

# Infrastructure to Support Advanced Autonomous Aircraft Technologies in Ohio



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The Ohio Department of Transportation,  
Office of Statewide Planning & Research

Project ID Number: 111453  
June 2021  
Final Report



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### Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.	
FHWA/OH-2021-18			
4. Title and Subtitle		5. Report Date	
Infrastructure to Support Advanced Autonomous Aircraft Technologies in Ohio <i>Economic Impact Report for Advanced Autonomous Aircraft Technologies in Ohio</i>		June 2021	
		6. Performing Organization Code	
7. Author(s)		8. Performing Organization Report No.	
Dr. Rubén Del Rosario, Tom Davis, Michael Dymont, Dr. Kelly Cohen			
9. Performing Organization Name and Address		10. Work Unit No. (TRAVIS)	
Crown Consulting, Inc. 1400 Key Blvd, Suite 1100, Arlington, VA 22209			
		11. Contract or Grant No.	
		34689	
12. Sponsoring Agency Name and Address		13. Type of Report and Period Covered	
Ohio Department of Transportation 1980 West Broad Street Columbus, Ohio 43223		Final Report	
		14. Sponsoring Agency Code	
15. Supplementary Notes			
The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Ohio Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.			
16. Abstract			
The State of Ohio faces both opportunities and challenges with regards to future transportation systems. Advanced Air Mobility is a concept of air transportation that moves people and cargo between places not conveniently served by surface transportation or underserved by aviation. Driven by the economic and societal promise of AAM, the Ohio Department of Transportation (ODOT) commissioned this Economic Impact Analysis for Advanced Autonomous Aircraft Technologies in Ohio. This report forecasts the industrial and economic benefits of AAM systems and services through the year 2045.			
17. Keywords		18. Distribution Statement	
Advanced Air Mobility (AAM), Unmanned Air Systems (UAS)		No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161	
19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	89	

Form DOT F 1700.7 (8-72)

Reproduction of completed pages authorized

# Credits and Acknowledgements

Prepared in cooperation with the Ohio Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration

*The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Ohio Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.*

*The Crown team acknowledges and is thankful for the input of the many people directly involved and consulted during the performance of this effort. Special gratitude for guidance on this project goes to the Technical Advisory Committee members, including Fred Judson, Rich Fox, Jordan Collins of the Ohio UAS Center, and Tim Sweeney from JobsOhio*

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### *About Crown Consulting Inc.*

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Crown Consulting, Inc. is shaping the future of air transportation with concept development, design, and deployment of systems and aircraft. Crown brings more than three decades of experience working with aviation innovators and is a leader for innovation in advanced air mobility and intermodal transportation, air traffic management, and advanced aerospace systems that enable profitable commercial services, cost-effective government services, and communities of the future. Crown provided overall management of this project. Crown brought expertise in regulatory input, technical challenges, and potential implementation barriers of advanced air mobility (AAM), including the development of the use cases developed herein for small-unmanned air systems and AAM.

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### *About NEXA Capital Partners, LLC*

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NEXA Capital Partners, LLC, is a specialist investment bank providing corporate and strategic financial advisory services, market intelligence, and capital investment to the aerospace, transportation, logistics and geomatics sectors. For this project, NEXA Subsidiary UAM Geomatics, Inc. provided geospatial mapping and analysis of all relevant geographic features for the State of Ohio. NEXA subsidiary NEXA Advisors provided business case studies for the urban air mobility and advanced air mobility use cases developed herein. NEXA Advisors also performed in-depth economic impact analysis of job creation opportunities for the State of Ohio.

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### *About the University of Cincinnati*

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The University of Cincinnati's (UC) Department of Aerospace Engineering and Engineering Mechanics is intimately involved with the advancement of small unmanned aircraft systems and AAM technologies in the USA. The department is leading various efforts for UAS and artificial intelligence for the state. For this project, UC provided Ohio UAS technology insights and subject matter expertise for characterizing the aerospace supply chain for the state. UC supported the outreach to key national and state stakeholders and conducted an assessment of the potential impact of noise for AAM operation.

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## Executive Summary

The State of Ohio faces both opportunities and challenges regarding future transportation systems. In Ohio, surface traffic operations have grown to cost taxpayers over \$12 billion annually. The future transportation needs and expectations of Ohio citizens include a heightened emphasis on sustainability, affordability, and efficiency. Technological innovations and new business models offer enormous potential for innovative approaches to passenger and cargo mobility. Advanced air mobility (AAM) is a concept of air transportation that moves people and cargo between places not conveniently served by surface transportation or underserved by aviation, bringing urban and regional mobility into the third dimension.

Driven by the economic and societal promise of AAM, the Ohio Department of Transportation (ODOT) commissioned this economic impact analysis for advanced autonomous aircraft technologies in Ohio. The overall goal of this project was to forecast the economic benefits of advanced autonomous aircraft systems and services through the year 2045. There are many challenges associated with developing and applying a forecasting method that accounts for significant uncertainties—uncertainties in services, markets, technology maturity levels, and operating constraints. To obtain meaningful, policy-relevant benefit estimates, ODOT needs forecasts built on realistic assumptions on the nature of AAM products and services, their impacts on Ohio's own supply chain, and the constraints of the regulatory environment in which they operate.

The team followed a multi-step plan designed to deliver benefit estimates that account for technology and regulatory realities, emphasizing interaction among team experts in economics, AAM, and small Unmanned Aircraft Systems (sUAS) programs.

The first stage of the project was to gather industry perspectives on AAM and sUAS modes, technology readiness, and gaps in industry research by conducting a series of interviews and surveys with the most relevant and key stakeholders.

The second stage of the investigation phase required critical infrastructure to be identified, categorized, and mapped using ArcGIS, a geospatial mapping and analysis tool. Over 35 different data layers important to the implementation of AAM were researched, compiled, and loaded into the ArcGIS software to be mapped onto the State of Ohio.

The information obtained through the interviews, coupled with the analytical ArcGIS data, was used to develop the potentially most impactful use cases and were fed into the AAM Business Case Model to determine the region's ability to adopt and sustain AAM operations. ArcGIS infrastructure data was paired with over 100 other inputs to produce operating expenses (OpEx) and capital expenditures (CapEx) figures for ground infrastructure, development of infrastructure for Providers of Services for Unmanned Air Vehicles (PSU), total electric vertical takeoff and landing (eVTOL) aircraft expenditures, and operator revenues for passenger, cargo, and emergency medical use cases. Concurrently the sUAS cases were analyzed to forecast and qualify the efficiency, safety, productivity and societal benefits of its services.

Outputs from the AAM Business Case Model were then used as inputs to the AAM Economic Impact Model, calculating the total impact of AAM on the Ohio economy at three levels: the direct level, the indirect level, and the induced level, providing job growth forecasts and GDP estimates, in addition to tax revenues at the state and local levels.

The study produced important findings intended to guide the State of Ohio and its policy deliberations. These findings are supported by in-depth analytics guided by the experience of the senior team members working in the global AAM field.

The State of Ohio is well positioned to grow and sustain profitable AAM operations in urban, suburban, and rural areas over the 25-year forecast period.

- Commercial business activities among all pillars (revenues from operators and aircraft manufacturing, and capital and operational expenditures from providers of services for UAMA (PSU) and ground infrastructure) are expected to approach \$13 billion between 2021 and 2045 for six use cases of involving emergency services, passenger services and cargo movement.
- About 66% of the forecasted \$13 billion of value-added impact is considered direct and indirect; the remaining 34% from induced impacts
- More than 15,000 direct, indirect, and induced permanent, high-paying, full-time jobs are forecasted. Since the direct and indirect effects of AAM account for roughly two-thirds of the impact, we see that job types, or occupations needed, are closely aligned with the industries tied to AAM.
- More than \$2.5 billion in federal, state and local tax revenues is expected over the 25 years of the analysis. Local and state governments revenues account for \$464 million and \$542 million, respectively, while the federal revenues account for about \$1.5 billion. The local level represents totals for townships, cities, and counties for the entire state.
- The overall state-wide infrastructure revenue to investment (R/I) ratio is in the range of 2.2, suggesting that private capital sources will be attracted to make infrastructure investment.

The economic activity due to needed investment for ground and PSU infrastructure is estimated at more than \$1.4 billion over the 25-year forecast period.

- Investments in multiports will be needed in the future. Ohio's efforts with NASA Ames in vertiport planning are critical to better identify the most impactful locations of vertiports in urban environments within Ohio's largest cities. This work will inform future investments for new vertiports. However, immediate and near-term infrastructure investment will be concentrated in remediating existing heliports, adding airport multiport installations, and establishing logistic corridors PSU systems.
- Current Ohio efforts such as SkyVision, Ohio UTM and Remote Tower provide a strong foundation for investment to low-altitude air traffic management and PSUs systems. These efforts must be physically expanded to other areas, including investments in the PSU systems along the interstate corridors.

In addition, application of sUAS operations, although relative to AAM not bringing significant increase in direct job creation and economic benefit, will provide significant benefits by making more efficient use of resources (i.e., improving productivity), enabling the fidelity of data, increasing social benefits such as workplace safety, and decreasing the environmental impact of other operations. Use of sUAS will also significantly enhance the mission of execution of ODOT and other government entities by improving infrastructure inspection, and workforce operating efficiency and productivity.

The team provides actionable recommendations in four categories:

- Strategy, policy, and legislative framework
- Studies, demonstrations, pilot programs, and local AAM planning initiatives
- National AAM leadership activities
- AAM supply chain, manufacturing and service opportunities for Ohio

## Introduction

Driven by the economic and societal promise of advanced air mobility (AAM), the Ohio Unmanned Aircraft Systems Center (UAS Center) operating as part of the DriveOhio initiative of the Ohio Department of Transportation (ODOT) commissioned this economic impact analysis for advanced autonomous aircraft technologies in Ohio. The report, produced by Crown Consulting, Inc. (Crown) in partnership with NEXA Capital Partners, LLC (NEXA) and the University of Cincinnati (UC), forecasts the industrial and economic benefits of AAM systems and services through the year 2045 to inform ODOT's policy decisions.

### The Transportation Challenge

The State of Ohio faces both opportunities and challenges with its future transportation systems. Surface congestion is high increasing safety challenges and costing residents and the State time, frustration, and money.

Ohio is the seventh most populous state in the country and one of the most centrally located. As such, it has one of the largest highway networks. According to a report by TRIPNET.org<sup>2</sup>, the annual statewide cost of congestion of the five major metropolitan areas in Ohio alone is more than \$4.6 billion (see Table 1).

Ohio citizens expect increased safety, sustainability, affordability, and efficiency with regards to their transportation needs. At the same time, technological innovations and

new business models offer enormous potential for new approaches to passenger and cargo mobility. Bringing urban and regional mobility into the third dimension—the airspace—may support cities to enlarge their smart mobility solutions portfolio by offering multimodal and integrated commuting solutions that are faster, more sustainable, safer, reliable, less stressful, and affordable.

### The Potential of AAM

#### What Is AAM?

AAM is a concept of air transportation that moves people and cargo between places not conveniently served by surface transportation, or underserved by aviation—local, regional, intraregional, urban—using revolutionary new aircraft that are now becoming possible. The vision of AAM relies mostly on eVTOL (electric vertical takeoff and landing) aircraft carrying passenger or cargo, and small unmanned aircraft systems (sUAS). The aircraft are envisioned to be powered by hybrid electric systems, batteries, or, at some point, hydrogen fuel cells.

**Table 1: TRIPNET.org Vehicle Operations, Safety, and Congestion Costs (in \$Million) for Selected Ohio Cities**

	Vehicle Operations	Safety	Congestion	Total
Cincinnati	\$574	\$391	\$1,057	\$2,022
Cleveland-Akron	\$873	\$306	\$1,001	\$2,180
Columbus	\$557	\$352	\$997	\$1,906
Dayton	\$649	\$460	\$631	\$1,740
Toledo	\$468	\$525	\$983	\$1,976

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<sup>2</sup> Modernizing Ohio's Transportation System: Progress and Challenges in Providing Safe, Efficient and Well-Maintained Roads, Highways and Bridges (2018)

AAM is an emerging technology landscape with the potential for robust positive socio-economic impact. It is also a key element in our nation’s emerging transportation system as it promises to be more environmentally friendly, more efficient, and more accessible to our entire population (urban and rural). Advances in technologies for high-density energy sources providing electric power enable aircraft to operate more simply, more reliably and more efficiently. Advances in automation enable more robust and high volume operations with reduce pilot requirements. These technological advances combined with advances in materials and reduction in aircraft maintenance, reliability and operation complexity brings more cost efficiency for many short-range aviation missions.

AAM’s potential first became evident when sUAS arrived on the market to provide new efficient and safer ways to inspect and monitor infrastructure and agriculture, lead search and rescue efforts, respond to natural disasters and emergencies, and recently to deliver medical tests and products, as well as foods and other goods. In Winston-Salem North Carolina, UPS is already using sUAS to deliver a time-critical pharmaceutical product in minutes across a sprawling hospital campus, vastly speeding up delivery of important medicines. Zipline is racing personal protective equipment to healthcare workers and patients in Charlotte in response to COVID-19, and UPS is delivering blood test samples in minutes across another hospital campus in Raleigh, shaving more than an hour off previous delivery times.

Recent industrial innovations have produced dozens of electric and hybrid-electric powered small aircraft capable of providing services to the public, from medical transport to large cargo movement to air taxi services. These new aircraft provide services that will enhance our lives with on-demand mobility and open the door more widely to affordable access to health care services, especially for rural areas of the country.

Companies are planning to transport critical medical tests and equipment, organ transplants, and even health care professionals to patients and emergency scenes and return accident victims to the hospital quickly, safely, and efficiently. Large package delivery operators such as UPS, FedEx, and Amazon are planning new methods of delivery to and from sort facilities and distribution centers while avoiding surface traffic congestion that often slows down last-



Figure 1: Beta Technologies UPS eVTOL

mile delivery by hours. Small and regional air service operators are considering newer, more efficient, and faster ways to provide their services, not just between major airports but to outlying rural communities, and at least one large ride-hailing service is developing platform services to enable air taxi services from downtown urban centers to airports and other transportation hubs. Recently Beta Technologies announced a deal with UPS to deliver over 150 aircraft for regional delivery (Figure 1).<sup>3</sup>

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<sup>3</sup> <https://evtol.com/news/beta-technologies-ups-deal-150-evtol-aircraft/>

This AAM vision will have broad financial implications. According to a recent report for NASA by Booz Allen Hamilton on the potential impact of Urban Air Mobility,<sup>4</sup> “Airport Shuttle and Air Taxi markets are viable markets with a total available market value of \$500B at the market entry price points in the best-case unconstrained scenario.” A concurrent study for NASA by Crown and McKinsey<sup>5</sup> concluded that AAM is “likely to be a commercially viable market with both parcel delivery and air metro operations by 2030,” projecting more than 500 million last-mile parcel deliveries and more than 740 million passenger trips. In addition, analysis performed by companies such as Morgan Stanley<sup>6</sup> and NEXA Advisors/UAM Geomatics<sup>7</sup> forecast a \$1.9 trillion market opportunity by 2045.

### Issues/Barriers of AAM

As with any great technological leap forward, especially one that will impact the lives of so many people, AAM must overcome numerous barriers before it can be implemented in a community, including:

- Interoperability standards, needed to facilitate and reduce time to market for aircraft manufacturers, fleet operators, and infrastructure and facilities managers, while at the same time imposing extremely high levels of safety for passengers and the communities of operation.
- Adequate capital and venture investment, required for development and commercialization of aircraft, control systems, and operational models. While venture, corporate, or institutional funders are closely watching, investment can only be forthcoming if supported by local business cases with reasonable cash-on-cash returns flowing within sensible timelines.
- Infrastructure investment are necessary to fund systems for urban air mobility traffic management (UTM), and systems for Providers of Services for Unmanned Air Mobility (PSU) that integrate sUAS and AAM eVTOLs into the existing airspace and vertiports (new landing and takeoff facilities) to facilitate cost-efficient and convenient passenger access.
- Sufficient market demand, including commercial, industrial, and consumer customers, where value delivered may significantly exceed cost.
- Public acceptance of these new systems and services, driven by positive perceptions of safety, mobility value, cost effectiveness, and affordability.
- Privacy, environmental impacts such as noise, and in some cases, property rights, which will weigh in this dimension, often at the local level.

During this study, we put special emphasis on the potential impact of noise to the evolution of AAM operations. It is believed that if AAM systems create unacceptable noise pollution in their operational communities, the potential economic benefits could be severely limited. The vision for AAM operations would realize hundreds or thousands of daily operations in populated urban, suburban, and rural environments. These aircraft would take off from vertiports in densely populated urban environments and fly over neighborhoods and communities at altitudes much lower than current commercial aircraft. The noise signature of these aircraft will be unlike any

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<sup>4</sup> “Urban Air Mobility Market Study” (<https://ntrs.nasa.gov/citations/20190000519>)

<sup>5</sup> “Urban Air Mobility Market Study” (<https://www.nasa.gov/sites/default/files/atoms/files/uam-market-study-executive-summary-v2.pdf>)

<sup>6</sup> <https://irei.com/news/morgan-stanley-flying-care-preparing-takeoff/>

<sup>7</sup> *Urban Air Mobility: Economics and Global Markets 2020-2040*. [www.nexa-uam.com](http://www.nexa-uam.com)

existing aircraft or helicopter, and the human response to these noise signatures is still unknown, but early research indicates that annoyance levels are still not well understood and may be in some cases higher due to the specific frequencies and tonal nature of the acoustic signatures. Appendix C: Noise and AAM presents in depth our findings and recommendations for the needed next steps to continue to gain understanding of this critical issue.

## Ohio and AAM

Ohio is keenly aware that a state that invests now in transforming itself into a center for AAM and sUAS technology adoption will reap first-mover benefits—top talent and wide-ranging investment opportunities—as well as significant benefits for its taxpayers including reduced congestion, increased technology industries and jobs, robust economic activity, and a larger tax base. ODOT intends to apply AAM for the safe, efficient, and equitable transportation of goods and people throughout the state. AAM is a strategic growth area for Ohio’s aerospace sector and enterprises within the state have made significant contributions to the research, development, and integration of AAM.

Ohio’s vision builds on the state’s long legacy in aerospace, embedded in the national consciousness as the birthplace of aviation and the birthplace of the first men to orbit the earth and walk on the moon. The Air Force Research Laboratory (AFRL) at Wright Patterson Air Force Base and NASA’s John H. Glenn Research Center (NASA Glenn) are major aerospace research hubs. AFRL’s AFWERX program spearheads innovation in AAM through the Air Force Agility Prime program. In addition to these federal laboratories, the state’s more than 550 aerospace companies and the numerous vibrant university-based research facilities, offer a rich ecosystem of aviation-related talent. Ohio is the nation’s largest aerospace industry supplier, with a workforce of more than 38,000 in the aviation and aerospace private industry. In addition, private and non-profit organizations, such as JobsOhio and the Ohio Federal Research Network (OFRN), support a statewide integrated approach to advancing technology and economic development.

The rapid evolution of the AAM and UAS sectors now brings dozens of new opportunities and initiatives in a to-be-defined industry and workspace to Ohio. As a tool to enable new modes of commerce and trade, Ohio intends to tap the full economic and efficiency benefits of optimally designed and operated lower altitude airspace. In the near future, Ohio will face many decisions, including:

- Prioritizing and phasing projects.
- Encouraging development where technology and implementation gaps exist.
- Investing in technology and infrastructure with viability, scalability and sustainability in mind.
- Deciding what investments have the most impact on critical AAM and UAS supply chains served by Ohio manufactures and suppliers.

To obtain meaningful, policy-relevant benefit estimates, ODOT needs forecasts built on realistic assumptions on the nature of AAM products and services, their impacts on Ohio’s own supply chain, and the constraints of the regulatory environment in which they operate. Appendix D highlights several of the state’s ongoing AAM and sUAS programs and initiatives.

## Study Goals and Objectives

Studying how AAM will integrate into and enhance Ohio’s transportation infrastructure is an important goal for ODOT to maintain its lead in aviation and to prepare for this exciting new future of transportation by air.

The goal of this study was to complete an AAM economic impact report for managed air corridors for the State of Ohio connecting Ohio's major urban centers. The team had five objectives:

Objective 1: Forecast economic effects and benefits of AAM for Ohio based on expert opinions.

Objective 2: Guide Ohio in attracting and sustaining AAM operators and businesses.

Objective 3: Predict Critical AAM and sUAS Supply Chains Embedded in Ohio.

Objective 4: Model viable AAM and sUAS use cases.

Objective 5: Understand the industry's perspectives on the evolution of AAM.

The approach undertaken in this effort was designed to consider these questions:

- What is the business and commercial opportunity for AAM and sUAS, and what does it look like from the standpoint of infrastructure costs and manufacturing?
- Does existing infrastructure in Ohio, including airports, heliports, logistics corridors, air traffic management systems, and others, provide a starting point?
- Can AAM and sUAS operators expect to become profitable, and can this profit be sustained over a 25-year period?
- Will these same operators be able to fund and eventually support new infrastructure?
- Will passenger and cargo services built on eVTOL aircraft become affordable and add value such as GDP growth and new jobs to Ohio's economy?
- What kinds of jobs will need to be filled, and will Ohio's system of schools and universities be capable of training them?
- What are the supply chains that will play an essential role in realizing AAM for Ohio, and are they already present in the state?
- Are there going to be meaningful economic and catalytic benefits for urban and rural areas of Ohio?
- What will be required by the taxpayers of the State of Ohio to kickstart and support this new economic sector?

To answer these and other questions, the team developed a multi-track approach to deliver appropriate findings with perspectives and to quantify results whenever possible.

## Methodology

### Overview of the Approach

As shown in Figure 2, the team followed a multi-step plan designed to deliver benefit estimates that account for technology and regulatory realities, emphasizing interaction among team experts in economics, AAM, and Ohio's UAS programs.



**Figure 2: Study Methodology**

After ensuring mutual understanding with ODOT on goals and objectives, the team proceeded to bring industry perspectives on AAM and sUAS modes, technology readiness, and gaps in industry research by conducting a series of interviews and surveys with the most relevant stakeholders. Concurrent with the interviews, team members began assessing and inventorying existing transportation infrastructure available throughout the State of Ohio using ArcGIS. This geospatial mapping and physical inventorying tool provided unique capabilities for applying location-based analytics. The team documented over 35 layers of information that will become indispensable when designing and operating new airborne systems within the State of Ohio.

The information obtained through the interviews, coupled with the analytical ArcGIS data, was used to develop the potentially most impactful use cases and were fed into the AAM Business Case Model to determine a region's ability to adopt and sustain AAM operations. ArcGIS

infrastructure data was paired with over 100 other inputs, such as PSU systems costs, aircraft supply constraints, and passenger demand curves, producing operating expenses (OpEx), and capital expenditures (CapEx) figures for both PSU and ground infrastructure development, total eVTOL aircraft expenditures, and operator revenues for passenger, cargo, and emergency medical use cases, defined later.

Outputs from the Business Case Model were then used as inputs to the Economic Impact Analysis Model, using the economic assessment tool IMPLAN.<sup>8</sup> IMPLAN calculates the total impact of AAM on the Ohio economy at three levels: the direct level, the indirect level, and the induced level. These calculated impacts provide job growth forecasts and GDP estimates, in addition to tax revenues at the federal, state, and local levels.

## Interviews with Key Stakeholders

The first stage of the investigation phase included collecting insight, through interviews or survey questions, from key stakeholders, including industry, government, and academia. AAM and sUAS have the potential to impact a large part of the economic landscape, and interview plans were designed to engage a diverse input to the process. The targeted stakeholders included those with current or potential presence in Ohio.

Based on earlier experience, the importance of in-person interviews was given priority. However, due to time and resource constraints, the team also identified the key stakeholders who could provide the most value during a one-hour interview, with other stakeholders receiving a survey to complete. This resulted in a wealth of information, which helped validate the use-case scenarios and provided reference when reviewing the demand-and-benefit forecasts produced by the team.

The team reached out to 54 potential interviewees, with 29 responding. Although it was not expected that all those contacted would respond, the 50% response rate could be attributed to a variety of factors, including the time of year and challenges faced during the COVID pandemic. Also, some industry partners were unwilling to share their market focus and looked to protect their strategic plans. Nonetheless, the team was able to engage the key stakeholders identified in Table 2.

The survey questions were used during the one-hour interviews conducted virtually, which proved beneficial, allowing more flexibility for the interviewee and a greater interview team participation. The format of the interview included an overview of the project, ODOT's AAM focus, including the broader vision, and an overview of Ohio's initiatives such as SkyVision and the US-33 UTM Research Project. The questionnaire helped guide the conversation, allowing the interviewer to pivot to dynamically respond to the interviewee's answers. In some cases, the interview team had worked with the partner over the years and had an established relationship. In other cases, this was the first time the interviewee was being briefed on AAM work in Ohio, and the initial discussion led to follow-up conversations on how to collaborate with the ODOT team on future opportunities. An added benefit of the stakeholder engagement was the greater national visibility with leading AAM stakeholders.

For those unable to be interviewed by the team, the questionnaires were sent via email to be completed within a specified timeline. This allowed the team to engage a broader group of key stakeholders outside of the interviews.

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<sup>8</sup> <https://www.implan.com>

**Table 2: Interview Participants by Categories**

Operators	Manu-- facturers	UTM/PSU	Airports	Cities	Federal Agencies	Academia	Economic Development
FedEx	Matternet	AirMap	Ohio Airports Association	Columbus	NASA Glenn Research Center	University of Cincinnati	Ohio's 33 Smart Mobility Corridor - Councils of Government
UPS Flight Forward	Moog	ANRA Technologi es	Cincinnati/ N.Kentucky Internation al Airport (CVG)			The Ohio State University	JobsOhio
Uber Elevate	Alaka'i	Kitty Hawk	Cincinnati Municipal Lunken Airport (LUK)			Georgia Tech	
Wing	Kelkona		John Glenn Columbus Internation al Airport (CMH)				
Ohio Dept. of Public Safety			Rickenback er Internation al Airport (LCK)				
City of Columbus Division of Police			Bolton Field (TZR)				
Ohio Depart- ment of Trans- portation			Cleveland Hopkins Internation al Airport (CLE)				
			Akron- Canton Airport (CAK)				
			Lorain County Regional Airport (LPR)				

The team also recognized that engaging key industry stakeholders and asking questions about their future plans would require a level of confidentiality, since the team often engaged multiple partners competing against each other in the AAM space. The team drafted a confidentially

release form that offered three levels of visibility in the public report. This provided a path for industry to contribute to the study, while not revealing their strategic growth plans publicly.

### ArcGIS Methodology (Mapping of Existing Infrastructure)

Concurrent with the interviews, team members began assessing and inventorying existing transportation infrastructure available throughout the State of Ohio using ArcGIS. This geospatial mapping and physical inventorying tool provides unique capabilities for applying location-based analytics. Contextual tools are also able to visualize and analyze geospatial data via maps, datasets, algorithms, and reports. The team documented more than 35 layers of information that will become indispensable when designing and operating new airborne systems within the State of Ohio. These layers, shown in Table 3, were researched, compiled, and loaded into the ArcGIS software to be mapped onto the State of Ohio.

**Table 3: Documented Data Layers Loaded into the ArcGIS Software**

35+ Data Layers	
Demographic Information Overlay	Colleges and Universities
General Aviation Airports	Water and Shipping Ports
Commercial Airports	Military Bases and Airports
Roadways	Agriculture Zoning
Highways	Laboratories
Waterways	Fire Stations
Political Boundaries	Police Stations
Hospitals	Noise Measurement TIMS
Cargo Rail Stations	Towers/Antennae
Ports	Helipad Confirmation
Part 135 Operator Fleets and Lists	Passenger Rail Stations
Airport O/D, A/D, Fleet, FBO Data	Power Grid
Logistics Centers	Air-Based Cargo Hubs @ Airports
Manufacturing Plants	Major Shopping Centers
Headquarters of Fortune 1000 corporations	Major Music Venues
Major Local Employers	Government Facilities—Federal, Local
Major Sports Venues	MSA Demo Layer
Ohio Bridge Database	

With those layers, the ArcGIS analysis tools provide insight on critical infrastructure within given parameters. For example, we can determine how many helipads are within a city’s metropolitan statistical area (MSA) or how many manufacturing and logistics centers are within five miles of Interstate 71. The tool provides myriad analysis options that offer the most accurate inputs for the business case model.

### Business Case Model Methodology

#### AAM Passenger and Emergency Services Methodology

In addition to the geo-coded datasets, the Business Case Model analysis makes use of more than 100 additional sources of information necessary to perform demand and costing analysis, and to aid in estimating capital and operating costs for AAM ground facilities and UTM traffic management facilities, as described in Table 4.

**Table 4: Sources of Economic Information**

<b>Ancillary Data Useful for Cost and Demand Modeling</b>	<b>UAM Ground Facility Cost Inputs</b>	<b>PSU Facility Cost Inputs</b>	<b>Other Demand Inputs</b>
Population	Urban Planning Study Costs	UATM One Time Facilities Planning	Drivers of Cost of UTM
Population Density	Site Selection Study Costs	Finalization of InterOperability Standards	Passenger Traffic (Pass Per Day)
GDP in million purchasing power parity (PPP)	Environmental Study Costs	Site/Network Selection Studies	Average Vertiport/Heliport Nodes
Median Per Capita Income	Airspace Flight Approach Study	Systems Specifications	Flight Operations (Flights per Day)
Electricity Cost	Concession Agreements	Power Grid Studies	Other TBD
Jet Fuel Cost	Secure Project Financing	NOC Architecture/Interface with ANSP	
Average Taxi Cost Per Mile	Purchase Land/Lease Equivalent	Cyber Security Architecture	eVTOL Avionics - Incremental Capability Costs
Public Transport Cost	Acreage and Cost/Acre (varies by city)	Physical Security Architecture	GPS/DGPS/GNSS
Vehicle Ownership Cost	Construction Permitting Costs	Network Operations Center	Inertial/MEMS
Cost of Living	Architectural and Engineering Costs	Facilities (Offices) Rental Costs	Beacon Navigation System
Average Monthly Net Salary	Site Preparation	SQFT	Data Comm (Enhanced 5G)
2018 Business Arrivals & Departures	Site Construction	Cost/Sq Ft	Voice Comm
Cities in Motion Index Human Capital	Foundation or Building Modification	Annual Rent	Weather Information System (ADS-B In)
Distances from City Center to Largest Airport	Platform(s)	Geographic and Dynamic Geofencing Tools	LIDAR
City Total Area (Sq Mi)	Egress, Elevators, and Walkways	Furnishings	Kalman Filter Modules
Fortune G1000 Companies	Passenger Shelters or Larger Facilities	Big Data Analytics HW/SW	Advanced Display Screens for Passengers
Fortune G1000 Market Size	Parking	Automation Systems and Stations	
Fortune G1000 Employees	Lighting - General	Flight Decision Support Tools	Helicopter Fleet Operators (Part 135)
Airport Passenger Origins & Departures	Lighting - Landing Pad/Taxiways	Flight Plan and Flight Operations Database	Operator Type
Part 135 (or equivalent) Operators	Landing and CNS Systems	SCADA for Systems and Networks	Operator Name
Company Profile	IT and Security Systems	Computers and Equipment	Operator Fleets
Company Contact Info	Furnishings	Power Grid and Backup Systems	Aircraft Manufacturer
Personnel Profile with Contact Information	Power Grid Upgrades	Field Networks	Aircraft Model

Ancillary Data Useful for Cost and Demand Modeling	UAM Ground Facility Cost Inputs	PSU Facility Cost Inputs	Other Demand Inputs
Commercial Aviation Aircraft Fleet	Inspections	Network Design and Site Selection Studies	Aircraft Variant
Manufacturer	FAA Permitting and Certification	Weather Information Systems - Areal	Aircraft Full Name
Model Variant	Refueling Capability and Systems	Micro Weather Detection Sensors	Related Engine Model
In Service or Stored	Recharging Capability and Systems	Beacon Navigation Nodes	Aircraft InService
On Order	Fire Suppression Systems	Resilient Communications Nodes	Aircraft Stored
Grand Total	Airspace Approach Templates	High Density Radar	Aircraft OnOrder
Leased In	Aeronautical Chart Preparation	Annual UATM Operations Costs	Aircraft Average Age
Leased Out	Total CAPEX	Headcount	Owner Info
Average Age	Annual Operating Costs	Director/Managers	Name
Engine Type/Variant	Labor - Operations	ATC Specialists	Phone
	Labor - Facility Maintenance	Data Analytics Specialists	Fax
	IT and Security	Maintenance and IT Technicians	Email
	Power and Utility Services	Field Support Personnel	Website
	Other	Administrative Personnel	Year Founded
	Total OPEX	Other Professional Personnel	Business Types
	UATM Cost Inputs	Total Headcount	Total Employed
		Annual Salary (\$'000)	Military Supplier
		Director/Managers	Small Business
		ATC Specialists	Disadvantaged Business
		Data Analytics Specialists	Helicopter Related
		Maintenance and IT Technicians	Space Related
		Field Support Personnel	FAA Repair Station
		Administrative Personnel	ISO9000
		Other Personnel	Sales Dollars
		Labor - Operations	Sales Euros
		ANSP Servicing Fees	Sales Pounds
		Annual Rent	Sales Yen
		Facility Overheads	Cage Codes
		Geofencing Services	
		Legal and Accounting	
		Telecom, IT, and Security	
		Power	
		Other	

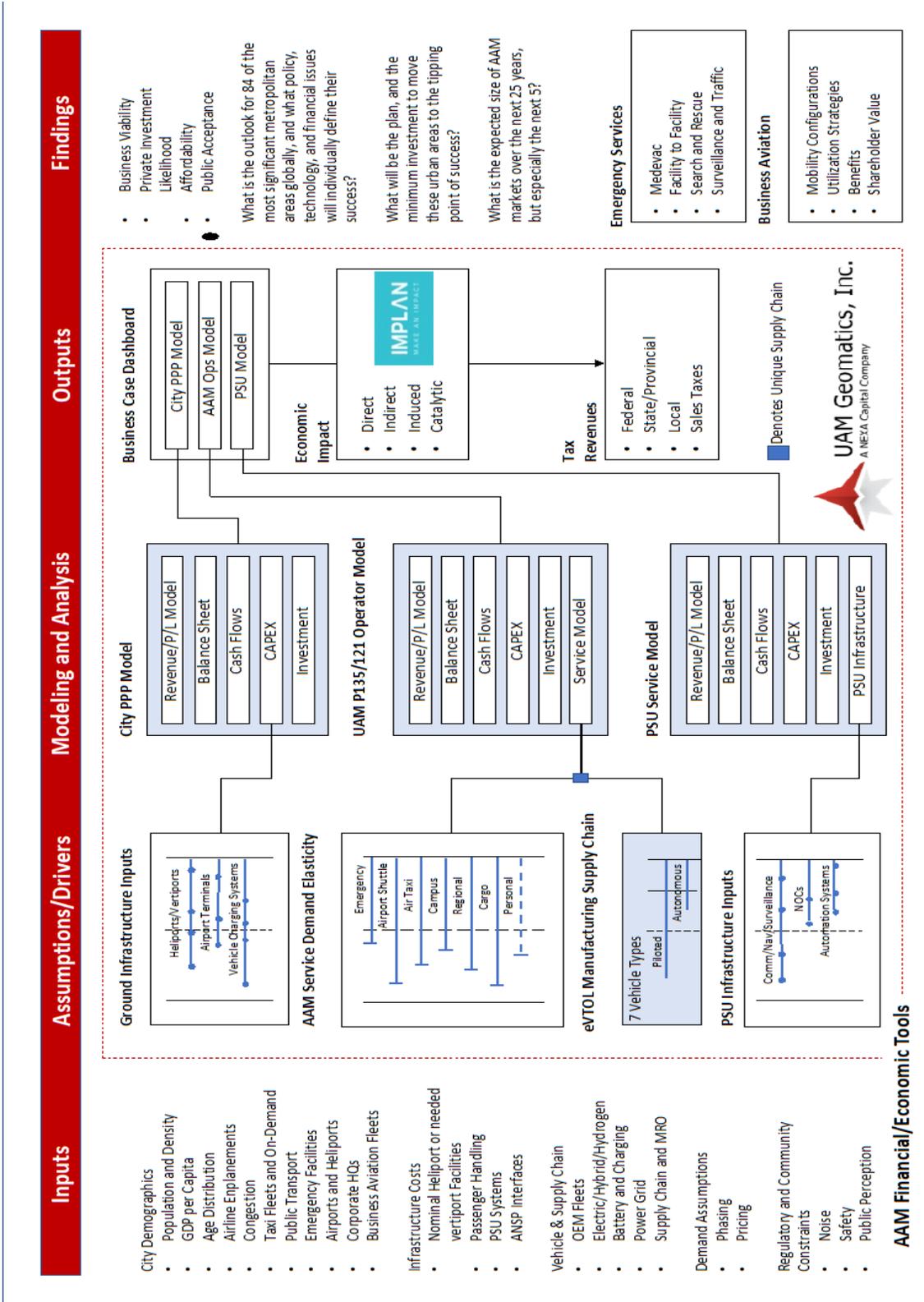


Figure 3: Study Analytical Framework

Team members bring experience forecasting the emerging trends and global market opportunities in AAM aircraft, systems, services, and infrastructure to explore new concepts in AAM products and services, and develop future revenue and market forecasts. The toolset also uses econometric forecasting to determine the size, composition, and probity of the market impacts by country and urban area. The analytical framework for the study is presented in Figure 3.

Key to this analysis tool is the three business case models in the center of the diagram. The tool accepts assumptions used for input drivers of each model:

- Aircraft Operators: Airport shuttle, on-demand air taxi, regional transport, corporate campus to destination, medical/emergency services, and cargo.
- Public/Private/Partnership model for AAM ground infrastructure.
- Public/Private/Partnership model for PSU infrastructure.

By modelling these three classes of stakeholders, we were able to ensure profitability on all fronts. The costs of these three entities are all accounted for when calculating ticket price. This allows for reasonable return horizons on the infrastructure, as well as profitability in the case of the operators. We posited the following investment thesis: for a city market, or in the case of Ohio, a region, to reach sustainable AAM revenue activities, operators and infrastructure investors must achieve profitability break-even success or, as a better outcome, a profitable bottom line.

Passenger demand is one of the most important inputs for the model, and for this forecast, the study team carefully developed supply and demand assumptions based upon a dynamic range of elastic and inelastic ticket prices.

There are, however, some fundamental questions that cannot be answered through financial and economic analysis. For example:

- Will Ohioans embrace these new services, finding sufficient value from improved AAM, thereby offsetting ticket prices?
- Will an extensive network operation involving dozens of aircraft flying above residential areas, generating noise and visibly daunting, find acceptance?

### Key Assumptions and Findings on AAM Ground Infrastructure

In our report's 25-year forecasts, the team used the following macro assumptions while estimating the cost and schedule for AAM ground infrastructure:

- A large percentage of existing public, private, and unregistered heliports are first remediated to provide a baseline to support early eVTOL services before expansive new construction is undertaken.
- Certain numbers of heliports and vertiports are built or retrofitted to provide hybrid aircraft refueling, electric charging or fuel cell charging on a city-by-city basis. The estimated costs of such charging facilities or services are rolled into the ground infrastructure costs.
- All airports within a given city's economic catch basin, whether commercial air transport or general aviation/business aviation, will receive investment in vertiport facilities and AAM traffic management services to permit safe passenger handling and eVTOL traffic volume.

## Regional Analysis

To understand the dynamic needs of Ohio on a statewide basis, the methodology needed to be adapted. To accomplish this goal, the traditional MSA areas used as inputs in the models were expanded to include the state in its entirety. The counties that had not been captured by the traditional MSA breakdown were the more rural counties in the state. They were then grouped with one of the existing MSA groups. This was informed by the economic development regions from JobsOhio. These new composited statistical areas (or CSA) were formed based on economic interdependencies between the rural counties and their paired metropolitan area. Figure 4 shows the grouping.

### Importance of Business Case Tool for Infrastructure Financing

AAM ground infrastructure to support eVTOL operations will become a key prerequisite and enabler to sector success. As with other forms of transportation, AAM has specific infrastructure needs, which will also drive economic development and business investment. Research has shown that this is even more significant in global economies where economic opportunities have been increasingly related to the mobility of people, goods, and information. This is related to the quantity and quality of transport infrastructure in urban areas and the level of development needed. High-density transport infrastructure and highly connected networks are commonly associated with increased levels of economic growth, market development, and GDP output. AAM will have the most economic impact in the second decade of our forecasts.

While heliports and vertiports could have multiple landing zones with elaborate passenger handling features, most do not. The basic elements of a heliport are clear approach and departure paths, a clear area for ground maneuvers, final approach and takeoff area (FATO), touchdown and liftoff area (TLOF), safety area, and a wind cone. Figure 5 shows a typical heliport layout. This minimal facility may be adequate as a private-use-prior-permission-required (PPR) heliport and may even suffice as the initial phase in the development of a public use heliport capable of serving the emerging AAM segment of the helicopter and eVTOL community. The planning and organization required to properly design and construct new facilities is not trivial, involving the physical, technical, and public interest matters in the planning and establishment of a vertiport. For example, one of key differentiators of eVTOL ports is the flexibility provided by allowing for taxing, in addition to the vertical takeoff. For our work in Ohio, AAM infrastructure costs have been estimated for a viable ecosystem to be able to sustain itself on a city-by-city basis, using data collected from many industry experts. We estimate, for each of metropolitan areas, the entire life-cycle costs for sustainable operations. Beginning with the estimate that a single heliport platform can be remediated from

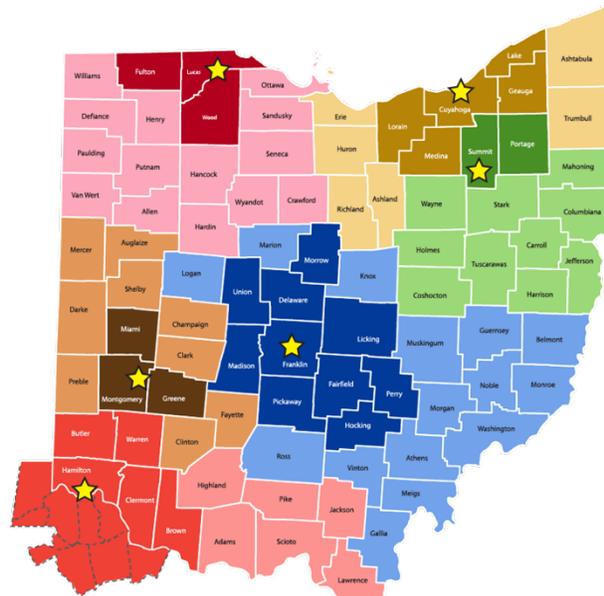


Figure 4: Map of Selected Regions by County

an existing state to one focusing on passenger convenience at a cost of under \$1 million, other cost elements include passenger facilities, lighting systems, airspace planning, and certification costs, all of which are included in our analysis.

PSU infrastructure-related costs, including automation platforms capable of urban eVTOL air traffic management, as well as resilient wireless communications systems, augmentation of GPS through

navigation beacons, and weather-related sensors, form an additive infrastructure category treated separately. AAM can provide a wide swath of benefits covering consumers and businesses, and supply chains dependent upon logistics. We identified the requirements and costs for densely placed heliports and vertiports in urban areas, as well as those suburban, exurban areas, and airports that will benefit from improved linkages within and between nodes. Importantly, airport elements will be identified at commercial, business, and general aviation airports, and at seaports and rail merge points. Ohio will also see a need to build out PSU infrastructure along its five main logistics corridors. These routes will see a high demand for time-sensitive cargo to be flown to many destinations between cities.

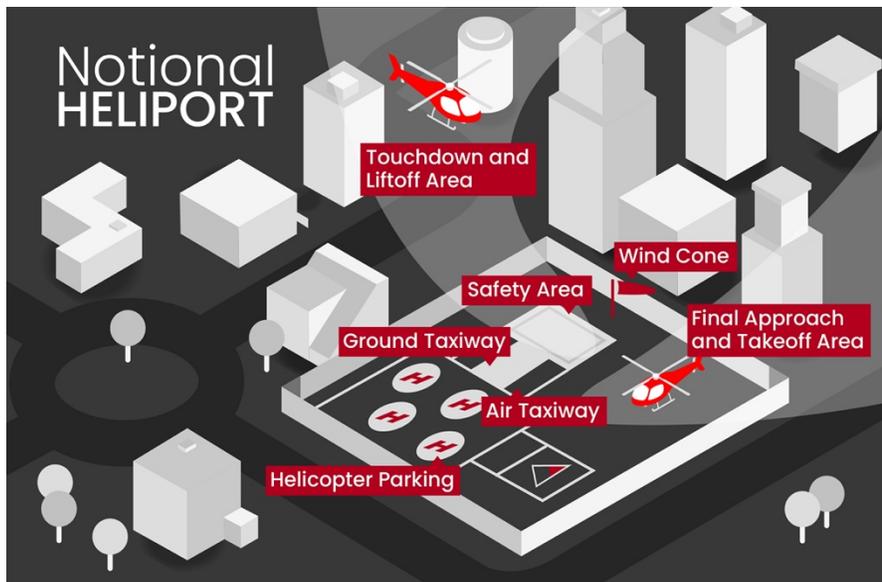


Figure 5: Notional heliport

### Cargo and Freight Delivery Methodology

In addition to the business case analysis for traditional AAM passenger use cases, a statewide heavy cargo and freight delivery eVTOL market analysis is presented. To determine the revenue potential of Ohio's eVTOL cargo market, we obtained existing air freight and trucking data from the Bureau of Transportation Statistic's Freight Analysis Framework 4 tool. The FAF4 tool provides both historical and projected freight movement data for the United States, categorized by commodity.

Both air freight and truck freight projections were used as inputs for the eVTOL cargo market model. These initial inputs were distilled to the eVTOL cargo market potential by three different filters, based on our stated assumptions: eVTOLs will transport cargo that is: 1) time Sensitive, 2) within payload capacity, and 3) high value.

First, the inputs were sorted by commodity codes and filtered by only time-sensitive commodities. Of the initial Standard Classification of Transported Good (SCTG) codes, the commodity categories relevant to eVTOL operations were Precision Instruments, Electronics, Machinery, Pharmaceuticals, and Perishables.

Next, the subcomponents of each of the five commodity categories stated above were assigned to a weight class. Commodities that were over 1,000 lbs. or under 50 lbs. were not considered. Each weight class corresponded to a market share percentage for each SCTG Code

subcomponent. These percentages based on weight class were applied to Ohio's freight projections to further sort for the eVTOL cargo market potential.

Finally, subcomponents were filtered by value classes. We assumed that eVTOL cargo operations would cater to high value, given the cost of eVTOL use compared to traditional freight modes. SCTG Code subcomponents were assigned a value class and a corresponding market share percentage that was applied to the inputs.

After sorting by time-sensitive and high-value goods between 50-1,000 lbs., we arrived at the eVTOL cargo market potential. To understand what share of this total market potential cargo eVTOL operators could capture, we applied five different exogenous factor constraints over the 25-year period to reach a conservative estimate of the annual eVTOL cargo market share. This market share was then distributed among five Ohio logistics corridors based on current and projected freight flow percentages along those routes. The five logistic corridors were defined around four interstate highways (I-70, I-71, I-75 and I-80) and the U.S. Highway 33. Figure 6 is an ArcGIS representation of the five Ohio corridors, showing the many distribution centers across the state.

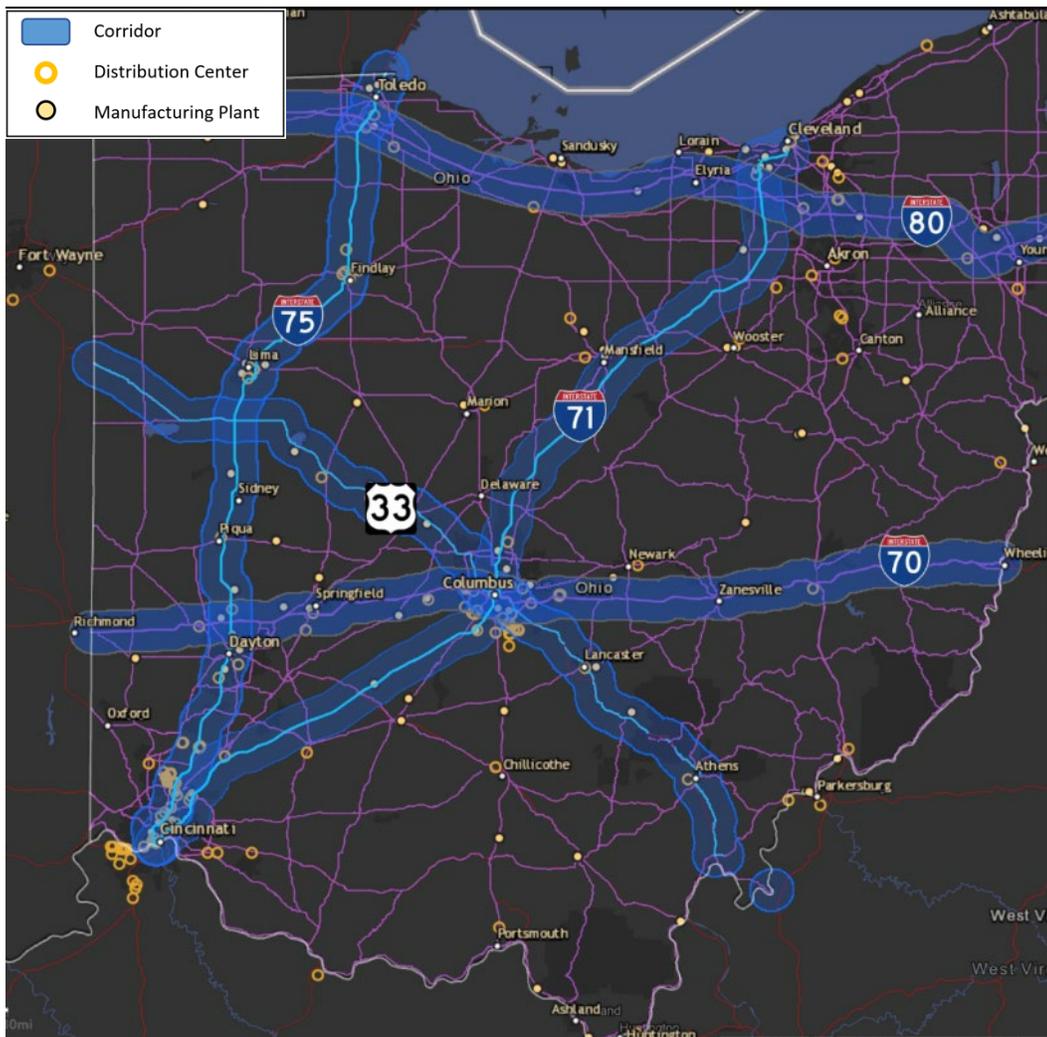


Figure 6: Ohio Logistics Corridors

## Economic Impact Tool Methodology (Implan Methodology)

To undertake a 25-year economic impact assessment of AAM for the State of Ohio, the team used the IMPLAN input/output modeling tool in combination with a previously developed 84-city business case analysis model featuring six Ohio cities: Akron, Cincinnati, Cleveland, Columbus, Dayton, and Toledo. The combination depicts the most accurate possible impact assessment of the benefits AAM will deliver to Ohio. These results will help mobilize Ohio's resources to act on the AAM opportunity and seize a first-mover advantage in a \$1.9 trillion market meant to improve safety, mobility, and economic growth.

In economics, an input/output model is a quantitative methodology that represents the interdependencies between different branches of a national economy or of regional economies. The IMPLAN input/output model depicts inter-industry relationships, showing how output from one industrial sector may become an input to another industrial sector. In the inter-industry matrix, column entries typically represent inputs to an industrial sector, while row entries represent outputs from a given sector. This format shows how dependent each sector is on every other sector, both as a customer of outputs from other sectors and as a supplier of inputs. This inter-industry relationship is expressed in the form of industry coefficients, or multipliers, that depict the rate of change of output among a set of interdependent industries, from a one unit increase in output by one industry.

IMPLAN's defines Output Multiplier as describing the total output generated as a result of one dollar of output in the target Industry. Thus, if an output multiplier is 2.25, that means that for every dollar of production in this Industry, \$2.25 of activity is generated in the local economy—the original dollar and an additional \$1.25.

Econometric and input-output models contain assumptions; after all, if every variable were known, we would have a list of facts and not a forecast. The most important assumption derived from our business forecast for Ohio includes the insertion of an “inflection point”—the introduction of highly automated flight systems requiring less human intervention. For example, an emerging view of AAM over the next 25 years is that cockpit automation will be necessary to improve the integrity and thus the safety of this new market sector. Automation should eliminate pilot error, enforce sense-and-avoid rules, and safely separate all aircraft, including eVTOLs and sUAS. Automation will reduce the cost of operations, as well as the demand for human operators. The cost structure of the entire industry will be dramatically impacted in synchronization with the expansion of aircraft and airspace capacity. The economic impact assessment in this report accounts for the inflection point, as will be reflected in the economic charts examined later. This is done through the input phase, whereby the model factors in automation and its impact on the overall AAM business case.

IMPLAN's input-output model also comes with certain assumptions and limitations. The first is the constant returns to scale: the same quantity of inputs is necessary to produce the additional unit of output. So, if outputs increase 10%, so too will the inputs. Second, it assumes no supply constraints: there are no restrictions to materials or labor, which may otherwise affect production capacities and prices. Third, the input structure is fixed: it will always require the same number and type of inputs to produce a certain output. Fourth, industries use the same technology to produce each of its products. Fifth, industry by-product coefficients are constant. This means that “an industry will always produce the same mix of commodities regardless of the level of production. In other words, an industry will not increase the output of one product

without proportionately increasing the output of all its other products.”<sup>9</sup> Finally, it is important to note that IMPLAN as a modelling tool only reports impacts using the latest data year available, which is 2019. Data fed into IMPLAN works off 2019 regional figures (e.g., 2019’s total output for Ohio is applied at every phase, despite expected growth year-over-year), and does not forecast economic indicators beyond it.

### *Understanding IMPLAN Impacts*

Economic impact analyses (EIAs) assess the impact of an “exogenous shock”—new economic activity that stimulates growth—exploring its impact on a number of indicators such as GDP, job creation, and tax revenues. Some of these indicators will be further evaluated at three levels of analysis: direct, indirect, and induced effect. Direct effects calculate the economic value that a business or industry generates by its own means through direct hiring of its own employees, revenue generation from sales, and the portion of its business activity that contributes to regional output. Direct effects include the initial change in expenditures by consumers and producers—the exogenous shock—producing the first round of economic activity in the form of new output, jobs, and revenues. Indirect effects gauge the economic impact that results from demand created by the direct impact. Products and services are bought to support this new activity (i.e., supply chain companies). Finally, there is the induced effect, which measures the economic impact on the broader economy resulting from demand created by employees of the new activity (direct component) and its supporting businesses (indirect component). IMPLAN defines the induced impact as follows: “the values stemming from household spending of Labor Income, after removal of taxes, savings, and commuter income. The induced effects are generated by the spending of the employees within the business’ supply chain.”<sup>10</sup>

In this instance, the direct effect of a \$12.9 billion AAM multi-industry exogenous shock (direct impact) to the State of Ohio over 25 years will produce a number of direct AAM jobs, revenues, and expenditures that will further produce inter-industry demand (indirect impact). Additionally, the induced impact will capture unrelated excess economic activity (e.g., consumer spending in the general economy from increased income provided by AAM). Based on the EIA numbers, we go one step further in identifying AAM’s catalytic effects for the state. Growth in AAM will improve labor market efficiencies and suburban/rural access, accelerate STEM education and funding, and boost investment in alternative energy for the AAM sector. These effects are discussed later as an extension to the EIA.

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<sup>9</sup><https://blog.implan.com/implan-io-analysis-assumptions#:~:text=It%20assumes%20that%20an%20industry,of%20each%20of%20the%20products.>

<sup>10</sup> <https://blog.implan.com/understanding-implan-effects>

# Analysis Results

## AAM Passenger and Cargo Carrying Use Cases

Working collaboratively with ODOT, the team finalized a series of use cases that presented the most potential for positive economic impact. For this, the team capitalized on our understanding of technology readiness, as well as the phasing of operations, and brought the input from interviewed stakeholders.

We explored various use cases for people movement, covering on-demand air taxi, air metro, medical evacuations (Medevac), organ delivery, corporate campus and business aviation, regional passenger transport, and personal aircraft. Cargo delivery considered last-mile, short-haul, medium, and long-haul, including medical services, freight transfer from airports to distribution hubs, neighborhood food delivery, and urban-to-rural delivery. Our ongoing analyses of these use cases provided insights into their feasibility and timing. Table 5 summarizes the final definitions of the key people and cargo movement use cases used during this economic impact analysis.

**Table 5: AAM Use Case Definitions**

Use Case	High-Level Definition
On-Demand Air Taxi	Defined as transportation in a city and the city’s metro region, has the potential to radically improve urban mobility. This mode of operation will alleviate the substantial time lost in daily commutes or getting from one location to another.
Regional Air Mobility	Regularly scheduled or on-demand transportation between cities, over 50-75-mile distances. Numerous studies find that going by air using AAM for short inter-regional trips (city center to city center, or city center to rural proximity) rather than inter-city, makes time-saving sense.
Airport Shuttle	Scheduled or on-demand transportation between major and regional airport and city center or suburbs vertiports. Tying city centers to airports will become a high-value application of AAM. Airports will seek to capitalize on AAM to maximize the utility and convenience of their facilities.
Emergency Services and Medical Air Ambulance	Robust medical services transportation system, including emergency medical evacuations, hospital-to-hospital patient and equipment transportation, organ delivery, and search-and-rescue operations.
Corporate/Business Aviation	Inclusive of transportation between corporate campuses and business destinations, interfacility corporate transport, regional campus transport, campus-to-customer transport, and specialist team mobility. Business aviation is a global US\$100 billion per year industry.
Cargo and Freight Delivery	Transportation of heavy cargo and freight from or between airports, distribution centers, and manufacturers and to end consumers. Logistics corridors and distribution operators providing freight and cargo to regional industries can provide value by prioritizing high value materials with rapid delivery using eVTOLs.

## sUAS Use Cases

sUAS, as defined by the Federal Aviation Administration (FAA) under Part 107, are autonomous aircraft weighing less than 55 pounds, including payload. Their small size enables them to fly within constricted areas, and Part 107 restricts operations to less than 400 feet without a waiver. When fitted with sensors, sUAS provide enhanced capabilities for inspections, monitoring, surveillance and mapping. Some package delivery sUAS can be used for delivery methods for smaller payloads, including medical supplies.

The assessment of the potential for each use case is informed not only by the team’s own experience with sUAS and interviews conducted for this project, but also on a national and global scale based on an industry-leading forecast by the Teal Group. While sUAS span a variety of applications, they share an important similarity that differs markedly from the passenger AAM use cases: relative to AAM they are not expected to generate a large number of new jobs nor to provide large additional revenue streams for the State of Ohio. In fact, even though sUAS are likely to provide potential cost savings in some use cases, that is rarely the primary driver for businesses and government to adopt sUAS technology. Rather, all the non-passenger sUAS use cases will provide significant benefits by making more efficient use of resources. Appendix C: Discussion of sUAS Operations is dedicated to an in-depth analysis of the potential market of sUAS in Ohio. Table 6 summarizes the use cases studied under this effort with acknowledgement that there are many other direct and indirect utilization of sUAS.

**Table 6: sUAS Use Case Definitions**

Use Case	High-Level Definition
Infrastructure Inspection - Bridges, Tunnels, Highways	Regularly scheduled visual inspection for cracks, corrosion, other deterioration. Bridge and some tunnel inspections currently performed by snooper bucket trucks, mostly involving lane closures. sUAS will supplement existing methods.
Infrastructure Inspection - Airport	Visual inspection of runway conditions, wildlife incursion control, lightning strikes damage, building inspection, and security perimeter monitoring
Infrastructure Inspection - Powerlines, Towers, Pipelines	Regularly scheduled and ad hoc visual inspection of assets. Allows up close inspection of towers for structural faults and pipeline inspections including leak monitoring
Law Enforcement and Public Safety	Applications, including accident investigation, event and crowd monitoring, prison and other secure facility protection, search and rescue, and fire prevention
Agriculture and Livestock	For agriculture, includes monitoring crop health, seeding, and spraying. For livestock management, includes herd location, health monitoring, and pasture monitoring
Package Delivery	Smaller packages and cargo or freight. Includes delivery of various items within facilities and to consumers, including last-mile e-commerce and restaurant
Medical Non-Passenger Transport	Includes services such as organ and device transport, isotope delivery, vaccine delivery, blood transport, and lab specimen transport

## Supply Chains

It will take four supply chains to build a commercially viable AAM ecosystem. Supply chains have an end-product producer or Original Equipment Manufacturer shown as the Tier 0. Below the OEM are tiers of producers of systems, components and parts - show here in red and blue - that flow up through the supply chain to provide that finished product. Figure 7 summarizes these four critical supply chains, with further elaboration in the sub-sections below.

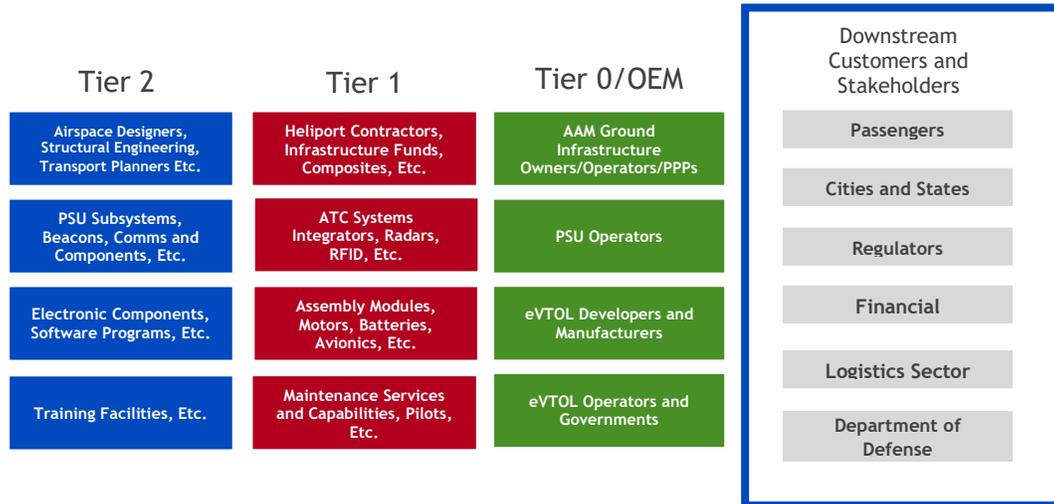


Figure 7: Four AAM Supply Chains

### Supply Chain 1 - AAM Ground Infrastructure: Building Vertiports and Multiports

AAM ground infrastructure is needed to provide landing facilities. The world is well populated with heliports; however, fewer than half are in locations convenient for AAM applications. Ground infrastructure will require expansion into network configurations, with each node or vertiport carefully located and built to ensure passenger convenience and value. It will be easiest to create vertiports by remodeling existing heliports. This existing infrastructure can be updated for eVTOL aircraft by adding battery recharging stations and fuel stations for hybrid aircraft, as well as perimeter security, shelters, and other amenities. The region's power grid becomes an essential factor in determining vertiport locations.

Globally, many cities have heliports that are rarely or no longer used. It is likely that some of the unused or underutilized heliports, particularly those near hospitals, may be renovated to receive the new aircraft.

However, at some point in the future, eVTOL aircraft will land and take off from multiports. These large, specially designed transportation hubs will be able to service several aircraft at once and may offer passenger amenities such as food, restrooms, and shopping.

Integrating an eVTOL aviation network with the existing system of public transportation modes requires detailed planning and analysis. While the technology is available to upgrade heliports to vertiports and establishing multiports, there are still no agreed-upon standards. These regulations may be dependent on the types of aircraft selected, their footprint and weight, and their electric or hydrogen charging requirements.

While certain aspects of vertiports remain to be determined, it is safe to say that the development of infrastructure to support an eVTOL network has significant cost advantages over heavy-infrastructure approaches such as roads, light rail lines, bridges, and tunnels.

### *Supply Chain 2 - PSU: Managing the Air Traffic Flow*

An air traffic management system ensures the safe and efficient movement of aircraft. Airplanes and helicopters are guided through the airspace by air traffic controllers. sUAS and eVTOL passenger and cargo aircraft must also be safely and efficiently managed. It is likely that the first passenger use cases will rely on the FAA's existing system of air traffic controllers: those eVTOL aircraft replacing and/or complementing existing aircraft operations.

It is unlikely, however, that the many new uses and new routes of eVTOLs—both passenger aircraft and sUAS—will rely on the traditional system of air traffic controllers for traffic management when volumes become challenging. The addition of hundreds more aircraft movements a day in Ohio alone will put too great a strain on the system. AAM will need its own air traffic management system working in conjunction with the current system. There are various concepts of how the airspace could be managed.

AAM must, within a few years, become economically viable to investors, as well as pay recurring costs such as equipment maintenance and upgrades, and employee salaries, and maintain public safety and convenience.

### *Supply Chain 3 - eVTOL Aircraft Manufacturers*

Several eVTOL prototypes around the world are either in advanced stages of development or operational trials. Designs vary widely in terms of numbers of passengers, number of rotors, and operational capabilities. Even those developers furthest along have not released all details about their aircraft, but the expectation is that they will be lighter, quieter, and more flexible than helicopters. Emergency service eVTOLs, for instance, will be able to land safely in a smaller area, a great benefit when emergency rescue personnel need to reach a critically injured person on a congested road.

Several of these eVTOL aircraft currently in development are also designed to be piloted, at least initially. The next two decades will see increasing use of automation and autonomy performing many functions traditionally performed by humans. Increased automation offers the opportunity to reduce workload and enhance safety for critical aviation functions.

### *Supply Chain 4 - Operators of eVTOLs and sUAS*

Current operators of helicopters are today's vanguard for eVTOL services. Helicopter companies have excellent longstanding safety records, trained pilots, weather dispatching expertise, and systems, quality, and safety programs. They are also familiar with the regulations, terrain, and locations of the heliports and airports in the region. However, there are many new potential players that will represent enormous opportunities.

sUAS operators can be independent individuals, small companies, and large players such as Amazon, FedEx, and DHL. Their missions are diversified and range from healthcare (isotope delivery, vaccine delivery, COVID test kits, blood transport) to package delivery, agricultural purposes, bridge inspection, and other useful applications.

## **ArcGIS Analysis Outputs**

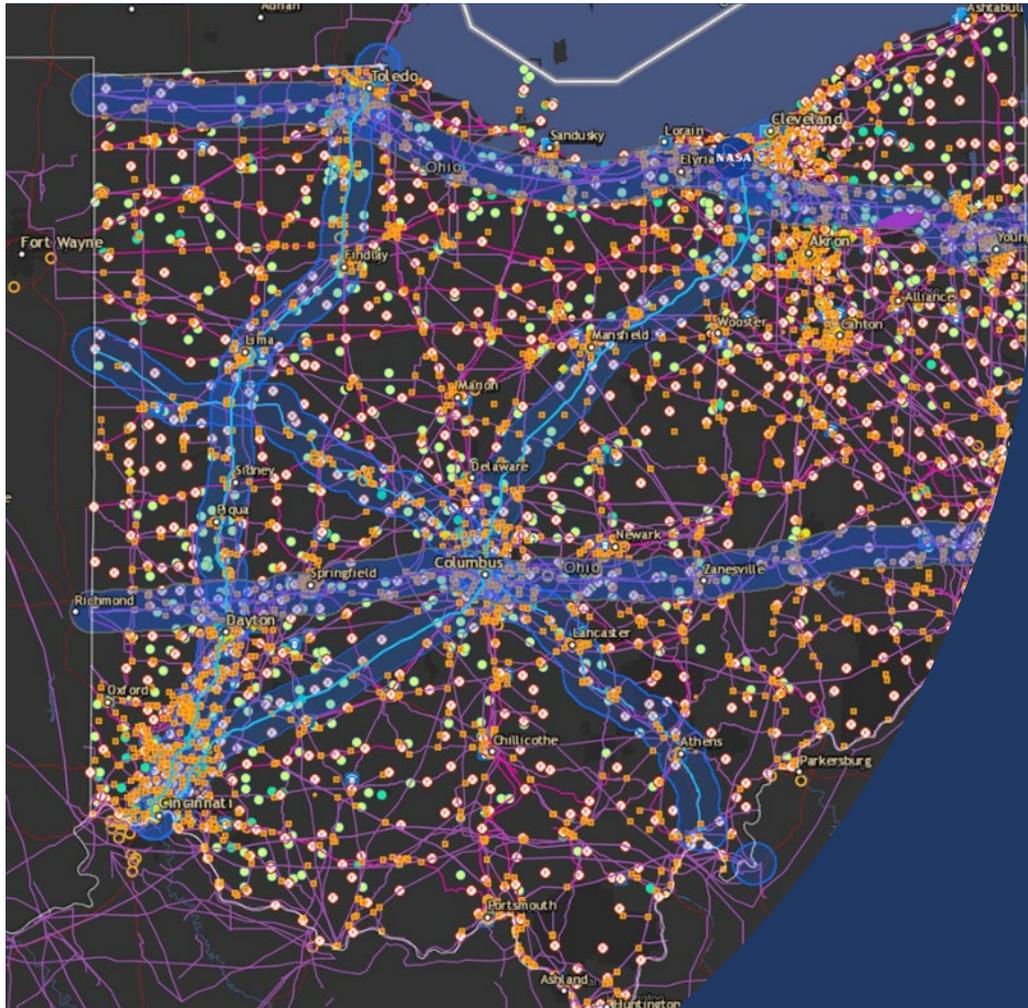
The statewide infrastructure mapping effort provided the inputs for the AAM Business Case Model. Ohio is already well positioned for the implementation of AAM, as there are more than 270 helipads and 500 runways within the state.

Cargo eVTOL operations will benefit from the 112 manufacturing centers and 138 logistics centers across the state, allowing eVTOL operations to swiftly integrate into existing freight

transportation modes. With more than 1,100 fire departments and 171 hospitals, Ohio will have a high demand for eVTOL medical use cases, such as medevacs and patient transfers.

All the 35+ layers included in the ArcGIS data sets helped to determine a specific city's ability to adopt and implement AAM. These metrics were used as inputs in the Business Case Model to calculate a city's demand for eVTOL services over the 25-year period.

Figure 8 provides a graphic representation of the many layers of ArcGIS data information available during our analysis.



**Figure 8: Layers of ArcGIS Data Available During Analysis**

The state was analyzed within six regions, or CSA, based on the major cities and five logistic corridors. Figure 9 shows the ArcGIS visualization of the six CSAs showing the layers of hospitals, blood banks, fire departments and universities, among others. Previously, in Figure 6, the logistic corridors were shown.

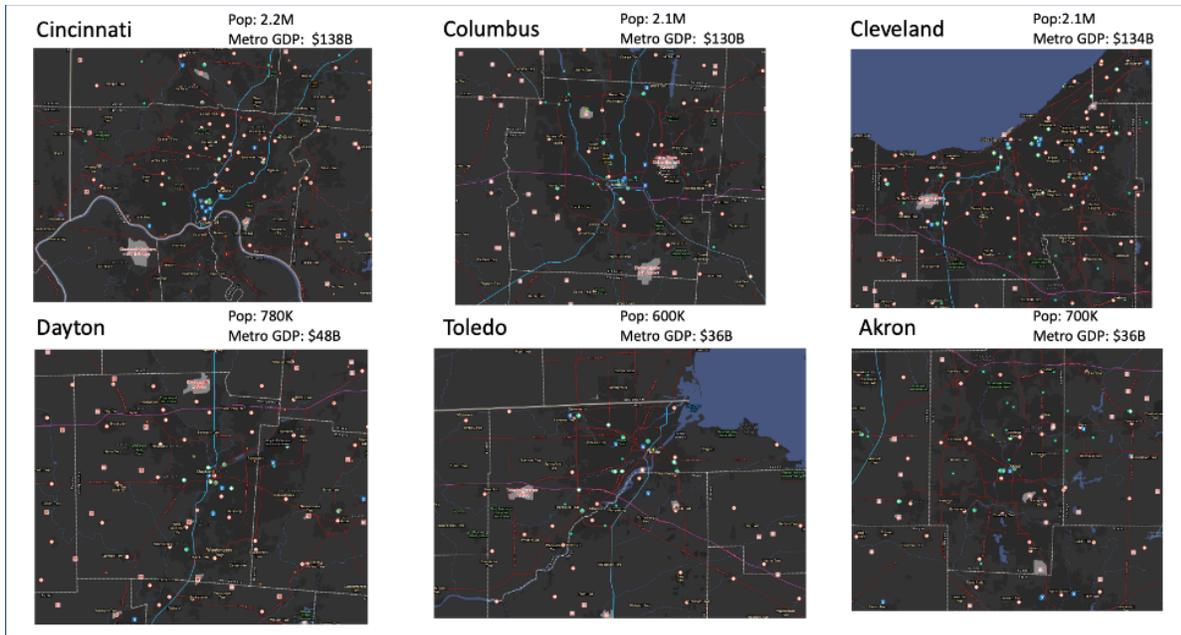


Figure 9: ArcGIS Visualization of Six Combined Statistical Areas (CSA)

## Business Case Tool Output

### Use Case Outputs for Six Major Cities

Table 7 shows the extensive analysis provided by the financial and economic tools used in the AAM Business Case Tool. The results are comprehensive including all the CSAs for all the use cases defined in Table 5 and the logistic corridors defined in Figure 6. The results are presented in five-year increments, referred also as the phases 1 to 5, for a total of 25-year revenue and capital investment estimates for Ohio. These financial estimates fall into three categories:

- CAPEX: Those capital expenditures funds used to acquire, upgrade, and maintain physical assets such as property, plants, buildings, and specialized facilities, technology, or equipment.
- OPEX: Costs that a business incurs through normal business operations. Operating expenses include rent, equipment, inventory costs, marketing, payroll, insurance, step costs, and funds allocated for research and development.
- Aircraft: Fleet acquisition and maintenance costs to acquire and operate sufficient eVTOL aircraft to sustain the use cases identified.

As ground infrastructure is built over the 25-year period, CAPEX costs decline and OPEX costs increase to run and maintain the new pieces of AAM infrastructure. PSU expenses are primarily focused in the earlier phases, with additional costs incurred in the later years to expand networks for larger operations.

**Table 7: Economic Activity by Operators, PSU, Ground infrastructure, and Aircraft**

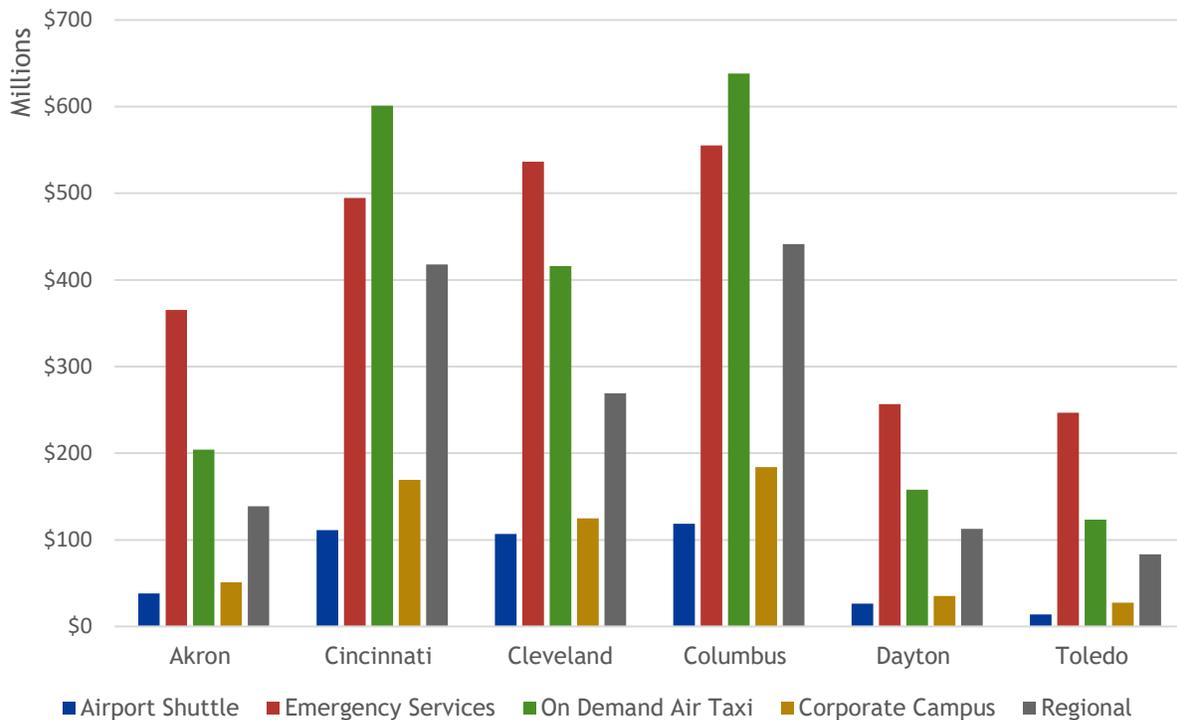
	Year	2020-2024	2025-2029	2030-2034	2035-2040	2041-2045	SUM	Pillar Totals
Ground Infrastructure	OPEX	\$30,378,227	\$78,781,611	\$142,434,815	\$213,474,139	\$272,555,871	\$737,624,663	\$1,060,532,154
	CAPEX	\$80,365,680	\$74,474,160	\$118,745,280	\$15,065,280	\$34,255,080	\$322,905,480	
PSU	OPEX	\$4,897,999	\$7,299,488	\$33,766,518	\$106,097,559	\$109,654,734	\$261,716,297	\$464,669,827
	CAPEX	\$23,614,110	\$69,155,607	\$35,421,164	\$40,481,331	\$34,281,319	\$202,953,530	
AAM Operators	Passenger Revenues	\$52,371,092	\$350,161,775	\$623,322,304	\$1,363,453,265	\$2,220,513,798	\$4,609,822,234	\$9,177,228,119
	Emergency Services Revenues	\$52,510,693	\$271,881,831	\$500,063,439	\$750,816,715	\$879,786,522	\$2,455,059,199	
	Cargo Revenues	\$75,998,775	\$197,417,439	\$348,616,702	\$670,269,311	\$820,044,458	\$2,112,346,685	
Vehicles	Vehicle Purchases	\$85,800,000	\$356,920,000	\$436,828,750	\$707,691,125	\$694,598,839	\$2,281,838,714	\$2,281,838,714
Ohio Grand Total		\$405,936,575	\$1,406,091,910	\$2,239,198,973	\$3,867,348,725	\$5,065,690,620	\$12,984,266,803	\$12,984,268,814

Due to the regulatory hurdles of AAM passenger operations, using eVTOLS for emergency services and medical air ambulance operations will be one of the first use cases to begin generating revenue. While annual passenger counts are low, emergency services “ticket” costs, or cost per use, are very high, producing high revenues in the early years. Cargo operations are also likely to occur before passenger use cases such as on-demand air taxis as a service of cargo using eVTOLS will improve just-in-time deliveries for manufacturers, including timely on-demand delivery, reducing warehouse costs and keeping inventory low.

Passenger revenues in Table 7 include the total for the four passenger use cases: on-demand air taxi, business aviation, airport shuttle, and regional air mobility. Figure 10 further represents the total 25-year revenues of passenger and emergency services by CSA.

Regulatory hurdles present challenges for operators in the early phases, but once those are overcome and aircraft supply can meet demand, passenger AAM revenues take off.

These statewide figures prove AAM to be a profitable business over the 25-year period, which is crucial to the development of initial infrastructure that could be funded by government initiatives, private sector investments or a combination though public private partnership models. It is concluded that with a profitable long-term business model, investors can safely provide funding for AAM development knowing they will receive their returns in the future.

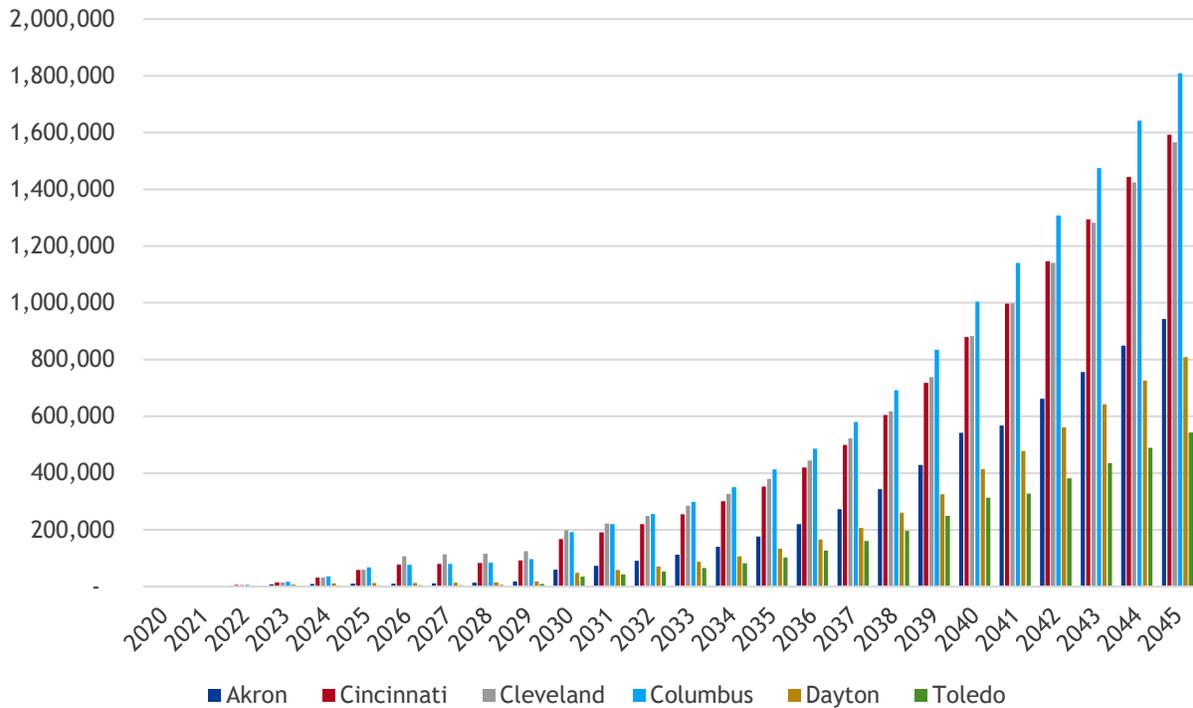


**Figure 10: Ohio CSA Revenue by Market Type**

The state will continue to see passenger demand grow as infrastructure is built to accommodate the increased demand. Figure 11 shows annual passenger traffic growth by CSA over the 25-year period. It is estimated that by the year 2045, the AAM demand will be over 7.2 million passenger per year.

Table 8 provides details on each CSA’s ability to adopt AAM and the associated costs (excluding cargo revenues).

Due to their similar cost and demographic characteristics, Cincinnati, Cleveland, and Columbus all have similar volume of yearly passengers. Components such as population, cost of living, cost of construction, and GDP affect the Business Case Tool’s outputs, and these three cities have very similar inputs. Accordingly, their CAPEX and OPEX numbers for both ground infrastructure and PSU are closely related, accommodating a similar demand curve in each city and the included counties in the CSA. Smaller CSAs such as Akron, Dayton, and Toledo forecast fewer annual passengers and operator revenues, but they are still financially viable options for operators and investors to pursue.



**Figure 11: Estimated Passenger Traffic by Year by CSA**

**Table 8: Market Value and Forecasted Demand by City (excluding cargo)**

City	Projected Vertiports	Total Yearly Passengers (2040)	Total Passenger Operator Revenues	Total Ground Infra CAPEX	Total Ground Infra OPEX	PSU CAPEX	PSU OPEX	Total PSU Costs	Total Passenger Vehicle Costs
Akron	14	943,597	\$799,099,084	\$59,746,800	\$135,540,656	\$29,270,861	\$33,609,690	\$62,880,550	\$254,828,084
Cincinnati	16	1,592,298	\$1,770,277,399	\$64,711,680	\$148,228,363	\$42,427,070	\$53,798,495	\$96,225,565	\$306,772,056
Cleveland	16	1,565,761	\$1,481,763,386	\$64,711,680	\$148,228,363	\$40,987,909	\$52,298,167	\$93,286,077	\$306,772,056
Columbus	22	1,809,336	\$1,932,905,244	\$70,759,080	\$159,988,020	\$48,534,143	\$60,191,314	\$108,725,457	\$375,132,111
Dayton	9	808,225	\$591,180,802	\$55,932,840	\$128,872,598	\$23,041,994	\$32,701,945	\$55,743,938	\$206,782,308
Toledo	4	1,171,842	\$489,655,519	\$7,043,400	\$16,766,664	\$18,691,553	\$29,116,687	\$47,808,240	\$218,253,750
<b>Total</b>	<b>81</b>	<b>7,891,059</b>	<b>\$7,064,881,434</b>	<b>\$322,905,480</b>	<b>\$737,624,663</b>	<b>\$202,953,530</b>	<b>\$261,716,297</b>	<b>\$ 464,669,827</b>	<b>\$1,668,540,366</b>

Each city and the surrounding CSA will also have its own vertiport buildout timeline, breaking out the required infrastructure in each phase of AAM operations over the period. In the earlier phases the majority of the investment will concentrate in remediating current helipad and heliport to accommodate eVTOL operations. As the adoption of AAM continues new vertipads both with and without co-located services will be needed as well as integration of eVTOL capabilities to existing airports. Figure 12 shows the total number of vertiports by type of investment and by phases. Figure 13 shows the total number of vertiports needed by phases for each of the CSA.

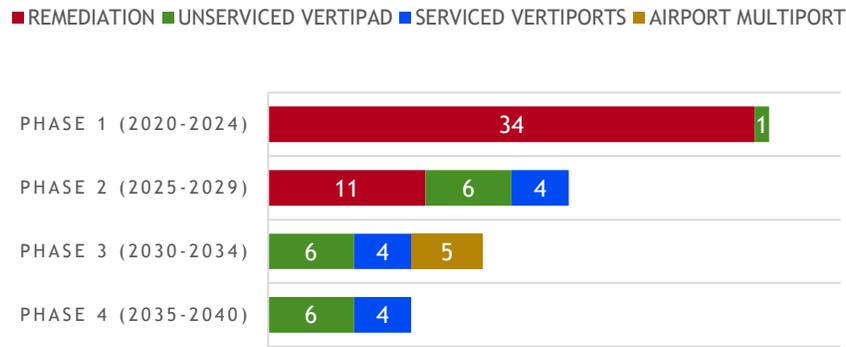


Figure 12: Number of Vertiports by Type

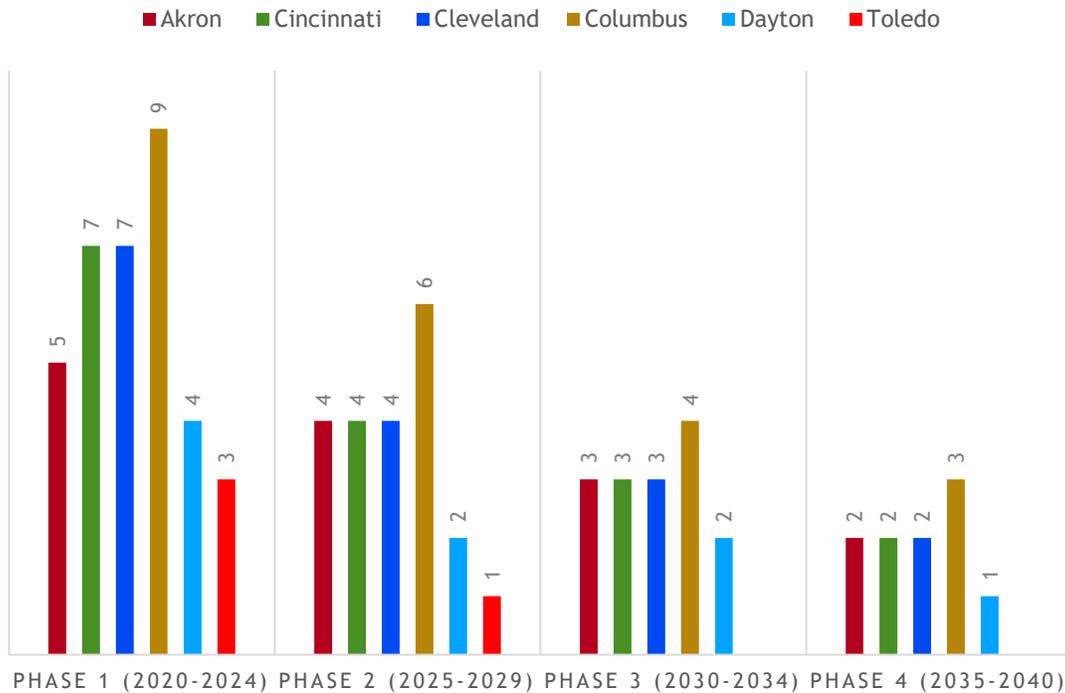


Figure 13: Vertiports by CSA and Phase

### Cargo Along Corridors

The analysis shows that the total eVTOL cargo market share over the 25-year period would move more than 1.2 million tons of commodities valued at more than \$5.5 billion. Revenues over the 25-year period total more than \$2.1 billion, growing from \$76 million in Phase 1 to \$820 million in Phase 5.

Our analysis shows that a majority of eVTOL cargo flows will follow the I-71 corridor, as this corridor connects Ohio’s three largest cities: Cincinnati, Cleveland, and Columbus. In Phase 5, the I-71 corridor will see more than \$325 million in revenue during that five-year period. Over the entire 25-year period, I-80 increases its share of the eVTOL cargo market. Connecting Cleveland to Toledo and eventually Chicago, we anticipate increased interstate freight

operations as cargo eVTOL technology advances, allowing for more revenue along the I-80 corridor in the later phases. Figure 14 shows estimated cargo revenues by corridor.

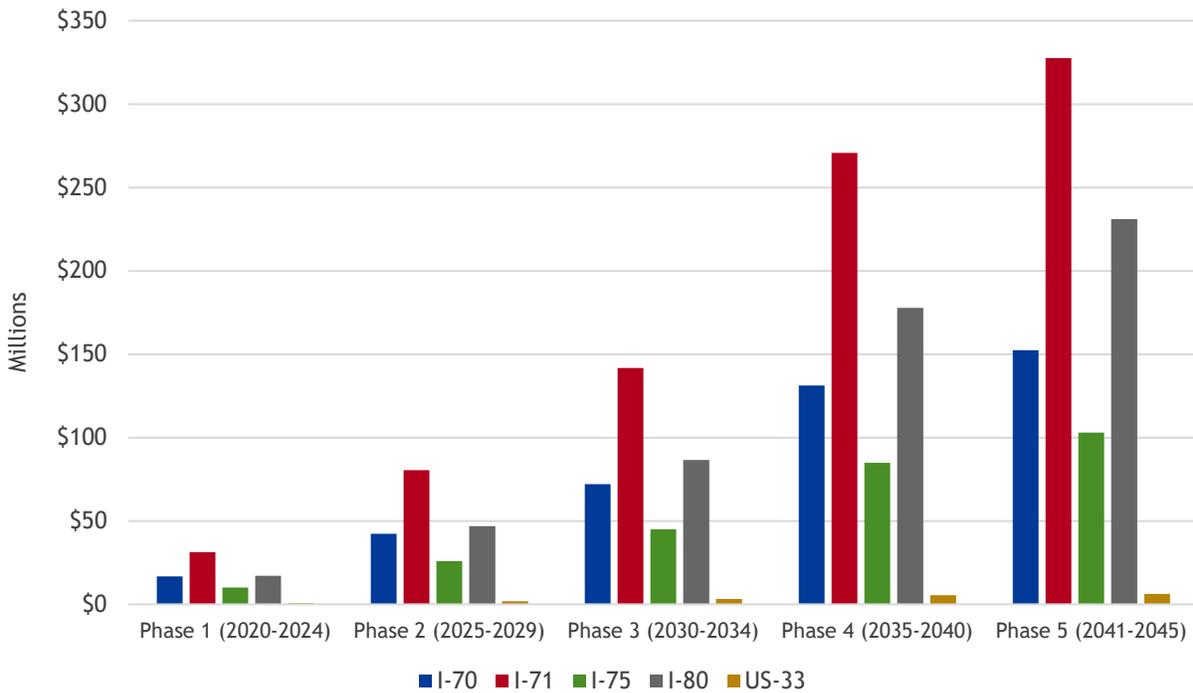


Figure 14: Cargo Revenues by Corridor

## Economic Impact Analysis

### IMPLAN and Results

The IMPLAN input/output model was the model of choice in studying AAM for Ohio. IMPLAN is a recognized modeling tool used to study impacts on all sectors and at all levels of an economy. Some relevant examples include a 2014 technical report on the impact of airports on Ohio’s economy<sup>11</sup> and a 2019 study on the economic impact of NASA’s Glenn Research Center, published by Cleveland State University.<sup>12</sup> IMPLAN was also used last year to assess the national and state economic impact of NASA’s Moon to Mars Program.<sup>13</sup>

As mentioned before, in this study, the team analyzed the business case for CSA around six cities across the state, with each city comprising their MSA and proxy counties. Together, the six CSA capture every county in the state, allowing distribution of the outputs for the state as whole. As a result, the IMPLAN industry multipliers used in this scenario are state averages, with total impact represented at the state level.

<sup>11</sup> CDM Smith, “OHIO AIRPORTS ECONOMIC IMPACT STUDY,” October 2014

<sup>12</sup> Iryna V. Lendel, Ph.D., Jinhee yun, Courtney Whitman, CSU Maxine Goodman Levine College of Urban Affairs, “The NASA Glenn Research Center: An Economic Impact Study Fiscal Year 2019,” June 2020

<sup>13</sup> ASRC Federal Analytical Services, “National Aeronautics and Space Administration & Moon to Mars Program,” August 2020

In combining the business case totals, the team produced consolidated operational expenses (OPEX), capital expenses (CAPEX), and revenues along the four supply chains discussed previously, with OPEX and CAPEX for ground infrastructure, PSU, and aircraft, in addition to revenue for the operators. These totals, or economic outputs, have been forecasted for each phase of AAM’s development in Ohio until 2045. The flow of the analysis is represented in Figure 15.

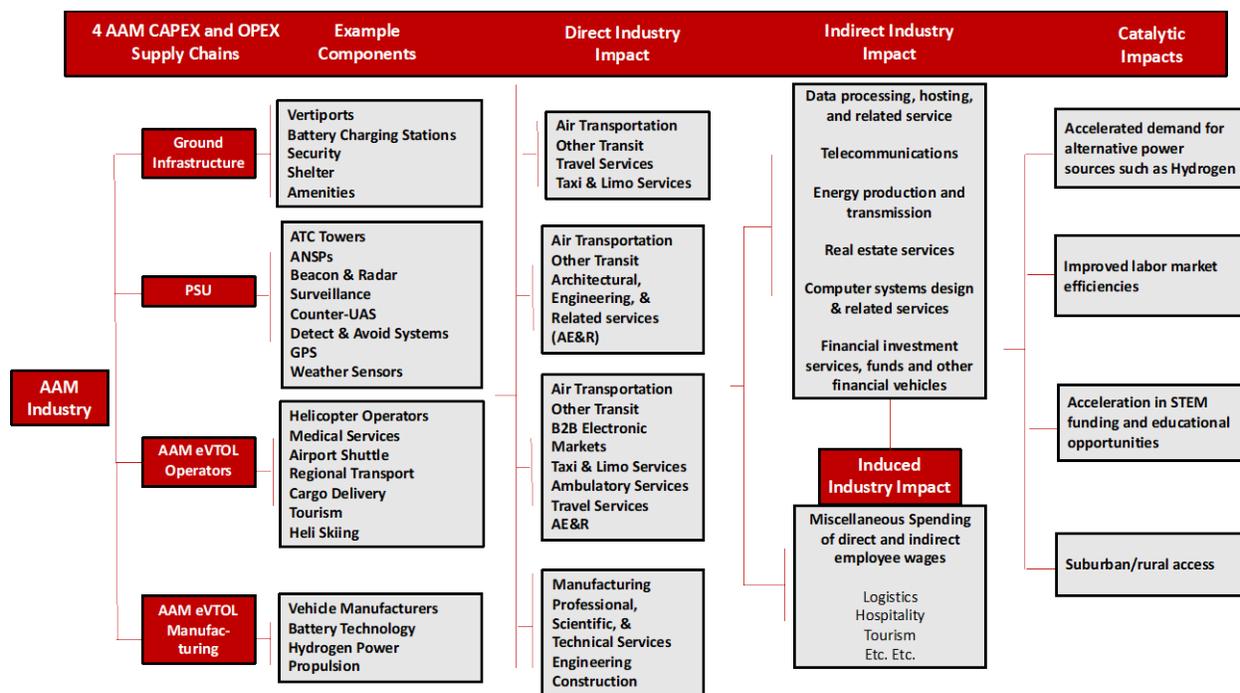


Figure 15: Economic Impact Analysis Flow Diagram

The OPEX and revenue outputs were then apportioned to seven inter-linked industries defined by the National American Industry Classification System (NAICS), a “standard used by Federal statistical agencies in classifying business establishments for the purpose of collecting, analyzing, and publishing statistical data related to the U.S. business economy.”<sup>14</sup> These industries were analyzed for best fit as it pertains to the infrastructure and businesses necessary to support and maintain AAM operations. These are:

- 1) air transportation,
- 2) other transit and ground passenger transportation and scenic and sightseeing transportation and “support activities for transportation,”
- 3) taxi and limousine services,
- 4) architectural, engineering, and related services,
- 5) travel arrangement and reservation services,
- 6) miscellaneous ambulatory services, and

<sup>14</sup> <https://www.census.gov/naics/>

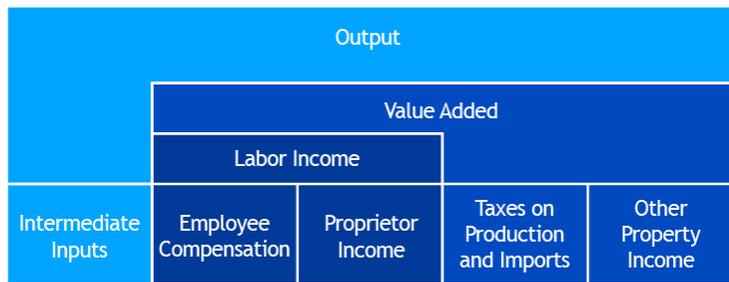
7) business-to-business electronic markets, and agents and brokers.

The CAPEX outputs were apportioned in similar fashion to the OPEX, using the same method and classification system, except in this case distributing along NAICS-classified commodities. The distribution for CAPEX was more complex and included 17 distinct commodity types determined to be necessary for AAM operations. Examples of these commodities include electric motors and generators, computers, computer peripherals and parts, and navigational and guidance instruments, among many others.

All of these OPEX industry and CAPEX commodity types are assigned a portion of the value produced by the four supply chains in the business case analysis, for each phase of development. These values are inputted into IMPLAN, applying the industry coefficients embedded in the system to produce economic impact values specific to industry and region (Ohio). Impacts of interest include GDP growth, jobs, and tax revenue.

**Economic Impact: GDP**

GDP, or gross domestic product, is defined as the total value of all domestic final goods and services produced within a specified period (typically a year). It is also known as value added, which according to IMPLAN, is defined as the difference between total output and the total value of intermediate inputs throughout an economy during a specified period. It is the total output minus intermediate inputs (see Figure 16).<sup>15</sup> In the case of AAM, total output over 25 years calculated using the business case analysis model, is \$12.9 billion. IMPLAN calculated the value added of this output at \$11.4 billion (see Figure 17 for details). \$4.6 billion is attributed to the direct impact; \$2.9 billion is attributed to the indirect impact, and \$3.8 billion is attributed to the induced impact. Together, this total represents a GDP increase of 1.63% for the State of Ohio, measured against the state’s 2019 GDP of \$702 billion. Note that the contribution of the direct impact to GDP is 40% of the total. Indirect and induce make up the remaining 60%.



**Figure 16: Representation of GDP**

<sup>15</sup> <https://implanhelp.zendesk.com/hc/en-us/articles/360017144753-Understanding-Value-Added-VA->

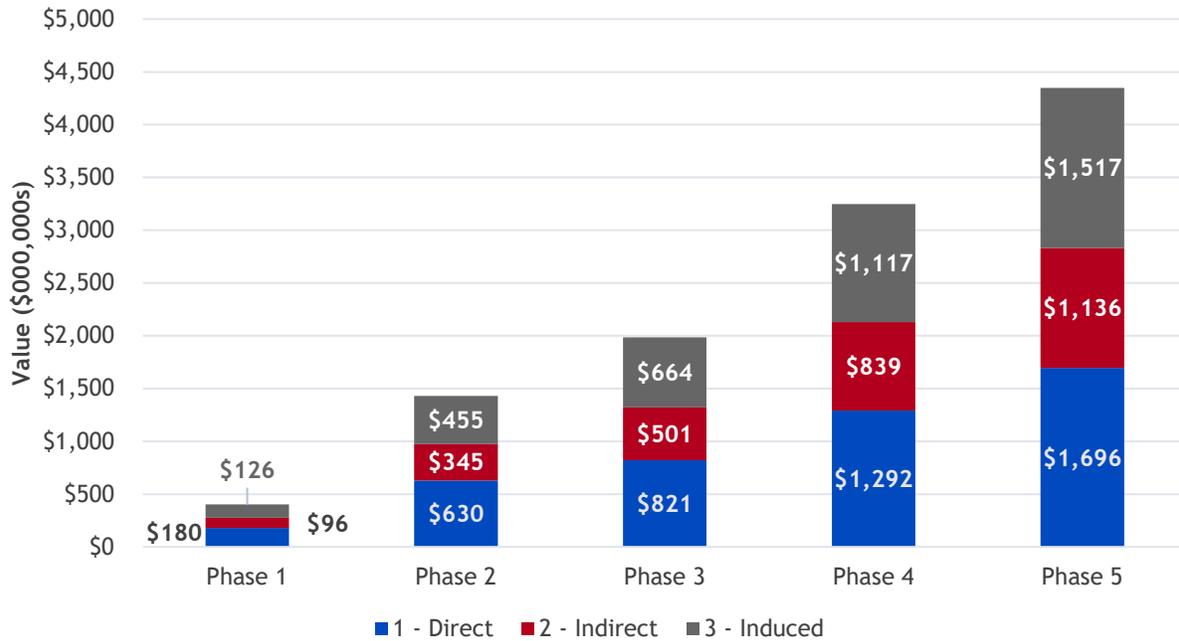


Figure 17: AAM Contribution to Ohio GDP

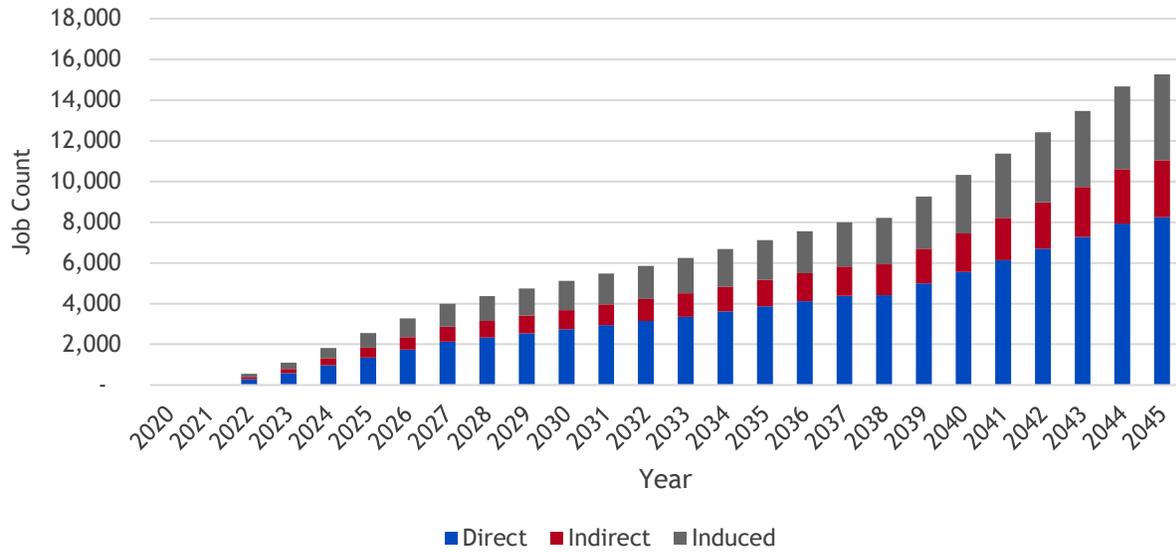
### Economic Impact: Jobs and Occupation

Jobs were calculated first in terms of employment, which IMPLAN defines as including both part-time and full-time annual employment.<sup>16</sup> In this study, employment was derived from the total output produced by AAM at the direct, indirect, and induced levels. Since the employment count does not differentiate between type of employee, a conversion to full-time equivalent (FTE) is necessary to capture a tangible estimate of the labor count. IMPLAN provided a conversion sheet to identify the corresponding FTE count.

The jobs captured in the impact come in three tranches: the direct, indirect, and induced. The jobs gained directly from AAM, the jobs gained indirectly by the supply-chain industries supporting AAM, and the subsequent jobs gained from induced spending in all sectors of the economy. Together, they represent the total impact on jobs for the State of Ohio.

The job numbers in Figure 18 reflect cumulative jobs gained year over year. As the value of AAM increases every year, so does the labor required to support it. This means that by 2030, the value of AAM at the direct, indirect, and induced levels will require roughly 5,000 jobs to support it. In 2045, that number reaches just above 15,000. Note that this job forecast does not account for jobs that could be replaced by AAM jobs.

<sup>16</sup> <https://implanhelp.zendesk.com/hc/en-us/articles/115009510967-Employment-Data-Details>



**Figure 18: Cumulative Permanent Jobs 2021-2045**

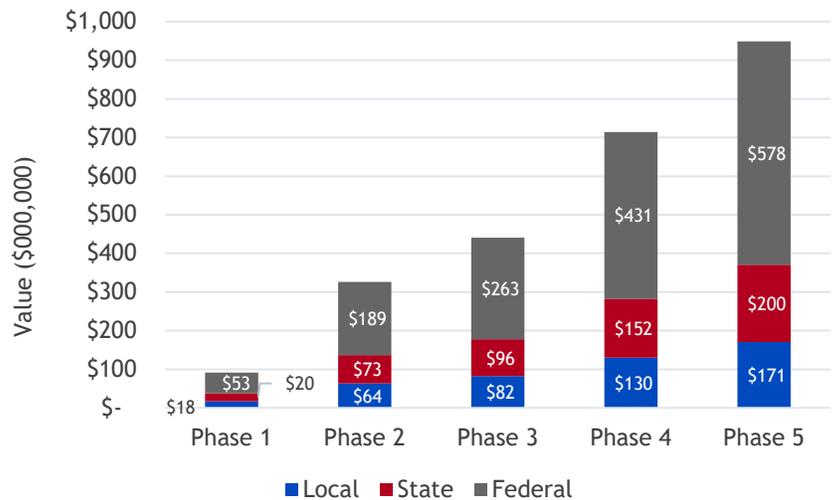
Since the direct and indirect effects of AAM account for roughly two-thirds of the impact, we see that job types, or occupations, closely align with the industries tied to AAM. Some of these occupations are reflected in the U.S. Bureau of Labor Statistics’ Standard Occupational Classification system, such as business and financial operations. Other categories, like engineering and intelligence transportation systems, reflect an evolving technology sector that more accurately describes the type of jobs AAM will create. The top 10 occupation categories are listed in Table 9, in no particular order, with example occupations that were produced in IMPLAN.

**Table 9: Top 10 Occupation Growth Categories**

<b>Engineering, Intelligent Transportation Systems</b>	<b>Quality Control and Safety Engineering</b>
Architectural and Civil Drafters	Aircraft Mechanics and Service Technicians
Computer and Information Research Scientists	Software Developers and Software Quality Assurance Analysts and Testers
Computer Hardware Engineers	Computer Systems Analysts
<b>AAM Operations</b>	<b>Medical and Supporting Services</b>
Pilots (includes emergency)	Paramedics
Cargo Pilots	Emergency Dispatchers
Air Traffic Controllers	Registered Nurses
<b>AAM Operational Support</b>	<b>Travel Support Services</b>
Laborers and Freight, Stock, and Material Movers	Travel Agents
Security Guards	Tour and Travel Guides
First-Line Supervisors of Transportation	Reservation and Transportation Agents
<b>Vehicle Design and Manufacturing</b>	<b>Hospitality</b>
eVTOL Mechanics and Electric Engine Specialists	Waiters and Waitresses
Electrical Engineers	Cooks, Restaurant
Airline Pilots, Copilots, and Flight Engineers	Food Preparation Workers
<b>Business and Financial Operations</b>	<b>All Other</b>
Retail Salespersons	Clergy
Accountants and Auditors	Animal Caretakers
Financial Managers	Teachers

### Economic Impact: Taxes

IMPLAN captured tax revenues at the local, state, and federal level. The local level represents totals for townships, cities, and counties for the entire state. Increased government revenues generally translate into additional government expenditures, which offers the state more investment opportunity into state infrastructure, economic and social programs, and so forth. Figure 19 depicts these revenues at the local, state, and federal levels over each phase of growth. These figures are additive, with total revenue of \$2.5 billion gained over 25 years. The local and state governments account for \$464 million and \$542 million in revenue, respectively, totaling approximately \$1 billion. Federal revenues account for about \$1.5 billion.



**Figure 19: Total Tax Revenues by Level Over Each Phase of Growth**

## sUAS Forecast Analysis

As mentioned before, the assessment of the potential impact of the use of sUAS is informed not only by the team's own experience and interviews conducted for this project, but also on a national and global scale based on an industry-leading forecast by the Teal Group. While the team assessed a wide span of applications, they share an important similarity that differs markedly from the passenger AAM use cases: relative to AAM they are not expected to generate a large number of new jobs nor to provide significant additional revenue streams for the State of Ohio. Rather, all the non-passenger sUAS use cases will provide significant benefits by making more efficient use of resources while improving productivity, enabling higher fidelity of data, increasing social benefits such as workplace safety, and diminishing environmental impact.

How the non-passenger use cases, all of which demonstrate significant catalytic benefits, translate into precise numbers of sUAS in Ohio skies depends on a number of factors unique to each use case and unique to Ohio. For public use cases, budgets will be a large driver. For private entities, underlying economic conditions will play an enormous role in their ability to increase the utilization of sUAS. Meanwhile, package and medical delivery are only in nascent stages and will remain there until a robust beyond visual line of sight (BVLOS) operating environment is possible and safety and reliability challenges of small package delivery is addressed. Package delivery itself is highly exposed to consumer demand.

Therefore, a 25-year outlook invariably means that there will be a host of economic swings, potentially with one or more recessions, that are not predictable to a level that provides a meaningful picture of the sUAS fleet by use case over the entire period. Nevertheless, some broad, shorter-range analysis combined with an understanding of Ohio's role in the U.S. economy can provide some guidance on how each use case could affect the overall development of AAM and sUAS in Ohio.

The Teal Group Forecast estimates total UAS fleets by year through 2029 by use case for the United States and the world. While it is the most thorough year-by-year assessment of future UAS fleets, it does not break out small and large UAS (with overlapping definitions between prosumer UAS of under 55 pounds and several other small UAS categories). Furthermore, their growth assumptions by use case in some cases seem too optimistic, without detailed evaluation of the projected life cycle of sUAS and how this, combined with annual production, would affect the overall fleet. Nevertheless, the Teal Group forecast does provide a meaningful baseline for understanding the potential size of each use case market in the United States. Table 10 shows Teal Group's Forecast by use case for 2020 (the baseline) and 2029.

Removing the largest category, general photography/real estate, which already has a large installed base, cumulative annual growth to 2029 would be 26.8%. In general, this approach seems reasonable, but there is the possibility that industrial applications are too high and will depend on economic conditions over the course of this decade. Meanwhile, delivery is working from a small installed base, and the numbers for 2029 are perhaps the most difficult to estimate because the robustness of the BVLOS regime at that point in time will dictate fleet size. Most industry observers believe that the bulk of delivery sUAS growth will occur in the early 2030s.

An examination of current sUAS fleets shows that Ohio has 37,746 registered UAS (as of November 2020). This stands for 2.8% of the national fleet. Commercial UAS (which are reflected in Table 10 for Teal) represent 33.8% of all UAS, according to FAA estimates. Thus, Ohio is currently estimated to have 12,773 commercial service sUAS. This number could be substantially higher or lower depending on the size of industry, agriculture, and public service applications occurring in the state.

**Table 10: Teal Group Forecast Summary - U.S. sUAS Units**

Teal Group Forecast Summary - sUAS Units United States			
	2020	2029	9-year CAGR
US Government/Civil	1,638	11,066	23.6%
<b>Industrial Applications</b>	<b>Construction</b>		
Construction	11,000	108,500	29.0%
Energy	9,500	63,050	23.4%
Insurance	5,080	40,600	26.0%
<b>Subtotal</b>	<b>25,580</b>	<b>212,150</b>	<b>26.5%</b>
Agriculture	21,000	77,500	15.6%
Delivery	40	130,000	145.6%
<b>Other use cases not similar to CCI</b>			
Communications	105	3,850	49.2%
General Photography/Real Estate	400,200	600,600	4.6%
Other Industrial Inspection	1,760	18,800	30.1%
Entertainment	10,000	55,000	20.9%
<b>Grand Total</b>	<b>460,323</b>	<b>1,108,966</b>	<b>10.3%</b>

Other factors to consider are population and GDP. Ohio’s population was 3.53% of the national total as of October 2019. Based on 2019 figures, Ohio’s GDP was the seventh largest in the nation, representing 3.24% of the total for the United States. These two metrics are especially relevant to the package delivery use case. Population figures could drive the total sUAS need for law enforcement and public safety. Appendix C provides an in-depth analysis of the various sUAS use case and the relevance for Ohio.

### Other Catalytic Impacts

Economic catalytic impacts are commonly studied when assessing air transport systems, and advanced air mobility is no exception. By definition, an "economic catalyst" is an entity that has:

- (a) two or more groups of customers;
- (b) who need each other in some way;
- (c) can't capture the value from their mutual attraction on their own; and
- (d) rely on the catalyst to facilitate value reactions between them.

Modern economists claim that in air transport, catalytic effects are even greater than the direct and indirect effects. In air transport, for example, catalytic impacts arise from connectivity and interaction benefits, among other things, and social benefits that lift communities with the jobs and spending that create new businesses. Table 11 presents four important catalytic impact elements further discussed in this section.

**Table 11: Summary of Catalytic Impact Elements**

Improved Labor Market Efficiencies	Suburban/Rural Access	Acceleration in STEM Funding and Educational Opportunities	Accelerated Demand for Alternative Power Sources such as Hydrogen
Improved mobility of the labor market better matching employees to employers	AAM will link the rural with urban, better integrating Ohio’s economy and improving opportunities	New academic programs will be built around the AAM industry to support its growth and understanding	The growth of AAM will spur growth in energy R&D Alternative sources to power AAM
<ul style="list-style-type: none"> <li>• Geography of labor market expands with AAM</li> <li>• “A 10% improvement in access to labor increases productivity and regional output by 2.4%”</li> </ul>	<ul style="list-style-type: none"> <li>• Meets JobOhio goals to “bolster economic growth in underserved regions”</li> <li>• Expanded customer base</li> <li>• Increased spending in the rural economy</li> </ul>	<ul style="list-style-type: none"> <li>• US is a powerhouse in the aerospace and defense sector</li> <li>• AAM will be a driver in recruiting and retaining talent in STEM</li> <li>• Many Ohio universities offer an expanding plethora of courses relevant to AAM</li> </ul>	<ul style="list-style-type: none"> <li>• Coincides with DOE 2020 Hydrogen Program</li> <li>• Complement and boost Ohio’s existing energy sector and infrastructure</li> <li>• Reduce carbon footprint</li> </ul>

**A Tale of Two Economies: Improved Labor Market Efficiencies, and Improved Suburban and Rural Access**

In addition to the near-term economic value for Ohio, AAM will provide catalytic benefits. For instance, the state has two distinct economies which can be better connected for mutual benefit. In 2019, Ohio’s GDP was \$702 billion, and its population approximately 11.6 million. According to the U.S. Health Resources and Services Administration, of Ohio’s 88 counties, 50 are considered rural, the rest urban or suburban.<sup>17</sup> Despite the rural majority, these 50 counties have 2.4 million people, or 21% of the state’s population. The urban and suburban portions have 9.2 million people, or 79% of the state’s population. Unsurprisingly, the urban and suburban economy makes up 83% of GDP, with the rural economy contributing the remaining 17%. Often, the rural community is excluded from opportunities present in the more prosperous 83% of the economy. Due to the geographic isolation of the two disparate economies, people are compelled to work within their defined economic bubbles.

When convenient and affordable AAM travel is available, someone from London, Ohio, who would otherwise be limited to job prospects within roughly 10 miles of his or her hometown, can find gainful employment in cities across the state, such as Dayton and Columbus. Essentially, AAM will bridge the geographic gap between the two economies, creating a synergy that will improve employment prospects for all. Lower-income communities will also benefit from more rapid transportation to prospective employers. Employers will have a wider pool of

<sup>17</sup> <https://www.hrsa.gov/sites/default/files/hrsa/ruralhealth/resources/forhpeligibleareas.pdf>

talent to choose from—matching “the right talent to the right position at the right company,” a goal stated in the JobsOhio 2019 Annual Report.<sup>18</sup>

The expansion of AAM operations across the state would support key initiatives in the JobsOhio report designed specifically to curtail isolated economic bubbles. One such initiative would implement an inclusive economic development growth strategy to “bolster economic growth in underserved regions...initiatives designed to promote equal growth across the state.”<sup>19</sup>

A diversified labor pool and expanded economic geography allows for wealth to be created in one part of the state and spent in another part: employees will be able to work in the urban economy and spend in the rural economy. Increased consumer spending in the rural economy will necessarily attract new businesses and opportunities, thus contributing to rural expansion, and improving income for Ohioans across the state.

Ease of transportation from outlying areas will also expand the customer base for urban businesses, increasing revenues and helping to grow that economy. Securing America’s Future Energy (SAFE), an energy policy research organization, cited the following in its 2018 Autonomous Aircraft Study:<sup>20</sup>

- A 1% improvement in accessibility to a region’s central business district improves regional productivity by 1.1%.
- A 10% increase in average speed of transportation, all other things being constant, leads to a 15-18% increase in the labor market size, resulting in a 2.9% increase in productivity.
- A 10% improvement in access to labor increases productivity and regional output by 2.4%.

Clearly, improved transportation plays an essential role in enhancing economic growth and overall productivity. Affordable, quiet, low-emission AAM aircraft and systems will allow for residents to live further from their workspace, both decongesting inner-city traffic and diversifying labor in a cost-efficient, environmentally friendly, and equitable manner.

It is important to note that the reduction of commuting times only begins in the sixth mile from departure. In 2020, members of our team conducted a study comparing eVTOL flight times to ground vehicles commute times using ArcGIS real-time traffic analytics. At around the fifth mile of a commute in average traffic congestion (the average between peak and minimal congestion hours), it takes both cars and eVTOLs between 15-20 minutes to get to their destination. At the sixth mile, car commute times begin to increase at a faster rate than eVTOLs, reaching 20 minutes. If the commute is 10 miles—the average commute in the United States—it will take cars in average congestion just over 30 minutes to arrive at the destination. By comparison, an eVTOL would take approximately 20 minutes, as shown in Figure 20.

The 10-mile commute shows a 33% time reduction, which is three times larger than the 10% speed increase suggested in the SAFE study. It follows, then, that the labor market size for the

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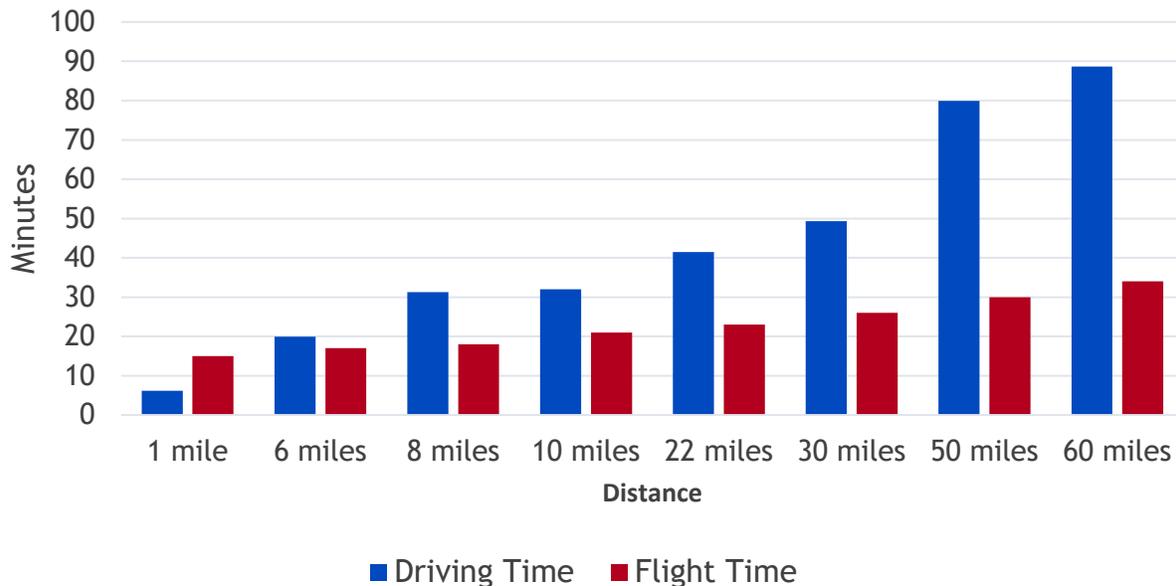
<sup>18</sup> JobsOhio, “2019 Annual Report, 2020 Strategic Plan”, 2020 <https://www.jobsohio.com/annual-report-2019/>

<sup>19</sup> JobsOhio, “2019 Annual Report, 2020 Strategic Plan”, 2020 <https://www.jobsohio.com/annual-report-2019/>

<sup>20</sup>[https://avworkforce.secureenergy.org/wp-content/uploads/2018/06/Americas-Workforce-and-the-Self-Driving-Future\\_Realizing-Productivity-Gains-and-Spurring-Economic-Growth.pdf](https://avworkforce.secureenergy.org/wp-content/uploads/2018/06/Americas-Workforce-and-the-Self-Driving-Future_Realizing-Productivity-Gains-and-Spurring-Economic-Growth.pdf)

impacted region could increase 45-54%, which then translates to a roughly 8.7% increase in regional productivity.

While members of the working public may not take an eVTOL to shave 10 minutes off their commute, those living further out would have a compelling reason to do so. Current AAM technology would allow for travel distances up to 200 miles and, as the graph shows, the time gap between cars and eVTOLs continues to grow exponentially with every additional mile, showcasing the potential of AAM to efficiently connect every region of the state.



**Figure 20: eVTOL-Ground Aircraft Commute Travel Time Comparison**

In short, the potential to improve Ohio’s labor market and connect its two economies into one highly efficient and equitable economy is a highly attractive prospect that AAM is uniquely capable of accomplishing.

### Accelerated Demand for Alternative Power Sources

#### *The Challenge*

Though AAM technologies promise a revolutionary transformation of urban and regional transportation, significant challenges remain. One such potential challenge facing the technology is the current limitation of power sources. eVTOLs require massive amounts of energy for lift and for landing, as well as for maintaining altitude. Current battery technology is not capable of sustaining the amount of power required to operate an eVTOL at rates that are commercially viable. In a presentation to the Vertical Flight Society, BAE Systems posit that “While significant advancements continue to be made in battery technology, storage density, and cycle life, battery cells ideal for electric cars and most other common applications don’t match the usage profile of eVTOLs.”<sup>21</sup>

<sup>21</sup> <https://www.aviationtoday.com/2020/02/03/battery-supply-problems-faced-electric-air-taxis/>

Automakers look to procure battery packs for between \$100-\$150 per kilowatt-hour (kWh), but that price point is currently unattainable for aerospace.<sup>22</sup> Today, the price ranges more realistically in the thousands.<sup>23</sup> eVTOLs will struggle to operate at scale, becoming more affordable, until there exists an energy source with enough power and storage capacity to fulfill the rigorous demand of commercial flight.

*The Need for Alternative Paths*

Many in the AAM industry are well aware of this challenge and are working on alternative solutions. That is why some leading VTOL developers, such as Alaka’i, are pursuing aircraft concepts with other fuel sources in mind, such as hydrogen (hVTOL). Hydrogen is one of the most powerful forms of energy, with an energy density value of 120 megajoules per kilogram (mj/kg). In comparison, diesel has an energy density of 45.5mj/kg. The strongest current lithium-ion batteries obtain approximately 250 watt-hours of power per kilogram, which translates to approximately 0.9 megajoules. Thus, hydrogen fuel cells can hold 133 times more power per kilogram than the best batteries on the market. And hydrogen can be one of the cleanest power sources on Earth.

Though the exact route to powering hydrogen is still largely undefined, it is undeniable that hydrogen power remains one of the most promising forms of energy. The U.S. Department of

**Table 12: Current Consumption and Future Economic Consumption Potential of Hydrogen in the United States (MMT/year)**

	Today	R&D Success Scenario
Oil refining	6	7
Metals refining	negligible	4
Ammonia production	3	4
Biofuels/synfuels production	1	9
Transportation FCEVs (LDVs, MDVs, HDVs) <sup>25</sup>	negligible	17
<b>Total hydrogen market</b>	<b>10</b>	<b>41</b>

Energy (DOE) believes it will play a leading role fulfilling future power requirements as well. It has created a national hydrogen program plan whose mission is “to research, develop, and validate transformational hydrogen and related technologies including fuel cells and turbines, and to address institutional and market barriers, to ultimately enable adoption across multiple applications and sectors.”<sup>24</sup> Table 12 shows the current and estimated market demand for hydrogen power, by application from the DoE

report. Today, an estimated 10 million metric tons (MMT) of hydrogen are produced for various applications. Notice that none can be attributed to transportation applications. But the expected demand for hydrogen power is forecasted to increase four-fold to 41 MMT by 2050, with transportation responsible for 55% of market growth. In addition to the DOE analysis, a group of more than 20 industry partners projected a two-fold increase in hydrogen demand, to

<sup>22</sup> <https://www.aviationtoday.com/2020/02/03/batery-supply-problems-faced-electric-air-taxis/>

<sup>23</sup> <https://www.aviationtoday.com/2020/02/03/battery-supply-problems-faced-electric-air-taxis/>

<sup>24</sup> [U.S. Department of Energy Hydrogen Program Plan](#)

20 MMT, by 2050 as a base case scenario, and a six-fold increase in an ambitious scenario.<sup>25</sup> The growth of AAM, beginning with Ohio, may propel the forecast into the ambitious estimates.

### *Ohio Can Lead the Way*

In adopting AAM technologies, the State of Ohio would begin its journey into hydrogen power in earnest, leaping ahead of its competitor states. And it will be able to do this for two reasons. First, Ohio has an existing capacity consisting of skilled labor, supply-chain networks, and infrastructure to support R&D and market application. Second, hydrogen energy and fuel cell projects and initiatives are already underway in the state.

Ohio is a leading state in energy production, with a highly skilled and diverse workforce. The state ranks tenth in the country in total energy production, sixth in electricity production, and fifth in natural gas production.<sup>26</sup> With this profile comes many skilled workers with technical knowledge of energy production and engineering. In 2018, Ohio held:<sup>27</sup>

- 100,000 jobs in traditional energy, about 3% of the nation's total.
- 82,000 jobs in energy efficiency, about 3.5% of the nation's total.
- 166,000 motor aircraft jobs, about 6.6% of the nation's total.

In addition:<sup>28</sup>

- In 2015, more than \$100 million in fuel cell components were purchased from Ohio supply chain companies. Example company profiles include Plug Power, Johnson-Matthey Process Technologies, Nexceris, LG Fuel Cell, Crown Equipment, and Stark Area Regional Transit Authority.
- In 2015, \$150 million was invested in fuel cell development by Ohio companies.
- More than \$93 million has been invested by the State of Ohio for fuel cell R&D and market-readiness projects.

Ohio is also home to the Ohio Fuel Cell Coalition, an organization partnered with the DOE hydrogen program. Its objectives include to “build upon existing industry and academic strengths of research and development, advanced manufacturing, advanced materials technologies, components, and services to advance the integration of a coordinated, robust fuel cell infrastructure and supply chain.”<sup>29</sup> The coalition highlights key attributes unique to Ohio:<sup>30</sup>

- Access to existing supply chains.
- Research and development: collaborations between companies and universities facilitated by programs like the coalition.
- Manufacturing and innovation infrastructure: boasting a legacy of advanced manufacturing assets/expertise and advanced materials technology.
- Central logistics: Ohio is within 500 miles of 60% of U.S markets.

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<sup>25</sup> [U.S. Department of Energy Hydrogen Program Plan](#)

<sup>26</sup> [Ohio - State Energy Profile Overview - U.S. Energy Information Administration \(EIA\)](#)

<sup>27</sup> [Ohio \(squarespace.com\)](#)

<sup>28</sup>

[http://www.midwesthydrogen.org/site/assets/files/1252/hydrogen\\_roadmap\\_for\\_the\\_midwest\\_09152\\_017.pdf](http://www.midwesthydrogen.org/site/assets/files/1252/hydrogen_roadmap_for_the_midwest_09152_017.pdf)

<sup>29</sup> <https://www.fuelcellcorridor.com/about-us-1>

<sup>30</sup> <https://www.fuelcellcorridor.com/why-ohio-1>

Another key organization is the Renewable Hydrogen Fuel Cell Collaborative, a “regional ambassador for the advancement and adoption of hydrogen-powered, zero-emission aircraft and infrastructure in the Midwest.”<sup>31</sup> It, along with the Stark Area Regional Transit Authority, released a roadmap that lays out a plan to deploy 135,000 fuel cell electric vehicles, build 250 hydrogen stations, and create 65,000 new jobs over the next 15 years.<sup>32</sup> Ohio was the standard-bearer in the roadmap, having been cited as *the* Midwestern state recognized for its dynamic fuel cell technology industry and extensive fuel cell supply chain.<sup>33</sup> The report echoes the findings of the Ohio Fuel Cell Coalition, as well as some of the figures reported above.

One example of this concerted push toward hydrogen power can be found in the Longridge Energy Terminal, a 485-megawatt powerplant in Lancaster, Ohio, which is currently under construction and scheduled to be operational in November 2021. It will run a blended operation combining natural gas and hydrogen power (the combustion turbine can burn up to 20% hydrogen), with the goal of operating at 100% hydrogen in 10 years.<sup>34</sup> The 1,600-acre site was once an abandoned aluminum smelter but has now found new purpose with a rising demand in green energy. When completed, it will power approximately 100,000 homes and serve as a steppingstone for the state’s evolving energy market.

The introduction of AAM will add significantly to the existing momentum found in Ohio’s hydrogen initiatives, supporting industries, and infrastructure. It will greatly enhance R&D, funding, and planning for the hydrogen market, further propelling Ohio to the forefront of hydrogen fuel cell technology.

### Boost for Academic Growth in AAM Related Programs

Given the substantial potential economic impact of AAM in the State of Ohio, described in this report, coupled with Ohio’s desire to set in motion the adoption of AAM through leadership in infrastructure and capability, there is a unique opportunity for academic institutions in Ohio to contribute to workforce development by creating new and effective educational programs.

The aerospace and defense advisor for the State of Ohio has stated that Ohio is a “powerhouse” in the U.S. aerospace and defense industry.<sup>35</sup> Furthermore, he broke down the governor’s priorities as follows:

- Recruit and retain young talent in the STEM field.
- Increase Ohio’s research portfolio.
- Attract new jobs within the manufacturing and defense sector to the state.
- Work to support and increase the local workforce.

Ohio has laid out a three-part strategy of essential initiatives to achieve these visions:

- Getting to know the local educational sector and understanding what the pipeline looks like at universities and colleges.
- Building on the state’s economy by attracting new businesses.

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<sup>31</sup> <http://www.midwesthydrogen.org/about/>

<sup>32</sup> <http://www.midwesthydrogen.org/about/>

<sup>33</sup>

[http://www.midwesthydrogen.org/site/assets/files/1252/hydrogen\\_roadmap\\_for\\_the\\_midwest\\_09152\\_017.pdf](http://www.midwesthydrogen.org/site/assets/files/1252/hydrogen_roadmap_for_the_midwest_09152_017.pdf)

<sup>34</sup> [Long Ridge power plant in Ohio to use hydrogen and natural gas \(dispatch.com\)](https://www.dispatch.com)

<sup>35</sup> (<https://www.bizjournals.com/dayton/news/2019/10/10/heres-why-ohio-is-a-powerhouse-in-the-u-s.html>)

- Seeking advantageous alliances to grow the state's aerospace and defense reputation.

JobsOhio has singled AAM as one of the important targeted areas for growth by stating: “Ohio is a living lab for advanced mobility and integrated autonomous systems on the road and in the air. Here’s how Ohio is prepared to test and deploy this technology in transportation and delivery.”<sup>36</sup> Furthermore, according to JobsOhio, in Ohio one may “hire from a skilled and continuously expanding workforce—currently at nearly 38,000—prepared for in-demand careers. Ohio’s colleges and universities educate, train, and upskill workers in engineering, UAS, aerospace manufacturing, technology and more.”

The State of Ohio has been investing through the Ohio Federal Research Network (OFRN), with most funds in the past rounds invested in the area of UAV/AAM, where proposing teams need to have at least two collaborating academic institutions.

With the realization that AAM can serve as a substantial STEM catalyst, it is envisioned that the number of initiatives such as the OFRN will further strengthen the capability of the academic institutions across the State of Ohio in key AAM technologies.

A sampling of academic areas offered in Ohio’s academia that can directly contribute to developing the desired AAM work force include:

- UAV Applications and Operations
- sUAS for Emergency Management Operations
- Unmanned Aerial Traffic Management Systems
- Automated Air/Ground Networked Mobility
- Multi-Agent systems & Optimal Swarming Strategies
- AI-based Assured Autonomy
- Human-AI Interaction
- Acoustics and Noise Mitigation
- Energy Transformation & Fuel Cells
- Traditional Aerospace Sciences: Aerodynamics; Flight Control Systems; Aerospace Structures & Materials; Electric, Internal Combustion or Jet Propulsions Systems
- Machine Vision, Big Data, and Machine Learning
- Cybersecurity
- Robotics and Intelligent Autonomous Systems
- Intelligent Maintenance Systems and Aircraft Maintenance Management
- Industrial Artificial Intelligence

Many Ohio universities contribute to the State of Ohio’s aerospace and AAM capabilities with various active academic and research programs. These include in alphabetical order:

- Air Force Institute of Technology ([www.afit.edu](http://www.afit.edu)), Dayton
- Baldwin Wallace University ([www.bw.edu](http://www.bw.edu)), Berea
- Case Western Reserve University ([www.case.edu](http://www.case.edu)), Cleveland
- Cedarville University ([www.cedarville.edu](http://www.cedarville.edu)), Cedarville
- Central State University ([www.centralstate.edu](http://www.centralstate.edu)), Wilberforce
- Cleveland State University ([www.csuohio.edu](http://www.csuohio.edu)), Cleveland
- Kent State University ([www.kent.edu](http://www.kent.edu)), Kent
- Marietta College ([www.marietta.edu](http://www.marietta.edu)), Marietta

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<sup>36</sup> <https://www.jobsohio.com/industries/aerospace-aviation/>

- Miami University ([www.miamioh.edu](http://www.miamioh.edu)), Oxford
- Ohio Northern University ([www.onu.edu](http://www.onu.edu)), Ada
- Ohio University ([www.ohio.edu](http://www.ohio.edu)), Athens
- The Ohio State University ([www.osu.edu](http://www.osu.edu)), Columbus
- University of Akron ([www.uakron.edu](http://www.uakron.edu)), Akron
- University of Cincinnati ([www.uc.edu](http://www.uc.edu)), Cincinnati
- University of Dayton ([www.dayton.edu](http://www.dayton.edu)), Dayton
- University of Toledo ([www.utoledo.edu](http://www.utoledo.edu)), Toledo
- Wilberforce University ([www.wilberforce.edu](http://www.wilberforce.edu)), Wilberforce
- Wright State University ([www.wright.edu](http://www.wright.edu)), Dayton
- Youngstown State University ([www.ysu.edu](http://www.ysu.edu)), Youngstown

Community colleges in Ohio have also established technical programs in relevant areas important for the advancement of AAM in the state. These include:

- Cincinnati State Technical and Community College ([www.cincinnatiastate.edu](http://www.cincinnatiastate.edu)), Cincinnati
- Columbus State Community College ([www.csccl.edu](http://www.csccl.edu)), Columbus
- Cuyahoga Community College ([www.tri-c.edu](http://www.tri-c.edu)), Parma
- Lakeland Community College ([www.lakelandcc.edu](http://www.lakelandcc.edu)), Kirtland
- Lorain County Community College ([www.lorainccc.edu](http://www.lorainccc.edu)), Elyria
- Sinclair Community College ([www.sinclair.edu](http://www.sinclair.edu)), Dayton

It may be stated with high certainty that a meaningful investment in AAM-related academic programs will have a substantial catalytic effect on the State of Ohio, yielding an excellent return on investment (ROI), further boosting academic R&D investment.

## Summary of Findings

The study produced a number of important findings intended to guide the State of Ohio and its policy deliberations. These findings are supported by in-depth analytics guided by the experience of the senior team members working in the global AAM field.

- Ohio will be able to grow and sustain profitable AAM operations in urban, suburban, and rural areas over the 25-year forecast period.
  - Commercial business activities among all pillars (revenues from operators and aircraft manufacturing, and capital and operational expenditures for PSU and ground infrastructure) are expected to approach \$13 billion between 2021 and 2045 for six use cases of involving emergency services, passenger services and cargo movement.
  - About 66% of the forecasted \$13 billion of value-added impact is considered direct and indirect; the remaining 34% from induced impacts
  - More than 15,000 direct, indirect, and induced permanent, high-paying, full-time jobs are forecasted. Since the direct and indirect effects of AAM account for roughly two-thirds of the impact, we see that job types, or occupations needed, are closely aligned with the industries tied to AAM.
  - More than \$2.5 billion in federal, state and local tax revenues is expected over the 25 years of the analysis. Local and state governments revenues account for \$464 million and \$542 million, respectively, while the federal revenues account for about \$1.5 billion. The local level represents totals for townships, cities, and counties for the entire state.
  - The overall state-wide infrastructure revenue to investment (R/I) ratio is in the range of 2.2, suggesting that private capital sources will be attracted to make infrastructure investment.
- sUAS holds promise in increased efficiencies and productivity, but relative to AAM does not offer significant direct economic benefits in terms of new jobs creation or direct cost savings.
  - sUAS operations provide significant benefits by making more efficient use of resources (i.e., improving productivity), enabling higher fidelity of data, increasing social benefits such as workplace safety, and decreasing the environmental impact of other operations.
  - Use of sUAS will also significantly enhance the mission of execution of ODOT and other government entities by improving infrastructure inspection, and workforce operating efficiency and productivity.
- Significant differences between the five major cargo logistics corridors are due to highly varied commercial activity concentrations. The team analyzed the cargo corridors along four major interstates (I-71, I-75, I-80, I-70) and along U.S. Route 33. Based on intrastate analysis, the I-71 corridor, connecting Cincinnati, Cleveland and Columbus, is the most promising for early adoption. However, all corridors have enormous potential for interstate routes for midwestern U.S. states. U.S. Route 33 has also special impact on rural access to the southeastern and the west-central regions of the state.

- The economic activity due to needed investment for ground and PSU infrastructure is estimated at more than \$1.4 billion over the 25-year forecast period.
  - Investments in multiports, which are specially designed transportation hubs for AAM capable of servicing several aircraft at once and offering passenger amenities, will be needed in the future. Ohio's efforts with NASA Ames in vertiport planning are critical to better identify the most impactful locations of vertiports in urban environments within Ohio's largest cities. This work will inform future investments for new vertiports. However, immediate and near-term infrastructure investment will be concentrated in remediating existing heliports, adding airport multiport installations, and establishing logistic corridors PSU systems.
  - Current Ohio efforts such as SkyVision, Ohio UTM and Remote Tower provide a strong foundation for investment to low-altitude air traffic management and PSUs systems. These efforts must be physically expanded to other areas, including investments in the PSU systems along the interstate corridors.
- AAM will facilitate access to far suburbs and rural areas, helping to close the physical gaps and economic disparities between rural and urban populations, a key objective of the State of Ohio.
- AAM will capitalize and build upon Ohio's strong capabilities in aerospace, advanced manufacturing, materials technologies, and university and R&D capacity.

## Recommendations for Implementation

The team's recommendations fall into four categories:

- Strategy, Policy and Legislative Framework
- Studies, Demonstrations, Pilot Programs, and Local AAM Planning Initiatives
- National AAM Leadership Activities
- AAM Supply Chain, Manufacturing, and Service Opportunities for Ohio.

### Recommendation 1

#### Strategy, Policy, and Legislative Framework

Build upon Ohio's reputation and heritage as a first mover and visionary aviation leader, using AAM to bring the state (government and industry) to the next level by developing a policy, infrastructure, and R&D roadmap for state-wide AAM implementation.

- a. Within the ODOT and Ohio UAS Center, establish a project office and advisory team, including state and federal policy making, investment banking, project financing, AAM supply chain, transportation engineering, regulatory and other expertise to advise ODOT and the State of Ohio. The advisory team will assist in the realization of the approximately \$13 billion Ohio AAM opportunity.
- b. Develop a **mission** [statement], **blueprint**, and related **roadmap** to strengthen ODOT leadership in AAM, with emphasis on: 1) Realization of the approximately \$13 billion Ohio AAM opportunity; 2) Private-sector participation and capital with early-stage involvement from eVTOL suppliers; 3) Job creation, skills development, and improving labor market efficiencies; 4) Identification and investment strategies for addressing technological gaps for the adoption of AAM and 5) Ensuring R&D leadership for Ohio educational institutions.
- c. Making use of this report, brief local, state and federal transportation leaders and policy professionals, and airports, on the specific economic and job creation benefits of AAM for the State of Ohio.
- d. Develop AAM policy guidance for Ohio city and county governments, economic development agencies, and airports.
- e. Form a broad-based coalition of AAM stakeholders able to meet monthly and provide consistent input to the Ohio UAS Center (See recommended key stakeholders in Table 13).

**Table 13: Key AAM Stakeholders**

State/Municipal Agencies	Federal Agencies	eVTOL Manufacturers	AAM Supply Chains	Ohio P135 and P91 Operators	Financial, Investment and Institutional	Universities and Colleges
ODOT FlyOhio DriveOhio JobsOhio Municipal Economic Development Agencies Regional and Local Planning Authorities Airports Transit Agencies Others	USDOT FHWA FAA NASA Volpe Center DOD/AFWERX AFRL Others	Kitty Hawk Moog Reliable Robotics Joby Archer Beta Lilium Boeing VEA Vertical Others	Ground Infrastructure PSU/UTM Infrastructure ANRA Technologies CAL Analytics Raytheon Thales L3 Harris Skyward AirMap Crown Consulting Ohio-specific suppliers Others	UPS Fedex Ohio P135 Operators Corporations /P91 flight departments NetJets Others	Incubators Infrastructure Funds Venture Funds Family Offices Project Financing, e.g. NEXA Capital Partners Others	University of Cincinnati Ohio State University Ohio University Sinclair College & Other Community Colleges Others

- f. Identify the elements of and further develop state and municipal linkages to federal legislative strategies to steer AAM legislative programs including: 1) The Advanced Air Mobility Coordination and Leadership Act<sup>37</sup>; and 2) (Future) Federal Infrastructure Programs<sup>38</sup>, where some \$2 trillion in funding can be tapped to advance AAM programs for Ohio.
- g. Evaluate and continue to employ options available through USAF, AFRL, AFWERX and Agility Prime for matters such as use of military flight release (MFRs), vehicle certification, access to DoD bases and airspace, and others.
- h. Work with state and municipal agencies and advise The Ohio Legislature to develop and implement programs to memorialize the roadmap and strengthen industry participation for the four key AAM supply chains:
  - i. eVTOL manufacturing - electric vehicles and critical Tier 1 and 2 supply chain participants.
  - ii. Ground infrastructure (e.g. vertiports, airport multiports, electrical charging systems, lighting systems, etc.). Capitalize on the UAS Center’s current vertiport design activities with NASA Ames to inform the appropriate location of vertiport for the future.
  - iii. PSU/UTM low-altitude air traffic management infrastructure, including communication, navigation and surveillance systems and staffed network operations centers. Current Ohio efforts led by the Ohio UAS Center such as SkyVision, Ohio UTM and Remote Tower provide a strong foundation for investment in low-altitude air traffic management and PSU systems. The State must physically expand these efforts to other

<sup>37</sup> “Advanced Air Mobility Coordination and Leadership Act” U.S. Senate, sponsors Senators Moran and Sinema, introduced March 2, 2021

<sup>38</sup> “America Jobs Plan”, tabled March 31, 2021, the White House

areas, including providing additional investments in the PSU systems along the interstate corridors.

- iv. Eventual eVTOL operations, making use of Ohio Part 135 and Part 91 helicopter operators, whose trained pilots, safety, and quality programs, training curricula, dispatch capabilities, etc. will help ensure the highest industry safety standards.
- i. Using the project office and advisory team (Recommendation 1a.), evaluate private capital options for infrastructure financing using innovative financing structures and potential public-private partnerships (PPP).
  - i. Allocate state funding for studies in the formation of innovative financing structures and PPPs.
  - ii. Pursue regulations, evaluations, and adjustments that would enable development of project financing for AAM infrastructure.

## Recommendation 2

### **Studies, Demonstrations, Pilot Programs, and Local AAM Planning Initiatives**

Work with state and local community planning organizations and with heavy involvement of Ohio universities and colleges.

- a. Identify long-term opportunities to partner with federal agencies to explore how AAM will impact the nation's passenger and cargo transportation in the future.
- b. Engage Ohio airports early and through all stages. Pursue legislative assessment and action on the Ohio Airport Protection Act (Ohio Administrative Code) to include vertiports. This focuses on protecting the airspace around vertiports, including the approach and departures paths.
- c. Understand local and regional passenger demand, cargo/freight transportation arteries, and intermodal connectivity that will flourish with AAM. With that information, plan and pursue early prototype vertiports for demonstrations.
- d. Undertake studies to select locations within the downtown cores of Cincinnati, Cleveland, and Columbus for prototype vertiports. Build prototype vertiports for early demonstrations:
  - i. Identify commercial incentives for vertiport construction in Ohio to attract early adopters.
  - ii. Choose one or more phase 1 locations within the downtown core of Cincinnati, Cleveland and Columbus for AAM launch vertiports.
- e. Investigate transportation patterns in and out of major airports and their connection to suburbs. Airport delivery has a strong opportunity due to its established safety and public mitigations for air travel.
- f. Work with The Ohio Legislature to seek clarity of the role of state and local government in management and control of low-altitude airspace.
- g. Advance rural/urban integration:

- i. Understand regional healthcare network operations and delivery, especially intra-facility and urban-to-rural delivery for potential early adopters.
- ii. Continue development of air mobility services, including health care delivery, to rural areas of Ohio.
- iii. Identify small airports that may serve as rural service centers for early adopters.

### Recommendation 3

#### National AAM Leadership Activities

Demonstrate national leadership through Ohio-based AAM projects underway today or starting shortly.

- a. Develop concepts of operation in concert with federal concepts and policies and incorporation of environmental and community integration considerations.
- b. Focus initial ODOT and UAS Center efforts in three of the most promising AAM use cases that will produce early results: regional air mobility, emergency services, and heavy cargo logistics.
- c. Continue development of low-altitude airspace design led by the Ohio UAS Center (Skyvision, Ohio UTM, and Remote Towers) in support of the three use cases, with initial emphasis in the I-71 corridor and its three major metropolitan areas.
- d. Produce a regular series of white papers, guided by complementary technical, industry, and economic themes, for national publication, demonstrating Ohio-based leadership in AAM:
- e. Emphasize ways and means to ensure that catalytic benefits are captured for the State of Ohio with respect to 1) improved labor market efficiencies, 2) suburban/rural access, and 3) acceleration in STEM funding and educational opportunities.
- f. Identify linkages to important initiatives such as Smart Cities, SMART Columbus, etc., and climate change initiatives led by organizations such as the Ohio Environmental Council.
- g. Sponsor conferences in the state at least annually to showcase Ohio leadership in the field.
- h. Capitalize on the presence of federal laboratories in Ohio.
- i. Establish and credentialize the Ohio AAM Center of Excellence. The Center will ignite a transition to daily operations that can scale to provide affordable price points and position Ohio as a clear leader, attractive to technology firms, OEMs and operators.

- j. Extend operations and demonstration beyond the UAS Center in Springfield and into real-world demonstrations and operations across the logistic corridors and into rural areas.<sup>39</sup>
- k. Address the integration of local and state government policies and regulations with the federal government.

## Recommendation 4

### **AAM Supply Chain, Manufacturing and Service Opportunities for Ohio**

Position Ohio to attract participants within each of the four supply chains for the AAM industry.

- a. See Recommendation 1h.
- b. Undertake a program to encourage R&D and manufacturing partnerships between auto makers, eVTOL developers and Tier 1 and Tier 2 supply chain participants.
- c. Identify and pursue future AAM job categories and establish suitable training programs in conjunction with higher education institutions, capitalizing on the strong base of courses and programs already in existence.
- d. Retain highly skilled AAM-oriented talent in Ohio to fill the more than 15,000 potential full-time jobs by 2045, with 80 percent of those jobs expected in supply chain categories.
- e. Study the establishment of a state-funded R&D granting organization and incubator to anchor entrepreneurs for the AAM sector in Ohio.
- f. Capitalize on Ohio leadership in energy production, and on current initiatives, such as the Ohio Fuel Cell Coalition, to lead the nation in the transition to alternative energy sources such as Hydrogen power.

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<sup>39</sup> Current UAS test sites partnered with the FAA around the country are testing various use cases, scenarios, vehicles and supporting technologies. With only minor exceptions operations are limited by the constraint of the Centers without exploration into non-sterile environments. Operations over dense populations creating noise and public perception issues are needed, as well as operations in regular airspace without the sterilization (and protection) that is put in place at test sites.

## Appendix A: High-Level Task Descriptions

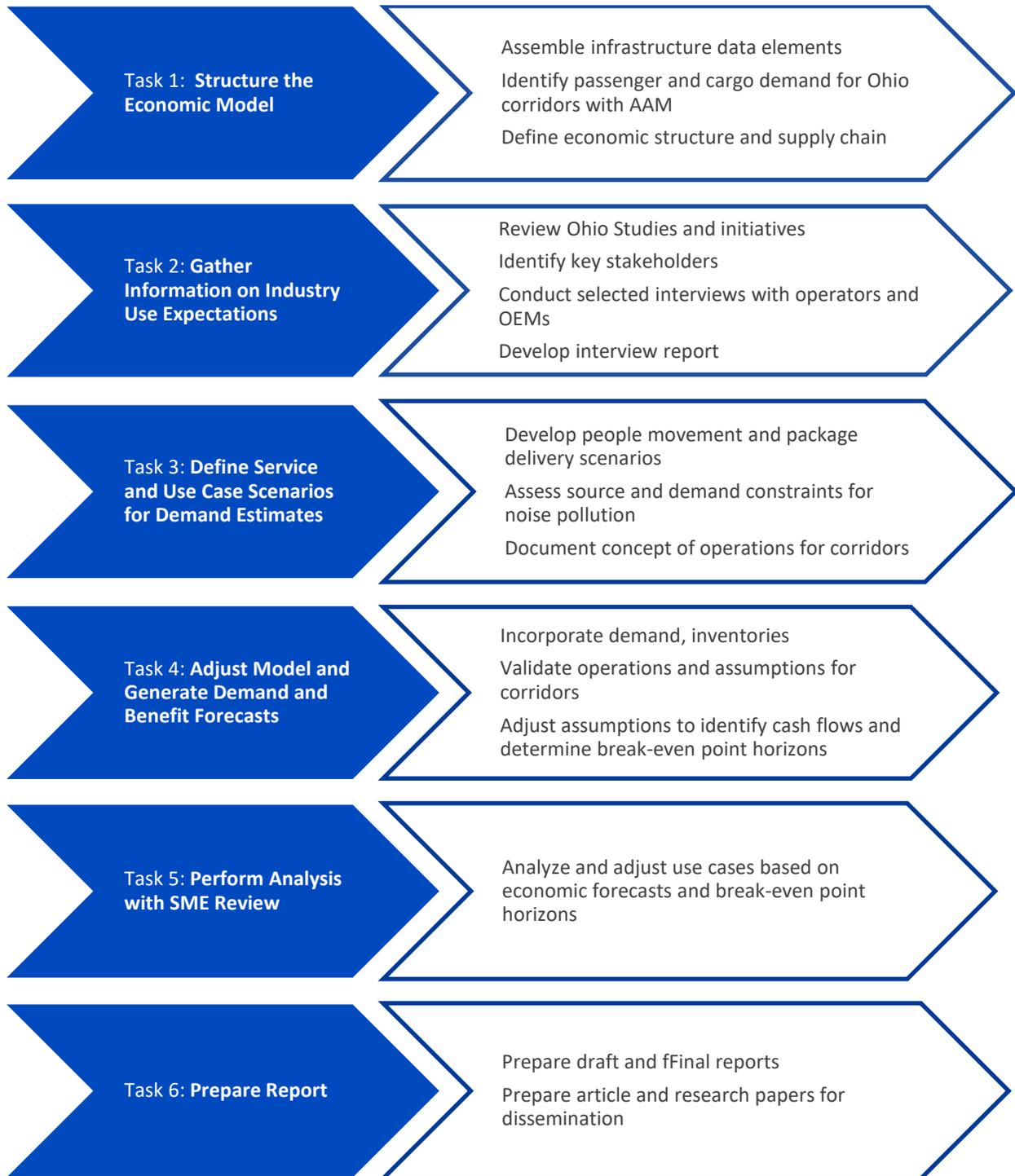


Figure 21: Summary of Study Tasks

## Appendix B: Noise and AAM

There may be the potential for a significant economic impact of AAM and eVTOL aircraft for the transportation of cargo and passengers. However, if AAM systems create unacceptable noise pollution in their operational communities, the economic impact could be severely limited.

The vision for AAM operations would realize hundreds or thousands of daily operations in populated urban, suburban, and rural environments. These aircraft would take off from vertiports in densely populated urban environments and fly over neighborhoods and communities at altitudes much lower than current commercial aircraft. The noise signature of these aircraft will be unlike any existing airplane or helicopter, and the human response to these noise signatures is still unknown, but early research indicates that annoyance levels will be much higher due to the specific frequencies and tonal nature of the acoustic signatures.

History offers many examples of limited economic impact of aircraft due to unacceptable noise pollution. This includes the Concorde Supersonic Transport (SST) aircraft that was prohibited from flying over land due to the sonic boom and deafening engine noise, which resulted in limited flight routes overseas and eventually failure of the business model. Another example is the constant battle over helicopter noise in dense cities such as Chicago, Los Angeles, and New York. Noise regulations have restricted helicopter use primarily to emergency services and law enforcement activity.

To ensure that proposed AAM visions are realized, a comprehensive approach to understanding the impact of noise on urban, suburban, and rural communities is paramount.

A high-level technical summary of aircraft noise is presented here to assist in assessing the complex landscape of noise impacts and regulation. The purpose of this section is to highlight the challenges that eVTOL noise may face in terms of widescale adoption, acceptance, and ultimately the realization of the economic projections laid out in this report.

### [New aircraft classes and designs](#)

The field of aeroacoustics focuses on the acoustics or noise generated from aerodynamic phenomena, which is the primary acoustic source for aircraft. The aircraft envisioned to operate in the eVTOL market are radically new aircraft designs that are as varied and diverse as the hundreds of companies vying to develop these aircraft. The aircraft payloads may range from small cargo deliveries to four-to-six passengers to larger regional passenger and cargo transportation. The noise of these aircraft will be dominated by the propulsion systems, including the propellers, rotors, and electric motors (hybrid-electric powerplants may also find application). Distributed electric propulsion (DEP) is an enabling technology, allowing aircraft designers to use anywhere from four to 20 or more propulsors distributed across the aircraft. For a given aircraft mission and payload, there may be multiple aircraft with vastly different propulsion system architectures and aircraft configurations that will result in different noise signatures.

Helicopters generate all lift and thrust from a single main rotor. Airplanes generate forward thrust from the propulsion system and lift from the wings in forward flight. Current proposed AAM eVTOL concepts use combinations of lift from propulsors and airframe and thrust from forward facing propellers/rotors or by tilting the rotors and transitioning from vertical to forward flight regimes. The primary noise-reducing design change for eVTOLS comes from using multiple smaller distributed rotors that can operate at lower tip speeds ( $M_{tip} = 0.3 - 0.6$ ), compared to helicopters, which tend to operate with transonic tip Mach numbers. This design change alone nearly eliminates the primary noise sources (blade-vortex interaction and high-

speed impulsive noise) of helicopters. By distributing the thrust load over multiple propulsors, an aircraft designer can add more rotors to achieve the required thrust, while helicopters often need to increase the rotor speed. The general consensus among the aeroacoustics community is that this is a very powerful design change, but further advancements must be made in reducing the remaining noise sources throughout the flight mission in order to enable operations near populated areas without adversely affecting the noise landscape and achieving community acceptance.

### Lower Altitude Flights and Unique Operations

The noise problem for eVTOL aircraft is unique in many ways. This emerging market will increase aircraft operations at low altitude (500-3,000 ft ASL). To achieve market viability and large-scale adoption, flight operations on the order of hundreds to thousands of daily operations in a metropolitan area have been projected. This outpaces current aircraft operations and, in terms of noise, eVTOL aircraft will need to be imperceptible at cruising conditions to gain widespread acceptance. The aircraft noise emission to achieve imperceptibility on the ground will vary by location based on the ambient soundscape and background noise.

The value proposition for eVTOL operations is strongly linked to the unique capability of being able to take off and land in populated urban city centers. This will likely be the limiting case for aircraft noise levels since the vertical portions of flight require the highest loading (thrust) from the propulsion system and this operation will be closest to the populations. Vertiports are envisioned to be constructed on top of parking structures, high-rise buildings, and near ground level, distributed throughout urban and suburban regions around cities. This is in contrast with the legacy strategy of locating airports away from the most populated urban areas to control noise pollution and limit community exposure. Noise standards for VTOL operations in populated areas will be required.

### Unknowns on Aircraft Noise Signatures

A unique hurdle for assessing and predicting the noise impact of eVTOL aircraft is that most of these aircraft are very early in their development, many existing only as concepts or prototypes, particularly the larger-scale aircraft for transporting passengers. In line with this report, we will discuss aircraft noise for two eVTOL classifications: 1) sUAS aircraft for small payloads and 2) AAM aircraft capable of passenger transport and larger payloads. This discussion will mostly focus on AAM aircraft due to the potential for higher sound levels and higher numbers of operations.

For AAM aircraft that are further along in the development cycle, the acoustic signatures are held as proprietary information with the company. There are some publicly known data sharing agreements between companies and federal agencies such as NASA and the FAA, but the data is not widely available to the community. Since AAM aircraft are effectively a new class of aircraft from helicopters, jet aircraft, and general aviation airplanes, it is very difficult to predict noise using existing modeling tools. Additionally, higher fidelity tools that can capture the flow physics related to the acoustics sources are not practical for capturing all the complex aeroacoustics interactions. This points to a significant effort needed in terms of characterizing the aeroacoustics of these aircraft across operational conditions, flight modes, operating environments, and for various sizes and payloads. These efforts should encompass all aspects, from fundamental research all the way to aircraft certification and flight test. These technical hurdles and needs are laid out in detail in the NASA Urban Air Mobility Noise: Current Practice, Gaps, and Recommendations (NASA/TP-20205007433).

Another unique issue with AAM aircraft is based on the projected business model for this new class of aircraft, which hinges on a high number of operations in densely populated areas. This

contrasts with past approaches of constructing airports away from densely populated areas in much of the United States. Obviously, airport noise is more pronounced in large cities and in Europe, which has more land constraints. The issue of conducting many operations in densely populated areas will likely result in the most stringent noise limitations for these aircraft being applied for the takeoff and landing phases of the mission. In conjunction with densely populated areas, this will likely occur in reverberant environments surrounded by tall buildings and populated structures. This will require creative engineering and architectural solutions, as well as methods and standards for regulating AAM aircraft noise for these critical phases. This consideration goes beyond the current regulations and must be considered for the business models and economic projections for AAM to be realized.

### Literature Review

A summary of the fundamentals of measurements and standards used in aircraft and helicopter noise regulation is provided here. These metrics will be described at a high level to aid in understanding an example noise study that has been conducted by Booz Allen Hamilton<sup>40</sup>.

### Noise Metrics and Regulation for Aircraft and Helicopters

There are a few primary noise metrics used in the regulation of aircraft and helicopter noise, described below.

Sound Exposure Level (SEL): A noise metric used in helicopter certification. SEL is a normalized time integration of the A-weighted sound pressure level in decibels (dBA) that spans at least +/- 10 dB from the maximum SPL level measured. A-weighted SPL weights the measured SPL to approximate human hearing response to the frequency content of the sound. Figure 22 shows the equation ( $L_{AE}$ ) and some diagrams for SEL calculation. Noise limits are set based on the maneuver (takeoff/landing/flyover) and maximum takeoff weight.

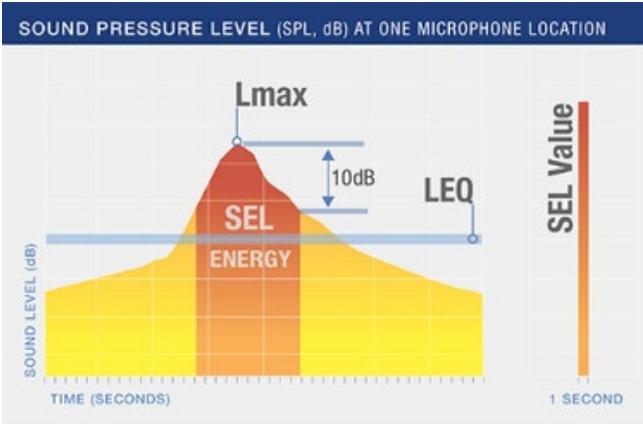
Effective Perceived Noise Level (EPNL): A noise metric used for commercial jet aircraft which takes into account duration of the noise event and tones in the acoustic spectra. The units of EPNL are EPNdB. The calculation for EPNL corrects the measured sound pressure to noisiness in units of ‘noys’ for human perception instead of A-weighting, but the two methods are similar. The weighted pressure-time history is corrected (penalized) for tones based on the frequency and amplitude of the dominant tone in the third-octave band spectra. Another correction (penalty) for the duration of the event is computed to account for the time-variation of the noise around the maximum. It is not anticipated that EPNL will be used for AAM certification, however, there is some credence to a similar metric that accounts for tonal content in the acoustic signature to be penalized, based on psychoacoustic research conducted by NASA<sup>41</sup>.

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<sup>40</sup> [BAH Market Study - NASA HQ-E-DAA-TN65181 \(https://ntrs.nasa.gov/citations/20190001472\)](https://ntrs.nasa.gov/citations/20190001472)

<sup>41</sup> [NASA Advanced Air Mobility Noise White Paper NASA/TP-20205007433 \(https://ntrs.nasa.gov/citations/20205007433\)](https://ntrs.nasa.gov/citations/20205007433)

$$\int_{t_1}^{t_2} \left( \frac{P_A(t)}{P_0} \right)^2 dt \text{ dB}$$



(a)

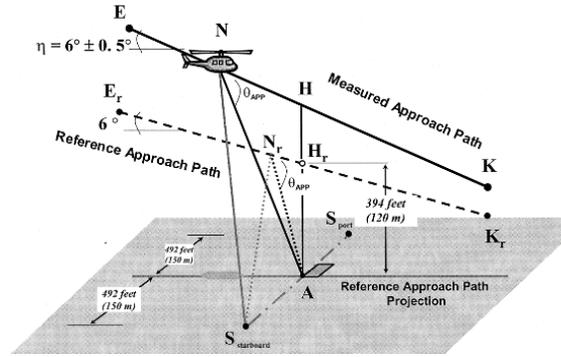


Figure H3.  
Comparison of Measured and Reference Approach Profiles

(b)

**Figure 22: Diagrams Showing (a) Calculation Limits of SEL and (b) Helicopter Landing Approach Used in Noise Certification**

**Day-Night Average Sound Level:** The Day-Night Average Sound Level (DNL) is a metric used in airport planning which is the average A-weighted sound pressure level over a 24-hour period. The metric penalizes noise levels by 10 dB between the hours of midnight-7 A.M. and 10 P.M.-midnight. Figure 23 shows the distribution of hourly averaged sound levels that average to a 65 DNL level, which is a threshold that most residential and public use areas aim to stay below. The equation for computing DNL over the 86,400 seconds in a 24-hour day is shown in Equation 1 which requires continuous data-logging.

As the number of flight operations increase, the maximum SEL of each individual event will need to be lower. Figure 24 provides an example showing that to maintain a DNL of 65 dBA, if there is one event/day then an SEL of 104.4 dBA can be endured. For 10x increase in operations, the SEL needs to decrease by 10 dBA (10 events/day @ SEL=94.4 dBA or 100 events/day @ SEL=84.4 dBA). Keeping in mind that dBA is log-scale, a 10 dBA reduction is reducing the sound pressure to 1/3 of the original level, which is not trivial. This example maintains certain assumptions which could change the result, such as the time of occurrence of each event, the background noise level, and it assumes each event is equally loud.



Figure 23: Hourly Sound Levels in dBA Illustrating the 10 dB Penalty Applied During Evening Hours

$$L_{dn} = 10 \log_{10} \left[ \frac{1}{86400} \left( \int_{0000}^{0700} 10^{[L_A(t)+10]/10} dt + \int_{0700}^{2200} 10^{L_A(t)/10} dt + \int_{2200}^{2400} 10^{[L_A(t)+10]/10} dt \right) \right]$$

Equation 1: Equation for Calculating DNL Over 86,400 Seconds of a Day

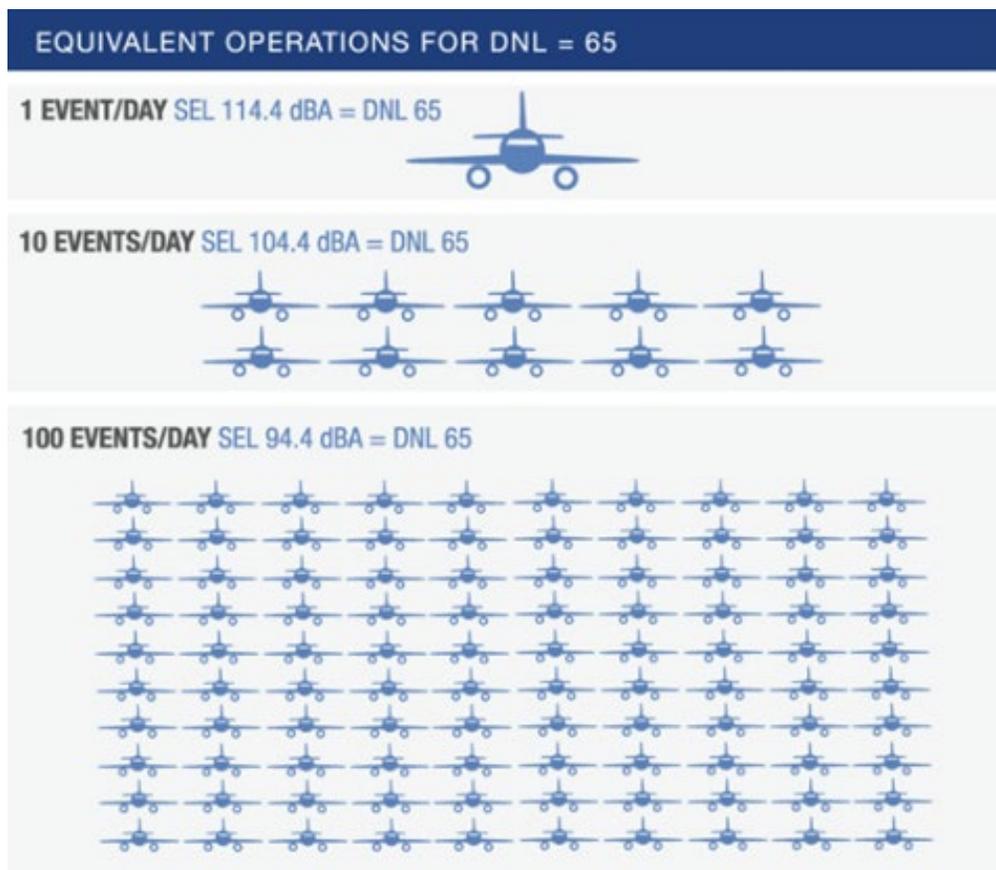


Figure 24: Illustration of the Number of Events That Can Be Incurred at a Given SEL Level for a DNL Level of 65 dBA

## Booz Allen Hamilton AAM/UAM Market Study

Booz Allen Hamilton conducted a preliminary noise modeling assessment using the FAA's Aviation Environment Design Tool (AEDT), which is a software tool used in regulating aircraft based on noise exposure on the ground.<sup>42</sup> The study utilized data on the Robinson R22, R44, and Eurocopter EC130 helicopters for the analysis. The noise levels were decremented for a R22 helicopter by 10, 20, and 30 dB for a conceptual study of the impact on noise metrics, shown in Figure 25a with  $L_{A,max}$  at 1,000 ft altitude indicated. For a R22 helicopter decremented by -30 dB (very optimistic), the 65 dBA  $L_{A,max}$  ground contour decreased by a factor of 10 for arrival and by a factor of three for departure. The 65 dBA DNL ground contour was reduced slightly, particular for a 30 dB reduction. It should be noted that a 30 dB reduction of the R22 reduces the  $L_{A,max}$  noise level near the aircraft from 95 dB to 65 dB. This will require significant technology advancement to achieve over a 30x reduction in sound pressure, which most likely will need to be achieved through a combination of aircraft noise reduction and flight path optimization for low noise. This further highlights the importance of takeoff and landing noise, which will be governed by aircraft noise and the surrounding physical environment. The study also demonstrated that for the 100 operations per day, the increase in DNL level is 22% for departure operations and 35% for arrival operations, as shown in Figure 25b, for the standard helicopters studied (no noise decrement). These levels would far exceed the suggested one dBA maximum increase in DNL for a given area recommended by existing regulations per the Uber White Paper,<sup>43</sup> corresponding to 1.4% for 70 dBA. Further research and operational studies are needed, with much greater detail and rigor to adequately assess the noise impact of these air mobility operations.

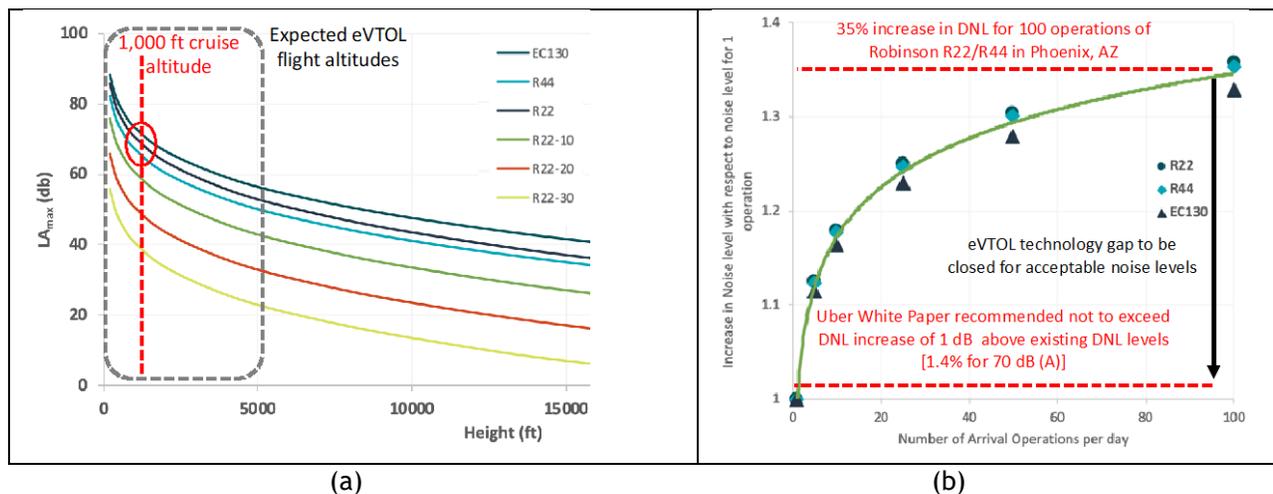


Figure 25: (a) SEL Levels for Low-Noise Helicopters and the R22 Hypothetically Decrement by -10, -20, and -30 dBA (b) Increase in 65 DNL Noise Contour Area as a Function of the Number of Operations (no noise decrement)

## Noise Risk to Economic Projections

Noise is inherently a human issue; if there are no humans to be annoyed, it is only sound. There are real and major risks that the noise from AAM aircraft may significantly impact the economic

<sup>42</sup> BAH Technical Outbrief Slides (<https://core.ac.uk/download/pdf/189597661.pdf>)

<sup>43</sup> Uber Elevate White Paper (<https://www.uber.com/elevate.pdf>)

projections presented in this report. This should be a major incentive to invest in noise reduction across the ecosystem, from aircraft engineering to policy making. Some of these risks are summarized below.

#### Aircraft Noise: Individual Events

The aircraft is the inherent source of acoustic energy, the majority of which will come from the propulsion system. There are distinct flight regimes for AAM aircraft that include vertical takeoff and landing, maneuvering, transition to forward flight, and steady level flight. Each of these flight regimes have the potential to drastically alter the acoustic levels and directionality (propagation direction). The propulsion system generates noise from the motors and from the aeroacoustics of the propellers due to flow acceleration and blade-wake interaction. Additionally, interactions of the propeller flow with the aircraft structure, and surrounding propellers will generate secondary acoustic sources. All of these phenomena need to be understood in much greater detail in order to understand the noise sources that result in the highest levels of annoyance and to engineer the system for minimal acoustic signature. With the massive number of proposed aircraft configurations, this is a significant undertaking, but will be critical to making measurable advancements in reducing the noise of the aircraft to the desired levels. This is the first step in ensuring that the number of operations needed for a viable business model can be realized.

#### Operations Noise: Multiple Events

Limitations of operations based on existing noise metrics (EPNL, SEL, DNL) may artificially constrain operations due to the inadequacies of these metrics to properly capture annoyance from eVTOL noise signatures. In order to create accurate models for operations noise, accurate and relevant spectrally resolved acoustic data is needed during all of the critical flight modes and mission phases. Additionally, knowledge of the background noise along proposed flight paths and in areas surrounding vertiports are needed to accurately model the impact of an AAM aircraft operation in the relevant operating environment. With models grounded in data, meaningful recommendations and goals can be laid out for aircraft designers in terms of noise levels during specific operations.

#### Vertiport Noise in Populated Environments

Noise levels in and around vertiports and areas for takeoff and landing of AAM aircraft will be critical for ensuring acceptance of AAM operations. The design of structures and surrounding landscaping for acoustic mitigation are some ideas for reducing the acoustic footprint of a vertiport. However, there will undoubtedly be areas where vertiports will be in reverberant environments and minimizing the aircraft noise will be the primary need to minimize noise on while operating at low altitudes prior to takeoff or landing.

#### Local Noise Ordinances

While the (FAA) sets the limits for aircraft noise during certification, there is no guarantee that those noise levels will be acceptable for a given community. Noise ordinances are controlled at a local level and there is a large risk that AAM operations could be artificially constrained by local ordinances. There should be a concerted effort to reach out to local communities and local policy makers in communities that are anticipated to be impacted by high levels of AAM operations. Activities could include educating communities on what to expect and the benefits that AAM would bring, surveys of the community background noise levels throughout the day, pilot programs to test flight operations and gauge annoyance for full-scale systems, and more.

### Recommendations for Potential ODOT AAM Noise Related Activities

- Utilize state resources such as the Ohio UAS Center to create a center of excellence for conducting field acoustic measurements.
- Incentivize companies to fly their sUAS and AAM systems at the Ohio UAS Center to generate acoustic data for sharing with the broader community.
- Advocate for state-funded research at universities and with companies to advance the knowledge and technology related to AAM aircraft noise.
- Advocate for and support noise surveys along interstates, highways, and in anticipated high traffic vertiport locations.
- Guide policy making and outreach to local communities about noise ordinances.
- Conduct community noise surveys and pilot programs in local communities to assess sUAS and AAM annoyance.

## Appendix C: Discussion of sUAS Operations

Small UAS (sUAS), as defined by the FAA under Part 107, are autonomous aircraft weighing less than 55 pounds, including payload. Their small size enables them to fly within constricted areas, and Part 107 restricts operations to less than 400 feet above ground level without a waiver. When fitted with sensors, sUAS provide enhanced capabilities for inspections, monitoring, mapping and surveillance. Some package delivery sUAS can be used for delivery methods for smaller payloads, including medical supplies.

There are a range of these aircraft in development and in production, as shown below.



### Amazon Prime Air delivery drone

- Seattle, Washington - [www.amazon.com](http://www.amazon.com)
- Targeted use case: Package delivery
- Max payload: 5 pounds
- Range: 15 miles
- Max speed: 50 mph
- Max flight time w/payload: 0.5 hours



### DJI Matrice 200 Series V2

- Shenzhen, China - [www.dji.com](http://www.dji.com)
- Targeted use case: Infrastructure inspection
- Max payload: 3.2 pounds
- Range: 5 miles
- Max speed: 50 miles
- Max flight time w/payload: 38 minutes



### DJI P4 Multispectral

- Shenzhen, China - [www.dji.com](http://www.dji.com)
- Targeted use case: Agriculture
- Max payload: 0
- Range: 4.3 miles
- Max speed: 31 mph
- Max flight time: 27 minutes



### DJI Matrice 300 RTK

- Shenzhen, China - [www.dji.com](http://www.dji.com)
- Targeted use case: Law enforcement/Public safety
- Max payload: 5.95 pounds
- Range: 9.3 miles
- Max speed: 51 mph
- Max flight time: 55 minutes



### Drone Delivery Canada Sparrow

- Vaughan, Ontario, Canada - [www.dronedeliverycanada.com](http://www.dronedeliverycanada.com)
- Targeted use case: Package delivery
- Max payload: 9.9 pounds
- Range: 18.6 miles
- Max speed: 50 mph
- Max flight time: *unspecified*



### Matternet M2

- Mountain View, California - [www.matternet.com](http://www.matternet.com)
- Targeted use case: Medical/Package delivery
- Max payload: 4.4 pounds
- Range: 12.4 miles
- Max speed: 31 mph
- Max flight time: 30 minutes



### Skydio 2 Enterprise

- Redwood City, California [www.skydio.com](http://www.skydio.com)
- Targeted use cases: Infrastructure inspection, Law enforcement/Public safety
- Max payload: n/a
- Range: 2.1 miles
- Max speed: 36 mph
- Max flight time: 23 minutes



### UPS Flight Forward/Wingcopter 178 Heavy Lift

- Wietertstadt, Germany [www.skydio.com](http://www.skydio.com)
- Targeted use case: Package delivery
- Max payload: 13.2 pounds
- Range: 75 miles
- Max speed: 93 mph
- Max flight time: 3 hours



### Wing Delivery Drone

- Palo Alto, California - [www.wing.com](http://www.wing.com)
- Targeted use case: Package delivery
- Max payload: 3.3 pounds
- Range: 12 miles (roundtrip distance)
- Max speed: 70 mph
- Max flight time: *unspecified*

For this study, the term “targeted use case” is important because several sUAS targeted to a particular use case may be suitable for multiple use cases. This has certainly been true in the first decade of sUAS commercial deployment as first adopters are using aircraft designed for mapping, for example, in surveillance/public safety roles. As use cases have become better defined and as sensors have become more customized to specific applications, many aircraft have become more tailored to an application. We expect some versatile enterprise sUAS such as the Skydio 2 to be employed across a variety of use cases. Package delivery, however, as evidenced by some of the above models, will have the most customized sUAS as a necessary function of their mission and operating environment.

## Definition of sUAS Use Cases

Our assessment of the potential for each use case is informed not only by the team’s own experience with sUAS and interviews conducted for this project, but also on a national and global scale based on an industry-leading forecast by the Teal Group. We discuss each of the non-passenger UAS use cases individually below. While they span a variety of applications, they share an important similarity that differs markedly from the passenger AAM use cases: they are not expected to generate a significant number of new jobs nor to provide additional revenue streams for the State of Ohio. In fact,

even though sUAS are likely to provide cost savings in a variety of use cases, even that is not the primary reason businesses are adopting sUAS technology. Rather, all the non-passenger sUAS use cases will provide significant benefits by making more efficient use of resources (i.e., improving productivity), enabling the fidelity of data, increasing social benefits such as workplace safety, and diminishing environmental impact. This was a key finding in a recent survey by Drone Industry Insights that asked businesses that use sUAS their top reason for adopting them. As shown in Figure 26, while 47% of respondents said saving costs was a very important reason, 60% said saving time (a proxy for improved productivity), and 59% cited improved quality as very important reasons.<sup>44</sup>

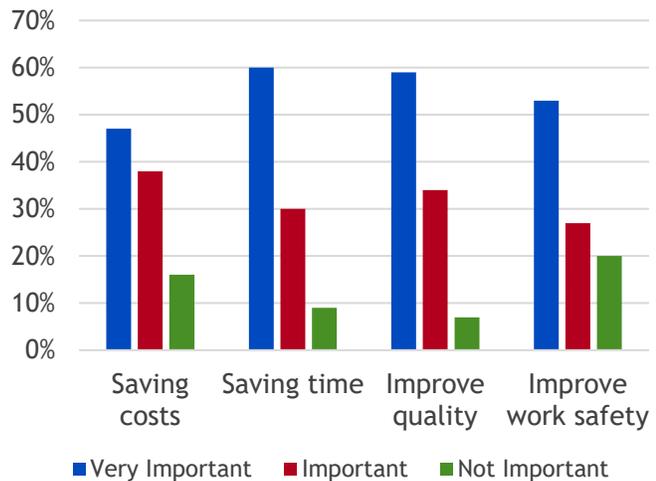


Figure 26: Reasons for Adopting sUAS

The sUAS will serve as a tool that is one of several solutions utilized to accomplish the tasks of the given use case. Fundamentally, sUAS are another tool in the toolkit of practitioners in specific fields.

The non-passenger use cases also all provide catalytic benefits with both primary and secondary effects. These catalytic benefits are considerable and, particularly in the case of package delivery, will have a significant impact on their sectors. These benefits are realized within the use case domain itself (e.g., for the medical delivery use case, the benefit is within the medical establishment), as well as beyond the use case, for example by improving public safety or the environment. Generally, these catalytic benefits increase with greater adoption of UAS technology and with advances in the technology itself.

The team reviewed numerous use cases for UAS, resulting in seven key categories determined to be most relevant to Ohio:

- Infrastructure Inspections: Bridges, Highways, Tunnels.
- Infrastructure Inspections: Airports.
- Infrastructure Inspections: Powerlines, Towers, Pipelines.
- Law Enforcement and Public Safety.

<sup>44</sup> Drone Industry Barometer 2020, Whitepaper, September 2020. Hamburg: Drone Industry Insights. Sample size = 227.

- Agriculture and Livestock.
- Package Delivery.
- Medical Non-Patient Delivery.

### *Infrastructure Inspection and Mapping: Bridges, Highways, Tunnels*

Bridges, highways, and tunnels are inspected both at regular intervals, as well as on emergency bases for structural integrity. In the United States, this function is carried out by state highway agencies as well as local jurisdictions. In addition photogrammetry and technology such as LiDAR are use to map roads and large areas using a wide variety of sensors.

In Ohio, most of these inspections are carried out by the Ohio Department of Transportation (ODOT), which already operates a fleet of sUAS, on an increasing basis.

ODOT provided information to the team about its bridge inspection efforts, which have begun to incorporate UAS. There are approximately 45,000 bridges in Ohio, most of which are inspected by cities and counties.<sup>45</sup> ODOT inspects 14,500 annually at varying levels of detail. About 400 inspections per year require the use of snooper trucks that contain a bucket that lifts the inspector close to the underside of the bridge. For ODOT, use of the snooper trucks requires lane closures and, in the average about eight employees working eight hours per bridge inspection. With a UAS, the same bridge inspection requires only an average of two employees working four hours each. Though lane closures may still be required with UAS, they are fewer and lower in duration than when using a snooper truck.

Bridge inspection is a good example of the UAS as an additional tool; it does not replace all existing methods. Indeed, ODOT believes that only about half of the 400 snooper truck inspections could be handled by UAS. Yet, this is enough to generate considerable savings: ODOT conservatively estimates annual savings of just over 58% by splitting bridge inspections between snooper trucks and UAS evenly.<sup>46</sup> A less conservative estimate comes from Michigan where, according to a survey by the American Association of State Highway and Transportation Officials (AASHTO), use of UAS in lieu of snooper trucks resulted in a 74% reduction in costs.<sup>47</sup>

From a process standpoint, tunnel inspections with UAS experience similar benefits as bridge inspections. There are very few tunnels classified as such—approximately seven—in Ohio. The major inspection concerns are leaks and overall structural integrity. Snooper trucks may be used in cases where the logistics of lane closures pose the same challenges as they do for bridges. Many tunnel-like culverts exist by major roads and are sometimes inspected via sUAS. According to ODOT, most tunnel-like structures are the underside of bridges and are included in bridge inspection.

Highway inspections will benefit from UAS implementation as well, but the metrics are more varied than for bridges and tunnels. This is because highway inspection costs vary by location and features. A highway that is straight and flat is, in most respects, easier to inspect than one that changes elevation or curves, or both. This is not to say that a UAS cannot still be a useful tool in highway inspection, rather that its advantages may be diminished in certain conditions.

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<sup>45</sup> According to the ODOT Administrator of Structural Engineering, the number of bridges statewide that meet the federal definition of a bridge is 28,269 (email from David Gallagher, February 2, 2021).

<sup>46</sup> “How Ohio Department of Transportation Overcame 4 Major Roadblocks to Build a Drone Program”, Ohio Department of Transportation, Ohio Unmanned Aircraft Systems Center, webinar, November 10, 2020.

<sup>47</sup> Cited in Teal Group

On a curved highway, for example, an additional visual observer may be required if the UAS must fly at a low elevation to carry out the inspection. Once BVLOS is allowed, however, it is likely that many such disadvantages in the highway arena will decrease.

In addition to the cost savings, inspectors' time is freed up, enabling them to spend more time on data analysis and developing solutions for any structural problems they identify.

The catalytic benefits of this use case include:

- Lower accident rates generated by the improved quality of inspections, as well as reduced lane closures (which can contribute to accidents) when inspections take place.
  - Lower insurance costs stemming from lower accident rates.
- Reduced traffic congestion, stemming from fewer lane closures, which generate several secondary benefits:
  - Reduced user delay costs (time savings).
  - Improved air quality.
  - Increased trade as lower congestion enhances the ability to move goods by road efficiently.

Table 14 summarizes the characteristics of the use case for Infrastructure Inspection of Bridges, Highways, and Tunnels.

**Table 14: sUAS Use Case Characteristics - Infrastructure Inspection of Bridges, Highways, and Tunnels**

Characteristic	Characteristic Details
Use Case	Infrastructure Inspection - Bridges, Highways, Tunnels
Payload	1-3 pounds
Infrastructure	sUAS fleet storage
Scheduling	Regular intervals and ad hoc
Locations of Flight	<ul style="list-style-type: none"> <li>• Urban, suburban, rural</li> <li>• Low altitude</li> </ul>
Range	Under 5 miles, possibly as far as 20 for highway w/BVLOS
Density of Operations	<ul style="list-style-type: none"> <li>• Urban, suburban, rural</li> <li>• 1 vehicle flying per dispatch</li> </ul>
Diversity of Vehicle Types and Procedures	<ul style="list-style-type: none"> <li>• Approximately 10 different vehicle types</li> <li>• Multiple sensor configurations</li> <li>• VLOS and BVLOS</li> </ul>

### *Infrastructure Inspection: Airports*

Airport runways are inspected both for general runway conditions, as well as for the presence of foreign object debris (FOD). FOD is anything that could interfere with the safe operation of flights and consists of everything from broken pavement to animals to litter. Checking for FOD is primarily done with a car or truck driving at high speed down the runway. Although these inspections are generally brief, while a runway is being inspected, no take-offs or landings can take place on it. Furthermore, ground vehicles moving across active taxiways can add to airport congestion at large commercial airports. An alternative method for FOD detection is the use of small wavelength radar and cameras that minimize the need for vehicular dispatch for

detection, although personnel must still be dispatched to remove any debris identified. Such systems have had limited uptake and may not be reliable in all weather conditions.

Although use of an sUAS still closes the runway to departures and arrivals, its deployment is quicker than for a road vehicle and can be done by overflying taxiways. As technology develops, it may be possible for sUAS to remove low payload debris without putting personnel on the runway. Additionally, sUAS can perform inspections of other airport areas such as perimeter fences, windsocks, and buildings as well as verification of runway and taxiway markings.

While a major commercial airport checks runway conditions several times per day, smaller general aviation airports may only do so twice per day. It is unlikely these smaller facilities will acquire a commercial sUAS for that purpose, though they may be contracted in when reviewing potential maintenance, signage, and marking work.

Additional sUAS uses include aircraft inspections after a lightening or bird strike, perimeter inspections, navigational aid inspections, and facility inspections, including parking lots and buildings.

Operation of sUAS for airport work may reside in different areas depending on the airport. FAA recently selected Rickenbacker International Airport in Columbus, Ohio as one of five host airports to test and evaluate sUAS aircraft detection and mitigation systems as part of the agency's Airport Unmanned Aircraft Systems Detection and Mitigation Research Program.<sup>48</sup> These airports meet FAA requirements for diverse testing environments and represent airport operating conditions found across the United States. The research will lead to the implementation of new technologies that will make airports safer for passengers and manned aircraft.

At Cincinnati Northern Kentucky International Airport (CVG), the airport's fire and police departments each have an sUAS aircraft that can be deployed for various inspection functions. An outside contractor is also used for facility inspections.<sup>49</sup> It is reasonable to assume that all the major commercial passenger and cargo airports in Ohio will have at least one and likely two sUAS in operation by the end of this decade. Additionally, large general aviation airports such as Burke Lakefront in Cleveland and Cincinnati's Municipal Lunken Airport would be likely to incorporate sUAS into their operations by 2045.

The catalytic benefits of the Infrastructure Inspection—Airport use case are:

- Improved aircraft arrivals and departures.
  - Reduced user delay costs.
- Reduced airfield incursion risk by removing road vehicle from taxiway.

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<sup>48</sup> [https://www.faa.gov/news/press\\_releases/news\\_story.cfm?newsId=25780](https://www.faa.gov/news/press_releases/news_story.cfm?newsId=25780)

<sup>49</sup> Interview with Naashom Marx, Cincinnati Northern Kentucky International Airport, Dec. 15, 2020.

Table 15 summarizes the characteristics of the use case for Infrastructure Inspection of Airports.

**Table 15: sUAS Use Case Characteristics - Infrastructure Inspection of Airports**

Characteristic	Characteristic Details
Use Case	Infrastructure Inspection - Airports
Payload	1-5 pounds
Infrastructure	Ground station
Scheduling	Minimum 4x/day and ad hoc
Locations of Flight	<ul style="list-style-type: none"> <li>• On-airport</li> <li>• Low altitude</li> </ul>
Range	Under 3 miles
Density of Operations	1 vehicle flying
Diversity of Vehicle Types and Procedures	<ul style="list-style-type: none"> <li>• Approximately five different vehicle types</li> <li>• Sensors could be integrated with existing FOD systems</li> <li>• VLOS, BVLOS unlikely on active airfield</li> </ul>

#### *Infrastructure Inspection: Powerlines, Towers, Pipelines*

The infrastructure cases we have discussed thus far for sUAS involve operation by public entities. Inspection of powerlines, towers, and pipelines, however, is conducted by private industry. The Teal Group notes that this characteristic has made this use case one of the primary drivers of sUAS technology development as several entities, from large aerospace companies to smaller service companies, have sought to meet the needs of this market, and growth is expected to remain robust through the end of this decade.<sup>50</sup> Energy revenues have taken a hit in the wake of the COVID-19 pandemic, but the business case for accurate and cost-effective inspection has not. Environmental regulation is only expected to increase, and the energy firms are keen to ensure vigilant monitoring of their transmission and fuel transport assets. These firms not only contract in sUAS services, but they also establish large sUAS fleets of their own.

Powerlines, towers, and pipelines often traverse areas off roadways, quickly entering rural, hilly, forested areas that can be time-consuming for crews to access and navigate. Overflight by helicopter is costly and does not provide the sUAS's ability to get up close to an asset for further inspection if need be. Nevertheless, until BVLOS is established, the cost-savings of UAS will be limited, especially for transmission line inspection.

Powerline inspection includes not just inspection of the line itself, which can become damaged over time from a variety of factors, including birds, but potentially encroaching hazards such as trees. Power lines are increasing in the United States as demand for energy has increased.<sup>51</sup> These lines must be inspected twice per year. While LIDAR is used in some aspects of the inspection, approximately 70% of the current work involves visual inspection. DroneHive, Inc.,

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<sup>50</sup> Teal Group at 184

<sup>51</sup> Teal at 192

a U.S. service provider, recently estimated that a two-person line inspection team can inspect three utility poles per hour. It is important to note that distance between poles varies by location and topography. Separately, for the linear asset, they can cover two miles of linear asset per hour.<sup>52</sup> The latter could be accomplished more quickly in a BVLOS environment. Ohio has 6,983 miles of high voltage line and 112 miles of low voltage lines.<sup>53</sup>

Towers are also threatened by trees, but the structure itself must be inspected for cracks and corrosion on a vertical basis. Prior to the development of sUAS technology with associated sensors, the only means to accomplish this was for personnel to climb the tower. With the sUAS, the risks associated with climbing are highly minimized, if not fully eliminated. The inspector can conduct real-time analysis safely on the ground, thereby saving time in the identification of tower issues.

On pipelines, sUAS are valuable resources for detecting methane and other chemical leaks. Inspections do not just involve pipeline above ground, but thermal imaging of underground pipelines in conjunction with vegetation mapping. Frequency of inspection varies by location and use, and whether the pipeline is wholly within a state. According to Teal, a typical petroleum pipeline is patrolled (checking rights-of-way for leaks, damage, or incursions) 26 times per year to meet federal guidelines; a natural gas pipeline only requires one patrol per year. These are often conducted using fixed-wing aircraft and occasionally helicopters, which are more expensive but considered more accurate. sUAS will capture more of the market if they can deliver a high level of accuracy with improved costs, but they will need BVLOS to provide that efficiency.

Ohio plays a crucial role in the nation's shale oil and gas industry; it is fourth in terms of the 24,066 miles of natural gas gathering lines, based on a 2017 estimate. In terms of larger lines that transmit oil and gas out of state, Ohio ranked seventh at 9,796 miles.<sup>54</sup>

The catalytic benefits of the Infrastructure Inspection - Powerlines, Towers, Pipelines use case are:

- Higher grid reliability, less downtime.
  - Increased business and trade.
- Greater energy security.
- Improved employee safety resulting from:
  - Fewer tower climbs.
  - Fewer piloted aircraft.
    - Frees up airspace at airports and heliports.

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<sup>52</sup> Data provided by Paul Huish, DroneHive, Feb. 8, 2021

<sup>53</sup> <https://www.energy.gov/sites/prod/files/2015/05/f22/OH-Energy%20Sector%20Risk%20Profile.pdf>

<sup>54</sup> <https://www.bizjournals.com/columbus/news/2017/06/28/ohio-has-among-the-most-natural-gas-pipelines-in.html>

Table 16 summarizes the characteristics of the use case for Infrastructure Inspection of Powerlines, Towers, Pipelines.

**Table 16: sUAS Use Case Characteristics - Infrastructure Inspection of Powerlines, Towers and Pipelines**

Characteristic	Characteristic Details
Use Case	Infrastructure Inspection - Powerlines, Towers, Pipelines
Payload	1-5 pounds
Infrastructure	Ground station, sUAS fleet storage
Scheduling	<ul style="list-style-type: none"> <li>• Annual schedules for routine inspection</li> <li>• Ad hoc flying, especially post-storm</li> </ul>
Locations of Flight	<ul style="list-style-type: none"> <li>• Suburban</li> <li>• Rural</li> <li>• Low and medium altitude</li> </ul>
Range	< 20 miles
Density of Operations	<ul style="list-style-type: none"> <li>• Large fleets for oil and gas</li> <li>• 1 vehicle flying, possibly 2 in combined powerline/tower inspections</li> </ul>
Diversity of Vehicle Types and Procedures	<ul style="list-style-type: none"> <li>• 10-20 vehicle types</li> <li>• Linear and vertical assessments</li> <li>• BVLOS, limited VLOS</li> </ul>

### *Law Enforcement and Public Safety*

The small footprint of sUAS combined with new collision-avoidance technology enable law enforcement and public safety (LEPS) to better conduct operations and provide more effective security while reducing the exposure of personnel to risks. Although helicopters and fixed-wing aircraft are considered common police assets, they are used by only about 2% of U.S. law enforcement agencies because of the high cost of operation.<sup>55</sup> Although sUAS costs are lower, they still represent an additional cost for many fire and police departments dealing with limited budgets for equipment acquisition and training. Police agencies also face a public relations challenge when sUAS are used for routine surveillance as the public often views them as overly intrusive and a risk to privacy. Yet in those cases where sUAS have proved effective in high-risk situations and averting crises, they have fostered good will and great interest by a number of agencies. The events of 2020 stemming from the COVID-19 pandemic and political protests as well as natural disasters helped highlight some of the potential advantages of sUAS technology for this use case.

Search and rescue is one area of this use case where there is strong support. The flooding which often follows large storms and hurricanes can quickly strand victims and knock out regular communications. Public safety officers using a small sUAS equipped with speakers can fly to a stranded area, communicate updates, and get up-close photographs of the conditions affecting victims. Based on this data, rescuers can best prepare their mission and remotely triage which

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<sup>55</sup> Teal at 102

persons need attention and which areas are most in need of immediate assistance. In more extreme circumstances, sUAS may be able to drop small survival kits and emergency supplies.

Missing person searches are expedited via sUAS. Thermal imaging sensors not only show where a person is, they also indicate where a person is not, which is particularly useful in helping eliminate areas that do not need to be searched. Such a strategy was successfully used last year in Minot, North Dakota to help locate a missing child.<sup>56</sup>

Firefighting has also been incorporating sUAS to get visual assessments of conditions at fires of both structures and forests. Hot spots can quickly be identified to help direct firefighters away from danger, as well as to areas that require suppression. Despite current cost considerations, we believe it is likely that every one of Ohio's 1,116 fire stations will have one sUAS by 2045, with some large stations having two or more.

Crowd control and monitoring are areas where sUAS provide much more efficient coverage than helicopters and have the advantage of much lower noise. While their use at some protests may be viewed as controversial, their demonstrated flexibility should benefit monitoring safety for popular gatherings such as large sporting events, concerts, and parades. It is possible that the trajectory of their acceptance will follow that of security cameras which, though initially viewed by some as intrusive, have become more accepted and fairly ubiquitous.

For high-risk law enforcement situations, sUAS can help limit law enforcement officers' exposure to potential harm. SWAT teams responding to hostage or barricade situations must assess the environment where a perpetrator is located as close as possible before attempting any entry or apprehension. Occasionally this requires trying to position heavily protected staff dangerously close to the perpetrator and exposure to possible booby traps. In recent decades, SWAT teams could deploy radio-controlled robots on such missions, but their slow speeds and limited use on varied terrain or on stairs negated their effectiveness. Using sUAS however, SWAT teams have been able to stay hundreds of feet away from the target, maneuver the aircraft through trees, and quickly view directly into windows and over fences to assess and diffuse situations. In fact, some departments have found the mere presence of the sUAS is enough to make a perpetrator realize their position is not tenable, thus leading to a quick and relatively safe resolution of the situation.<sup>57</sup>

The catalytic benefits of the Infrastructure Inspection - Powerlines, Towers, and Pipelines use case are:

- Better use of public funds.
- Increased trust/public well-being.
- Enhanced public safety.
- Quicker disaster recovery.
- More successful search and rescue operations:
  - Lives saved.
- Employee safety, ability to go where humans are otherwise in danger.
  - Lives saved.
  - Fewer injuries.

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<sup>56</sup> <https://www.suasnews.com/2020/06/how-a-missing-child-was-found-with-help-from-drones/>

<sup>57</sup> Skydio Round Table with First Responders - Stories from Autonomous Drones in the Field (Webinar), Dec. 16, 2020.

Table 17 summarizes the characteristics of the use case for Law Enforcement and Public Safety.

**Table 17: sUAS Use Case Characteristics - Law Enforcement and Public Safety**

Characteristic	Characteristic Details
Use Case	Law Enforcement and Public Safety
Payload	<ul style="list-style-type: none"> <li>• 1 to 5 pounds</li> </ul>
Infrastructure	<ul style="list-style-type: none"> <li>• Ground station</li> </ul>
Scheduling	<ul style="list-style-type: none"> <li>• Ad hoc</li> </ul>
Locations of Flight	<ul style="list-style-type: none"> <li>• All areas</li> <li>• Low and medium altitude</li> </ul>
Range	<ul style="list-style-type: none"> <li>• &lt; 20 miles</li> </ul>
Density of Operations	<ul style="list-style-type: none"> <li>• SWAT - 1 vehicle flying</li> <li>• Fire, rescue, events - 1-5 vehicles flying</li> </ul>
Diversity of Vehicle Types and Procedures	<ul style="list-style-type: none"> <li>• 10 vehicle types</li> <li>• Close-in and surveillance flying</li> <li>• Mostly VLOS, BVLOS for search &amp; rescue</li> </ul>

### *Agriculture and Livestock*

Small UAS are able to perform a number of functions in this use case, including thermal mapping, crop monitoring, and livestock tracking. They can also perform seeding and spraying, but these applications, especially spraying, require additional regulatory authority.

According to the Teal Group, agricultural spraying represents the largest installed base of sUAS worldwide, but in the United States this is likely to remain a niche market because of FAA and environmental regulations. It is proving worthwhile for high-value crops such as wine grapes and berries and has gained some traction in Napa Valley, California, although with UAS that are slightly over 55 pounds. For lower-value crops, ground-based spray booms provide a more effective coverage area than low-capacity sUAS, which require multiple re-loading.

As for crop monitoring, additional improvements are required in existing sensors and software to address the myriad crops and pests that exist. The costs of hyperspectral sensors best suited to this work are high but are expected to come down over time, fostering eventual adoption. Many farmers currently rely on satellite-based imaging that meets needs to an extent, but the fidelity is measured in meters and does not work in cloudy conditions, which is where sUAS offer an advantage.

Although many farmers in the United States were among the first groups to express interest in the potential for sUAS, costs and the time needed to learn the systems were greater than anticipated. At the time the technology began to establish itself, many farmers were still struggling from the financial effects of the 2008 financial crisis. Teal estimates, however, that more farmers will take on the technology as costs lower, but that they are only likely to be farmers who generate annual income of over \$100,000. It is possible seed companies will provide the equipment for seeding only, but not for general use by the farms.

The livestock sector has not yet adopted sUAS at a significant level because of VLOS requirements. Once BVLOS regulations permit, the sector will be better to take advantage of the technology for both monitoring and herding. Helicopters are occasionally used in such

functions, especially the latter, though their noise can be disruptive to herds. The quieter hum of sUAS may encourage cattle to move, but at a gentler pace.

The catalytic benefits of the Agriculture and Livestock use case are:

- Better crop yield at lower cost.
- Automation of farm tasks as work force declines.
- Increased investment in crops and livestock.
  - All the above lead to enhanced food supply and food security.
- Reduced environmental impacts through:
  - Better water management.
  - Smarter use of pesticides and other chemicals.

Table 18 summarizes the characteristics of the use case for Agriculture and Livestock.

**Table 18: sUAS Use Case Characteristics - Agriculture and Livestock**

Characteristic	Characteristic Details
Use Case	Agricultural and Livestock
Payload	1-5 pounds
Infrastructure	Ground station
Scheduling	<ul style="list-style-type: none"> <li>• Schedules based on monitoring need</li> <li>• Ad hoc for seeding, spraying, livestock</li> </ul>
Locations of Flight	<ul style="list-style-type: none"> <li>• Rural</li> <li>• Low and medium altitude</li> </ul>
Range	< 20 miles
Density of Operations	1 vehicle flying
Diversity of Vehicle Types and Procedures	<ul style="list-style-type: none"> <li>• 10-20 vehicle types</li> <li>• Very low altitude for specialty crops</li> <li>• Low altitude for spraying and seeding</li> <li>• Low and medium altitude for monitoring</li> <li>• VLOS, BVLOS for larger areas</li> </ul>

### *Package Delivery*

Package delivery using sUAS is the least developed of all non-passenger use cases. This is because BVLOS operations are required for the technology to be cost-effective. Flights, by necessity, must eventually take place above people and residential structures, and must ultimately safely land or otherwise deposit their payloads near residences and places of work. Yet limited trials of such applications are underway, and the potential for sUAS is a game changer for the package delivery industry.

The largest drivers of an sUAS solution for package delivery are the big shippers UPS and FedEx, as well as the world’s largest online retailer, Amazon. Each is developing its own sUAS solution, and even the parent company of Google, Alphabet, has its own delivery sUAS, known as Wing. Wing’s aircraft are already providing limited deliveries in Australia, Finland, and Christiansburg, Virginia, where it offers deliveries of coffee, food, FedEx shipments, and materials from the public school system.

In package delivery, grounds costs as a share of total shipment cost have been estimated at 30-33% for FedEx and UPS.<sup>58</sup> The largest portion of that cost is covering the last mile. Jenkins has estimated that cost at \$2.50 based on Amazon's costs with the U.S. Postal Service, but this varies widely.<sup>59</sup> Except in the densest of urban settings, multiple packages are not sharing costs over the last delivery mile as the package reaches a unique address. Even urban settings pose challenges on the last mile because of traffic congestion. Teal cites figures from UPS that state last-mile delivery within a city can cost \$20 to \$75.<sup>60</sup> That cost is not directly recaptured on the shipment. To the extent an sUAS can cover this last mile at a cost below that of current road methods, it could generate significant cost savings for shippers, but the industry is not quite there. As recently as early 2019, a member of UPS's Flight Forward effort told an industry webinar that they "were still solving the economics issue."

The delivery firms are not only interested in direct cost reduction, but also in minimizing some of the hazards posed to their drivers by reaching the last mile. The less distance they drive, the less likely they are to risk collisions. They would no longer be required to enter individual properties, where they risk falls, trips on sidewalks, and threats from animals. By parking their vehicles in convenient spots for sUAS launch, they will reduce road congestion, and not just while driving. In metropolitan areas, drivers are often forced to double park their vehicles to attempt deliveries. And while delivering packages to buildings, drivers often leave large shipments temporarily unguarded.

What is the best structure for sUAS operations? One vision is to have a fleet of sUAS at numerous mini-hubs responsible for deliveries in a given range, perhaps 15 miles in the case of Amazon. Another, which is being examined by all of the firms, is for delivery vans to operate as mobile bases. The driver positions the van at a logical launching point from which they launch and monitor the sUAS to cover the last miles. In such a scenario, the precise launch location and optimum route could change each day and even on the same route to optimize the economics of the service.

On the revenue side, firms might be able to charge more for sUAS services, especially if they allow speedier delivery of items, than the case would otherwise be. Consumers have shown a willingness to pay for next day delivery versus two days or longer. A study in Utah showed that about two-thirds of online shoppers are willing to pay more for goods to be delivered faster than the standard delivery time. The study further estimated that these consumers are willing to pay an additional \$10 per delivery for the faster delivery.<sup>61</sup> To maximize revenue potential, the ability to capture consumer surplus via sUAS delivery may depend on offering items that are already deliverable the same day, such as groceries, but with a delivery time of one or two hours instead of several hours.

In addition to the large companies providing sUAS package delivery as a replacement for truck delivery, it is envisioned that a new industry will develop with small businesses providing local package delivery, replacing courier services today.

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<sup>58</sup> Jenkins at 10.

<sup>59</sup> Ibid at 13.

<sup>60</sup> Teal at 164.

<sup>61</sup> George Mason University Study 2019: Design of On-Demand Drone Transportation System for Tooele, UT

<http://nebula.wsimg.com/3f7efdc65dbe545c4bc29a7b1a2fc367?AccessKeyId=0609873DEB58FF70A0BF&disposition=0&alloworigin=1>

The catalytic benefits of the Package Delivery use case are:

- Lower traffic congestion from both delivery vehicles and shoppers choosing to buy from home:
  - Greater trade as goods move more efficiently and greater variety of goods moved
  - Higher propensity to use delivery services.
  - Fewer traffic accidents and road deaths.
  - Improved environmental conditions.
  - Time savings for all road users.
- Consumer time savings.
- Lower warehousing and inventory carrying costs.
- Improved employee safety from lower traffic accidents and delivery injuries.

Table 19 summarizes the characteristics of the use case for Package Delivery.

**Table 19: sUAS Use Case Characteristics - Package Delivery**

Characteristic	Characteristic Details
Use Case	Package delivery
Payload	Up to 5 pounds
Infrastructure	<ul style="list-style-type: none"> <li>• Fixed ground station</li> <li>• Mobile grounds stations (delivery trucks)</li> <li>• Regional control centers</li> <li>• Storage facilities for fleets</li> </ul>
Scheduling	<ul style="list-style-type: none"> <li>• Function of specific delivery logistics</li> <li>• Some on-demand</li> </ul>
Locations of Flight	<ul style="list-style-type: none"> <li>• All areas</li> <li>• Medium altitude</li> </ul>
Range	<ul style="list-style-type: none"> <li>• Most within 15 miles</li> <li>• Max 75 miles</li> </ul>
Density of Operations	<ul style="list-style-type: none"> <li>• Multiple vehicles airborne in large networks</li> <li>• Potentially 5-10 simultaneously from ground station</li> </ul>
Diversity of Vehicle Types and Procedures	<ul style="list-style-type: none"> <li>• 5-10 vehicle types</li> <li>• Delivery by landing and gentle air drop</li> <li>• Low and medium altitude operations</li> <li>• BVLOS essential</li> </ul>

### *Medical Non-Passenger Transport*

The medical delivery use case covers transport of blood, lab samples, organs, and pharmaceuticals. The sensitive nature of such deliveries and the dynamics of various operating environments (including socioeconomic factors) make medical delivery substantially different from standard package delivery in general, and for sUAS applications, as well. Yet these challenges have actually benefitted the sUAS case. Pilot programs in the United States and throughout the world have demonstrated that they can enhance the overall medical delivery system and public health as a result.

Zipline has pioneered dispatch of blood in Rwanda. The African nation has very poor road infrastructure outside the capital of Kigali. Yet using a specialized sUAS and proprietary UTM system, blood deliveries to rural clinics take as little as five minutes. An advantage in Rwanda is the ability to fly BVLOS, where the potential has proven itself: between October 2016 and the middle of 2020, Zipline had flown 13,000 deliveries in Rwanda and has since expanded the service to Ghana.

On medical campuses, Matternet of Mountain View, California has deployed its sUAS with four hospital groups in Switzerland. In Zurich, the system is delivering blood and lab samples on a two-kilometer network in four minutes, twice the speed of the existing road courier service. Multiplied over many such journeys per day, the time savings is significant. A similar deployment has also been established with the WakeMed Health & Hospitals system in North Carolina. The quicker delivery times of lab samples by sUAS enable quicker turnaround time of lab results, which means patients get care more rapidly.

The speed of the lab turnaround time stemming from the sUAS is not just because of the direct difference in travel time versus a road vehicle, it is because that speed generates a change in the working model of lab operations that is more efficient overall. With road deliveries, in most cases at most hospitals, lab samples are gathered into batches that are moved from the hospital to the lab two or three times per day. In addition to the drive time, the courier has to exit and enter secure areas, sometimes having to walk a significant distance and show credentials to obtain and deliver the lab specimens. With an sUAS, the cargo (sample) is loaded in a secure area close to the point it was acquired and flies to a secure location, where it is closer to lab staff. Because hospitals can send the sUAS many times per day, the labs are able to increase utilization with minimize down-time. In turn, this has led some labs to avoid batch rushes, offer more lab services, and generate additional revenue throughout the day.

Another advantage may include reducing medicine strength because of faster delivery. When a patient receives treatment sooner rather than later, they often require lower-strength medication, and less medication overall, resulting in fewer side effects. Rapid organ delivery, meanwhile, is especially valuable because every minute saved increases the potential to save a life.

While the aircraft are ostensibly similar to other sUAS, their unique cargo means their structure for cargo protection is unique. Many high-end medical products such as isotopes have to be strongly protected to maintain their integrity. Therefore, the cargo hold of an sUAS used for delivering isotopes is the bulk of the payload—much more than the isotope itself.

The catalytic benefits of the Medical Delivery use case are:

- Improved patient care through timelier test and supply deliveries.
- More lives saved through faster organ delivery.
- Decreased spoilage of time-sensitive medical cargo.
- Maximization of blood supply at critical locations.
- More efficient use of lab capacity.
- Lower traffic congestion:
  - Reduced environmental impact.
  - Time savings for all road users.

Table 20 summarizes the characteristics of the use case for Medical Delivery.

**Table 20: sUAS Use Case Characteristics - Medical Delivery**

Characteristic	Characteristic Details
Use Case	Medical Delivery
Payload	Up to 5 pounds
Infrastructure	<ul style="list-style-type: none"> <li>• Fixed ground stations</li> <li>• Storage facilities for fleets</li> </ul>
Scheduling	<ul style="list-style-type: none"> <li>• Multiple daily flights for lab/blood</li> <li>• On demand for organs</li> </ul>
Locations of Flight	<ul style="list-style-type: none"> <li>• Within medical campuses</li> <li>• Urban, suburban, rural</li> </ul>
Range	<ul style="list-style-type: none"> <li>• Most under 3 miles, but longer range for rural</li> <li>• Max 75 miles</li> </ul>
Density of Operations	<ul style="list-style-type: none"> <li>• 1-3 vehicles simultaneously on medical campus</li> <li>• 1 vehicle flying in most other cases</li> <li>• Potentially 5-10 simultaneously from ground station</li> </ul>
Diversity of Vehicle Types and Procedures	<ul style="list-style-type: none"> <li>• 3-5 vehicle types</li> <li>• Significant cargo reinforcement is bulk of payload</li> <li>• Low and medium altitude operations</li> <li>• BVLOS essential</li> </ul>

## Appendix D: Ohio AAM Initiatives

The Ohio UAS Center, operating as part of the DriveOhio initiative of ODOT, is focusing on the future of mobility, managing and performing all unmanned aircraft operations for ODOT and serving as the state's one-stop shop for developing, testing, and deploying AAM technologies. Through synergy with DriveOhio and working collaboratively under one umbrella on both aircraft and ground vehicle advances, Ohio leverages resources from both sectors to make smarter decisions enhancing the diversity of a three-dimensional transportation system.

The following programs and initiatives highlight the leadership of the state in AAM efforts.

### **FlyOhio**

The FlyOhio initiative focuses on the expansion of AAM technologies in Ohio by enabling the use of the lower-altitude airspace above cities and rural areas. This initiative, supported by OFRN, unites Ohio's aviation stakeholders to promote and advance Ohio's strong aviation history and to leverage its investments to continue its lead in the aviation industry. FlyOhio seeks to address AAM technological gaps by coordinating ongoing UAS research throughout Ohio, while identifying and pursuing future research opportunities, to make Ohio airspace among the first in the nation ready to adopt AAM.

### **Ohio UAS Traffic Management (UTM)**

The Ohio UTM project was formed to develop a framework that can be scaled to manage lower-altitude airspace for all aircraft and all levels of autonomy. The objective is to develop a robust UTM system for the State of Ohio. Under the leadership of Ohio State University (OSU), this vision will first be implemented along the 33 Smart Mobility Corridor, offering abundant opportunities for innovative teaming of autonomous aircraft with autonomous ground vehicles.

Ohio's UTM infrastructure is a comprehensive solution for ensuring safety of flight and enabling the promise of autonomous unmanned aircraft operations in concert with the Smart Cities initiative. The envisioned UTM system is based on industry-leading active radar technology, with advanced signal processing and data fusion strategies optimized for UTM.

### **SkyVision**

ODOT has partnered with AFRL to field and operate the award-winning ground-based detect-and-avoid (GBDAA) system at Springfield-Beckley Municipal Airport (KSGH). This system, known as SkyVision, enables UAS operations beyond visual line of sight (BVLOS) and supports detect-and-avoid (DAA) services for optionally piloted aircraft.

At KSGH, SkyVision is connected with the FAA Air Traffic Control network. Specifically, real-time data is provided from three local radars (the ASR-9 at Dayton International Airport, the ASR-9 at Columbus International Airport, and the CARSAR long-range radar at London, Ohio). Overlapping coverage provides high probability of detection (Pd) of manned aircraft flying in the unrestricted airspace southeast of KSGH.

Several aircraft OEMs have recently conducted research and development with AFRL and the Ohio UAS Center, addressing all the DoD groupings, as well as optionally piloted vertical takeoff and landing (VTOL) and conventional takeoff and landing (CTOL) concepts.

## **Remote Tower Plans**

The concept of remote or virtual tower (R-TWR) has entered the world of air traffic control within the past decade. This concept uses an array of sensing and communication technologies on the airfield and in the surrounding airspace, while performing the control functions using certified controllers in a separate facility at the same airfield or remotely at a considerable distance. In the case of low-activity airports, it is possible to locate controllers responsible for several small airports in a single remote tower center.

The State of Ohio's strategy includes implementing an R-TWR infrastructure for deployment at selected airports in Ohio, incorporating the FAA selection criteria for the pilot program outlined in the 2018 FAA Reauthorization Act. This approach will enhance the safety of manned aircraft operations and will become part of the infrastructure enabling unmanned operations under positive control throughout the state. The remote tower pilot program provides a cost-effective alternative to control air traffic without the need for a brick-and-mortar air traffic control tower, enabling the rural-to-urban transportation mode of AAM.

## **Vertiport Planning with NASA Ames**

The Ohio UAS Center is working with NASA Ames, using their vertiport design tool to identify vertiport locations in urban environments within Ohio's seven largest cities. The work includes community outreach working with cities, local representatives, and planning commissions to gain support for NASA AAM NC by demonstrating vertical take-off and landing (VTOL) operations, collaborating on location analysis, defining business use cases for UAS technology, and providing a better understanding of how UAS will change the transportation landscape.

## **33 Smart Mobility Corridor**

The 33 Smart Mobility Corridor serves as a real-world proving ground for autonomous and connected aircraft with high-capacity, fiber-optic cables and roadside sensors to link researchers and traffic monitors. Smart corridor initiatives like these will help accelerate the deployment of AAM in Ohio.

## **Combined Aircraft Sensor Network to Detect and Track Lower Altitude Aircraft**

Ohio has the goal of creating a comprehensive framework combining all low-altitude airborne sensor data (including data from local, state, and federal entities) into a centralized clearinghouse. This data will be kept and managed through a statewide low-altitude air traffic monitoring center and be accessible to all interested parties. This project will enhance the safety and security of aircraft operations in lower-altitude airspace throughout the State of Ohio.