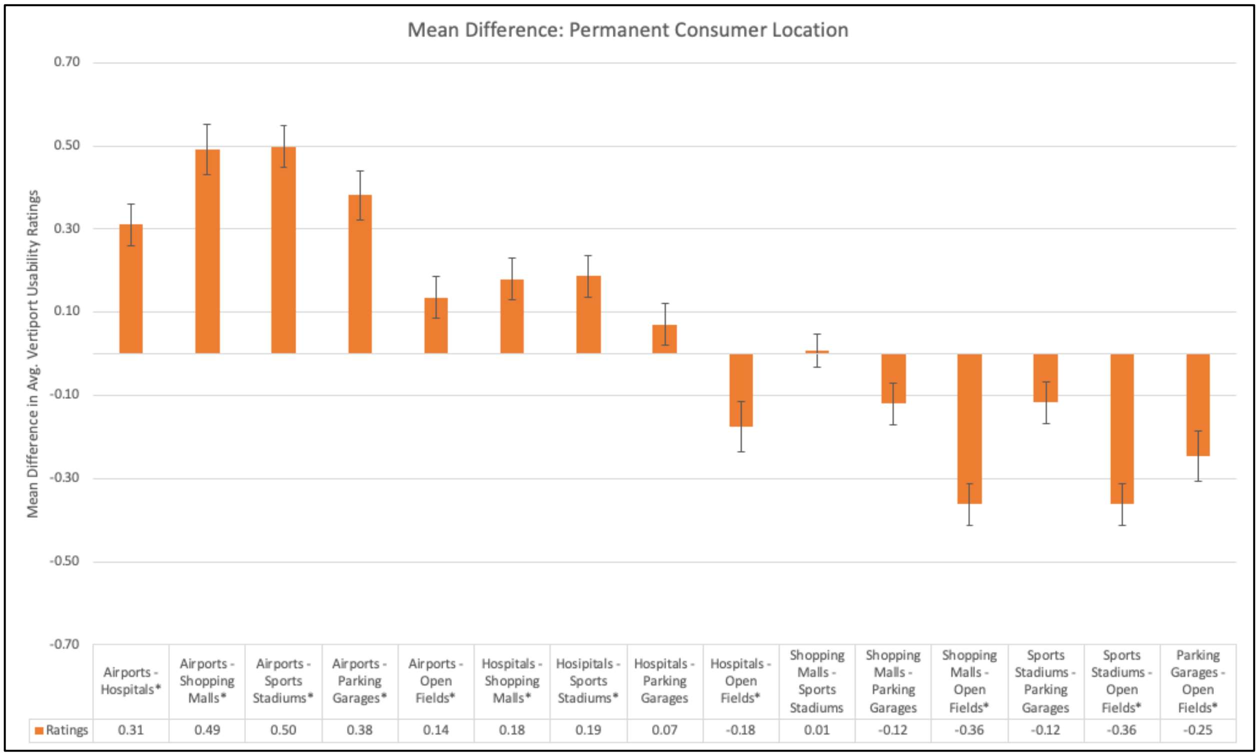


Figure 16

The Mean Difference in Scores Across Locations within the Permanent Consumer Scenario



Note: An * indicates a significant difference using the Bonferroni correction.

Study 3 – Discussion

The purpose of study 3 was to identify the preferred locations for vertiports across three scenarios. Using a multi-stage process, participants helped to generate possible locations, rate the preferred locations, and compare locations within each scenario. The three scenarios assessed were temporary disaster location, permanent disaster location, and permanent consumer location. The findings demonstrate the preferred locations across these three scenarios for the location of vertiports in response to natural disasters and permanent consumer usage.

Study 4 – Introduction

The purpose of Study 4 was to collect interview data to assess participants' perspectives on the usability of urban air mobility in response to natural disasters. The study was conducted in three stages. Stage 1 recruited participants through an online advertisement at Embry-Riddle Aeronautical University. Stage 2 used a purposeful sampling technique to select individuals to interview with a predetermined script. In Stage 3, the interviews were analyzed to identify emerging trends from participants and similarities and differences from the first three quantitative studies.

Author Biases

Due to the subjective nature of qualitative research and its interpretation, it is essential to identify any possible biases the researchers may have for the current study. The author who wrote this section (SC) is a professor at Embry-Riddle Aeronautical University. The researcher has extensive knowledge of UAM and the types of natural disasters covered in the report. Additionally, the researcher is receiving funding to conduct the research. The author (SC) conducted the purposeful sampling of Stage 2 of the current study. The researcher completed this purposeful sampling to reach a broad base of genders, ethnicities, pilot status, and college majors to ensure a wide variety of responses. The same researcher also conducted all interviews after completing the purposeful sampling. The study's protocol was designed and written by a different researcher (SW) to avoid any possible biases introduced before the interview process. All interviews were conducted online via Zoom without cameras to remove potential biases from individuals' perceptions based on appearance.

Stage 1: Participant Recruitment

Participants

Forty-five individuals completed Stage 1 and included 31 males and 14 females. The average age of participants was 19.11 (*SD* = 1.92) years old. Participants self-reported ethnicities as 69% Caucasian, 18% Asian, 9% Hispanic, and 4% other. Participants were recruited via a CANVAS announcement at Embry-Riddle Aeronautical University students in an introductory level psychology course. This course was selected due to the wide range of students required to take this course. This allowed researchers to have a wider group of participants for the purposive sampling in Stage 2. Participants were offered extra credit from their course instructor to complete the interview.

Materials, Stimuli, and Procedure

Participants were first presented with an announcement in their online course via CANVAS. The announcement read, "*Dear Students, you are being requested to participate* *in a research study to examine your perceptions on the use of urban air mobility and vertiports in response to natural disasters. This study is expected to take approximately 45-60 minutes of your time. For completion of the study, you may receive points of extra credit offered by your course instructor. Participation in this study is voluntary. Prior to beginning the study, you will be briefed and asked to sign an informed consent document. You may choose to opt out of the study at any time. Please click the link below.*" Participants then clicked on the link, which brought them to a Google Forms ® page where they were presented with an informed consent form. After completing the informed consent form, participants were asked to complete several demographic questions and provide contact information.

Results

Recruitment efforts led to 45 participants volunteering to take part in the interview. Table 9 provides descriptive and demographic information for the participants.

Table 9

Descriptive and Demographic Statistics of Study Participants

	Variable	*N*	*M*	*SD*
	Age	45	19.11	1.92
Gender	Male	31		
	Female	14		
Ethnicity	Asian	8		
	Caucasian	31		
	Hispanic	4		
	Other	2		
Pilot	Yes	22		
	No	23		
College	Aviation	24		
	Engineering	10		
	Arts and Sciences	10		
	Business	1		

Stage 2: Selection and Interviews

Participants

The average age of the participants was 19.7 (*SD* = 1.88) years old. There were four males and six females interviewed. The self-reported ethnicities of the individuals were 60% Caucasian, 20% Asian, 10% Hispanic, and 10% other.

Materials, Stimuli, and Procedure

Purposive sampling was used to identify participants based upon the researchers' judgment. The purposive sampling technique focuses on characteristics in a set of the population that is of interest to assist the researchers in answering their questions. Therefore, the sample may not represent the population but is tailored towards the researcher's needs and brought in a wide variety of individuals from different genders, races, and educational backgrounds.

Participants were emailed and asked if they would like to participate in the interview study for which they volunteered. Those who responded were asked to complete a new informed consent form before the interview. The date and time were scheduled via Zoom ® at the participant's convenience. Once the interview started, the researcher followed a script to ensure all participants received the same questions and treatment. This script included the pre-interview script that was not recorded and the interview script which was recorded. Participants reviewed the informed consent form with the researcher and were then given a series of instructions and definitions for the interview. When there were no other questions, the interview began. The researcher had nine pre-determined questions to ask each participant to gauge perceptions about UAM and its usability in response to natural disasters. The full Interview Protocol can be found in Appendix E. Once complete with the questions, participants were asked if there were any other questions, given a short out brief, and dismissed from the study.

Results

Recruitment efforts led to 10 participants being selected for the interview. Ten interviews were completed, recorded, and transcribed via the researchers' audio recording into a Microsoft Word ® file. A detailed list of participants can be found in Table 10. The names and other identifying demographics have been removed to ensure the anonymity of the participants.

Table 10

Descriptive Listing of Interview Participants

Participant ID	Gender	Ethnicity	Age	Major	Pilot
P1	Male	Asian	21	Aeronautical Science	Yes
P2	Female	Caucasian	22	Human Factors	No
P3	Female	Hispanic	19	Aeronautical Science	Yes
P4	Female	Caucasian	18	Homeland Security	No
P5	Male	Caucasian	21	Unmanned Aerial Systems	No
P6	Male	Other	19	Aviation Maintenance Science	No
P7	Female	Caucasian	18	Communications	No
P8	Male	Caucasian	18	Business Administration	No
P9	Female	Asian	23	Aeronautical Science	Yes
P10	Female	Caucasian	18	Space Physics	No

Stage 3: Data Analysis

Data Exploration and Preparation

The researchers transcribed the interviews from Stage 2 from the recorded interview and then put them into a Microsoft Word ® document. The ten resultant transcriptions were then loaded into NVivo ® for data analysis. Reports were saved based upon their participant ID for easier identification during analysis.

Node Hierarchy

Due to the structured nature of the interview, the researchers were able to have pre-identified parent themes for the analysis. All interviews were analyzed using the parent themes, which led to the discovery of child nodes for the analysis. Table 11 shows the node hierarchy and number of identified child nodes for the analysis. The researchers set a requirement that for a child node to be valid, it must be present in at least two interviews.

Table 11

Node Hierarchy and Number of References

Question Number*	Parent Node	Number of Identified Child Nodes	Number of coded references
1, 9	General Thoughts	9	21
5	General Vertiport Locations	7	20
3	Operations	3	13
8	Permanent Consumer Locations	7	18
7	Permanent Vertiport Location	8	30
6	Temporary Vertiport Locations	7	20
4	Types of Missions	5	32
2	Types of Natural Disasters	7	35

Note: *Question number relates to the order questions given in the interview (see Appendix E).

Coding Process

Coding was conducted using an iterative and incremental process as themes were identified in the text about the parent node. Two researchers conducted the coding analysis to ensure that all items were accurately represented in the child node. As mentioned before, each child node required two separate instances in the interviews to become a child node, and both researchers had to identify the instances.

Study 4 – Results

Demographic and Descriptive Statistics

All interview participants' identifying information was removed from the reports as described in the study protocol (see Appendix E). Table 12 provides descriptive statistics of the 10 interviews, including total codes and references per individual contributor.

Table 12

Interview Reports Descriptive Statistics

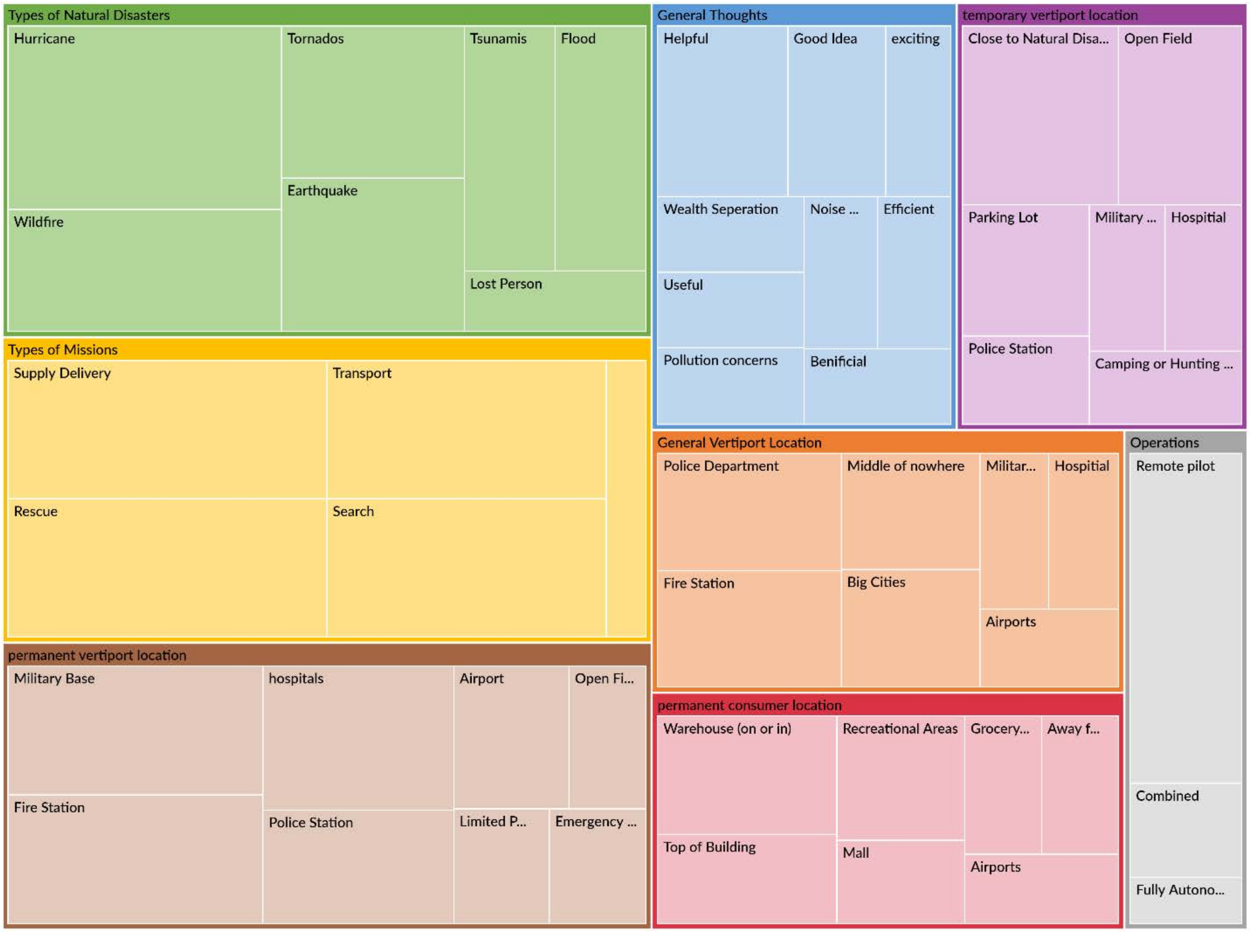
ID	File Name	Date of Interview	Starting Codes	Starting References	Final Codes	Final References
P1	1072116SRC	October 7, 2021	52	107	45	100
P2	10112110SRC	October 11, 2021	32	38	30	36
P3	10132111SRC	October 13, 2021	48	98	46	96
P4	10182114SRC	October 18, 2021	37	49	32	44
P5	10182117SRC	October 18, 2021	40	66	36	62
P6	10202111SRC	October 20, 2021	41	78	39	76
P7	10182111SRC	October 18, 2021	41	60	38	57
P8	10262111SRC	October 26, 2021	42	73	35	66
P9	10222114SRC	October 22, 2021	43	70	37	62
P10	10262116SRC	October 26, 2021	33	54	31	52

Note: Starting numbers represent all coded items with final numbers representing all that met the criteria to remain in the analysis.

No data was missing from any of the interviews. A coding composition chart was generated in NVivo to explore the themes in the interviews. The diagram is shown in Figure 17.

Figure 17

Thematic Analysis Coding Composition



Emerging Themes

The study produced three main occurring themes present amongst the interviews. The first theme and the one that did not fully support the findings from Study 1 dealt with human involvement in UAM operations. The second theme involved the type of natural disasters and missions. The final theme that emerged involved the setup and deployment of the UAM vehicles.

Theme 1 – Human Involvement in UAM Operations

An interesting finding from the interviews is that most participants ($n = 7$) wanted a remote pilot for all UAM operations in response to natural disasters. Two participants suggested a combination of remotely piloted and fully autonomous, with only 1 participant identifying a desire for a fully autonomous system. The results from Study 1 revealed that participants did not have any difference in willingness to support the use of UAM based on whether the vehicle was remotely or autonomously operated. However, in the qualitative study, the participants indicated a preference for remotely piloted. It would be interesting to conduct a follow-on study to determine if, given a choice, participants would choose remotely piloted over fully autonomous vehicles in the given scenario. Table 13 contains quotes from participants on remote operations over automated operations.

Table 13

Participant Responses for UAM Operations

ID	Quote
P4	*"…I would do remote pilot. I have a little bit more trust over a human, even though they're not there, than autonomous."*
P7	*"…A remote pilot, I think that, with our technology today, this could be more beneficial to humans and would make humans feel more safer in the aircraft knowing that there is someone behind it."*
P9	*"I would say, remote pilot because we, despite autonomous is actually not bad, but… having remote is better because, if anything goes wrong, you know there's someone you can trust that knows how to function the UAM."*

Theme 2 – Scenarios for Usage

The second theme emerging from the interviews was the scenarios for usage. This included both the type of natural disaster and the type of mission. The results of this analysis show there were four types of natural disasters identified the most: hurricanes, wildfires, tornados, and earthquakes. Tsunamis and flooding can be grouped as they both are flood-based threats. The identification of these natural disasters is the five categories used in Study 1. The only addition that was not identified in Study 1 was the *lost person*. While a lost person is not a natural disaster, it was recognized by two participants in this category as a type of mission where UAM would be beneficial, so it was included in the summary. However, it more closely resembles a mission type (search and rescue). The missions were evenly distributed between supply delivery, transport, search, and rescue, with 2 participants identifying surveillance. These represent most of the missions used in Study 1, apart from news delivery. However, a single participant did identify communication as a mission type.

Theme 3 – Setup and Deployment of Vehicles

The final emerging theme was surrounding the setup and deployment of UAM vehicles. The findings from the interviews strongly mirrored the results of Study 3 for general, temporary, and permanent locations. One general location from the interviews that emerged not identified in Study 3 was an Emergency Operation Center (EOC). This would be ideal as EOCs are the central hub designed to support emergency response. Interview participants identified two other items regarding temporary locations but were not present in Study 3. Those items are *close to the natural disaster* and *camping or hunting grounds*. Table 14 shows participant responses for the most identified theme in temporary locations, close to a natural disaster. It could be that proximity was an afterthought to Study 3 due to the question's wording presented to respondents. The open-ended interview questions are designed to be more engaging and allow for deeper exploration of the questions, which could be why these themes emerged.

Table 14

Participant Responses for Temporary Locations Close to Natural Disaster

ID	Quote
P1	*"… relatively close to the disastrous event."*
P2	*"…I would think that having a temporary vertiport near the natural disaster, probably would be helpful."*
P3	*"Okay… um… areas that would be mostly affected like if-if a certain city was the one that got affected, maybe."*
P4	*"For a temporary one, I would do wherever the disaster is so… but I wouldn't do it a few towns over from-for a. Certain range away from the disaster…"*
P7	*"Maybe in areas that…Where it most needs helping these disasters, I would say pretty close."*

Additional Notable Comments from Participants

There were multiple commonalities between the general thoughts of the participants in the current study. Common general positive thoughts include efficiency, benefits, excitement, usefulness, and helpfulness. Common general negative thoughts include concern for noise pollution and environmental pollution and the concern that this technology may only be available to the wealthy. Table 15 provides quotes from participants on their general thoughts of using UAM in response to natural disasters.

Table 15

Participant Responses for General Thoughts of Using UAM in Response to Natural Disasters

ID	Quote
P4	*"It's a great use of resources to help when it's really needed."*
P7	*"I do think it would be very beneficial, knowing that in emergency situations, these vertiports and aircraft services can be right there for humans in easy places to get to even alongside other…emergency services."*
P5	*"With the urban air ability, I think it's-I think it's a good idea and a good concept, I like it being that we can-we can get to more remote areas if needed."*
P2	*"I'm-the only thing that I'm hesitant on or with, I would say, as I'm with which I'm hesitant is… the air pollution or the noise pollution…"*
P9	*"And I think vertiports are usually for those that are on the higher luxury side as compared to like the moderate side of people so it's not really effective for… Those that kind of already has covered those can afford it..."*

Study 4 – Discussion

The findings from Study 4 offer unique insights to complement the quantitative findings from Studies 1-3. In general, the themes and comments from Study 4 are aligned with the findings from the earlier studies. The most noticeable divergence is related to the type of operation of the UAM. In Study 1, participants indicated no significant difference in whether the UAM was remotely operated by a human or fully autonomous. However, participants in the qualitative study strongly indicated a preference for remote operation by a human pilot. It is possible that this difference between studies was somewhat related to the designs of the studies. The open-ended nature of the interview questions allows for the participant's thoughts to be shared without much prompt or influence by the researchers. In the quantitative studies, participants were described the scenarios they were asked to rate. These data provide very interesting findings, and the type of operation remains a variable that warrants further investigation.

FINDINGS, CONCLUSIONS, RECOMMENDATIONS

The purpose of the current studies was to assess and understand participants' willingness to support urban air mobility in response to natural disasters. This project fits within the Center for Advanced Transportation Mobility's Theme 2 on optimizing mobility in emergency situations. Through conducting four studies, perceptions were gathered on the use of UAM in response to natural disasters from quantitative and qualitative perspectives. Study 1 conducted a factorial experiment to assess participants' willingness to support the use of UAM based on the type of operations of the UAM, the type of natural disaster, and the type of mission being completed. Study 2 created a valid instrument to measure vertiport usability. Through several stages, a scale was developed that can be used in future research of proposed and current locations of vertiports. This scale was used in Study 3, where the researchers determined the top-rated sites for vertiports under three conditions: temporary disaster locations, permanent disaster locations, and permanent consumer locations. Finally, in Study 4, a qualitative investigation provided an alternate series of data to understand participants' willingness to support UAM in response to natural disasters. These data were compared to the quantitative data collected in Studies 1-3. In Study 4, three main themes emerged from the data: (1) Human Involvement in UAM Operations, (2) Scenarios for Usage, and (3) Setup and Deployment of Vehicles.

In Study 1, the first hypothesis stated that there would be a difference based on the type of operation of the UAM, either human-operated or fully autonomous. The findings from the study failed to support this hypothesis. In other words, participants had no difference in their willingness to support based on the type of operation. This finding is different from several prior studies (Ragbir et al., 2018; Ragbir et al., 2020; Rice et al., 2014; Winter & Rice, 2019, 2020); however, those previous studies primarily focused on passenger operations. It is possible that participants felt the use of UAM was valuable regardless of the type of operation within the natural disaster and emergencies. Additionally, autonomous operations may be perceived as preventing some first responders from being put at additional risk, as may be the case in typical emergency helicopter responses where several crewmembers may be onboard. Also, autonomous operations may assist in search and rescue operations where specific grid patterns could be programmed into the automation to ensure the desired area is scanned (Boukerche & Coutinho, 2018; Lygouras et al., 2019; McClure, 2019; Tariq et al., 2018; Thipphavong et al., 2018), even if it may mean covering a place that would not be safely conducted with human operators onboard.

The second hypothesis of Study 1 predicted that there would be significant differences in willingness to support based on the type of natural disaster. While the data from the study failed to support this hypothesis, the findings indicate robust and overall support for the use of UAM in natural disasters. Previous studies focused on passenger operations have found varying levels of support based on the types of missions and external factors such as weather (Ragbir et al., 2020). Given the findings from the current study, it is recommended that manufacturers of UAM vehicles and municipalities may want to consider their deployment through first responders as both a viable tool to use this technology, along with a way perhaps to gain more support from the public for passenger operations. Future studies should expand on these findings of robust willingness to support and examine if successful operations from first responders would significantly improve the likelihood of participants to use UAM for more traditional, passenger-carrying operations.

The third hypothesis of Study 1 proposed that there would be significant differences in willingness to support UAM based on the type of mission. The findings indicated that this hypothesis was supported, where participants indicated significantly less willingness to deliver news information over the other mission types provided. It is possible that, given the other missions, participants felt news information was not urgent. Also, this result may have been influenced by considerations that cell towers, smartphones, or other connected devices could serve the same purpose. Future research should investigate this finding in more detail, perhaps specifying whether other forms of communication were possible to receive news information. However, it is worth noting that while news delivery was significantly lower than the other mission types, there were still high willingness ratings for all mission types. This data further demonstrates the robust support for the use of UAMs in response to natural disasters.

The last hypothesis of Study 1 anticipated some interactions to occur within the data. Given the high levels of support for UAM, the data did not support this hypothesis. However, within the current study’s limitations, there appears to be robust support for using UAM in these scenarios. Future research should continue to develop an understanding of the viability of UAMs in emergencies and natural disasters. Due to participants' high levels of support, these events could be prime areas to demonstrate the capabilities and usability of UAM vehicles and technology. It may also minimize the risks and threats commonly undertaken by first responders working in these emergencies.

The purpose of Study 2 was to fill a noticeable gap in the literature related to vertiports. Vertiports are the proposed locations where UAM vehicles will take off and land (Batty et al., 2012; Caragliu et al., 2011; Niklaß et al., 2020; Preis, 2021; Rothfeld et al., 2018; Straubinger et al., 2020; Taylor et al., 2020). Given a literature review, few valid scales were available to measure the vertiport usability of current or proposed vertiport sites. A valid scale was developed through a four-stage process to assess vertiport usability. The Vertiport Usability Scale consists of seven items. The scale was utilized in Study 3 of the current study, but it is a scale that can be used in future research. There are several advantages to a valid scale when conducting research. First, using a scale enhances reliability measures through multiple items (Rice et al., 2020). Several items help to ensure that participants are giving consistent responses to questions. In addition, the psychometrics conducted on the scale help to demonstrate that a unidimensional construct of the proposed topic has been met, in the current study, relating to vertiport usability. Participants were involved in creating the instrument through the multi-stage process, which further adds to the scale's validity. Lastly, the scale is efficient with only seven items. It can be administered quickly and used within latent variable models or other quantitative methods, such as experiments.

Building upon the creation of the Vertiport Usability Scale from Study 2, Study 3 assessed participants' ideal locations for the placement of vertiports. It is important to note that location is relative to the activity being performed. Therefore, three categories were proposed: temporary disaster locations, permanent disaster locations, and permanent consumer locations. Temporary disaster locations were those locations that would be created in a short period in response to natural disasters with the intention of the locations being removed once the emergency was resolved. Permanent disaster locations would be designed to support emergencies but remain in place, like a fire station. Finally, permanent consumer locations would be where UAMs could be used for non-emergency passenger-carrying operations.

Open fields, military bases, and fairgrounds were the most significant locations for the temporary disaster location. The possible common theme across these locations would be the space available to establish and operate UAMs. Aside from the UAM vehicle, there would likely be some command operations and support from ground vehicles and personnel. These three areas provide the room to operate and quickly set up emergency response operations.

Military based and airports were the most significant locations for the permanent disaster locations. While not significant, police and fire stations rated highly, and future research should be conducted to determine if these additional sites would provide value. It is possible that when considering a permanent place, participants thought about those types of locations where UAM could be integrated rather seamlessly into existing operations. Airports already have flights arriving and departing, so it makes sense that UAM operations could be incorporated there. Similarly, military bases typically have aircraft and helicopter operations and facilities. Participants may also consider UAM deployment by responses such as the National Guard. The latter are commonly activated in advance of or in response to natural disasters within each state.

Open fields, hospitals, and airports were identified as the ideal locations for permanent consumer locations of vertiports. Similar to permanent disaster locations, it is possible that participants were considering the implementation of UAM in areas where air operations already occur, such as airports. While these locations were proposed for permanent consumer usage, it is also possible that they could be used in emergencies, if necessary. In addition, participants may have been considering the infrastructure needs surrounding the vertiport location. As with airports, there are numerous support facilities in the vicinity of airports. Establishing vertiports in open fields may allow for these additional items. However, it is interesting to notice a lack of highly rated urban areas such as shopping malls and sports stadiums. A tenant of UAM is the ability to transport individuals around highly congested areas (Thipphavong et al., 2018). Still, it does not seem that these areas were at the forefront of participants' minds in the current study. Future research should be conducted to understand these relationships further.

The final study of the project was a qualitative assessment to gain more insights into the perspectives of UAM in response to natural disasters and vertiports. Three themes emerged from the data: 1) human involvement in UAM operations, 2) scenarios for usage, and 3) setup and deployment of vehicles. The finding in the first theme is notable because it is somewhat different from Study 1, where participants indicated no significant difference between remotely piloted and fully autonomous. In assessing comments related to this theme, it appears that trust was a commonly discussed aspect as to why participants felt remotely operated was better than fully autonomous. These data provide some valuable insights, and they highlight an area where future investigation should expand on the current studies to understand these relationships in more detail.

The theme of scenarios for usage aligned well with the conditions reviewed in Study 1. However, a condition that was highlighted by participants related to lost persons or search and rescue. These data offer powerful insights because, while not necessarily linked to natural disasters, helping to find lost persons could be a practical use of UAM by first responders. The ability to scan accurate patterns and gain access to inhospitable terrain offers valuable tools to provide timely assistance to those in need. The last theme was the setup and deployment of the vehicles. In general, the findings were like those from Study 3. An interesting addition was the mention of the emergency operations center as a location or using areas such as hunting grounds. These data provide strong evidence of the support demonstrated throughout these studies on using UAM to respond to natural disasters.

REFERENCES

Adkins, K. A., Akbas, M., & Compere, M. (2020). Real-time urban weather observations for urban air mobility. *International Journal of Aviation, Aeronautics, and Aerospace*, *7*(4), 11. https://doi.org/10.15394/ijaaa.2020.1540

Airbus Aerospace Company. (2019). *Airbus urban mobility*. https://www.airbus.com/innovation/urban-air-mobility.html

Al Haddad, C., Chaniotakis, E., Straubinger, A., Plötner, 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

Almeida, M., Hildmann, H., & Solmaz, G. (2017). Distributed UAV-swarm-based real-time geomatic data collection under dynamically changing resolution requirements. *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences; Gottingen*, *XLII-2/W6*, 5–12. https://doi.org/10.5194/isprs-archives-XLII-2-W6-5-2017

Anania, E. C., Rice, S., Walters, N. W., Pierce, M., Winter, S. R., & Milner, M. N. (2018). The effects of positive and negative information on consumers' willingness to ride in a driverless vehicle. *Transport Policy*, *72*, 218–224. https://doi.org/10.1016/j.tranpol.2018.04.002

Augustino, Jocelyn. (2005). *Aerial of people sitting on a roof waiting to be rescued as flood water surrounds their home.* FEMA. https://www.fema.gov/multimedia-library

Asgari, H., & Jin, X. (2019). Incorporating attitudinal factors to examine adoption of and willingness to pay for autonomous vehicles. *Transportation Research Record*, *2673*(8), 418–429. https://doi.org/10.1177/0361198119839987

Batty, M., Axhausen, K. W., Giannotti, F., Pozdnoukhov, A., Bazzani, A., Wachowicz, M., … Portugali, Y. (2012). Smart cities of the future. *The European Physical Journal. Special Topics*, *214*(1), 481–518. https://doi.org/10.1140/epjst/e2012-01703-3

Bayirhan, İ., & Gazioğlu, C. (2020). Use of unmanned aerial vehicles (UAV) and marine environment simulator in oil pollution investigations. *Baltic J. Modern Computing,* *8*(2), 327–336. https://doi.org/10.22364/bjmc.2020.8.2.08

Boukerche, A., & Coutinho, R. W. L. (2018). Smart disaster detection and response system for smart cities. *2018 IEEE Symposium on Computers and Communications (ISCC)*, 01102–01107. https://doi.org/10.1109/ISCC.2018.8538356

Buhrmester, M., Kwang, T., & Gosling, S. D. (2011). Amazon's Mechanical Turk: A new source of inexpensive, yet high-quality data? *Perspectives on Psychological Science, 6*(3), 3-5.

Caragliu, A., Del Bo, C., & Nijkamp, P. (2011). Smart cities in Europe. *Journal of Urban Technology*, *18*(2), 65–82. https://doi.org/10.1080/10630732.2011.601117

Center for Climate and Energy Solutions. (n.d.). *Wildfires and Climate Change.* https://www.c2es.org/content/wildfires-and-climate-change/

Centers for Disease Control and Prevention (CDC). (2012). *After a tornado*. https://www.cdc.gov/disasters/tornadoes/after.html

CDC. (2020). *Fighting wildfires*. https://www.cdc.gov/niosh/topics/firefighting/default.html

CDC. (2018). *Hazard based guidelines: Protective equipment for workers in hurricane flood response*. https://www.cdc.gov/niosh/topics/emres/pe-workers.html

CDC. (2021). *Stay safe during a wildfire*. https://www.cdc.gov/disasters/wildfires/duringfire.html

Clothier, R. A., Greer, D. A., Greer, D. G., & Mehta, A. M. (2015). Risk perception and the public acceptance of drones. *Risk Analysis: An Official Publication of the Society for Risk Analysis*, *35*(6), 1167–1183. https://doi.org/10.1111/risa.12330

Daskilewicz, M., German, B., Warren, M., Garrow, L. A., Boddupalli, S.-S., & Douthat, T. H. (2018). Progress in vertiport placement and estimating aircraft range requirements for eVTOL daily commuting. In *2018 Aviation Technology, Integration, and Operations Conference*. American Institute of Aeronautics and Astronautics. https://doi.org/10.2514/6.2018-2884

Downing, Shane. (2021, September 2). *7 urban air mobility companies to watch*. GreenBiz. https://www.greenbiz.com/article/7-urban-air-mobility-companies-watch

Eißfeldt, H. (2020). Sustainable urban air mobility supported with participatory noise sensing. *Sustainability: Science Practice and Policy*, *12*(8), 3320. https://doi.org/10.3390/su12083320

Endsley, K. (n.d.). *Earthquake magnitude scale*. Michigan Tech. http://www.geo.mtu.edu/UPSeis/magnitude.html

Fitzpatrick, F., Winters, K., & Mason, R. (n.d.). *USGS flood information.* U.S. Geological Survey. https://www.usgs.gov/mission-areas/water-resources/science/usgs-flood-information?qt-science_center_objects=0#qt-science_center_objects

Fleetwood, J. (2017). Public health, ethics, and autonomous vehicles. *American Journal of Public Health*, *107*(4), 532–537. https://doi.org/10.2105/AJPH.2016.303628

Florido, A. (2018, October 18). *Why stay during a hurricane? Because it's not as simple as "get out."* https://www.npr.org/2018/10/18/658258370/why-stay-during-a-hurricane-because-its-not-as-simple-as-get-out

German, B., Daskilewicz, M., Hamilton, T. K., & Warren, M. M. (2018). Cargo Delivery in by Passenger eVTOL Aircraft: A Case Study in the San Francisco Bay Area. In *2018 AIAA Aerospace Sciences Meeting*. American Institute of Aeronautics and Astronautics. https://doi.org/10.2514/6.2018-2006

Germine, L., Nakayama, K., Duchaine, B.C., Chabris, C.F., Chatterjee, G., & Wilmer, J.B. (2012) Is the web as good as the lab? Comparable performance from web and lab in cognitive/perceptual experiments. *Psychonomic Bulletin & Review, 19*(5), 847-857.

Gipson, L. (2019). *UAM Overview*. NASA. https://www.nasa.gov/uam-overview/

Government Accountability Office. (n.d.). *Wildland fire management.* https://www.gao.gov/wildland-fire-management

Goyal, R., Reiche, C., Fernando, C., Serrao, J., Kimmel, S., Cohen, A., & Shaheen, S. (2018). *Urban air mobility (UAM) market study*. https://ntrs.nasa.gov/citations/20190000519

Haboucha, C. J., Ishaq, R., & Shiftan, Y. (2017). User preferences regarding autonomous vehicles. *Transportation Research Part C: Emerging Technologies*, *78*, 37–49. https://doi.org/10.1016/j.trc.2017.01.010

Hammer, M. S., Swinburn, T. K., & Neitzel, R. L. (2014). Environmental noise pollution in the United States: Developing an effective public health response. *Environmental Health Perspectives*, *122*(2), 115–119. https://doi.org/10.1289/ehp.1307272

Harris, M. (2016, January). *Google reports self-driving car mistakes: 272 failures and 13 near misses.* https://www.theguardian.com/technology/2016/jan/12/google-self-driving-cars-mistakes-data-reports

Hinkin, T. R. (1998). A brief tutorial on the development of measures for use in survey questionnaires. *Organizational Research Methods, 1*(1), 104-121.

Hollands, R. G. (2008). Will the real smart city please stand up? *Cityscape*, *12*(3), 303–320. https://doi.org/10.1080/13604810802479126

Holmes, B. J. (2016). A vision and opportunity for transformation of on-demand air mobility. In *AIAA AVIATION Forum*. *16th AIAA Aviation Technology, Integration, and Operations Conference*. American Institute of Aeronautics and Astronautics. https://doi.org/10.2514/6.2016-3465

Hughes, J. S., Rice, S., Trafimow, D., & Clayton, K. (2009). The automated cockpit: A comparison of attitudes towards human and automated pilots. *Transportation Research. Part F, Traffic Psychology and Behaviour*, *12*(5), 428–439. https://doi.org/10.1016/j.trf.2009.08.004

International Federation of Red Cross (IFRC). *Types of disasters: Definition of hazard*. (2016). https://www.ifrc.org/en/what-we-do/disaster-management/about-disasters/definition-of-hazard/

Khalili, M. (2020, December 8). *Joby Aviation welcomes new $75m investment from Uber as it acquires Uber Elevate and expands partnership*. https://www.jobyaviation.com/news/joby-aviation-welcomes-new-75m-investment-from-uber-as-it-acquires-uber-elevate-and-expands-partnership/

Kitty Hawk. (2019). Cora - air taxi. https://cora.aero/

Kleinbekman, I. C., Mitici, M. A., & Wei, P. (2018). eVTOL arrival sequencing and scheduling for on-demand urban air mobility. *2018 IEEE/AIAA 37th Digital Avionics Systems Conference (DASC)*, 1–7. https://doi.org/10.1109/DASC.2018.8569645

Kossobokov, V. G., Nekrasova, A. K., Geophysical Center, RAS, Moscow, Russian Federation, & International Seismic Safety Organization, Arsita, Italy. (2018). Earthquake hazard and risk assessment based on unified scaling law for earthquakes:

Altai–Sayan Region. *Natural Hazards; Dordrecht*, *93*(3), 1435–1449. https://doi.org/10.1007/s11069-018-3359-z

Kyrkou, C., & Theocharides, T. (2020). EmergencyNet: Efficient aerial image classification for drone-based emergency monitoring using atrous convolutional feature fusion. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, *13*, 1687–1699. https://doi.org/10.1109/JSTARS.2020.2969809

Lim, E., & Hwang, H. (2019). The selection of vertiport location for on-demand mobility and its application to Seoul metro area. *International Journal of Aeronautical and Space Sciences*, *20*(1), 260–272. https://doi.org/10.1007/s42405-018-0117-0

Loh, J. (2019, May 27). *Aircraft company volocopter is bringing to Singapore its first-ever air taxi 'vertiport' by end 2019 – and test flights are already planned*. https://www.businessinsider.sg/aircraft-company-volocopter-is-bringing-to-singapore-its-first-ever-air-taxi-vertiport-by-end-2019-and-test-flights-are-already-planned/

Lygouras, E., Santavas, N., Taitzoglou, A., Tarchanidis, K., Mitropoulos, A., & Gasteratos, A. (2019). Unsupervised human detection with an embedded vision system on a fully autonomous UAV for search and rescue operations. *Sensors* , *19*(16). https://doi.org/10.3390/s19163542

Marin, L., Ruiz, S., & Rubio, A. (2009). The role of identity salience in the effects of corporate social responsibility on consumer behavior. *Journal of Business Ethics: JBE*, *84*(1), 65–78. https://doi.org/10.1007/s10551-008-9673-8

Marte, D. A., Anania, E. C., Rice, S., Mehta, R., Milner, M. N., Winter, S. R., … Ragbir, N. (2018). What type of person supports 24/7 police drones over neighborhoods? A regression analysis. *Journal of Unmanned Aerial Systems*, *4*(1), 61–70.

McClure, J. (2019). *A low-cost search-and-rescue drone platform* (Publication No. 13881673) [Master’s Thesis, Rochester Institute of Technology]. ProQuest Dissertations and Theses Global. https://scholarworks.rit.edu/theses/10076/

Mohammed, F., Idries, A., Mohamed, N., Al-Jaroodi, J., & Jawhar, I. (2014). UAVs for smart cities: Opportunities and challenges. *2014 International Conference on*

Unmanned Aircraft Systems (ICUAS), 267–273. https://doi.org/10.1109/ICUAS.2014.6842265

National Aeronautics and Space Administration (NASA). (2021). *UAM Vision ConOps/UAM maturity level 4*. https://www.nasa.gov/aeroresearch/uam-vision-conops-uml-4

National Hurricane Center (NHC) (n.d.). *Saffir-Simpson hurricane wind scale*. https://www.nhc.noaa.gov/aboutsshws.php

NHC Public Affairs Officer. 2020. *About the National Hurricane Center.* https://www.nhc.noaa.gov/aboutintro.shtml

National Oceanic and Atmospheric Administration. (2021, July 31). *Hurricane response.* https://oceanservice.noaa.gov/hazards/hurricanes/

National Weather Service [NWS]. (n.d. -a). *F5/EF-5 tornadoes in Oklahoma (1905-present).* https://www.weather.gov/oun/tornadodata-ok-f5tornadoes

NWS. (n.d. -b). *Tornado Safety*. https://www.weather.gov/safety/tornado

National Wildfire Coordinating Group (n.d. -a). *The National Wildfire Coordinating Group*. https://www.nwcg.gov/

National Wildfire Coordinating Group (n.d. -b). *Size class of fire*. https://www.nwcg.gov/term/glossary/size-class-of-fire#:~:text=Class%20D%20%2D%20100%20acres%20or,G%20%2D%205%2C000%20acres%20or%20more.

Niklaß, M., Dzikus, N., Swaid, M., Berling, J., Lührs, B., Lau, A., Terekhov, I., & Gollnick, V. (2020). A collaborative approach for an integrated modeling of urban air transportation systems. *Aerospace*, *7*(5), 50. https://doi.org/10.3390/aerospace7050050

Occupational Safety and Health Administration (OSHA) (n.d. -a). *Earthquake Preparedness and Response - Response/Recovery*. https://www.osha.gov/earthquakes/response-recovery

OSHA (n.d. -b). *Flood Preparedness and Response*. https://www.osha.gov/flood/response

OSHA (n.d. -c). *Hurricane eMatrix: general recommendations for working in all impacted areas*. https://www.osha.gov/etools/hurricane/recommendations

OSHA (n.d. -d). *Tornado preparedness and response.* https://www.osha.gov/tornado/response

OSHA (n.d. -e). *Wildfires*. https://www.osha.gov/wildfires/response

Phinney, J. S. (1996). When we talk about American ethnic groups, what do we mean? *The American Psychologist*, *51*(9), 918. https://psycnet.apa.org/journals/amp/51/9/918.html?uid=1996-05971-003

Preis, L., Amirzada, A., & Hornung, M. (2021). Ground operation on vertiports? Introduction of an agent-based simulation framework. In *AIAA SciTech Forum*. *AIAA Scitech 2021 Forum*. American Institute of Aeronautics and Astronautics. https://doi.org/10.2514/6.2021-1898

Pu, H., Liu, Y., Luo, J., Xie, S., Peng, Y., Yang, Y., … Qu, D. (2020). Development of an unmanned surface vehicle for the emergency response mission of the "Sanchi" oil tanker collision and explosion accident. *NATO Advanced Science Institutes Series E: Applied Sciences*, *10*(8), 2704. https://doi.org/10.3390/app10082704

Tariq, R., Rahim, M., Aslam, N., Bawany, N., & Faseeha, U. (2018). DronAID : A smart human detection drone for rescue. *2018 15th International Conference on Smart Cities: Improving Quality of Life Using ICT IoT (HONET-ICT)*, 33–37. https://doi.org/10.1109/HONET.2018.8551326

Ragbir, N. K., Baugh, B. S., Rice, S., & Winter, S. R. (2018). How nationality, weather, wind, and distance affect consumer willingness to fly in autonomous airplanes. *Journal of Aviation Technology and Engineering*, *8*(1), 1. https://doi.org/10.7771/2159-6670.1180

Ragbir, N. K., Rice, S., Winter, S. R., Choy, E. C., & Milner, M. N. (2020). How weather, distance, flight time, and geography affect consumer willingness to fly in autonomous air taxis. *The Collegiate Aviation Review International*, *38*(1). https://doi.org/10.22488/okstate.20.100205

Rajendran, S., & Srinivas, S. (2020). Air taxi service for urban mobility: A critical review of recent developments, future challenges, and opportunities. *Transportation Research Part E: Logistics and Transportation Review*, *143*, 102090. https://doi.org/10.1016/j.tre.2020.102090

Reiche, C., Cohen, A. P., & Fernando, C. (2021). An initial assessment of the potential weather barriers of urban air mobility. *IEEE Transactions on Intelligent Transportation Systems*, *22*(9), 6018–6027. https://doi.org/10.1109/TITS.2020.3048364

Reiche, C., Goyal, R., Cohen, A., Serrao, J., Kimmel, S., Fernando, C., & Shaheen, S. (2018). *Urban air mobility market study*. https://doi.org/10.7922/G2ZS2TRG

Rice, S., Kraemer, K., Winter, S. R., Mehta, R., Dunbar, V., Rosser, T. G., & Moore, J. C. (2014). Passengers from India and the United States have differential opinions about autonomous autopilots for commercial flights. *International Journal of Aviation, Aeronautics, and Aerospace*, *1*(1), 3. https://doi.org/10.15394/ijaaa.2014.1004

Rice, S., Mehta, R., Steelman, L., & Winter, S. R. (2014). A trustworthiness of commercial airline pilots (T-CAP) scale for Indian consumers. *International Journal of Aviation, Aeronautics, and Aerospace, 1*(3), 1-15.

Rice, S., Mehta, R., Winter, S. R., & Oyman, K. (2015). A trustworthiness of commercial airline pilots (T-CAP) for American consumers. *Journal of Aviation Technology and Engineering, 4*(2), 55-63.

Rice, S., Winter, S. R., Capps, J., Trombley, J., Robbins, J., Milner, M., & Lamb, T. L. (2020). Creation of two valid scales: Willingness to fly in an aircraft and willingness to pilot an aircraft. *International Journal of Aviation, Aeronautics, and Aerospace, 7*(1), Article 5.

Rice, S., Winter, S.R., Doherty, S. & Milner, M.N. (2017). Advantages and disadvantages of using internet-based survey methods in aviation-related research. *Journal of Aviation Technology and Engineering, 7*(1), 58-65.

Rice, S., Winter, S. R., Mehta, R., & Ragbir, N. K. (2019). What factors predict the type of person who is willing to fly in an autonomous commercial airplane? *Journal of Air Transport Management*, *75*, 131–138. https://doi.org/10.1016/j.jairtraman.2018.12.008

Rice, S., & Winter, S. R. (2019). Do gender and age affect willingness to ride in driverless vehicles: If so, then why? *Technology in Society*, *58*, 101145. https://doi.org/10.1016/j.techsoc.2019.101145

Rice, S., Winter, S. R., Deaton, J. E., & Cremer, I. (2016). What are the predictors of system-wide trust loss in transportation automation? *Journal of Aviation Technology and Engineering*, *6*(1), 1. https://doi.org/10.7771/2159-6670.1120

Rothfeld, R., Balac, M., Ploetner, K. O., & Antoniou, C. (2018). Agent-based simulation of urban air mobility. In *AIAA AVIATION Forum*. *2018 Modeling and Simulation Technologies Conference*. American Institute of Aeronautics and Astronautics. https://doi.org/10.2514/6.2018-3891

Schmelzer, R. (2016, September, 26). *What happens when self-driving cars kill people?* https://www.forbes.com/sites/cognitiveworld/2019/09/26/what-happens-with-self-driving-cars-kill-people/?sh=97d347e405ce

Shaheen, S., Cohen, A., & Farrar, E. (2018). *The potential societal barriers of urban air mobility (UAM)*. https://doi.org/10.7922/G28C9TFR

Shedlock, K.M., & Pakiser, L.C. (2016). *Earthquakes*. U.S. Geological Survey. https://pubs.usgs.gov/gip/earthq1/earthqkgip.html

Southern California Earthquake Data Center at Caltech. (n.d.). *Landers earthquake*. https://scedc.caltech.edu/earthquake/landers1992.html

Straubinger, A., Rothfeld, R., Shamiyeh, M., Büchter, K.-D., Kaiser, J., & Plötner, K. O. (2020). An overview of current research and developments in urban air mobility – Setting the scene for UAM introduction. *Journal of Air Transport Management*, *87*, 101852. https://doi.org/10.1016/j.jairtraman.2020.101852

Tariq, R., Rahim, M., Aslam, N., Bawany, N., & Faseeha, U. (2018). DronAID : A smart human detection drone for rescue. *2018 15th International Conference on Smart Cities: Improving Quality of Life Using ICT IoT (HONET-ICT)*, 33–37. https://doi.org/10.1109/HONET.2018.8551326

Taylor, M., Saldanli, A., & Park, A. (2020). Design of a vertiport design tool. *2020 Integrated Communications Navigation and Surveillance Conference (ICNS)*, 2A2–1 – 2A2–A12. https://doi.org/10.1109/ICNS50378.2020.9222989

Thipphavong, D. P., Apaza, R. D., Barmore, B. E., Battiste, V., Belcastro, C. M., Burian, B. K., Dao, Q. V., Feary, M. S., Go, S., Goodrich, K. H., Homola, J. R., Idris, H. R., Kopardekar, P. H., Lachter, J. B., Neogi, N. A., Ng, H., Oseguera-Lohr, R. M., Patterson, M. D., & Verma, S. A. (2018, June 25). Urban Air Mobility airspace integration concepts and considerations. *AIAA Aviation Forum (Aviation 2018)*. https://ntrs.nasa.gov/citations/20180005218

TomTom. (2020). *Traffic Index 2020*. https://www.tomtom.com/en_gb/traffic-index/ranking/?country=US

Uber Elevate. (2019). *The future of urban air mobility*. https://www.uber.com/us/en/elevate/

United States Geological Survey [USGC] (n.d. -a). *About*. https://www.usgs.gov/natural-hazards/earthquake-hazards/about?qt-science_support_page_related_con=0

USGS. (n.d. -b). *What are the two types of floods?* https://www.usgs.gov/faqs/what-are-two-types-floods?qt-news_science_products=0#qt-news_science_products

USGS. (n.d. -c). *Who we are*. https://www.usgs.gov/about/about-us/who-we-are

USGS. (2018). *2018 Long-term national seismic hazard map*. https://www.usgs.gov/media/images/2018-long-term-national-seismic-hazard-map

Vascik, P. D., & Hansman, R. J. (2017). constraint identification in on-demand mobility for aviation through an exploratory case study of Los Angeles. In *17th AIAA Aviation Technology, Integration, and Operations Conference*. American Institute of Aeronautics and Astronautics. https://doi.org/10.2514/6.2017-3083

Vascik, P. D., Hansman, R. J., & Dunn, N. S. (2018). Analysis of urban air mobility operational constraints. *Journal of Air Transportation*, *26*(4), 133–146. https://doi.org/10.2514/1.D0120

Viswan, V., & Madhav, M. L. (2013). Mission-critical management using media independent handover. *International Journal of Computer Applications in Engineering Sciences, vol. III, no. I,* 32–36.

Volocopter. (n.d). *We bring urban air mobility to life*. https://www.volocopter.com/en/

Werwitzke, C. (2018, October 18). *Air taxi Cora: Kitty Hawk teams up with Air New Zealand*. https://www.electrive.com/2018/10/18/air-taxi-service-kitty-hawk-teams-up-with-air-new-zealand/

Winter, S. R., Rice, S., & Lamb, T. L. (2020). A prediction model of consumer's willingness to fly in autonomous air taxis. *Journal of Air Transport Management*, *89*, 101926. https://doi.org/10.1016/j.jairtraman.2020.101926

Wisk. (2021). Autonomous urban air mobility starts here. https://wisk.aero/

Wolfe, C. (n.d.). *ANSS - Advanced National Seismic System*. (n.d.). https://www.usgs.gov/natural-hazards/earthquake-hazards/about?qt-science_support_page_related_con=0

Yigitcanlar, T., Butler, L., Windle, E., Desouza, K. C., Mehmood, R., & Corchado, J. M. (2020). Can building “artificially intelligent cities” safeguard humanity from natural disasters, pandemics, and other catastrophes? An urban scholar’s perspective. *Sensors* , *20*(10), 2988. https://doi.org/10.3390/s20102988

Zhou, Z., Chen, J., & Liu, Y. (2021). Optimized landing of drones in the context of congested air traffic and limited vertiports. *IEEE Transactions on Intelligent Transportation Systems*, *22*(9), 6007–6017. https://doi.org/10.1109/TITS.2020.3040549

APPENDIX

Appendix A – Conditions from Study 1

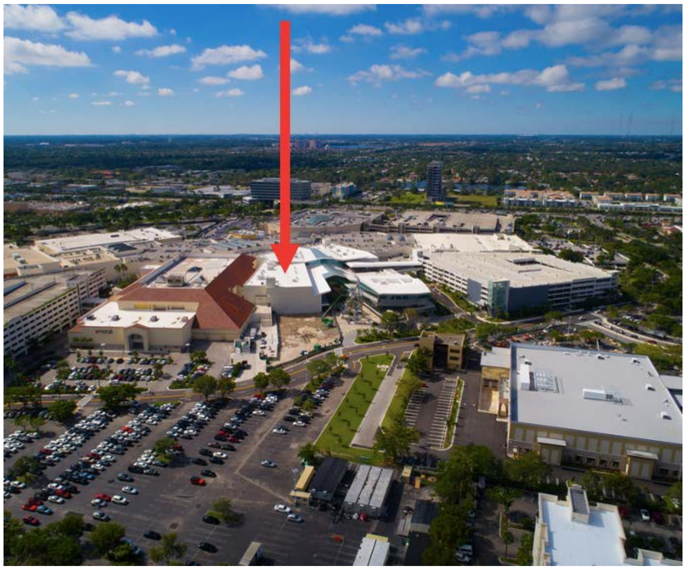
Case	Extremely Unwilling	Quite Unwilling	Slightly Unwilling	Neither Unwilling nor Willing	Slightly Willing	Quite Willing	Extremely Willing
An earthquake has occurred and the government is trying to deliver food and water to the victims.							
An earthquake has occurred and the government is trying to deliver medicine and medical devices to the victims.							
An earthquake has occurred and the government is trying to deliver survival equipment to the victims.							
An earthquake has occurred and the government is trying to deliver news and information to the victims.							
An earthquake has occurred and the government is trying to extract victims.							
A hurricane has occurred and the government is trying to deliver food and water to the victims.							
A hurricane has occurred and the government is trying to deliver medicine and medical devices to the victims.							
A hurricane has occurred and the government is trying to deliver survival equipment to the victims.							
A hurricane has occurred and the government is trying to deliver news and information to the victims.							
A hurricane has occurred and the government is trying to extract victims.							

A tornado has occurred and the government is trying to deliver food and water to the victims.							
A tornado has occurred and the government is trying to deliver medicine and medical devices to the victims.							
A tornado has occurred and the government is trying to deliver survival equipment to the victims.							
A tornado has occurred and the government is trying to deliver news and information to the victims.							
A tornado has occurred and the government is trying to extract victims.							
A flood has occurred and the government is trying to deliver food and water to the victims.							
A flood has occurred and the government is trying to deliver medicine and medical devices to the victims.							
A flood has occurred and the government is trying to deliver survival equipment to the victims.							
A flood has occurred and the government is trying to deliver news and information to the victims.							
A flood has occurred and the government is trying to extract victims.							
A wildfire has occurred and the government is trying to deliver food and water to the victims.							
A wildfire has occurred and the government is trying to deliver medicine and medical devices to the victims.							

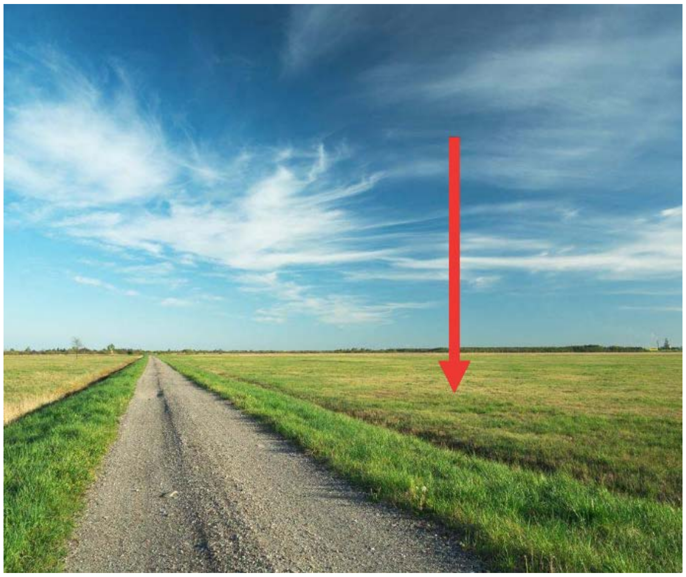
A wildfire has occurred and the government is trying to deliver survival equipment to the victims.							
A wildfire has occurred and the government is trying to deliver news and information to the victims.							
A wildfire has occurred and the government is trying to extract victims.							

Appendix B – Four Images from Study 2 Stage 4

Mall Condition



Field Condition

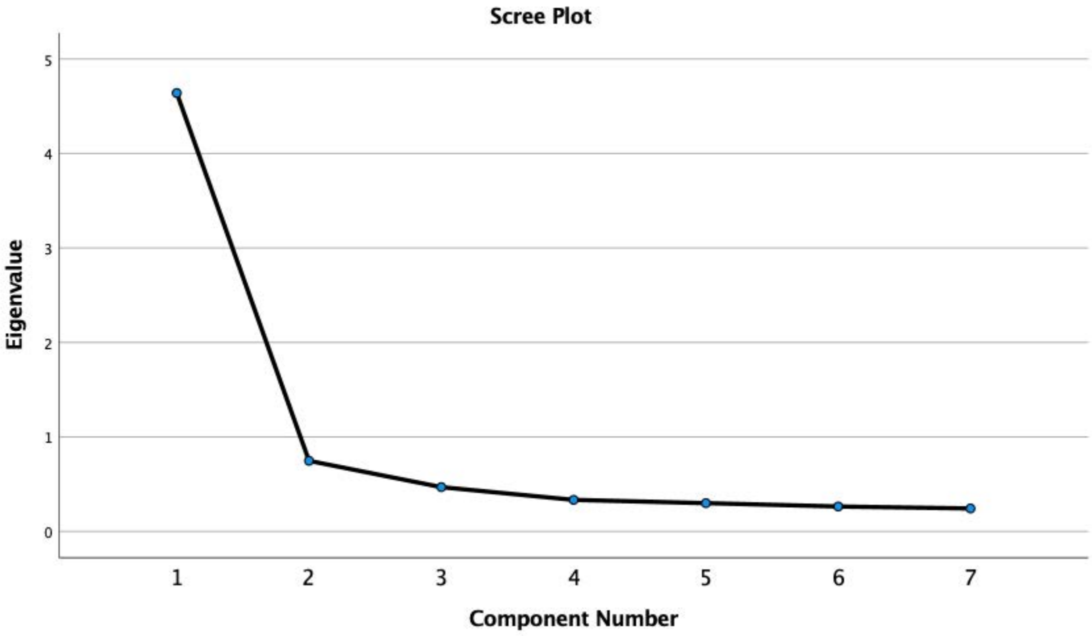


Skyscraper Condition

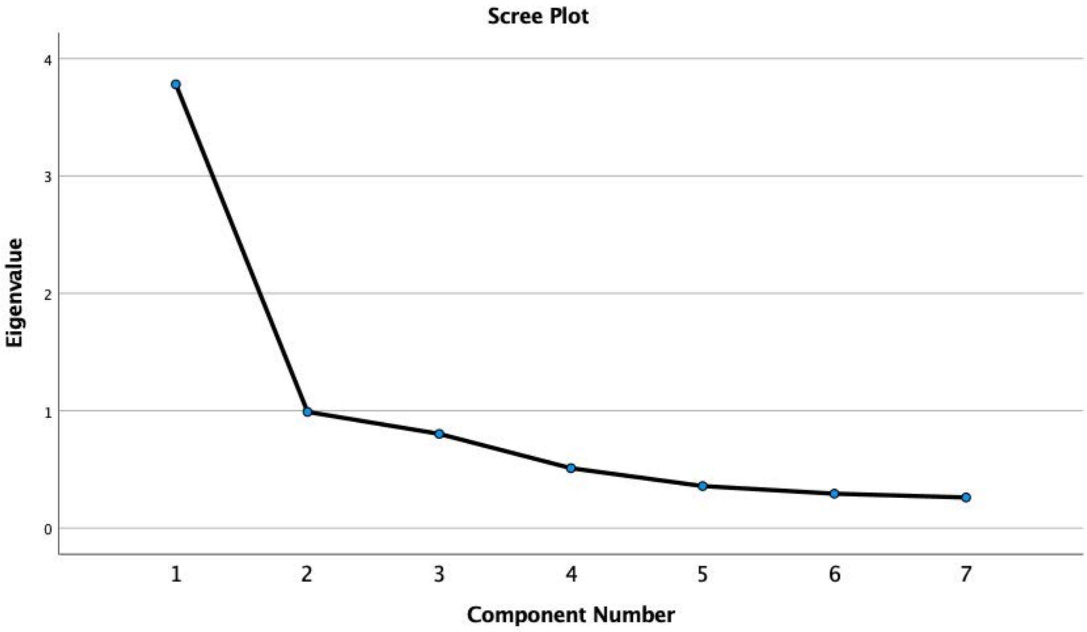
Mountain Condition

Appendix C – Four Scree Plots from Study 2 Stage 4

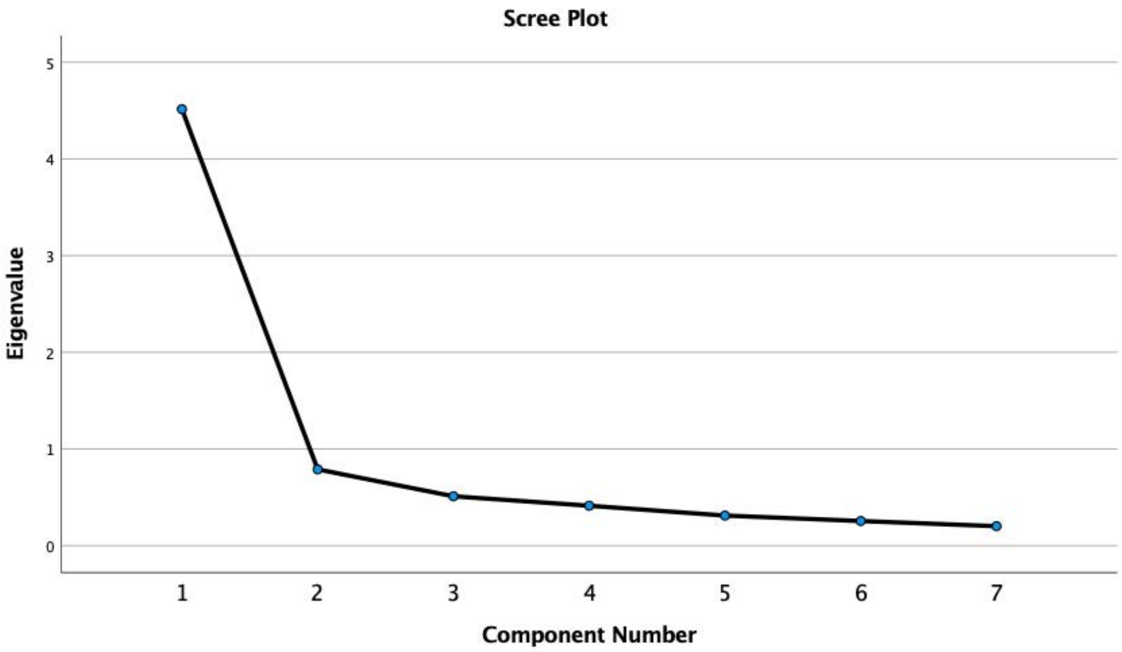
Mall Condition



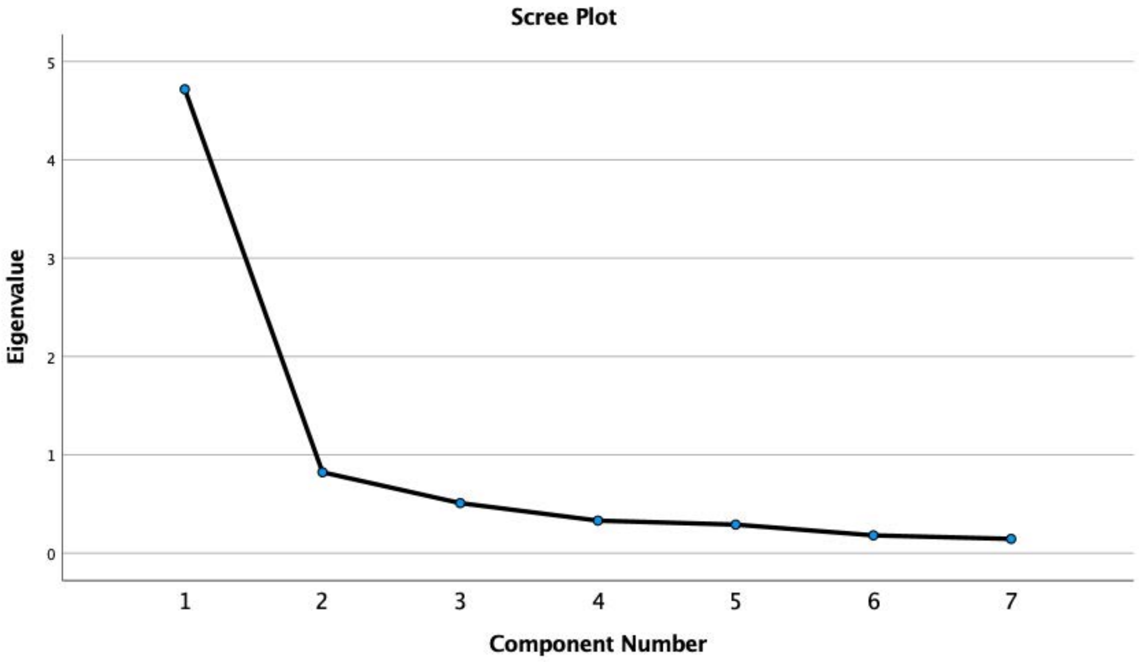
Field Condition



Skyscraper Condition



Mountain Condition



Appendix D – Study 3 Stage 1: Proposed Locations Based on Type of Scenario

Temporary Disaster Location

1. High school football field
2. Closed Interstate
3. Airport Runway
4. On a barge
5. In an open field
6. Local Fair Ground
7. Golf Course
8. Beach front
9. Professional Sports Stadium
10. Parking garages (Top Floor)
11. Convention centers
12. Large church locations (open fields preferably)
13. Gym
14. Parks & Playgrounds
15. Near residential areas
16. Colleges and Universities
17. Government institutions (courthouses, capital buildings)
18. Just outside of national/state parks
19. Junk yards
20. Military base
21. Farm Land
22. Police Station
23. Fire department
24. City Hall
25. Mall parking lot
26. Large parking lot
27. Top of building in disaster area
28. Emergency shelters
29. Shipyard
30. Hospitals

Permanent Disaster Location

1. Top of Firehouse.
2. Top of police station.
3. At the local airport.
4. Next to a bus station
5. Top of hospital
6. Military bases/airfields
7. Areas with open fields
8. Dispatch (9-1-1) communications centers
9. Near subway stations

10. Shipyards
11. Medical clinics
12. Broadcast stations
13. Train stations
14. Ship Yard
15. Pentagon
16. Top of buildings in metropolitan areas
17. University/Colleges
18. Government Buildings
19. Hospitals
20. Top of hotels
21. Shopping Mall Roofs/Parking Lots
22. Federally owned land

Permanent Consumer Location

1. Downtown top of building.
2. Near Airport
3. Next to bus station
4. Top of subway exit
5. Top of high-rise buildings
6. Gas Stations
7. Open areas (fields)
8. Beaches
9. Centralized locations around business offices
10. Near popular tourist attractions
11. Mall rooftops
12. Supermarkets
13. Train stations
14. Hotels
15. Parking garages
16. Train station
17. Near Sport Stadiums
18. Colleges/Universities
19. Shopping Malls
20. Hospitals
21. Large retail shopping districts
22. Near restaurant districts
23. By Amazon warehouses

Appendix E – Vertiport Qualitative Assessment Interview Protocol

The purpose of this document is to outline the interview protocol and ‘script’ that will be used by the researchers to conduct the interview, and interview.
The purpose of the study is discovering the opinions and perspectives of participants on the use of urban air mobility and vertiports in response to natural disasters.

Pre-Interview Checklist

- ✓ Ensure the participant has signed and returned the consent form to you.
- ✓ Have a copy of the consent form to go through it with the participant.
- ✓ Ensure your recording device is working, as power and is ready to record.
- ✓ Have the interview questions [included in this protocol] ready so you can follow it.
- ✓ Create the Participant ID number by:
  a. Date
  b. Time of interview (Universal Coordinated Time UTC)
  c. Initials of researcher

For example, **1031711SW**
10/3/17
11:00AM
Scott Winter

The interview recording **must** include the **participant ID**, directions on how to do this are included in prepared script. Interviews will consist of audio connect only, no video.
To preserve the credibility of the study, stick to this script for every participant.

The Pre-Interview (not recorded) Script

1) Introduction and pleasantries;
   a. “Good morning/afternoon/evening”.
   b. “Thank you for taking the time to speak with me today”.
   c. Introduce yourself (Name, School, Program).
2) Review consent form with participant
3) “The purpose of the interview today is to gain an understanding of your perceptions, feelings and concerns about using urban air mobility in response to natural disasters.”
4) “I will lead an interview where you will be able to share your point of view for a variety of questions”.
5) “Your responses will be recorded via audio recorder and transcribed by the researchers. I will begin the recording by a statement of the participant code so that the researchers can include the code in the transcription, the audio recording will be destroyed as soon as it is transcribed.”
6) “There are no benefits to participating other than knowing you have contributed to the advancement of scientific knowledge.”
7) “A quick reminder before we begin:
   a. Your participation is voluntary, and you are in no way required to provide information.
   b. At any point during the interview process you may stop or choose to not answer a question.
   c. The recording of the conversation will be destroyed after it has been transcribed by the researchers.

        d. The transcriptions and the resultant paper will have no personal information."

8) "There are nine questions on the topic, we have estimated the interview will take approximately 45 to 60 minutes".
9) "NASA defines Urban Air Mobility (UAM) as safe and efficient air traffic operations in a metropolitan area for manned aircraft and unmanned aircraft systems. These craft range from a passenger service (i.e., taxi) to delivery services (i.e., Amazon) and can be deployed for wide spectrum operations for both civilians and government agencies. A vertiport is the proposed takeoff and landing site for urban air mobility (UAM) aircraft."
10) "Before we start the interview, do you have any questions for me"?
    a. If you have any questions about the research, please contact Dr Scott Winter. If you have concerns about the treatment of research participants, please contact Teri Gabriel.
11) "Thank you, then let's begin."

Start recording device

Interview Code …

1. What are your general thoughts on using urban air mobility in response to natural disasters?
2. What are the main types of natural disasters where the use of UAM could be beneficial?
3. Would you rather have the UAM's be operated by a remote pilot or fully autonomous? Why do you feel this way?
4. What general types of missions do you feel would be most useful for UAM after a natural disaster?
5. When considering the location of a vertiport, what are some of the general locations that come to your mind?
6. In the case of a <u>temporary vertiport location</u> to respond to a natural disaster, what locations do you feel would be most useful and why?
7. In the case of a <u>permanent vertiport location</u> to respond to a natural disaster, what locations do you feel would be most useful and why?
8. In the case of a <u>permanent consumer location</u> to use in daily life, what locations do you feel would be most useful and why?
9. Are there any other thoughts you have on UAM in response to natural disasters or the locations related to their vertiport?

"Do you have any questions for me"?

If yes: Address and answer question.

If no: Continue with protocol below.

Stop Recording Device

Interview Completed

"Thank you for taking the time to participate in this interview. If you think of any questions or are interested in the results of this study, please feel free to contact us through email. Goodbye and thank you."

Post Interview Actions

1) Upload the recording to our 'GLIP' CATM study team, label it with the file name as the **participant code** to prepare for transcription.

2) Note any questions, points of interest from the interview and share these with the principal investigator, or post to the Glip team as appropriate.
3) If there were any concerns raised or you have any concerns share immediately with the principal investigator.