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# Advancing Air Mobility in Illinois

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**16. Abstract**

Advanced air mobility (AAM) is a nascent market within the aviation sector of Illinois' transportation system, promising enhanced movement of people and cargo to previously inaccessible or underserved locations. This project addresses AAM's prospects and impacts in the state. The research encompasses several tasks, starting with an examination of the current and projected state of the AAM industry, including pertinent regulations, technology advancements, and key industry players. Task two involves identifying the potential scale, operational profiles, and safety considerations of AAM within Illinois. Task three addresses the diverse geographic and operational environments across the state, encompassing urban, suburban, rural, intra-regional, and inter-regional areas, as well as congested and uncongested airspace. Moreover, the project aims to explore how AAM may influence Illinois' overall transportation system, including surface and aviation components. The surface transportation system aspect involves investigating potential vehicular traffic impacts, shifts, and reductions, while the aviation system aspect includes assessing the interaction with unmanned aircraft systems, helicopters, and low-level traffic as well as airport access and routing considerations. Enabling infrastructure and facility requirements, such as communication, surface transportation access, landing facilities, power and fuel availability, and utilities, are identified in task five. Subsequently, state-level policy and regulatory recommendations, aligned with federal and state statutes, are developed in task six, considering the Illinois Aviation System Plan. Last, the research provides a high-level assessment of potential impacts, encompassing economic, social, and environmental aspects. The project's outcomes are expected to enhance Illinois Department of Transportation's preparedness for AAM implementation, contributing to the progressive integration of this transformative aviation technology within the state's transportation landscape.

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- Jamie Abbott, Executive Director, Chicago Executive Airport
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# EXECUTIVE SUMMARY

Advanced air mobility (AAM) aims at transferring passengers and goods between urban, local, regional, and intra-regional areas using groundbreaking aircraft technology. A new generation of vehicles, including unmanned aerial vehicles (UAVs) and electric vertical take-off and landing (eVTOL) aircraft, promise transformative services for the mobility of passengers and goods, from flying taxis to drone deliveries, as well as an array of applications in sectors such as agriculture, construction, and infrastructure inspection in both urban and rural environments. Rapid developments in both technology and use cases call for a comprehensive assessment of the opportunities for these technologies, challenges and barriers facing deployment, as well as how those might integrate with the overall transportation and mobility systems.

The overall objective of this study is to provide Illinois Department of Transportation (IDOT) and policymakers with a clear picture of the potential for AAM service in Illinois and the opportunities it might provide for mobility and economic development in the state. This includes identifying and quantifying likely technological developments, with detailed assessment of application domains and use cases with significance to Illinois, along with potential impacts and deployment challenges of AAM. This assessment will provide the basis for policy recommendations aimed at advancing the development and deployment of AAM, encouraging and directing its future development, while identifying areas where regulatory intervention might be needed. The ultimate goal is to help Illinois to leverage existing public and private resources so as to play a leading role in the future development of AAM and benefit from its likely economic development benefits.

The research approach developed to address this objective recognizes two distinct groups of AAM use cases: (1) AAM as a *mode* with the focus on transporting people and/or goods and (2) AAM as a *tool* in areas such as agriculture, infrastructure construction and inspection, and emergency services. Within each group, several use cases (“verticals”) will be identified, and an analysis framework that addresses the following five components will be applied: (1) *supply-side* capabilities of and constraints on AAM service, (2) the level and mix of *demand* for AAM service, (3) *business models* for deployment that take into account both the supply constraints and demand for services, (4) *externalities* or broader impacts that affect society at large and economic development in the state, leading to (5) recommended *policy and regulation* actions. The research team will investigate policies and provide recommendations based upon the operations of AAM and on the externalities that arise due to service.

To accomplish the study objectives, the research team at the Northwestern University Transportation Center (NUTC) brings unique skills that combine transportation planning and operations with airspace modeling and air traffic management, along with experience in policy formulation and analysis, as well as long-established mechanisms for agency and industry outreach and engagement. The team proposes engaging with agency and industry stakeholders from the outset through an advisory board that would help guide technical development and its policy implications.

# TABLE OF CONTENTS

CHAPTER 1: CURRENT AND PROJECTED STATE OF THE INDUSTRY ........ 1

VEHICLE CONFIGURATIONS ........ 1

VERTIPORT CONFIGURATIONS OVERVIEW ........ 1

Vertiport Air Traffic Management ........ 2

Vertiport Location ........ 3

OPERATIONAL CONCEPTS ........ 3

DEMAND FOR AAM ........ 5

ENERGY SOURCES FOR AAM ........ 6

USE CASE SPECIFICS ........ 7

CHAPTER 2: OPERATIONAL PROFILES AND SAFETY CONSIDERATIONS OF AAM IN ILLINOIS ... 9

AIR-TAXI DEMAND ESTIMATION ........ 9

Estimation of Market Size and Scale of Operations ........ 9

Demographic Characteristics of Potential Users ........ 9

Quantitative Demand Estimation ........ 11

Regional Air Taxi ........ 16

Air-Taxi Conclusions ........ 20

EMERGENCY AAM SERVICES ........ 21

Service Introduction and Existing Operations ........ 21

Potential Use Cases ........ 21

APPLICATIONS IN AGRICULTURE ........ 22

Market Share and Equipment Costs ........ 22

Operational Capabilities ........ 23

Scale of Operations ........ 23

PACKAGE DELIVERY ........ 24

Existing Market ........ 24

UAV Delivery Limitations and Illinois Operations Estimation ........ 24

INFRASTRUCTURE INSPECTION ........ 25

Bridge Inspections ........ 25

Building Inspections ........ 27

**LATENT DEMAND ... 28**
**SAFETY CONSIDERATIONS ... 28**
Description of Risks ... 28
Specific Operations Risk Assessment and GRC Determination ... 31
Combined Levels of Risk ... 32
Risk Mitigations ... 32

**CHAPTER 3: GEOGRAPHIC AND OPERATING ENVIRONMENT DIVERSITY ACROSS ILLINOIS ... 33**
**GENERAL OVERVIEW ... 33**
**AGRICULTURAL-RELATED OPERATIONS ... 34**
**GAS, OIL, AND MINING INDUSTRY ... 36**
**ECONOMIC GROWTH ... 38**
**ILLINOIS AIRSPACE ... 40**

**CHAPTER 4: POTENTIAL INFLUENCE OF AAM ON THE OVERALL ILLINOIS TRANSPORTATION SYSTEM ... 44**
**GROUND TRANSPORTATION SYSTEM ... 44**
General Overview ... 44
Conceptual Framework Development ... 45
AAM and Ground Congestion Relation ... 49
Impacts Quantification Analysis ... 50
**AVIATION TRANSPORTATION SYSTEM ... 54**
General Synopsis ... 54
Airspace-Related Impacts ... 56

**CHAPTER 5: AAM INFRASTRUCTURE AND FACILITY NEEDS ... 62**
**ELECTRIC POWER NEEDS, INFRASTRUCTURE IMPACTS, AND CHANGES NEEDED ... 62**
AAM Operations’ Estimated Impacts and Infrastructure Needs ... 62
**GROUND INFRASTRUCTURE ... 65**
Spatial Requirements ... 65
Cost Overview ... 68
**COMMUNICATIONS ... 70**
**SAFETY RISKS AND CYBERSECURITY ... 72**

**CHAPTER 6: REGULATORY CONTEXT AND RECOMMENDATIONS FOR ILLINOIS .................. 74**

**REVIEW OF US FEDERAL POLICIES AND REGULATORY ENVIRONMENT .................................... 74**

FAA Regulations Impacting AAM/UAM Airworthiness Certification ....................................... 75

FAA Regulations Impacting AAM/UAM Operator Certification................................................ 78

Regulating the Commercial Use of UAS ...................................................................................... 79

Major Federal Activities on the AAM/UAM Regulatory Environment ..................................... 80

Federal Perspectives Relevant to State Policy Development .................................................. 82

**LAWS AND POLICIES FROM US STATES AND INTERNATIONAL CONTEXTS ................................ 82**

**REGULATORY AND POLICY CONTEXT FOR ILLINOIS................................................................. 84**

Connections with the Illinois Aviation System Plan ................................................................ 85

**SYNTHESIS AND RECOMMENDATIONS.......................................................................................... 85**

**CHAPTER 7: ECONOMIC, ENVIRONMENTAL, AND SOCIETAL IMPACTS OF AAM................... 87**

**ECONOMIC IMPACTS ........................................................................................................................ 87**

Passenger Travel Time Benefits .................................................................................................. 88

Medical Emergency Benefits........................................................................................................ 88

Driving-Related Accident Benefits ............................................................................................... 89

Cargo Delivery Benefits................................................................................................................ 90

Bridge Inspection Benefits ........................................................................................................... 90

Agriculture Benefits and Cost Savings ........................................................................................ 91

Tax Revenue .................................................................................................................................. 91

Benefits from Employment Opportunities ................................................................................. 91

**ENVIRONMENTAL IMPACTS.............................................................................................................. 92**

**SOCIAL IMPACTS ................................................................................................................................ 96**

Social Impacts Summary .............................................................................................................. 96

Accessibility and Affordability...................................................................................................... 98

Privacy ............................................................................................................................................ 99

Safety Issues................................................................................................................................... 99

Noise Pollution and Societal Impacts from AAM Aircraft Operations...................................... 99

Visual Pollution ............................................................................................................................ 103

**CHAPTER 8: CONCLUSION ........................................................................................ 104**

**RECOMMENDATIONS** 105
Impact on the Existing Transportation Systems 105
AAM Infrastructure 106
Economic, Social and Environmental Impacts 107
Regulatory Framework 108
Major Uncertainties and Areas of Additional Research 109
**REFERENCES** 111
**APPENDIX A: ADDITIONAL TABLES** 134
**APPENDIX B: ADDITIONAL FIGURES** 163
**APPENDIX C: METHODOLOGY ANALYSIS** 168
**GROUND RISKS** 168
**FORECASTING MODELS** 168
**ECONOMIC IMPACTS** 170
Passenger Travel Time 170
Medical Emergency 171
Driving-Related Accidents 173
Package Delivery 175
Bridge Inspections 176
Agriculture 177
State Taxes 179
**ENVIRONMENTAL IMPACTS** 179
**APPENDIX D: INFRASTRUCTURE COST-RELATED ADDITIONAL FIGURES AND ANALYSIS** 183

# LIST OF FIGURES

Figure 1. Graph. Airspace structures. .......... 5

Figure 2. Graph. General mission profile shown in blue with relevant constraints listed. .......... 11

Figure 3. Chart. Potential UAM travel time savings for trips above 30 minutes. .......... 12

Figure 4. Chart. Histogram of the times of day of passenger trips. .......... 14

Figure 5. Chart. Estimated demand for air-taxi service at airports with more than 10 forecasted daily trips. .......... 16

Figure 6. Graph. Short-haul air routes in Illinois. .......... 17

Figure 7. Chart. Short-haul air routes passenger share. .......... 17

Figure 8. Graph. Existing vs UAM travel times. .......... 18

Figure 9. Graph. Existing flight prices by flight frequency. .......... 18

Figure 10. Graph. Hourly temperatures (right axis) and relative humidity (left axis) for 2010 using NCEI data. Dates below the bottom black line and above the top green line are hours of unflyable weather conditions. .......... 26

Figure 11. Graph. Average daily wind speeds according to 2021 Navy weather data. Values below the red line are below the 33 mph (14.75 m/s) wind speed. .......... 26

Figure 12. Graph. Sunrise and sunset times over the course of a year in Chicago, IL (US Navy). Area between the curves indicate operable hours. .......... 27

Figure 13. Graph. Risk map based on infrastructure for the state of Illinois. .......... 29

Figure 14. Chart. Obstacle height distribution. .......... 30

Figure 15. Graph. Illinois infrastructure with height greater than 400 ft. .......... 31

Figure 16. Graph. Ground and air risk comparisons. .......... 32

Figure 17. Graph. Illinois population density. .......... 34

Figure 18. Graph. Prime farmland and optimal productivity areas in Illinois. .......... 35

Figure 19. Graph. Number of establishments (left) and the number of employees (right) in the agriculture, hunting, and forestry industry. .......... 36

Figure 20. Graph. Oil, gas, and mining in Illinois. .......... 37

Figure 21. Graph. Number of establishments (left) and the number of employees (right) in the industry of mining, quarrying, oil, and gas extraction. .......... 37

Figure 22. Graph. Number of establishments (left) and the number of employees (right) in the industry of construction and manufacturing. .......... 38

Figure 23. Graph. Illinois GDP per county. .......... 39
Figure 24. Graph. Mean travel time to work. .......... 40
Figure 25. Graph. Airspace classes across Illinois. .......... 42
Figure 26. Graph. Commercial aviation routes in Illinois. .......... 43
Figure 27. Graph. Relative change in non-UAM modes. .......... 49
Figure 28. Chart. Mode shares without a UAM service .......... 50
Figure 29. Chart. Sensitivity analysis for different cost per/passenger mile values. .......... 51
Figure 30. Chart. Sensitivity analysis for different out of vehicle travel time values. .......... 52
Figure 31. Chart. Sensitivity analysis for different aircraft speed values. .......... 53
Figure 32. Chart. Mode shares of a pessimistic UAM scenario. .......... 54
Figure 33. Graph. Early stages of UAM operations. .......... 58
Figure 34. Graph. Corridors with vertical passing zones. .......... 58
Figure 35. Graph. Corridors with lateral passing zones. .......... 59
Figure 36. Graph. Multiple tracks corridor framework. .......... 59
Figure 37. Graph. Projections of maximum number of UAM operations by interconnection. .......... 62
Figure 38. Graph. Power request of three configurations with current and 2035 technology. .......... 63
Figure 39. Graph. Cruise power vs. travel speed for an air vehicle and a road taxi. .......... 64
Figure 40. Graph. Dimensions of pad and approach/departure slope according to an FAA engineering brief on vertiport design. .......... 66
Figure 41. Graph. Hybrid surface configuration. .......... 67
Figure 42. Graph. Linear process configuration. .......... 68
Figure 43. Graph. AAM infrastructure requirements. .......... 70
Figure 44. Graph. FAA certification path decision tree. .......... 76
Figure 45. Graph. Evolution of UAM operational tempo and associated environment. .......... 81
Figure 46. Chart. Annual monetary and unit time passenger travel time savings. .......... 88
Figure 47. Chart. Number of individuals surviving OHCA due to UAV support. .......... 89
Figure 48. Chart. Monetary gains from OHCA survivors due to UAV support. .......... 89
Figure 49. Chart. Savings from reduced injuries and fatalities. .......... 89
Figure 50. Chart. Package delivery gains from UAV usage. .......... 90
Figure 51. Chart. Bridge inspection operational savings from UAVs usage. .......... 90

Figure 52. Chart. Agriculture-related monetary projections. 91

Figure 53. Chart. Comparison of $CO_2$ per km with today's technology. 93

Figure 54. Chart. Comparison of $CO_2$ per km with 2035 technology. 93

Figure 55. Chart. GHG emissions over different pax loads. 94

Figure 56. Chart. Amount of $CO_2$ gases released per kilometer travelled from different transportation modes depending on the trip distance. 95

Figure 57. Chart. Amount of NOx pollutants released per kilometer travelled from different transportation modes depending on the trip distance. 95

Figure 58. Chart. GHG emissions reduction related health savings. 95

Figure 59. Graph. Noise comparison between different aircraft. 100

Figure 60. Graph. UAM potential route connecting O'Hare Airport with Vertiport Chicago. 102

Figure 61. Graph. UAM potential route connecting O'Hare Airport with Vertiport Chicago. 102

Figure 62. Graph. Airspace classes across Illinois. 163

Figure 63. Graph. Airports and landing locations in Illinois. 164

Figure 64. Graph. Percentage of people employed in the health industry (left), median income of people employed in the health industry (right). 165

Figure 65. Graph. Percentage of people employed in the manufacturing industry (left), median income of people employed in the manufacturing industry (right). 165

Figure 66. Graph. Percentage of people employed in the construction industry (left), median income of people employed in the construction industry (right). 166

Figure 67. Graph. Percentage of people employed in the agriculture industry (left), median income of people employed in the agriculture industry (right). 166

Figure 68. Graph. Calculated dimensions based on the legally required areas for heliports. 167

Figure 69. Graph. Discretized obstacle limitation surface (red) for the vertical spatial analysis. 167

Figure 70. Equation. Output of a single neuron in a Neural Network (NN). 168

Figure 71. Equation. Nonlinear activation functions. 168

Figure 72. Equation. Hyperbolic tangent function. 168

Figure 73. Equation. Rectified linear unit. 169

Figure 74. Deep neural network with N hidden layers. 169

Figure 75. Equation. ARIMA model. 169

Figure 76. Equation. Forecasted value of travel time. 170

Figure 77. Equation. Volume of passengers. 171

Figure 78. Equation. Time saved by users using UAM. 171

Figure 79. Equation. Monetary value of the calculated time saved from passengers using UAM. 171

Figure 80. Equation. Estimated number of people suffering from OHCAE in Illinois. 172

Figure 81. Equation. Number of survivors due to the existence drone-delivered AEDs. 172

Figure 82. Equation. Total annual cost. 172

Figure 83. Equation. Total monetary savings. 172

Figure 84. Equation. Number of ground transportation fatalities. 173

Figure 85. Equation. Miles flown by the total number of passengers for each forecasted year. 173

Figure 86. Equation. Estimated number of reduced fatalities due to the use of eVTOLs. 173

Figure 87. Equation. Savings from the fatalities reduction. 173

Figure 88. Equation. Non-A-type ground transportation injuries. 174

Figure 89. Equation. A-type ground transportation injuries. 174

Figure 90. Equation. Estimated number of reduced non-A-type injuries due to the use of eVTOLs. 174

Figure 91. Equation. Estimated number of reduced A-type injuries due to the use of eVTOLs 174

Figure 92. Equation. Savings from injuries avoidance. 174

Figure 93. Equation. Global UAV package delivery market size. 175

Figure 94. Equation. US UAV package delivery market size. 175

Figure 95. Equation. US drone package delivery market size. 175

Figure 96. Equation. Cost-savings from shifting parcels delivered by trucks to UAVs. 176

Figure 97. Travel time cost savings for Illinois. 176

Figure 98. Equation. Number of annual vehicles facing delays due to bridge closing in Illinois, traditional inspection. 176

Figure 99. Equation. Number of annual vehicles facing delays due to bridge closing in Illinois, UAV inspection. 177

Figure 100. Equation. Value of the aforementioned travel time savings. 177

Figure 101. Equation. Travel time savings for every forecasted year. 177

Figure 102. Equation. Annual value of the increased production for corn, soybeans and wheat. 178

Figure 103. Equation. Annual cost savings for each commodity. 178

Figure 104. Equation. Labor cost savings from the use of UAVs in livestock related activities. 178

Figure 105. Equation. Illinois annual tax AAM revenue. ..... 179

Figure 106. Equation. Annual kg of CO2 in terms of GHG emissions from EV battery manufacturing activities in Illinois. ..... 179

Figure 107. Equation. Forecasted values of gas pollutants. ..... 180

Figure 108. Equation. Gallons of gasoline burned from ground vehicles, for each one of the forecasted years, in Illinois. ..... 180

Figure 109. Equation. Average of $CO_2$/gallon grams emitted in Illinois. ..... 181

Figure 110. Equation. Yearly emitted GHG in Illinois, for each of the forecasted years. ..... 181

Figure 111. Equation. Parameter accounting for the increase in GHG emissions that eVTOLs presented compared with BEVs. ..... 181

Figure 112. Equation. Generalized social cost savings from the reduction in GHGE for each of the forecasted years. ..... 182

Figure 113. Graph. NASA eVTOL Existing Building Landing Single Charging Station, Five Story Building cost analysis. ..... 183

Figure 114. Graph. Three Charging Stations Ground cost analysis. ..... 184

Figure 115. Graph. Ten vertiport ground cost analysis. ..... 185

Figure 116. Graph. Three charging station garage cost analysis. ..... 186

# LIST OF TABLES

Table 1. Assumed Cost, Speed, Time Values ........ 12
Table 2. Air-Taxi Scenarios Introduced ........ 13
Table 3. AAM Trip Purpose ........ 13
Table 4. Illinois AAM Demand in Different Regions ........ 14
Table 5. AAM Day-to-Day Unconstrained Demand Estimation Scenarios ........ 15
Table 6. Air-Taxi Network Capacities in Passengers Per Hour........ 19
Table 7. Charging Case Overview ........ 64
Table 8. Cost Analysis for 3 MW Plant........ 65
Table 9. Cost Analysis for 6 MW Plant........ 65
Table 10. Cost Analysis for 10 MW Plant........ 65
Table 11. Taxonomy and Definitions of Urban Air Mobility Infrastructure ........ 66
Table 12. Parameters of Airport Charging Infrastructure System........ 68
Table 13. Overview of Different Infrastructure Settings........ 69
Table 14. Comparison of Different Cellular Communication Networks........ 71
Table 15. Potential Cybersecurity Vulnerabilities Overview ........ 73
Table 16. Comparison of Top AAM Aircraft Developers ........ 78
Table 17. FAA UAS Integration Pilot Program Participants ........ 80
Table 18. AAM/UAM Market Size Estimation Studies........ 134
Table 19. AAM/UAM Survey-Based Studies ........ 135
Table 20. Risk Map Categories Description ........ 136
Table 21. Concept of Operations........ 137
Table 22. AAM Operations Risks and Risk Classes........ 139
Table 23. AAM Operations Risks and Mitigations ........ 140
Table 24. Percentage of Professions Which Have Remote Capabilities........ 144
Table 25. UAM/AAM-related Laws and Policies across US States ........ 146
Table 26. UAM/AAM-related Laws and Policies across US Cities........ 156
Table 27. International Laws and Policies ........ 158
Table 28. Illinois Compiled Statutes on Air Transportation........ 160

Table 29. AAM/UAM-Related Content within the Technical Report Chapters of the IL Aviation System Plan (source: IL Aviation System Plan)........................................................................................ 161

Table 30. Forecasted Variables........................................................................................................ 170

# LIST OF ACRONYMS

AAM: Advanced air mobility

AGL: Above ground level

ARC: Air risk classification

ATC: Air traffic control

ATM: Air traffic management

BEV: Battery electric vehicle

eVTOL: Electric vertical take-off and landing aircraft

FATO: Final approach and take-off area

GHG: Greenhouse gas

GRC: Ground risk class

ICEV: Internal combustion engine vehicle

IDOT: Illinois Department of Transportation

RPAS: Remotely piloted aerial systems

NAS: National airspace system

SORA: Specific operations risk assessment

STOL: Short take-off and landing aircraft

TLOF: Touchdown and lift-off area

UAM: Urban air mobility

UAS: Unmanned aerial system

UAT: Urban air transportation

UAV: Unmanned aerial vehicle

UTM: Urban air traffic management

VFR: Visual flight rules

VOA: Vertiport operations area

VPV: Vertiport volume

# CHAPTER 1: CURRENT AND PROJECTED STATE OF THE INDUSTRY

This chapter presents the current and projected states of the advanced air mobility (AAM) industry, by analyzing aircraft and infrastructure specification, energy usage, operational concepts and potential demand, along with potential use cases of AAM.

## VEHICLE CONFIGURATIONS

With companies and groups around the world developing AAM vehicles, various aircraft designs have been proposed (Electric VTOL News, 2022). However, many of the designs share similar ideas and configurations, making it possible to group them in the following categories (Bacchini & Cestino, 2019):

- **Vectored thrust:** angled propulsion system (Joby Aviation S4, Lilium Jet), designed for higher cruise speeds between 150 and 200 mph (Electric VTOL News, 2022), ideal for longer-range missions of 30 km or more, less efficient during take-off and landing (Bacchini & Cestino, 2019).

- **Lift & cruise:** two separate propulsion systems for take-off and landing (CityAirbus NextGen, Wisk Cora), operate at a cruise speed of 100 mph (Electric VTOL News, 2022), more energy intensive than either the vectored thrust or the wingless configurations for missions of all ranges (Bacchini & Cestino, 2019).

- **Wingless/multi-rotors:** rely upon an array of rotors to remain aloft (small commercial unmanned aerial vehicles, EHang 216, Boeing Cargo Air Vehicle), ideal for short-range missions within a few miles, lack the cruise efficiency from a wing and therefore tend to have limited range around 30 miles or less and slow cruise speeds of around 60 mph or less (Electric VTOL News, 2022).

- **Hoverbikes:** propelled by multi-rotors (Jetson ONE, ALI Technologies Hoverbike), pilot is either standing or seated in a saddle, usually without an enclosed cockpit, single- or two-person design, meant for recreational purposes and low altitudes, lower speeds and shorter ranges but high maneuverability (Electric VTOL News, 2022).

- **eHelos/electric helicopters:** single axle with one or more rotors (Aquinea Volta, Sikorsky Firefly), limited cruise speed and range, designed for short trips.

## VERTIPORT CONFIGURATIONS OVERVIEW

AAM aircraft will take off and land at specific facilities known as “vertiports” or “skyports.” They will provide landing, unloading, re-loading, and taking-off areas for AAM aircraft. Some vertiports will also manage air traffic near the vertiport, allow refueling or recharging, basic or advanced maintenance, and aircraft storage. Given these varied tasks, vertiports may range in setup from a single helipad without refueling infrastructure to a complex hub involving numerous take-off and landing platforms with dedicated loading and unloading areas as well as maintenance and refueling areas.

While designs of vertiports are still under development, it is possible to discuss several vertiport orientations that impact operations at the vertiport. The Northeast UAVS Airspace Integration Research Alliance (2021) defines three vertiport designs: single pad, hybrid, and linear process. A single pad design involves an aircraft landing, unloading, loading, and taking off from the same pad. A hybrid design involves one take-off and landing pad and a separate staging area for unloading and loading that the aircraft is moved to on the ground. The linear process design has separate pads for take-off and landing and a separate staging area. This design would work well for busy vertiports with separate approach and departure paths. Further details can be found in Chapter 5.

There are a few examples of vertiport configurations in the United States, either developed or under development. The city of Dallas created a “vertiport” at the Dallas Executive Airport. The vertiport makes use of existing heliport facilities and provides three parking spaces plus two landing areas in addition to a small terminal for passengers and pilots. This operation demonstrates that in the near term vertiports may simply be existing heliports, sometimes incorporating AAM-specific upgrades. Similarly, Uber Copter, which launched passenger service between Manhattan and John F. Kennedy International Airport using helicopters, makes use of existing helipads.

## Vertiport Air Traffic Management

Similar to airports, air traffic management near vertiports will be an important consideration. Aircraft must be able to take off and land safely at vertiports, and traffic originating from and destined for a vertiport would ideally have easy access to a vertiport. Furthermore, emergency operations or emergency landings at a vertiport need to be able to occur regardless of the congestion level in the network. The existing vertiport management concepts involve air traffic management at each individual vertiport for the airspace immediately surrounding the vertiport. While some limited work has begun to look at management of traffic near vertiports, it has largely been focused on the aircraft landing problem and optimizing the landing schedule (Pradeep & Wei, 2018; Kleinbekman et al., 2018; Zhou et al., 2020).

The goal is to schedule the arrival of aircraft as quickly as possible while considering vehicles’ varied battery states (Pradeep & Wei, 2018). A vertiport traffic arrival scheduling algorithm developed by Kleinbekman et al. (2018) suggests that each vertiport is given two arrival and two departure fixed flight paths, and on arrival, these flight paths begin the approach at 3,900 m horizontally away from the vertiport and at an altitude of 500 m. The aircraft then proceeds to a fixed waypoint 400 m horizontally and 200 m vertically away from the vertiport, before beginning its final descent. A similar geometry is adopted for departure flight paths. This setup is notable for not involving a straight vertical arrival or departure path and giving multiple paths, although it does still assume restricted airspace that other aircraft may not enter unless using the vertiport.

There is a similar configuration, where it is assumed that each vertiport would exist at the center of two volumes: the vertiport operations area (VOA) and the vertiport volume (VPV). The VOA would represent the outermost extent from the vertiport within which aircraft must coordinate with a service provider to provide information such as location and heading. The VPV would be an inner volume in which aircraft operations are controlled by the vertiport manager. An aircraft passing through the area could move across the VOA but cannot enter the VPV unless arriving or departing at that vertiport. Aircraft arriving at or departing from the vertiport would navigate through a defined series of fixes in the airspace to guide them, and these would be aligned over both a vertical and horizontal distance (Northeast UAVS Airspace Integration Research Alliance, 2021).

### Vertiport Location

The network design problem concerning the identification of suitable locations and infrastructure requirements for urban air mobility (UAM) operations has been the subject of investigation by various research groups (Sinha & Rajendran, 2020; Brühl et al., 2022; Wu & Zhang, 2021; Arellano, 2020). To address this challenge, clustering methods have been extensively employed, with the primary objective of grouping data points in areas characterized by concentrated demand or spatial coherence. These areas, deemed suitable for vertiport establishment, aim to effectively cater to the transportation needs of the population by facilitating the identification of spatial patterns and candidate vertiport locations (Lim & Hwang, 2019; Rajendran & Zack, 2019; Jeong et al., 2021; Peng et al., 2022).

In addition to clustering methods, optimization models have been utilized to tackle the network design problem. These models focus on diverse objectives, such as maximizing ridership and revenue as well as determining the quantity, distribution, and capacity of vertiports (Rajendran, 2021; Rath & Chow, 2022). Furthermore, other approaches, including suitability analysis theory (Fadhil, 2018), location-queuing models (Boutilier & Chan, 2022), and single-allocation p-hub median placement problems (Willey & Salmon, 2021) have been explored.

Moreover, researchers have delved into mathematical programs incorporating bilinear equilibrium constraints (Yu et al., 2023) as well as spatial analysis methods to repurpose existing infrastructure locations for UAM operations (Ribeiro et al., 2023). These multifaceted approaches represent concerted efforts to address the complexities associated with UAM network design, with the ultimate aim of establishing well-coordinated and efficient infrastructure to support the future of urban air transportation.

## OPERATIONAL CONCEPTS

Several government agencies and others both in the United States and abroad have developed Concepts of Operation (“ConOperations”) to provide a framework for AAM service operations. In a study for NASA, Johnson and Larrow (2020) outlined key concepts for AAM traffic management (UTM):

- Separation requirements between aircraft
- UTM system separate from but complementary to traditional air traffic management (ATM)
- Roles for service suppliers of unmanned aerial vehicles (UAVs), providing key flight information to AAM operators

- Conflict management model based on three levels:
    - Strategic conflict management
    - Tactical conflict management through aircraft separation
    - Emergency collision avoidance when tactical conflict resolution fails

NASA published a concept of operations that categorized the development of UAM service into six stages, ranging from aircraft testing and certification in UML-1 to high-density, widespread, automated UAM operations for UML-6 (Price et al., 2020). Automation of aircraft would be introduced across these phases, and airspace configurations would be developed accordingly. The authors suggested that UAV operations involving goods delivery should operate below 400 ft above ground level (AGL), while UAM operations might be confined up to 3,000 ft AGL. Initially UAM operations would occur within specific and controlled corridors during UML-2, but as UML-4 and later was reached, the airspace configurations would be adjusted to allow ubiquitous operation of UAM vehicles throughout an urban area.

The Federal Aviation Administration (FAA, 2020a, 2023b) has published two concept of operations documents for UAM, providing a vision for early UAM services within the United States that could serve as a common reference point. The key contribution of this document was the prescription of "UAM corridors," or corridors of airspace through other airspace classes designated for UAM use. While within these corridors, the vehicles would use UAM-specific procedures, although UAM vehicles could leave these corridors and revert to using the relevant local class of airspace. Corridors are envisioned to connect vertiports directly, creating a point-to-point network. FAA may also intervene with a demand capacity balancing system within the corridors, again highlighting a role for network-level traffic management of UAM. Initially the UAM vehicles are expected to be piloted and follow pre-specified tracks within the corridors, restricting their freedom of movement. According to FAA (2020a), UAM initiatives in city centers necessitate the establishment of air corridors to ensure the safe and efficient operation of aircraft. These corridors are designed to facilitate aircraft movement by following predefined "urban air highways" rather than enabling direct point-to-point travel in a linear manner. Specific regulations will be put in place to govern these highways, dictating factors such as altitude, speed, direction, and maneuvering protocols for transitioning between different corridors. Further analysis on corridors can be found in Chapter 4.

FAA (2023c, July) also published an AAM implementation plan that involves fostering collaboration through public–private partnerships. These partnerships will identify key locations and relevant use cases of interest to stakeholders within the AAM industry. The initiative adopts an inclusive "all-hands-on-deck" approach, ensuring that essential measures are taken to enable and support these integrated operations effectively.

Conceptualization of UAM services has taken place in Europe as well, where EUROCONTROL has published a concept of operations document (Hately, 2019). Within this document U-space is commonly used to refer to airspace designated for use by AAM systems. This U-space would primarily occupy low-altitude airspaces and would have separate rules and procedures for the unmanned flights within it. Additional airspace structure concepts have been proposed (Sunil et al., 2015, Pradeep & Wei, 2018)—namely, full mix, layers, zones, and tubes (Figure 1):

- **Full Mix**: All air vehicles share the airspace and move without barriers. Air traffic control does not require flight plans and manages the capacity of the airspace.
- **Layers**: Airspace is divided into layers where every altitude band corresponds to a heading range.
- **Zones**: Airspace is partitioned into zones for different types of vehicles based on their characteristics, such as speed, maneuverability, level of autonomy, as well as global directions to aid separation between vehicles.
- **Tubes**: This is a fixed-route structure. Aircraft can only follow the tubes and maintain an equal speed as other aircraft in the airspace, which offers the advantage of channeling traffic in a safely separated manner.

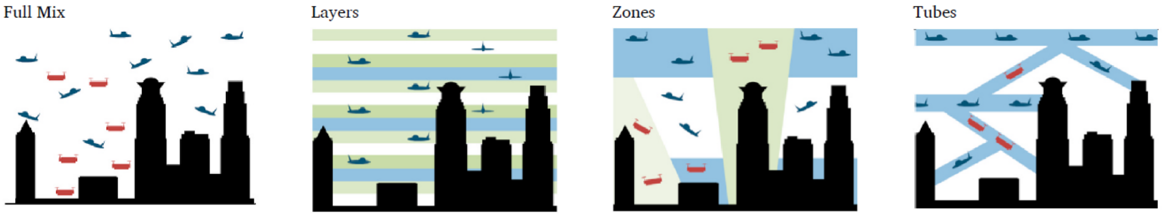


**Figure 1. Graph. Airspace structures.**

***Source: Concept from Sunil et al. (2015); graphics from Bauranov & Rakas (2021)***

Other work by Airbus (Balakrishnan et al., 2018) highlighted four key types of aircraft routing to consider for AAM service: basic flight, free route, corridors, and fixed route.

- **Basic flight**: Aircraft under basic flight are responsible for self-separation.
- **Free route**: Aircraft can fly in any path. Their planned path is coordinated with and deconflicted from the paths of other aircraft by a traffic manager and approved based on calculated risk. This is similar to the full mix concept.
- **Corridors**: There are defined volumes in space, which is useful for managing airspace in high demand or to manage traffic flow and separation.
- **Fixed route**: This is used to ensure safety when there is high traffic density or in any location where structure is required to ensure safe operations.

## DEMAND FOR AAM

Understanding the demand potential for AAM is critical to accurately assess the scope and scale of AAM operations. Since very few services similar to AAM currently exist, demand estimation is a challenge. Several approaches have been used, generally centering on either comparison with existing services (Rajendran & Shulman, 2020; Oh & Hwang, 2020; Alonso et al., 2017; Bulusu & Sengupta, 2020; Holden et al., 2016) or survey experiments of potential AAM users (Shaheen et al., 2018; Fu et al., 2019; Yedavalli & Mooberry, 2018). Studies comparing AAM services to competing services suggest that demand for AAM will materialize if it is competitive on key metrics such as travel time, waiting times, cost, or emissions. They also suggest that costs of AAM services could be high, so time savings would need to compensate for this. AAM is also expected to use electric power and generate lower emissions than similar ground modes, which are often based on gasoline-powered vehicles. Estimates arising out of these analyses vary, but studies have suggested a range in demand from hundreds of operations daily to serving tens of thousands of people within an urban area (Rimjha et al., 2021; Alonso et al., 2017). The domain of UAM has witnessed noteworthy progress and engagement in recent years, notably pertaining to the facilitation of personalized passenger per-seat air travel services. This evolution is exemplified through entities like the ride-hailing mobility leader Uber, as underscored by comprehensive studies and academic literature (Ale-Ahmad & Mahmassani, 2023; Garrow, German, et al., 2020; Garrow, Mokhtarian, et al., 2020).

Surveys of potential users try to better understand traveler and user preferences, behaviors, and choice processes. In early stages, air-taxi operating costs on a per-mile basis are expected to be more similar to a limousine or helicopter, while being significantly more expensive than ground taxis (Goyal et al., 2018). The US market was estimated to be close to 82,000 passengers daily (55,000 flights), served by roughly 4,000 aircraft. If weather, time-of-day, capacity, and infrastructure constraints could be solved in the long term, then demand could reach up to 13 million passengers daily served by nearly 700,000 aircraft. The findings also indicated challenges with noise concerns, airspace restrictions, and competition from telecommuting. The air ambulance market is another prominent domain, which already makes use of existing helicopter technology (Bulusu & Sengupta, 2020). Their findings indicated similar cost values between eVTOLs ($9,000 per trip) and existing rotary wing vehicles ($10,000 per trip) for air ambulance trips, in 2019 U.S. dollar values. The biggest constraint facing eVTOL usage is battery recharge time. Recharge times for eVTOLs are expected to be significantly longer than rotary wing aircraft refueling times. This lost time compromises an aircraft’s availability for further trips. Hybrid vehicles are suggested as an effective solution in addition to battery swapping or faster recharge times.

## ENERGY SOURCES FOR AAM

With existing aircraft being a significant contributor to emissions from the transportation sector, and with current fuel types contributing 3%–4% to total US carbon emissions, any company looking to invest in UAM must consider and implement clean fuel alternatives. Although there has been research in solar energy and storage for aircraft (Gao et al., 2015) as well as sustainable kerosene alternatives (Bauen, 2020), lithium-ion batteries, hydrogen fuel cells, and hybrid power sources are more popular and promising.

- Lithium-ion batteries: high energy density, highest stored energy per unit volume (Donateo & Ficarella, 2020), degrade quickly in unfavorable conditions, reducing the state of charge window, reducing capacity, and increasing replacement and maintenance costs (Liu et al., 2021; Button, 2021), many aircraft require 400 Wh/kg, current batteries have power energy densities of 64 Wh/kg (Button, 2021).

- Hydrogen fuel cells: higher energy storage capacity than batteries, faster response time, capable of handling rapid power transitions in vertical take-off and landing (Ng et al., 2019), do not have the same issues related to cycle life and replacement as batteries (Ahluwalia et al., 2021), can increase energy efficiency up to 12% compared to kerosene for long-range operations, and 5%–18% for short-to-medium range aircraft (Verstraete, 2015), increased weight (Cano et al., 2021), exceed performance of batteries but at higher cost (Ahluwalia et al, 2021).

- Hybrid: batteries and fuel cells alone are insufficient for AAM missions of distances larger than 75 miles (Ng et al., 2019), parallel hybrid electric powertrain with a turboshaft engine can reduce burn fuel between 12% to 24% (Donateo et al., 2021), can improve reliability, current hybrid aircrafts only marginally improve fuel efficiency, and energy efficiency as a whole is dependent on the evolution of battery energy density (Pinto Leite & Voskuijl, 2020).

## USE CASE SPECIFICS

Various identified use cases of AAM are briefly analyzed below:

- Passenger air taxi: Perhaps the AAM use case that has attracted the most attention, a passenger air taxi is expected to be particularly beneficial for long-distance urban trips in congested cities. Air taxis can bypass highway congestion, leading to shorter travel times in addition to higher speeds, competing with ground modes for longer trips. However, first-/last-mile travel times and loading/unloading times are thought to make an air taxi unattractive for shorter trips, which could be better served on the ground (Bulusu & Sengupta, 2020). Similar urban air taxis have been operated before or still operate in many large cities. These air taxis used helicopters to move passengers to, from, and around a central business district. Considering a multimodal air-taxi service (combining ground modes for access and egress), in order to deliver a satisfactory standard of service and substantial reductions in travel time, the operator has to commit to restricting the extent of delay attributable to waiting intervals and repositioning of passengers (Ale-Ahmad & Mahmassani, 2023).

- Shipping and package delivery: Package delivery to a customer or shipment of goods between two supply chain nodes such as warehouses could be other AAM use cases. Two primary advantages over traditional ground modes are faster travel times and service in areas without good ground transportation networks. UAV delivery suffers from weight capacity, with capacities ranging from 2 lb for small aircraft up to several hundred pounds for larger aircraft.

- Agricultural applications: Aircraft are already used heavily within agriculture. The National Agricultural Aviation Association (2022) estimates that about 28% of the total cropland in the United States is treated at least once each year by an aircraft, accounting for over 100 million acres each year. Aircraft can apply sprays to crops to improve growth or fight pests or diseases. AAM vehicles can take-off and land in very limited spaces, making them ideal for operations based on a farm or from smaller infrastructure near farms. A number of companies are developing air mobility applications for agriculture, with an example of Pyka, which has begun production of a fully autonomous, lidar-enabled, fixed-wing aircraft that can carry up to 700 lb in payload (Pyka, 2022).

- Emergency and medical services: Aircraft can offer faster travel times and coverage in areas with poor or no ground transportation network. There are already many existing air ambulance operations, with more than 1,000 operating across the United States, with AAM vehicles being able to perform the same tasks at a lower cost than helicopters (Goyal et al., 2018). Additionally, organ transplant transportation and medical equipment delivery can also be done via AAM vehicles, which is faster and safer than ground transportation (Tabor, 2021a; UAM News, 2020). Also, safer operations in cases where emergency personnel could be in danger can be achieved (e.g., intense wildfires [Tabor, 2021b], search and rescue missions, [Ball, 2021]).

- Infrastructure inspection: UAV inspections can improve inspections greatly by reducing inspection times and instances of workers going into hazardous areas, operate in difficult-to-access areas, and generally offer a safer and faster alternative to traditional inspection methods, for specific infrastructure.

# CHAPTER 2: OPERATIONAL PROFILES AND SAFETY CONSIDERATIONS OF AAM IN ILLINOIS

This chapter delves into the intricacies of AAM and UAM operations, highlighting the potential benefits and challenges they present in the context of Illinois. By examining the operational characteristics and safety implications, we aim to provide valuable insights into the integration of these innovative technologies, paving the way for a safer and more sustainable future of aerial transportation.

## AIR-TAXI DEMAND ESTIMATION

This section is devoted to the estimation of demand for air-taxi services, exploring the underlying drivers and potential market dynamics.

### Estimation of Market Size and Scale of Operations

There is a wide range of applications and market opportunities for AAM, one of which is the introduction of air taxis for different trip purposes. Since such a service is not yet available, various market size estimations have been done, along with stated preference surveys, in order to study and assess potential customers' inclination toward such services. Stated preference surveys are designed with questions and hypothetical scenarios that aim to identify behavioral responses in choice situations which are not yet revealed in the market. Regarding air-taxi market size estimations, values from \$2.5 billion annually, up to even \$500 billion (in 2018 and 2020 U.S. dollars) have been forecasted (Goyal et al., 2018; Garrett-Glaser, 2020; Lineberger et al., 2021) under different assumptions, scenarios, and cost values per passenger mile (from as low as \$0.50 per mile [Holden et al., 2016] to \$6.25 [Goyal et al., 2018]). Tables 18 and 19 in Appendix A present in detail these findings and the studies behind them.

### Demographic Characteristics of Potential Users

Based on the responses from various surveys related to AAM and UAM, different demographic characteristics of potential users are briefly presented as follows (Shaheen & Cohen, 2018; Fu et al., 2019; Yedavalli & Mooberry, 2018):

- Positive reactions
    - High income (above \$150,000)
    - Age (25–34 years old)
    - Education (college and/or graduate studies)
    - Work commute (40 minutes or more)
    - Trip purpose (long recreational trips)

- Negative reactions
    - Age (above 46 years old)
    - Area of residence (rural area residents)
    - Work commute (less than 20 minutes)

A number of barriers that could potentially delay the adoption of AAM services are listed as follows:

- Perceived high price
- Concern that the service will function similarly to a bus (with multiple take-offs and landings for a single passenger trip)
- Noise as well as visual pollution, which could discourage a number of potential users
- Privacy violation for both users and non-users
- Impracticality for traveling short distances
- Idea of having to take a first-and-last-mile connection using another mode of transportation to get to or from a vertical port necessitates a large number of inconvenient transfers
- Inadequate supply, leading to higher costs and/or longer wait times
- Restrictions on where aircraft can land
- Flying at low altitude may be risky or unappealing visually
- Crashes pose a greater threat to safety than with ground transportation

### *Beginning of Operations Assessment*

Regarding the anticipated year for AAM to enter the market, industry experts and stakeholders have identified the mid-2020s as a pivotal time for the emergence of viable air-taxi services. Eve already announced the first North American real-life UAM scenario simulation in Chicago (PR Newswire, 2022), while MarketWatch (2023) and others report that by 2030, the UAM market is forecasted to see a tremendous increase. McKinsey (2021) reports that people will be able to access such services by 2024. Recently, United Airlines and Archer announced that by 2025, UAM operations between O'Hare International Airport and Vertiport Chicago will be open to passengers (Tegler, 2023).

### *Altitudinal Analysis*

Regarding flying altitudes of the aircraft, restricting AAM aircraft flight altitudes at 990 ft above sea level, or below that threshold, significantly reduces the probability of having conflicts between aircraft (Bulusu et al., 2018). AAM operations would occur at altitudes of up to 5,000 ft, reaching speeds of approximately 150 knots (Lascara et al., 2019). Due to their limited duration, missions conducted by AAM aircraft are anticipated to occur at relatively low altitudes, typically ranging from one to a few thousand feet above ground level (AGL). The minimum safe altitude requirements defined by FAA (14 CFR §91.119) must be taken into account (United States Government, Title 14—Aeronautics and Space). While this regulation encompasses various elements, for AAM missions conducted over congested areas, it stipulates that an aircraft must maintain an altitude of at least 1,000 ft above the highest obstacle within a horizontal distance of 2,000 ft.

For the take-off and landing portions of a trip, two sub-phases exist, initial vertical ascent and final vertical descent near the ground, and angled ascent/descent when the aircraft is above 50 ft above ground level, as it can be seen in Figure 2 (Patterson et al., 2018).

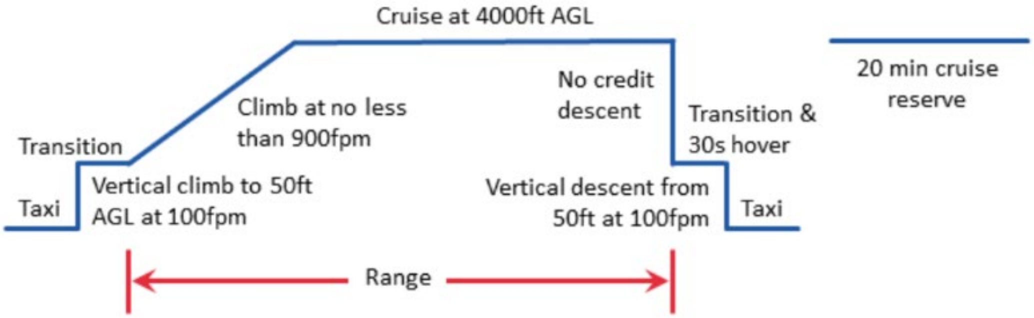


**Figure 2. Graph. General mission profile shown in blue with relevant constraints listed.**

***Source: Patterson et al. (2018)***

## Quantitative Demand Estimation

Within the air-taxi use case for air mobility, there are three key groups of trips to estimate: inter-regional air taxi, trips to/from an airport, and day-to-day trips. Longer day-to-day trips may form the bulk of demand for air-taxi service, because there are many such trips, and time savings from an air taxi can be competitive with ground modes. Several previous studies have used various methods for estimating the air-taxi demand from such trips, generally centered around travel time savings and cost competitiveness (Oh & Hwang, 2020; Alonso et al., 2017; Bulusu & Sengupta, 2020). This analysis of the potential demand most closely aligns with a study done by Goyal et al. (2018). In this method, a dataset of National Household Travel Survey trips from 2017 is used to represent daily travel. Based upon the trips' data and assumed parameters of air-taxi service, the levels of service between existing ground modes and a potential air taxi can be compared. A logistic mode-choice model using variable coefficients from the Chicago Metropolitan Agency for Planning (CMAP, 2018) is then executed. After the application of a willingness-to-pay constraint, predicted levels of unconstrained demand are calculated. Supply-side constraints on the network are then considered in conjunction with the unconstrained demand. In order to perform the calculations within the logistic mode-choice model, it is necessary to make several assumptions, however. The precise cost of AAM service, average aircraft operating speed, waiting time at vertiports, and access/egress times from vertiports are all important unknowns that affect the level of service for AAM. Assumed ranges of values for these variables were established (Table 1) and applied within the demand estimation.

**Table 1. Assumed Cost, Speed, Time Values**

| | Worst Case | Medium | Best Case |
|---|---|---|---|
| Cost ($ / pax-mile) | 9 | 7 | 4.75 |
| Aircraft Speed (mph) | 100 | 140 | 180 |
| Wait Time (minutes) | 15 | 10 | 5 |
| Access/Egress Time (minutes) | 30 | 20 | 10 |

The price of AAM service was estimated based upon an estimate of the cost of service per passenger mile. These cost levels were established based on 2018 U.S. dollar values (Goyal et al., 2018). Average aircraft operating speeds determine the travel times for aircraft between vertiports, and the assumed operating speeds are based upon the speeds of prototype air taxis currently under development (Bacchini & Cestino, 2019), with an allowance for a slower pace of operations during take-off and landing. Assumed waiting times and access/egress times ranging between 5 and 15 minutes were used, with the access/egress times doubled to represent both the first- and last-mile distances. Based upon the comparison of existing ground mode trips and calculated levels of service for an air taxi, Figure 3 shows the travel time savings for AAM aircraft. The analysis was only applied to trips of 30 minutes or longer, as these are trips long enough for an air-taxi service to be competitive. Within this segment, 88% of longer trips could see some travel time savings from an air taxi. The median travel time savings for such trips was 25%, which for most trips would amount to 15 minutes or less, and was not significantly faster than a ground mode. Twenty-two percent of longer trips saved at least 50% of their travel time by using an air taxi, and this market is more likely for air-taxi service because it represents significant time savings.

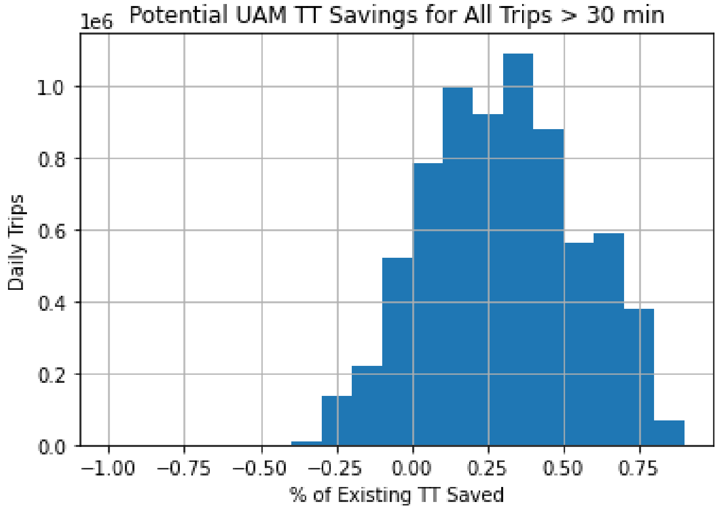


**Figure 3. Chart. Potential UAM travel time savings for trips above 30 minutes.**

Five scenarios were constructed from the ranges of parameters, to represent possible operating environments for an air-taxi service. The five scenarios include best-, worst-, and middle-case scenarios (Table 2). They also include scenarios for different network sizes, reflecting the number of aircraft and vertiports in the network. The large networks scenario assumes low wait time and access/egress time, while the small networks scenario assumes high wait time and access/egress time. Using the parameter levels for each scenario, estimates on the unconstrained number of daily trips were calculated. The unconstrained number of daily trips represents the number of trips before supply-side constraints such as vertiport and vehicle capacity, vertiport accessibility, times of day, and weather are considered.

**Table 2. Air-Taxi Scenarios Introduced**

| Scenario | Market Share | Unconstrained Daily Trips Estimate |
|---|---|---|
| Worst Case | 0.01% | 4,000 |
| Middle Case | 0.16% | 64,000 |
| Best Case | 0.95% | 380,000 |
| Small Network | 0.06% | 24,000 |
| Large Network | 0.45% | 180,000 |

The unconstrained demand estimates for day-to-day AAM trips range from a few thousand trips daily to tens of thousands of trips daily. Note that the largest demand estimates come from the most optimistic assumptions, including assumptions of short wait times, easily accessible vertiports, and low prices.

### *Types of Daily Trips*

An in-depth look at the types of trips that are suitable for air-taxi services reveals a few trends. These results are based upon the unconstrained demand estimates, so they answer questions about where demand for air taxis could be if service were supplied. When considering whether trips were work-related, it is estimated that about half of likely AAM trips will be work trips, whereas only a quarter of total trips are work-related (Table 3). This result differs from relevant survey responses about air-taxi use, however (Shaheen et al., 2018; Fu et al., 2019). In general, travelers are willing to travel farther and pay more for a commuting or work-related trip than other kinds of recreational trips. Air taxis will offer the greatest travel time savings for long distance trips, albeit at a higher cost (Bulusu & Sengupta, 2020; Goyal et al., 2018), making work-related trips relatively better suited for air taxis.

**Table 3. AAM Trip Purpose**

| Trip Purpose | AAM Trips | Total Trips |
|---|---|---|
| Work | 53.0% | 25.4% |
| Not Work | 47.0% | 74.6% |

Because air-taxi trips are predicted to have a relatively high share of work-related and commute trips, many of these trips are predicted to occur during peak morning and peak afternoon travel hours. Figure 4 provides a histogram of predicted unconstrained demand for day-to-day air-taxi trips by time of day. The most prevalent hours for air taxi use are between 6:00 a.m. and 10:00 a.m. and between 4:00 p.m. and 6:00 p.m. These times of day show demand levels of double or more the demand levels of other times of day. Given this finding, an air-taxi network may undergo hours of intense usage in the morning and afternoon, followed by longer intermediate periods of time with low travel demand.

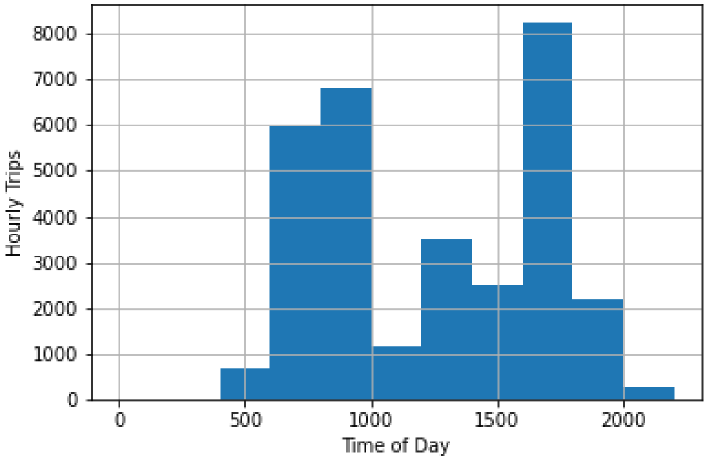


**Figure 4. Chart. Histogram of the times of day of passenger trips.**

There is also a great difference around Illinois in terms of the regions where the potential air-taxi trips occur. It is estimated that more than 85% of day-to-day air-taxi trips would occur in the Chicago area, while only about two-thirds of all trips occur in the Chicago area. There appears to be a larger concentration of likely air-taxi trips in Chicago because of the large number of trips to draw from but also because long-distance trips in and around Chicago more frequently suffer from long travel times due to congestion. Much of the non-Chicago demand is expected to occur in central Illinois away from either Chicago or St Louis (Table 4). But given that nearly all the potential demand for air-taxi services occurs near Chicago, it is possible that operators may simply only focus their day-to-day air-taxi services on the Chicagoland area.

**Table 4. Illinois AAM Demand in Different Regions**

| Region | AAM Trips | Total Trips |
|---|---|---|
| Chicago | 87.6% | 68.5% |
| St Louis | 2.4% | 6.6% |
| Central IL | 10.0% | 24.9% |

Last, given the high relative cost of air-taxi trips when compared with ground modes, it is expected that air-taxi trips may be concentrated among travelers with higher household income, consistent with the findings of Fu et al. (2019) and Yedavalli and Mooberry (2018). Cost was a key factor in the decision to take an air taxi or stay with the existing mode. Travelers with higher household incomes are less sensitive to price and have a higher value of time, making the time savings more attractive relative to the cost of an air-taxi service.

### *Airport Trips*

Trips to and from the airport refer to the first-/last-mile problem for existing commercial aviation services and involve trips from homes or businesses to and from an airport with long-distance service. Many of these trips are currently completed by car or ground taxi services; however, air mobility may be an effective alternative because it can use existing airport infrastructure. Such airport trips are often poorly represented in travel surveys because they are often irregular trips or trips made by non-residents of the city. Therefore, an alternative method of estimating these trips is used, based upon the methodology in Goyal et al. (2021). For airport trips, T100 Market data on airport demand collected by the Bureau of Transportation Statistics is used to gather an estimate of airport passenger demand. Transferring passengers are removed from the count. The passenger demand is then distributed to census tracts within the airport's region (within 75 miles of the airport) based on tract population to estimate a trip dataset. The ground (driving) and air (AAM air taxi) levels of service for this trip dataset are estimated along variables such as travel time, travel cost, access times, and wait times. The mode-choice model described above is then implemented to translate the service variables into a demand prediction for an airport air taxi.

Assumed parameters for air-taxi cost, average operating speed, waiting time, and access/egress time from Table 1 were used alongside the given data to construct estimates of air-taxi prices and travel times. The resulting service characteristics for ground and air-taxi modes were then compared in a logistic mode-choice model across three possible scenarios—worst case, best case, and middle case. The unconstrained demand estimates for each scenario are shown in Table 5.

**Table 5. AAM Day-to-Day Unconstrained Demand Estimation Scenarios**

| Scenario | Market Share | Unconstrained Daily Trips Estimate |
|---|---|---|
| Worst Case | 1.11% | 1,500 |
| Middle Case | 3.06% | 4,100 |
| Best Case | 10.26% | 13,600 |

The demand estimates for airport trips predict that airport trips may see a higher market share for air-taxi service compared to day-to-day trips. This occurs because airport trips are generally longer than day-to-day trips, and often more expensive than day-to-day trips after parking or taxi costs are figured in. There are several thousand potential airport trips by air taxi, representing a significant market. However, the market share for air taxis still does not approach a majority of airport trips, primarily due to the high-cost parameter for air taxis. The high-cost parameter puts the air-taxi cost beyond what many airport travelers are willing to pay, and this highlights the need for affordable air-taxi service if it is intended to serve the majority of people.

The large majority of forecasted airport air-taxi demand occurs at two airports—Chicago O'Hare (ORD) and Chicago Midway (MDW)—because the large majority of passenger demand at airports with commercial service in Illinois occurs at these two airports. Figure 5 shows the estimated demand for air-taxi service at airports with more than 10 forecasted trips per day. Air-taxi demand at the two large Chicago airports could approach 2,000 passengers per day, while other airports around Illinois may only experience a few dozen passengers per day.

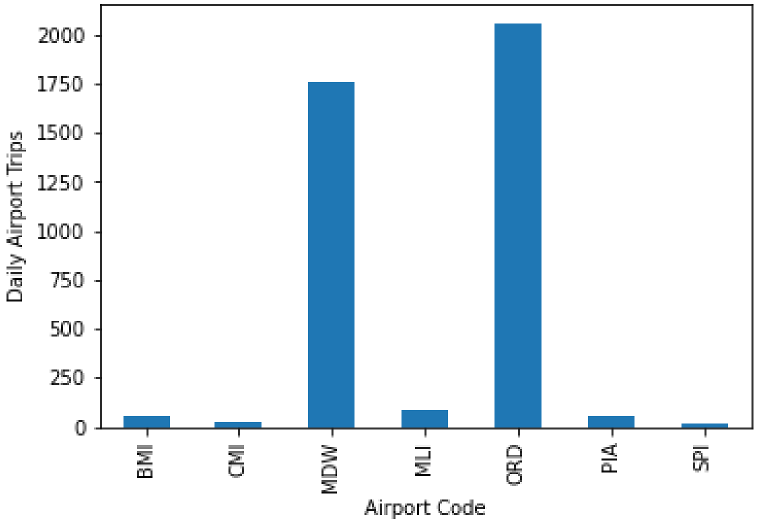


**Figure 5. Chart. Estimated demand for air-taxi service at airports with more than 10 forecasted daily trips.**

## Regional Air Taxi

Inter-regional trips represent a market segment of short-haul air trips currently served by commercial air service. These trips between small regional airports and larger hubs may be better served by smaller and more efficient air mobility vehicles. AAM vehicles, with a range up to 150 miles, could also serve this market, potentially competing on travel time, cost, and frequency of flights. Data on existing short-haul commercial air trips is considered along with the cost efficiencies of air mobility vehicles relative to existing aircraft. Based upon these considerations, a future market share for air mobility vehicles is identified.

There are relatively few short-haul air routes of less than 150 miles in Illinois with commercial flight service. Figure 6 depicts a map of these routes, with thicker lines representing a higher number of passengers. Three hub airports are present on every route: Chicago O’Hare (ORD), Chicago Midway (MDW), and St. Louis Lambert (STL). Figure 7 depicts the share of the roughly 6,600 daily passengers on these routes, with the vast majority of passengers traveling through Chicago O’Hare on one of these short-haul air routes.

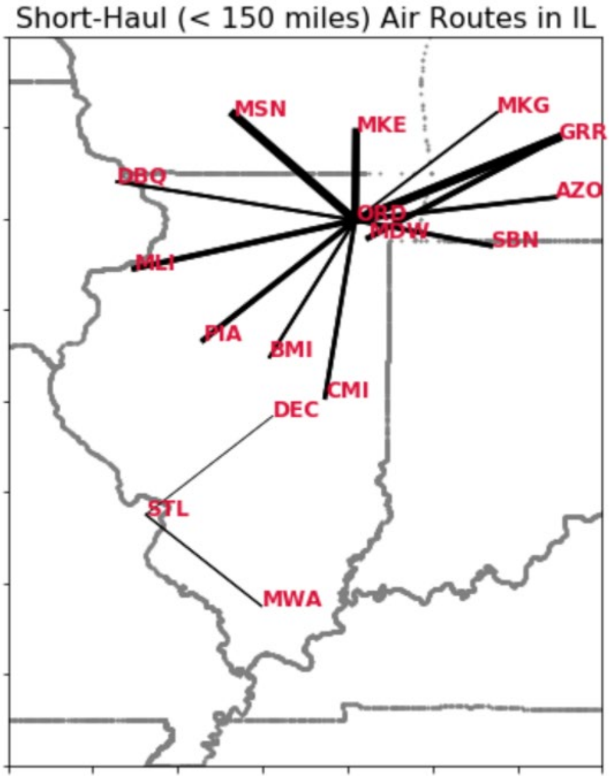


Figure 6. Graph. Short-haul air routes in Illinois.

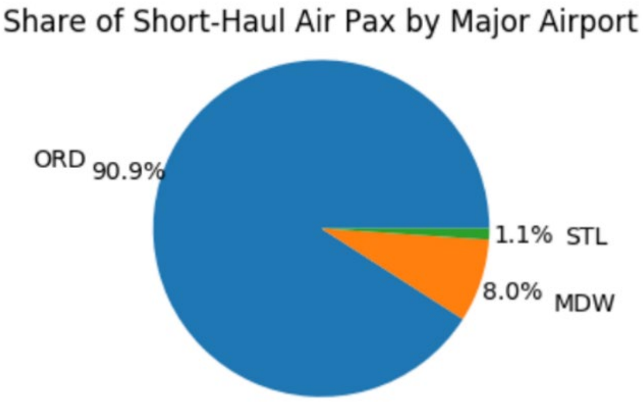


Figure 7. Chart. Short-haul air routes passenger share.

Regional air-taxi service as a replacement for short-haul air service may be able to compete in three categories: travel time, cost, and frequency of service. Figure 8 compares the existing gate-to-gate travel times of commercial flights on these short-haul routes with anticipated air-taxi travel times based upon a 150-mph anticipated average operating speed. Each point represents a route between two airports, with larger points representing more passengers. The results show that for the majority of routes, a regional air taxi would save travel time relative to existing commercial flight service, likely through more direct routing and less time spent taxiing at airports. However, the scale of the time savings tends to be 15 minutes or less, which may be an insignificant figure.

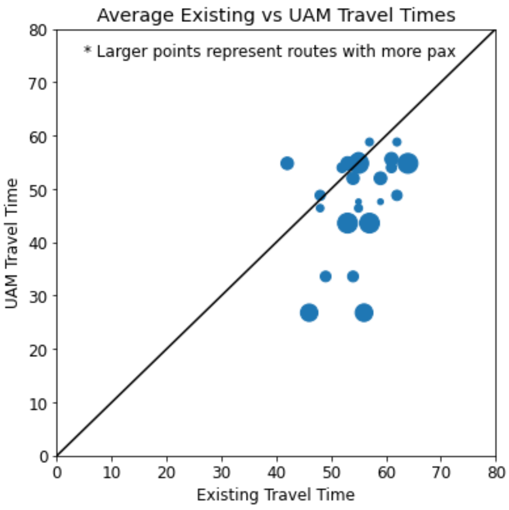


**Figure 8. Graph. Existing vs UAM travel times.**

It is also possible to compare potential air-taxi service with existing short-haul service on the basis of cost and frequency. Again, there is no set price for an air taxi yet. However, one would expect some cost efficiency to be gained from the longer routes. Several industry sources suggest that a regional air taxi in a mature state could operate at a cost between \$2.25 per passenger-mile and \$5 per passenger-mile in 2018 dollars (Goyal et al., 2018; Gerber, 2020). Of course, any cost estimates for a comparable horizon would likely be subject to fluctuations and changes based on the prevailing economy and market state. Meanwhile, an air-taxi service could offer high frequencies of service throughout the day, with potentially dozens of flights for high-demand origin-destination pairs. Figure 9 shows the price per passenger-mile compared with flight frequency for the existing short-haul air services in Illinois. Again, each point represents a route, with larger points indicating routes with more passengers. Additionally, the average route operates around six flights per day. While this frequency may not be as high as the frequency that an air-taxi service could achieve, it still suggests that such short-haul air routes are already relatively commonly served.

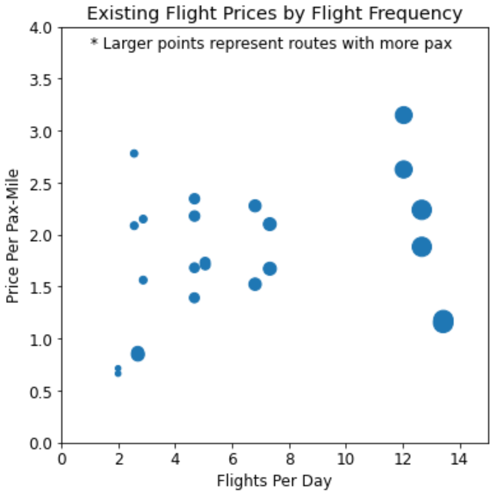


**Figure 9. Graph. Existing flight prices by flight frequency.**

One area of potential demand not captured in this analysis is new short-haul routes, possibly between smaller airports. However, there was no data available to evaluate the level of induced demand if a regional air-taxi service between smaller airports were added.

### *Supply-Constrained Demand*

When considering supply constraints, the scale of operations for an air taxi shifts considerably. Supply constraints include the percentage of trip origins and destinations that are accessible from vertiports, system throughput capacity (which includes aircraft and vertiport capacities), time-of-day constraints (air taxis will likely not operate 24 hours per day), and weather constraints (constraining operations only to visual flight rules [VFR] conditions with good visibility). The first constraint to consider is the accessibility of vertiports relative to trip origins and destinations. For an air-taxi service to be a competitive option, vertiports must be located close to trip origins and destinations. The share of trips for which vertiports are easily accessed depends both upon the number and placement of vertiports, but for the purposes of this analysis, assumed accessible shares of 30%, 50%, or 70% were used to represent small, medium, and large network sizes, respectively.

Other supply-side constraints include the time of day and weather conditions. Air-taxi services as currently envisioned will be mostly daytime operations. Given an assumption of operations between 6 a.m. and 10 p.m., an air-taxi service could supply 91% of the unconstrained demand for service. Similarly, air taxis may only operate within VFR conditions with good visibility (Goyal et al., 2021). Such conditions were found to exist around Illinois for approximately 95% of daytime hours, representing the large majority of time. One of the most critical supply-side constraints is system throughput capacity. System throughput capacity is determined by the capacity of aircraft and the capacity of vertiports, assuming that vertiports will be the bottleneck in the system. This assumption seems likely given the currently small number of possible vertiports and potential difficulties with siting and constructing future vertiports (Goyal et al., 2018; Rajendran & Zack, 2019). Aircraft capacities vary by configuration; however, most air-taxi configurations have passenger capacities between one and five passengers (Bacchini & Cestino, 2019; Swaminathan et al., 2022). Furthermore, vertiport capacities, or the number of operations per hour that a vertiport can manage, are also not known, but are estimated to be between 20 and 100 operations per hour (Goyal et al., 2018; Northeast UAVS Airspace Integration Research Alliance, 2021; Vascik & Hansmann, 2019). Therefore, each vertiport's capacity may range from a low of 20 passengers per hour and to a high of 500 passengers per hour.

**Table 6. Air-Taxi Network Capacities in Passengers Per Hour**

| *** 3 pax / veh-trip** | | **Operations per Vertiport per Hour** | | |
|---|---|---|---|---|
| **Network Capacities (pax per hour)** | | **20** | **60** | **100** |
| Vertiports in Air-Taxi Network | 25 | 1,500 | 4,500 | 7,500 |
| | 50 | 3,000 | 9,000 | 15,000 |
| | 100 | 6,000 | 18,000 | 30,000 |

Network sizes may vary by city, demand level, and operational capabilities, but existing studies on air-taxi services envision several dozen vertiports (Rajendran & Zack, 2019; Alonso et al., 2017). Several dozen vertiports would allow for good access around an urban area while creating some cost efficiencies by grouping together demand and operating footprints. A network size ranging from 12 vertiports to as many as 100 or more vertiports in an urban area suggests network capacities between a few hundred passengers per hour to 50,000 passengers per hour. While 100 hourly operations might be toward the higher end, it is not totally unreasonable. The Silverstone heliport holds a notable record in terms of helicopter movements, peaking at approximately 600 movements per hour (Vascik & Hansmann, 2019). Additionally, the Denver International Airport has recorded 298 helicopter movements per hour. In the case of eVTOLs, Vascik and Hansmann (2019) mention that Uber has estimated 338 hourly operations per vertiport, with Kohlman and Patterson (2018) simulating a network of 1,250 hourly operations per vertiport, with both values being closer to the extremes. However, other studies in the realm of AAM and UAM have reported values of 45, 50, and 53 hourly eVTOL operations (Syed et al., 2017; Goodrich & Barmore, 2018; Holden & Goel, 2016). Therefore, an estimate of each vertiport being capable of supporting 32 operations per hour would be an adequate value that could potentially correspond to the initial years of operation of a new transportation mode with these characteristics, cost, and demand profiles.

Assuming mid-range values of about three passengers per aircraft (not all aircraft will be full), 60 operations per hour at a vertiport with multiple take-off and landing areas and about 50 vertiports within an urban area suggests about 9,000 passengers per hour (Table 6). This level of supply would be able to sufficiently serve both the worst- or middle-case level of demand scenarios for day-to-day air-taxi trips. However, the best-case scenario envisioning potential demand of hundreds of thousands of trips would be outside of the capabilities of this system and would require hundreds of vertiports each managing multiple operations simultaneously throughout the day. Chapter 5 contains a detailed analysis regarding the construction of vertiports, spatial requirements, locations, and safety measures needed.

## Air-Taxi Conclusions

This section has reviewed relevant air-taxi literature and survey results and conducted analyses of potential demand for three different air-taxi use cases (daily trips, airport trips, and inter-regional trips) in order to arrive at a likely scale of operations for the air-taxi use case. The estimated demand level across Illinois ranges from several thousand passenger trips per day (between 6,000 and 10,000 trips) to as high as 400,000 passenger trips per day. The demand varies widely based upon the price, travel times, waiting times, and access times for an air-taxi service, with high prices and long times contributing to low demand, while low prices and short times create higher demand. This difference highlights the importance of such parameters to air-taxi operators, since they are key in determining the achievable scale of the operation. The wide range of the estimated demand is due to the wide range in operating parameters and is approximately in line with previous work (Goyal et al., 2018), which suggested a large difference between unconstrained demand and infrastructure-constrained demand. Similarly, other previous estimates of air-taxi service demands have arrived at demand estimates of several thousand trips per day (Alonso et al., 2017; Bulusu & Sengupta, 2020).

# EMERGENCY AAM SERVICES

## Service Introduction and Existing Operations

In the state of Illinois, several healthcare services provide emergency air operations. As of 2018, the Illinois Department of Transportation reported that 132 cities in the state have at least one hospital with a designated heliport. Chicago has 6 hospitals with heliports (IDOT, n.d.-a). Because these heliports are associated with hospitals, many of the emergency responses are limited to evacuation, faster transport to higher levels of care, and operate functionally similar to ambulances (Superior Ambulance; OSF Healthcare, n.d.; Illinois Emergency Management Agency, n.d.). These modes, however, can still be expanded to include automated driving and incorporate drone services. Automated patient vehicles and UAVs can be particularly helpful to aid in severe phenomena (ABC7 Chicago Digital Team, 2021, 2022), especially under severe weather and flooding concerns in Illinois (Illinois Emergency Management Agency, n.d.).

## Potential Use Cases

There are several different use cases for emergency AAM services, including:

- Organ transplant transportation
    - 33,000 organs are transplanted and transported every year in the United States, with ground transportation cost approximately $6,000 per transport and chartered flight something above $40,000 (Bernhard, 2019), accounting for 2018 U.S. dollar values.
    - 3,500 organs yearly are discarded, organs that could be transplanted within the current donor pool (Talaie et al., 2021). 1.5% of donor organ shipments did not make it to their intended destination, and nearly 4% had an unanticipated delay of two or more hours, according to the United Network for Organ Sharing (Scutti, 2019).
- Medical air transport
    - Cardiac arrest episodes
        - A North Carolina study (Bogle, 2019) found that cardiac arrest survival rates increased with shorter time-to-defibrillation, where 13.2% survived if defibrillated within 10 minutes after arrest, but 59.1% of those defibrillated within 2 minutes survived. That time reduction could be associated with an air-medical evacuation or delivery of necessary equipment via drone.
        - A study in Toronto (Boutilier et al., 2022) found that response-time reductions in cardiac arrest episodes achieved by drone network are associated with between a 42% and 76% higher survival rate and up to 144 additional lives saved each year.
    - Physical injuries
        - Air medical transport in the United States accounts for over 400,000 patients flown each year (Huber, 2018).

    - 830 helicopters providing Helicopter Emergency Medical Services (HEMS) in the United States transported more than 275,000 patients in 2007 (Sullivent et al., 2011).

The range of AAM aircraft is considered an issue. However, AAM aircraft have been proposed with a maximum flight range of 10 to 1450 km (Swaminathan et al., 2022). Therefore, with the necessary aircraft in hand, various services in the medical emergency sector can be fulfilled. In order to make a comparison regarding the range of helicopters and the potential range of AAM aircraft, some of the most commonly used helicopter types used for medical emergency purposes are the following, with their corresponding characteristics (FAA, 2015; Medical Air Services Worldwide, 2022):

- EC 135: flying at a speed of 200 km/h and covering a range of 620 km
- EC 145: which has a cruise speed of 210 km/h and covers 680 km
- AS 365 Dauphin: with a cruise speed of 210 km/h and a range of 825 km

Therefore, while not all the proposed AAM aircraft are suitable for medical emergencies, there are some that can operate in the same range as existing medical helicopters.

## APPLICATIONS IN AGRICULTURE

### Market Share and Equipment Costs

Low-flying UAVs are being used to survey large land areas; report on crop health, livestock, and irrigation; and improve the accuracy and efficiency of spraying materials such as pesticides on crops. This type of precision agriculture decreases costs associated with waste, maintenance, and van or truck transportation (IRIS AUTOMATION, 2022). UAV usage for such purposes is forecasted to exceed $1 billion in the market (Meola, 2021). Goldman Sachs (2021) goes so far as to forecast a $100 billion market for UAVs in total, with $5.9 billion in job opportunities in the business and civil government sectors, including agriculture, in 2021 U.S. dollar values. Take-off and landing infrastructure as well as ground control are needed for UAV operation. Regarding the latter, technology companies (e.g., Bayer and AcquahMeyer) equip farmers with autonomous aerial vehicles (AAVs) complete with remote sensors, satellite imagery, and a compatible device with which farmers can view and analyze the data (Reynolds, 2019).

UAV equipment costs can range from $25,000 for a small monitoring UAV (Quadrocopter, 2022) to hundreds of thousands of dollars for larger spraying aircraft. These equipment costs are comparable to ground sprayers (Applegate, 2019). Agricultural aviation can also offer crop yield improvements of around 2%–3% (Lee et al., 2021). Existing agricultural aviation uses small fixed-wing aircraft primarily for the application of pesticides. These fixed-wing aircraft can spray around 250 acres per hour (Air Ag, 2022), which is notably faster than UAV applications. The cost for existing spraying aircraft ranges from hundreds of thousands of dollars to $1.8 million (Air Ag, 2022). Satellites can also be used for monitoring purposes (Sentinel Hub, 2022). Satellite imagery can be done for as little as $0.50 to $1 per acre, while drone imaging is between $2 and $5 per acre. While these costs are cheaper, satellite imaging may not be as precise as drone imaging.

UAVs under development are estimated to have spraying work rates of up to 150 acres per hour, compared to between 40 and 120 acres per hour for ground spraying equipment (Applegate, 2019). Drone spraying can be more precise than ground or fixed-wing aircraft methods (Tegler, 2019). Additionally, monitoring of crops by drones can save significant time because drones can cover larger areas more quickly than ground methods. Informa Economics and Measure in a study estimated cost savings of $11.58 per acre of corn and $2.28 per acre of soybeans, which represents savings for farmers (Travelers, 2022). Cost values in the previous and current paragraph correspond to 2022 U.S. dollar values.

## Operational Capabilities

UAVs can irrigate crops with 90% less water and 50%–70% fewer chemicals, improving efficiency by a magnitude of 40–60 times (IPSOS Consulting, 2017). However, the Illinois Farm Bureau (2019) limits UAVs to carrying 2.5 gallons of pesticides or fungicides, and although remotely controlled, faster, and more accurate than manual spraying, FAA regulations (which currently require UAV piloting certification and limited size and weight thresholds) must be relaxed should crops beyond high price crops be accommodated. Nevertheless, the predetermined routes and tracking technology allows spray UAVs to follow the terrain better and to fly closer to the canopy, allowing up to 12 acres to be sprayed per hour using only a team of three to charge, refuel, and run the equipment (Rice, 2018).

UAVs can assist in detecting nitrogen deficiencies, weed problems, and drainage issues particularly in areas with a closed canopy, where manual inspection proves difficult (University of Illinois Urbana-Champaign, 2017). Gold Star FS, KT Precision, and Helio are leading UAV companies used in the state of Illinois to spray pesticides, fungicides, herbicides, and fertilizers. Other companies such as Flying AG offer lightweight, app-connected budget drones for farmers to monitor fields. Rantizo uses UAVs to identify trouble spots using heat and RGB maps; they have expanded to Illinois, Minnesota, Nebraska, Iowa, and Wisconsin (CropLife, 2019). Agribox uses thermal and lidar detection for fertilizer application, optimizing input to reduce costs, early identification and precise intervention, and early assessment after weather events. UAVs can identify areas in need of additional drainage, especially during the rainy season, which can save crops from quickly developing fungus (Knight, 2022).

Data analytics, aerial imagery, and deep learning have been used to launch IntelinAir to pinpoint trouble spots and provide guidance to farmers on what to prioritize (University of Illinois Urbana-Champaign, 2016). IntelinAir has expanded to Indianapolis and currently monitors approximately 5 million acres of farmland—the equivalent of 17% of total Illinois and Indiana corn and soybean crop acreage. Agricultural aviation can offer time savings, cost savings, and improved yield (Lee et al., 2021; Travelers, 2022; Tegler, 2019; Cummings & Mahmassani, 2023a; National Agricultural Aviation Association, 2022). The National Agricultural Aviation Association (2022) estimates that 28% of farmland in the United States is treated with aerial applications each year. The state of Illinois already has several dozen licensed operators for agricultural aviation, primarily applying pesticides to corn and soybeans (Illinois Agricultural Aviation Association, 2022).

## Scale of Operations

There are several inputs to consider when estimating the potential scale of agricultural AAM in Illinois. The size of the area and product to which AAM is applied, the frequency of application, and the timing of those applications are important considerations, along with the ownership and operations of agricultural AAM. Within Illinois there are 11 million acres of corn and 10.6 million acres of soybeans (USDA, 2017); however, not every farm will adopt AAM solutions. Existing agricultural aviation is only estimated to spray about 28% of the farmland in the United States each year (National Agricultural Aviation Association, 2022). Of the about 72,000 farms in Illinois, only 33% have sales exceeding $100,000. Additionally, 38% of Illinois farms are larger than 180 acres (USDA, 2017). These larger and more commercial farms represent farms with the monetary resources to invest in AAM. The frequency of use varies, with crop monitoring done every 5 and 10 days, while livestock monitoring is done daily or more. Applications of sprays may be done as often as every two weeks, or there may be several months in between. While spraying may be infrequent, there are times of the year when demand for spraying is higher, especially through the summer, creating a need for more capacity to meet the concentrated demand. Ownership must also be considered. For cheaper monitoring aircraft with more frequent usage such as daily or more, individual farms might invest in the aircraft themselves. Spraying and pesticide application, however, is relatively infrequent, and the equipment is more expensive. Therefore, most agricultural spraying services are currently run by separate businesses, and likely would continue to run as such, eliminating the need for each farm to have its own equipment.

## PACKAGE DELIVERY

### Existing Market

US parcel volume has been increasing the past several years. In 2022, FedEx shipped 6.21 million packages daily—a nearly 50% increase since 2016 (Statista, 2022). FedEx shipments comprise only 14.4% of total parcel shipments in the United States; other major carriers include USPS (38%), UPS (24%), and Amazon (21%) (Statista, n.d.). Amazon estimates a maximum of 200 delivery flights per day, or 52,000 delivery operations per year (Singh, 2022), anticipating that package deliveries will take no more than 30 minutes (Amazon Prime Air, 2019). Walmart, similarly, has partnered with DroneUp and has already planned operations in Phoenix, Dallas, Tampa, Orlando, Salt Lake City, and Richmond, with expectations to expand to over 34 different locations (Gunther, 2022) with UAVs of a 10-lb carrying capacity and a delivery time between 30 minutes and 2 hours.

### UAV Delivery Limitations and Illinois Operations Estimation

UAV package delivery is limited by two major factors: weight and weather. UAVs from companies like Wing have an upper limit of 2.6 lb, while other companies like Amazon can carry small packages up to 5 lb (Banse & Sierra, 2022). In 2021, 83% of parcels internationally weighed less than 2 kg (4.4 lb), and 67% weighed less than 1kg (2.2 lb) (Placek, 2021). Assuming domestic packages follow a similar distribution, weight limitations alone limit parcel delivery by 17%–33%.

Delivery UAVs can be flown only when there is a clear visual line of site. Thus, they cannot fly at night, fog, rain, or snow. Extreme winds that exceed two-thirds of a drone’s speed (Posea, 2023) (greater than 36 mph for a typical Amazon drone [Tarasov, 2022]), extreme cold (below 32°F [Gao et al., 2021]) and humidity (greater than 80% relative humidity) prohibit UAV flights. Based on 2010 NCEI hourly weather data for the city of Chicago, weather conditions alone reduce total flyable time by 25%: 2,041 hours of the year experience below-freezing temperatures, and 191 hours experience a relative humidity greater than the recommended 80% limit (Figure 10). Similarly, according to daily wind reports collected from the US Navy, 125 days of the year experience average recorded wind speeds greater than the recommended operating limits of 36 miles per hour (14.75 m per second) (Figure 11). Note that wind resistance depends on the weight and travel velocity of the drone and that because these are daily values, specific times of operation and duration of inoperable times are difficult to precisely estimate and predict.

Additionally, drones cannot be operated at night due to limited field of vision. In Chicago, the latest sunrise is 7:18 a.m. in January and the earliest sunset is 4:20 p.m. in December. Comparatively, typical FedEx deliveries occur between 8:00 a.m. and 8:00 p.m. (FedEx, n.d.); Amazon likewise delivers during these hours, but Amazon Prime members can receive packages as late as 10 p.m. (Amazon, n.d.). This results in 748 hours lost due to darkness in the evening. Of the 4,380 hours in which a parcel delivery typically occurs, drones would be unable to operate in 17% of those hours (Figure 12).

In sum, when considering both weather and daylight conditions, UAVs are unable to fly 5,091 hours of the year, which filters to 1,586 hours of lost operational time (i.e., hours that a UAV could be used but is unable to fly due to light or weather conditions). This translates to 3,159 operable hours—72% of the 4,380 total annual operating hours of delivery services. Accounting for weight limitations and outdoor operating conditions (28% reduction in operational time), UAVs can assist with package delivery for 48%–59% of total package volume (i.e., 3–3.7 million packages daily).

## INFRASTRUCTURE INSPECTION

Reduced risk as well as time and cost savings are the main parameters in favor of UAV usage for infrastructure inspection. With the passage of the Drone Infrastructure Grant Act (H.R. 5315, 2022), the Department of Energy is incentivizing UAV usage by investing a total of $200 million in UAV infrastructure inspection, education, and training. According to the American Association of State Highway and Transportation Officials (AASHTO, 2019), a single bridge inspection can cost $4,600, whereas UAVs can reduce costs to $1,200 (2018 U.S. dollar values). FORCE technologies UAVs use thermogenic software to detect issues on offshore oil and gas plants (Force Technology, n.d.). Airobotics, a private drone company, uses UAVs to collect and analyze data in real time (Urban Drone Infrastructure, n.d.).

### Bridge Inspections

The Department of Transportation estimates that the use of drones can result in 40% cost savings without reducing quality. Moreover, traditional bridge inspection requires the shutting down of lanes, heavy equipment, and at least two personnel (Intelligent Transportation Systems, 2019); while small bridges may only take a day to inspect, large bridges can take up to weeks (West Virginia Department of Transportation, 2020). Required personnel include highway technicians, inspectors, and traffic coordinators, translating to approximately 48 labor hours in high-risk, dark environments (Wells & Lovelace, 2021). In comparison, UAVs would only require two field workers and a total cost of $45 per bridge inspection (2021 U.S. dollars). Illinois ranks third in the nation in the number of structurally deficient bridges, so it can benefit significantly from adopting AAM.

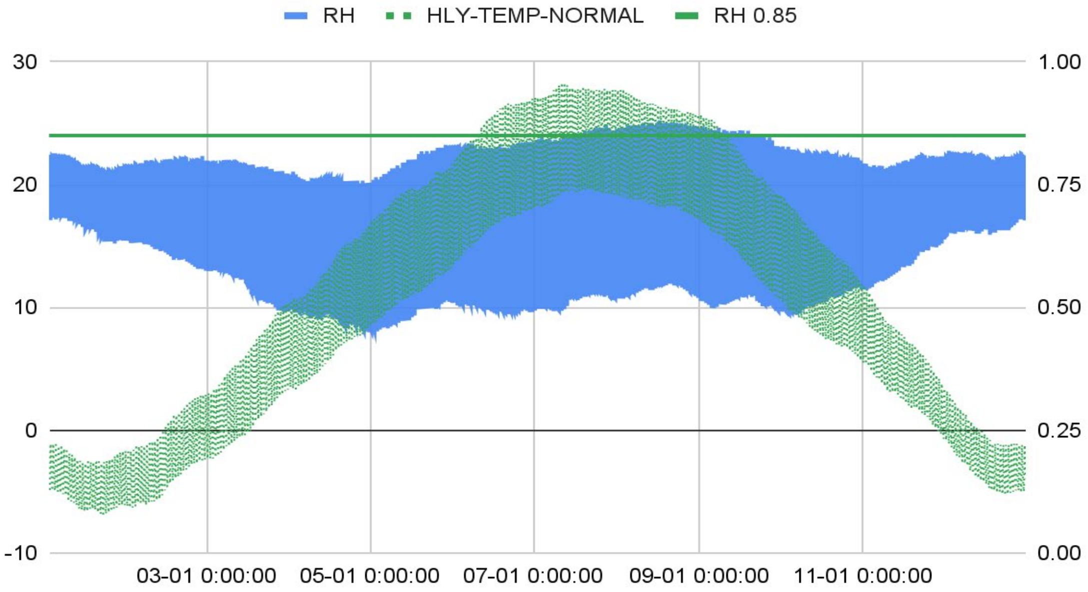


**Figure 10. Graph. Hourly temperatures (right axis) and relative humidity (left axis) for 2010 using NCEI data. Dates below the bottom black line and above the top green line are hours of unflyable weather conditions.**

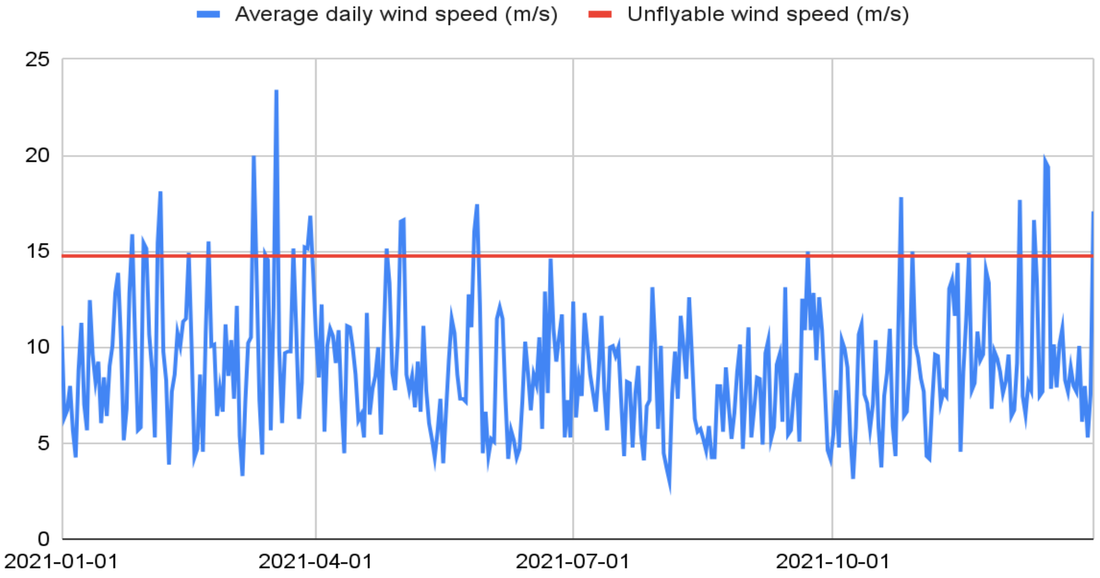


**Figure 11. Graph. Average daily wind speeds according to 2021 Navy weather data. Values below the red line are below the 33 mph (14.75 m/s) wind speed.**

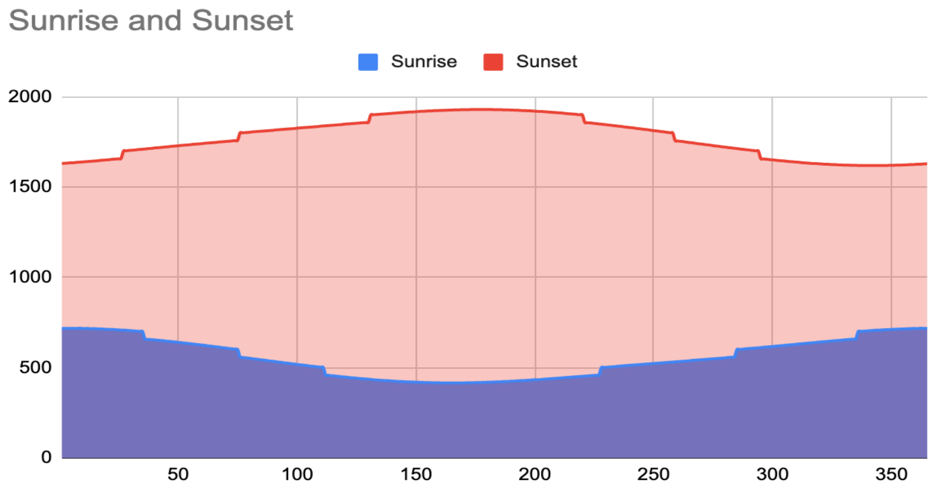


**Figure 12. Graph. Sunrise and sunset times over the course of a year in Chicago, IL (US Navy). Area between the curves indicate operable hours.**

At minimum, the National Bridge Inspection Standards require safety inspections at least every 24 months for bridges longer than 20 ft on public roads (US Department of Transportation, n.d.). The American Society of Civil Engineers reports over 600,000 bridges in the United States, of which nearly 27,000 bridges are in Illinois (American Road and Transportation Builders Association, n.d.). On a national level, because 83% of bridges must be inspected every 24 months, 12% annually, and 5% on a 48-month cycle (US Department of Transportation, n.d.), this results in approximately 328,000 bridges inspected annually, not including privately owned bridges. In Illinois, this translates to around 1,400 bridges inspected annually (26 weekly, on average). With one drone inspecting 100 bridges annually (two weekly), and assuming a bridge inspection can be completed on average in 1–2 days, a UAV with an 800-hour life span would need to be replaced every eight months. This averages to 21 UAVs per year to inspect 1,400 bridges.

## Building Inspections

Only 12 cities in the United States have mandatory facade ordinance laws, including Chicago (Brittingham, 2021). In Chicago, buildings taller than 80 ft must be inspected every 5 years; short form visual inspections must be performed every 2, 4, or 6 years; and critical examination reports written every 4, 8, or 12 years, depending on the nature of the building (Facade Ordinance Inspections, 2019). Assume, on average, that short form visual inspections must be performed every four years and critical examination reports every eight. The city of Chicago has 1,946 buildings taller than 80 ft, so 487 buildings must be superficially examined each year, and 244 of these require a more thorough examination annually. All these inspections can easily be completed by a single UAV, but due to maintenance and repair, a fleet of six should be considered.

Additionally, in an effort to become more energy efficient, building planners and examiners are also inspecting buildings, especially older infrastructure, to optimize for retrofitting (Rakha & Gorodetsky, 2018). Thermography in particular can perform safety assessments and determine optimal placement of energy-efficient technology like solar panels. Tunnel inspections will not constitute a major demand component for overall infrastructure inspections, since Illinois only has five tunnels, and inspection for those would likely not require more than a single UAV.

## LATENT DEMAND

Latent, or unobserved, potential demand is another important aspect, referring to potential users of AAM services who may not be currently performing those trips, either because of unavailable supply or low service levels (Cervero, 2002).

The addition of new transportation modes may change travelers' mode choices and destination decisions. New modes may also generate new trips that would not take place if AAM did not exist, since increased accessibility could lead to a higher probability to start a trip, and trip destinations could change due to the introduction of the new mode and therefore travelers' behaviors. A household may choose to relocate from an urban to a rural location because of the accessibility offered by AAM. Additional examples would be overnight trips becoming day trips due to shorter travel times and the cost-equivalence within the expenses for lodging and transportation. That could lead to more journeys while decreasing the need for lodging, and increased frequency of travel (i.e., long journeys including several activities could be divided into multiple trips). Also, journeys from remote locations for recreation or shopping presently merged into a single journey could be divided into several trips (Moreno et al., 2019). Also, trips that are not initiated due to the inconvenience of available transportation mode options could otherwise be initiated with the existence of a new mode such as AAM. However, these trips cannot be easily quantified due to their unobservability (Clifton, 2017).

According to Moore (2019), Uber Elevate suggests that eVTOLs can provide the highest time savings for long trips, and therefore, a city with greater spread between commute endpoints could present more latent demand for urban flight alternatives to their automobile commutes. Also, cities that have limited public transit and existing transit hubs may find that building vertiport infrastructure actually induces increased clustering of existing travel patterns. Limited public transit is not the case for the Chicago Metropolitan Area, but that could apply for the rural part of the state of Illinois.

## SAFETY CONSIDERATIONS

The following safety analysis captures the relevant safety risks for a multitude of potential AAM operations in Illinois. AAM operations related to the five use cases outlined in this study are considered (described in detail in Table 22 in Appendix A). These operations are first described along with risks specific to each use case. Then, a specific operations risk assessment (SORA) methodology is used to evaluate the relative risk level of operations for both ground and air risks (JARUS, 2019; Kohlman, 2018; Denney et al., 2018). Last, mitigation strategies are proposed in response to the specific risks and risk levels of each operation.

### Description of Risks

In general, aviation safety considers two broad risk categories: ground risk and air risk. Ground risks that arise from AAM services include obstacle and terrain collisions, crashes during take-off and landing, and the risk of an aircraft colliding with people or buildings during aircraft failure. The risk of obstacle collision is especially great near airports or vertiports, where aircraft may be flying at their lowest altitudes along an approach path.

A risk map of the state of Illinois was formulated, based on Causa et al. (2023). This map provides a picture of how different areas of the state could be affected by an accident, and even though this is an aggregate approach, this map gives a good overview of the whole state in terms of potential risks. Five risk categories were identified, and a risk score was calculated for each county, based on the percentage of each category in each county. A heat map was used to present that score conceptually, with a shade between red and blue for each county, corresponding to the aforementioned percentage of each category. The area in square miles of each county was used as a normalizing parameter. The categories considered included critical infrastructure, urban and industrial environments, infrastructure with human presence, infrastructure with low human presence, and environmental terrain. Each category includes different infrastructure or spatial types (based on data from Illinois State Geological Survey, n.d.-,), presented in Figure 13. Table 20 in Appendix A presents each risk category in detail.

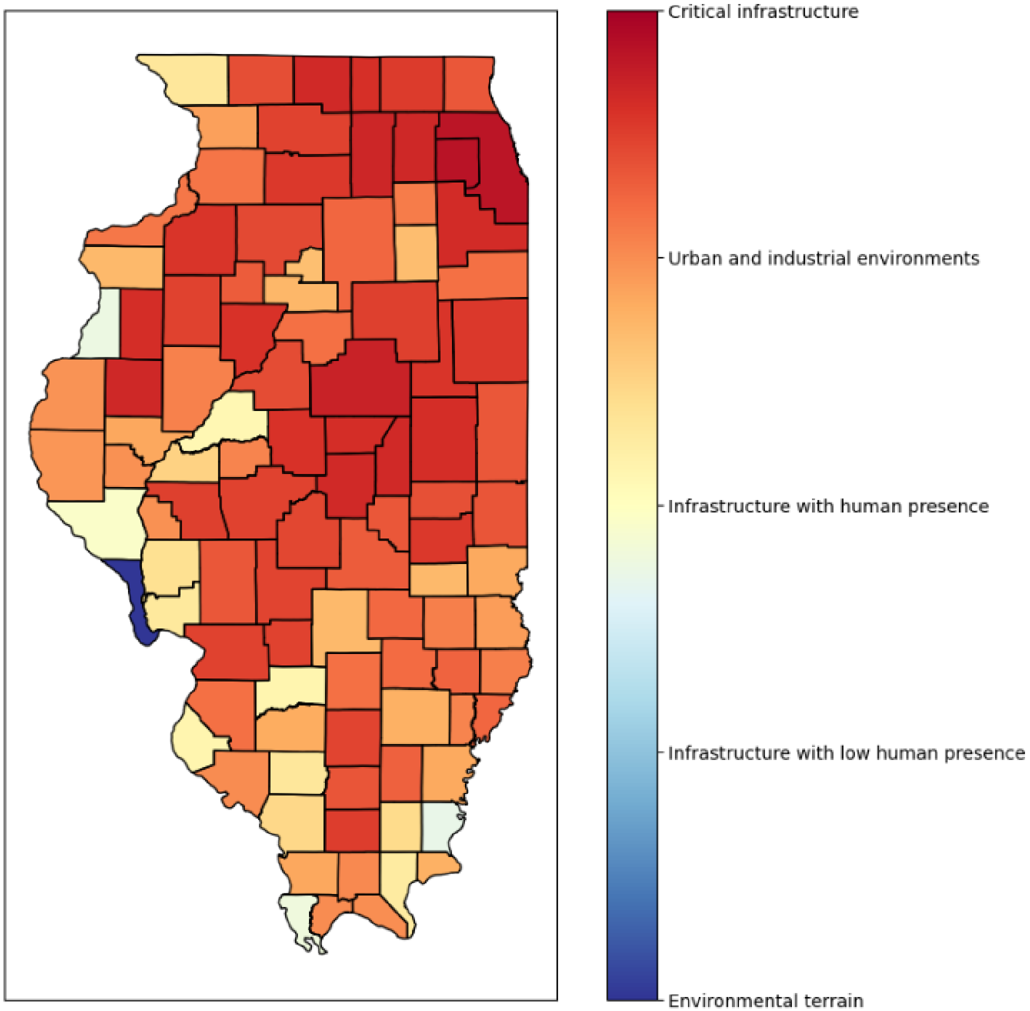


**Figure 13. Graph. Risk map based on infrastructure for the state of Illinois.**

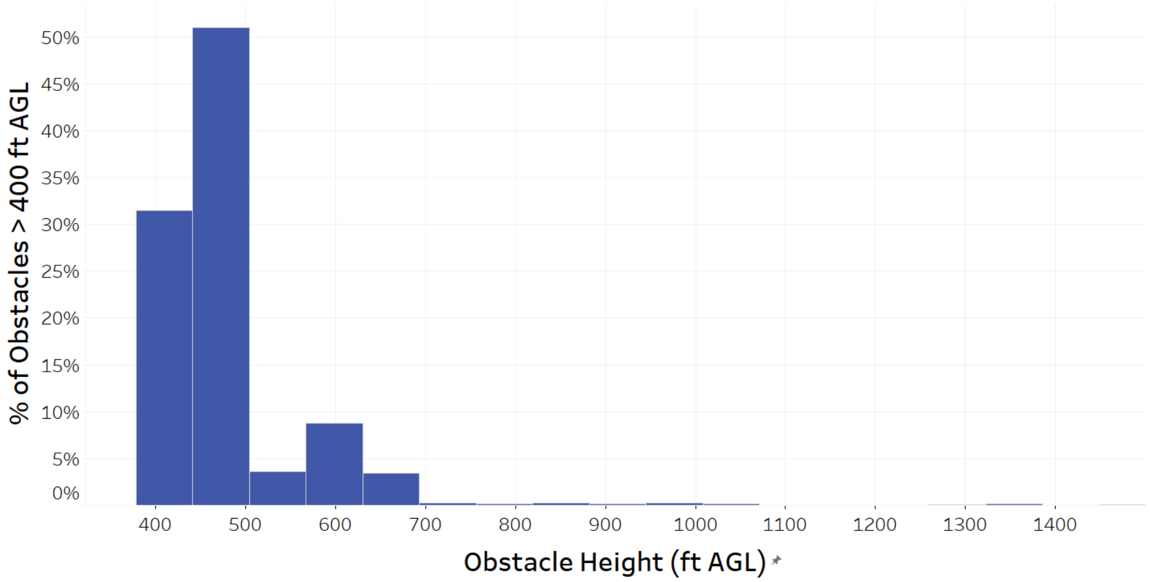


**Figure 14. Chart. Obstacle height distribution.**

The histogram in Figure 14 depicts the height (AGL) of potential obstacles to AAM aircraft, taller than 400 ft in Illinois. The 400 ft demarcation was chosen because it is the altitude above which FAA expects many AAM operations may take place. In total, there are roughly 3,000 such obstacles around the state. As the histogram illustrates, the large majority of such obstacles remain below 600 ft tall. A deeper look at the data reveals that a little more than 80% of these obstacles are windmills, which are generally 600 ft tall or less. Many of the taller obstacles represent buildings, found mainly in the Chicago area.

The locations of obstacles 400 ft or taller in Illinois are shown in Figure 15, with red dots representing individual obstacles. While there is a cluster of tall buildings in the Chicago area, there are numerous other clusters of infrastructure (mainly windmills) scattered throughout central Illinois. Other obstacles can be seen distributed in other regions of the state.

Terrain collisions are another concern for operations close to ground level. Low-visibility conditions such as fog or darkness significantly increase the chances of terrain collision (FAA, 2021b). Windy weather conditions could also affect aircraft, especially during take-off and landing, moving an aircraft off-course or leading to a dangerous trajectory.

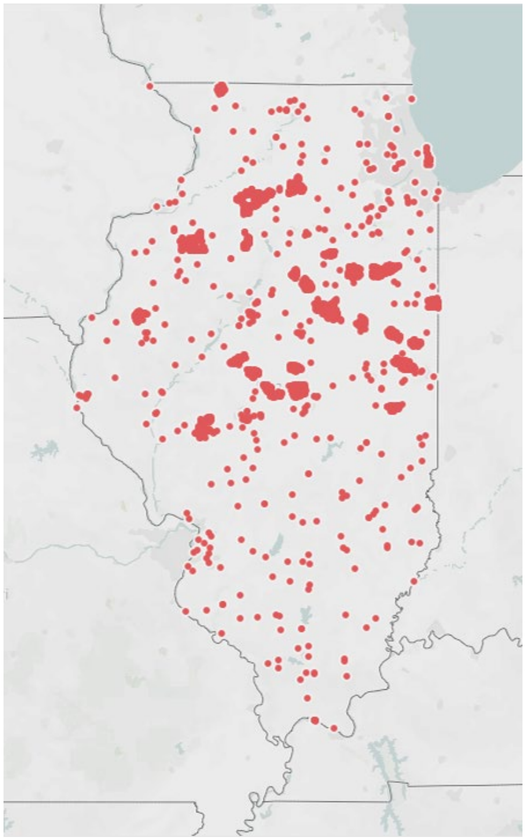


**Figure 15. Graph. Illinois infrastructure with height greater than 400 ft.**

## Specific Operations Risk Assessment and GRC Determination

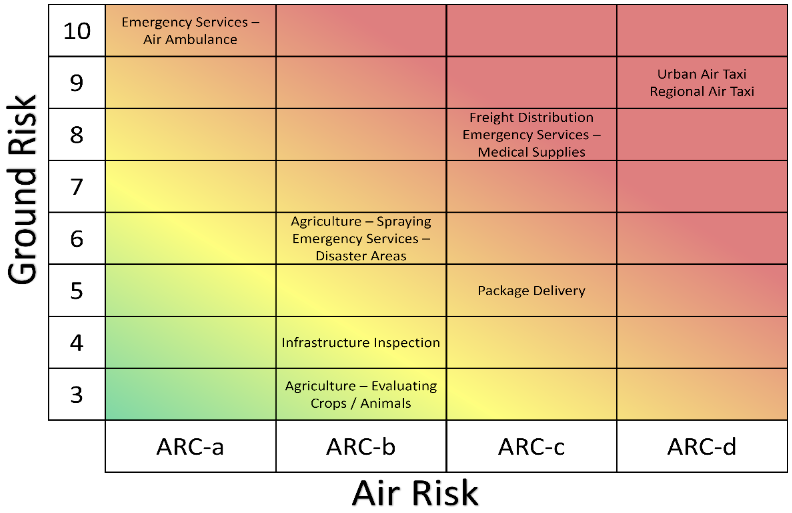
A specific operations risk assessment (SORA) is a method for determining the relative risk level of an AAM operation for both ground and air components. Risk classifications for both the ground and air are established, and the relative level of risk involved in an operation are described. Based upon the relative level of risk, a number of mitigation measures of varying robustness are proposed.

The ground risk class (GRC) determination is a measure of the relative risk that a person is struck by a falling aircraft in the event of a failure. The Initial GRC is determined using the approximate size of the aircraft along with the relative population density of the area of operation. GRC levels are determined for each of the operations outlined above. Several operations could occur with a range of vehicle sizes or in a range of populated areas; in these instances, the estimated level corresponds to the upper end of the risk classification.

The air risk classification (ARC) defines the risk of mid-air collision between two aircraft within a given airspace. The ARC is determined through a combination of altitude, airspace classification, airspace near airports, urban versus rural environments, and any segregation from other traffic in the airspace. ARC-a indicates a low risk probability of mid-air collision. ARC-b, ARC-c, and ARC-d increase in risk of mid-air collision, with ARC-d representing a higher risk probability. Mitigations to air risk include both strategic and tactical deconfliction. Strategic deconfliction may include re-routing or delaying aircraft, and tactical deconfliction may include trajectory-based operations to adjust aircraft trajectories. Table 22 in Appendix A lists the operations considered for air risk and the corresponding determination of air risk class.

## Combined Levels of Risk

A combined consideration of ground and air risk was constructed for each operation, presented in Figure 16. Air risk classifications further to the right indicate a higher risk level, while categories toward the top indicate a larger ground risk. Operations with high risk levels in both the ground and air categories will require mitigation measures to ensure safety, while operations scoring low in each risk category may require fewer or less robust safety measures. The highest levels of risk were seen in air-taxi operations, since large aircraft operate in dense urban areas and near airports with existing and conflicting aviation operations. The lowest relative levels of risk were seen in agriculture and infrastructure inspection.



| | ARC-a | ARC-b | ARC-c | ARC-d |
|---|---|---|---|---|
| 10 | Emergency Services – Air Ambulance | | | |
| 9 | | | | Urban Air Taxi<br>Regional Air Taxi |
| 8 | | | Freight Distribution<br>Emergency Services – Medical Supplies | |
| 7 | | | | |
| 6 | | Agriculture – Spraying<br>Emergency Services – Disaster Areas | | |
| 5 | | | Package Delivery | |
| 4 | | Infrastructure Inspection | | |
| 3 | | Agriculture – Evaluating Crops / Animals | | |

**Figure 16. Graph. Ground and air risk comparisons.**

## Risk Mitigations

There are five broad mitigation categories: strategic, reactive, tactical, adjacent airspace, and operational. Ground risk mitigations may be strategic (keep vehicles away from dense areas with pedestrians and buildings) or reactive (reducing the negative ground impact). Strategic air risk mitigations include re-routing aircraft away from densely populated airspace with a higher risk of collision with other aircraft or obstacles. Tactical air risk mitigations involve the creation of robust systems, procedures, and communications for detecting and resolving aircraft conflicts within the airspace. Adjacent airspace mitigations aim to maintain safety even if a system or aircraft failure causes it to deviate from its trajectory. Operational safety objectives describe procedures that apply to the operator to ensure a high level of reliability and safety both before and after an incident.

Several conflict mitigations could be applied within each category. Table 23 in Appendix A presents in detail the risks and risk levels of each operation as well as appropriate mitigations.

# CHAPTER 3: GEOGRAPHIC AND OPERATING ENVIRONMENT DIVERSITY ACROSS ILLINOIS

This chapter analyzes the geographic and operating environment diversity across the state. Through an examination of urban, suburban, and rural areas, as well as the intricacies of intra-regional and inter-regional transportation, we seek to provide a comprehensive understanding of the diverse operating environments present in Illinois.

## GENERAL OVERVIEW

Illinois has a strong manufacturing and transportation sector that spans multiple counties. Cook County, where Chicago is located, serves as a major economic hub, hosting a diverse range of industries. It houses manufacturing facilities producing machinery, automobiles, chemicals, and food products. The county’s strategic location and robust transportation infrastructure, including rail yards and ports along Lake Michigan, support the movement of goods and materials. Additionally, DuPage County and Will County also have a significant manufacturing presence, with a focus on sectors such as automotive, aerospace, and pharmaceuticals. Chicago’s financial district (The Loop) is home to major financial institutions, including banks, investment firms, and insurance companies. Cook County leads the state in financial and professional services, driving economic growth and employment opportunities. This sector extends beyond Chicago, with strong financial and professional services industries found in counties such as Lake, Kane, and DuPage. These counties benefit from their proximity to the city while providing a suburban and business-friendly environment for companies in the sector.

Illinois is renowned for its agricultural industry, with a significant presence of farms and food processing facilities throughout the state. Counties in Central and Southern Illinois, such as McLean, Sangamon, and Champaign, specialize in agricultural production. Corn, soybeans, livestock, and poultry are prominent in these areas. Food processing companies, including meatpacking plants, grain elevators, and dairy processing facilities, contribute to the agricultural economy and provide employment opportunities in counties like Tazewell, DeKalb, and Macon. A diverse energy sector that encompasses both traditional and renewable resources is also present. Counties in Southern Illinois, particularly Franklin and Saline, have significant coal mining operations. The state is also a leader in wind energy, with wind farms located in counties like Lee, McLean, and DeKalb. These projects generate renewable energy and contribute to the state’s transition toward cleaner energy sources. Additionally, counties such as Cook and Lake are investing in solar energy installations and promoting sustainable practices.

Starting with population, Figure 17 provides insights on the state’s population density. Counties such as Cook, DuPage, Will, and Lake have increased population density, with counties such as McLean, Winnebago, Rock Island (and more), having less and smaller in size densely populated areas. Focusing on the geographic and operating environment diversity in terms of urban, suburban, rural, and intra- and inter-regional areas, a wide range of data and data representations were found and used in order to form a better understanding of the diversity of Illinois.

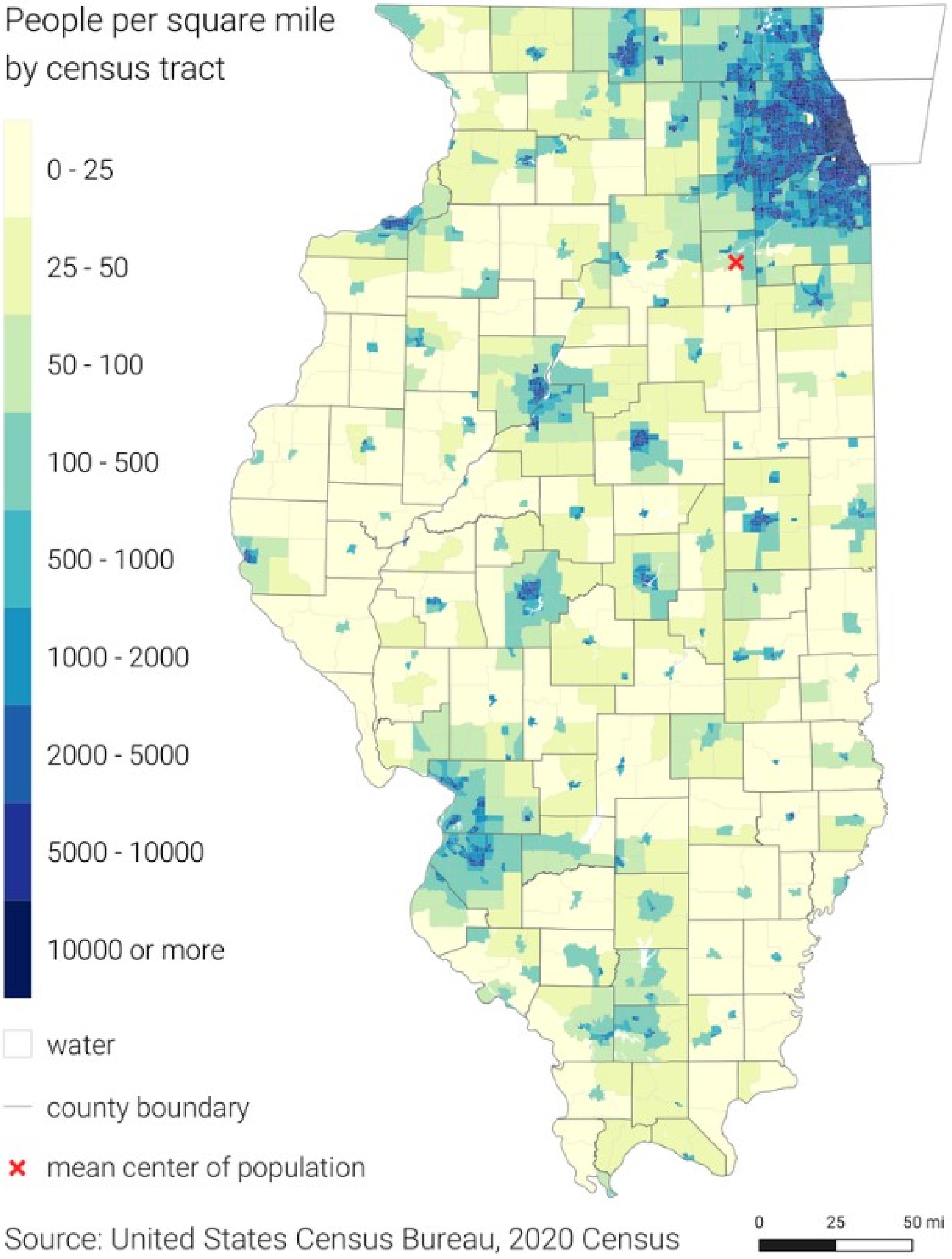


**Figure 17. Graph. Illinois population density.**

***Source: Wikimedia Commons (2020)***

## AGRICULTURAL-RELATED OPERATIONS

Using data provided by the US Department of Agriculture Natural Resources Conservation Service (2017), Illinois' geographic diversity in the realm of agriculture is depicted in Figure 18. Some areas are more prominent than others for agriculture activities, with a big majority of the state of Illinois being a welcoming environment for such activities.

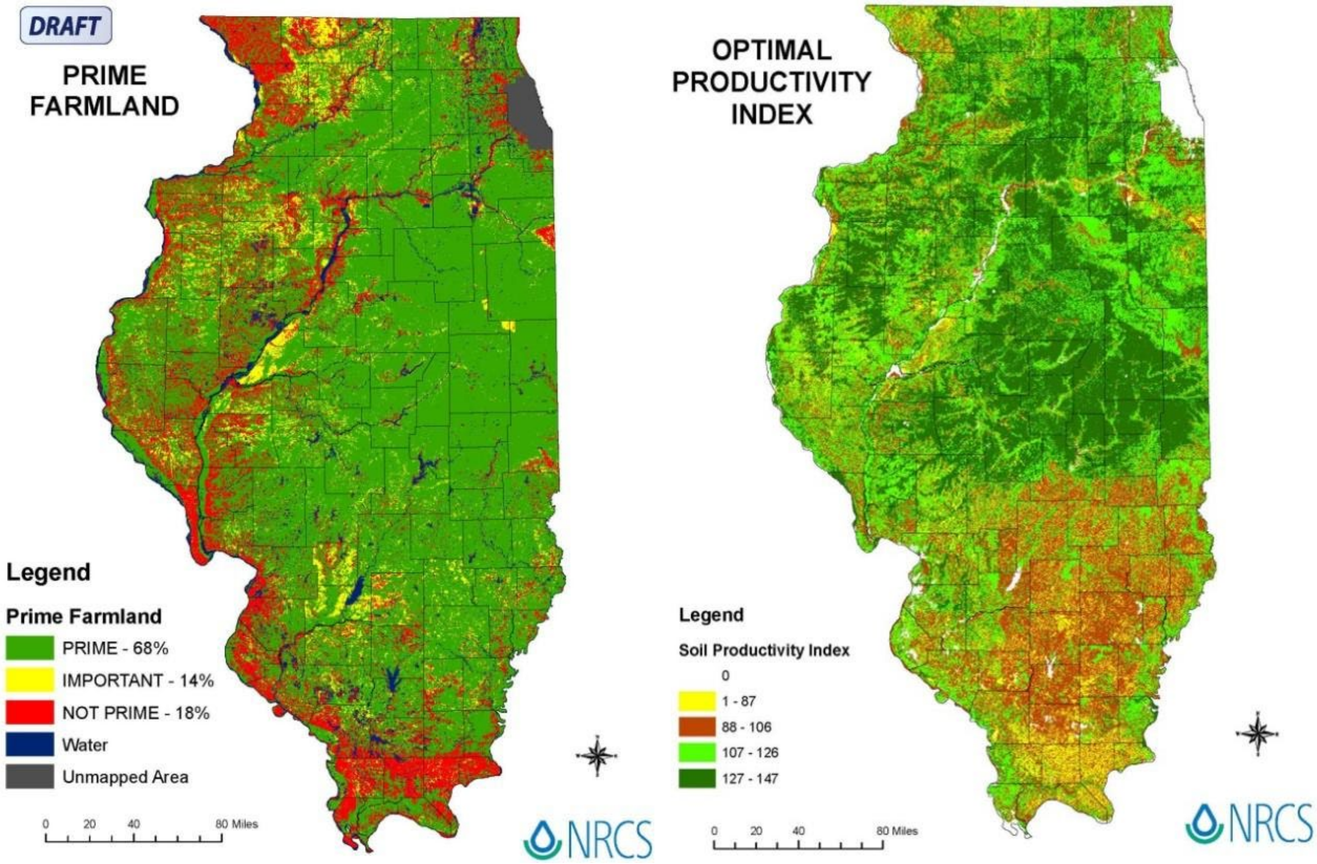


**Figure 18. Graph. Prime farmland and optimal productivity areas in Illinois.**

***Sources: Natural Resources Conservation Service (2017)***

Using data from the US Census Bureau (2021a), Figure 19 presents the number of establishments (left) and the number of employees (right) in the agriculture, hunting, and forestry industry at the county level. A significant portion of the workforce is in central and northwestern Illinois, which aligns with previous figures of farmland locations, a pattern that is also followed for the rest of the areas correlated with agricultural activities. The same pattern, but on a lower scale, can also be observed in terms of agricultural industry establishments. However, Cook County is an exception, where there is a significant number of establishments and employees, even though Cook County is not an agricultural-oriented part of the state. That can be justified by the fact that Cook County is a larger county in terms of population, so it is reasonable to have a certain portion of the agricultural world.

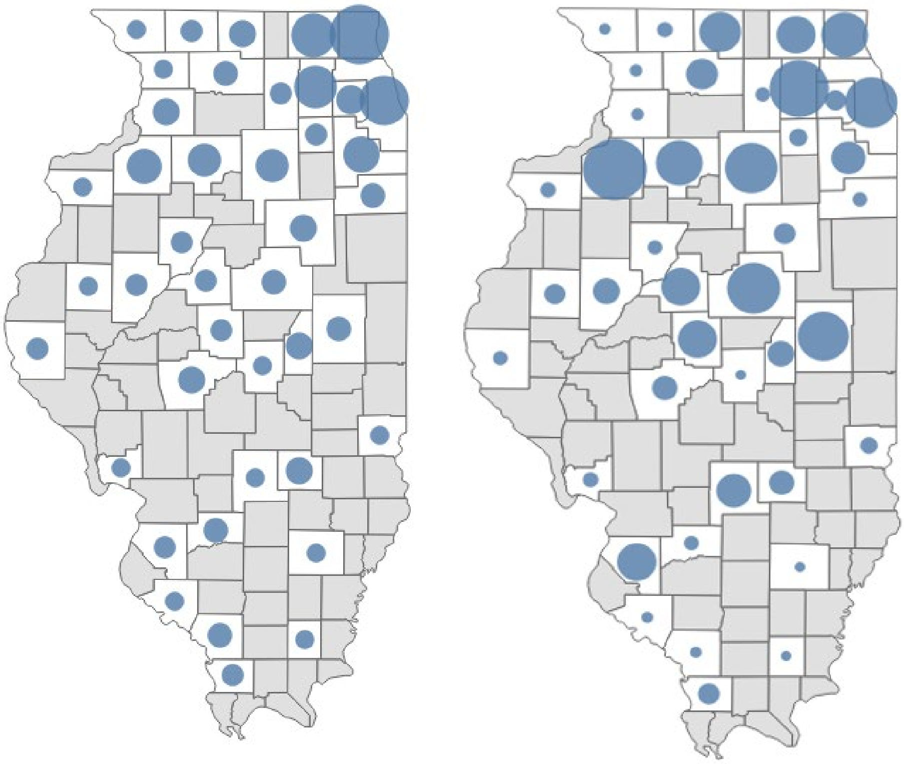


**Figure 19. Graph. Number of establishments (left) and the number of employees (right) in the agriculture, hunting, and forestry industry.**

***Source: US Census Bureau (2021a)***

## GAS, OIL, AND MINING INDUSTRY

With the use of data from Illinois Geospatial Data Clearinghouse (2023) and Statistical Atlas (2018), Figure 20 gives an elaborate picture of which parts of Illinois are more heavily involved in the gas, oil, and mining industry. The left sub-graph of Figure 20 presents oil (with green), gas (with red), and gas storage (with yellow) operations and infrastructure across Illinois, and the core of the industry is in southeastern Illinois. The right sub-graph presents the percentage of the population aged 16 or above employed in the industry, with the data following the same pattern.

Figure 21 demonstrates that a large majority of establishments and employees are in southern and southeastern Illinois. A significant part is located in northwestern counties (e.g., Cook County), which is reasonable considering the population size as well as the fact that Cook County is the most densely populated county (Figure 17). Therefore, it is statistically logical to have people from various industries residing there.

For the manufacturing and construction industries, the majority of economic development and interest can be found in the northeastern corner of Illinois (Cook, DuPage, Will, Lake, Kane, McHenry Counties) with lower volumes regarding the rest of the counties, with Madison, Saint Clair, Peoria, and Tazewell Counties having a higher number of both people and establishments related to manufacturing and construction (Figure 22).

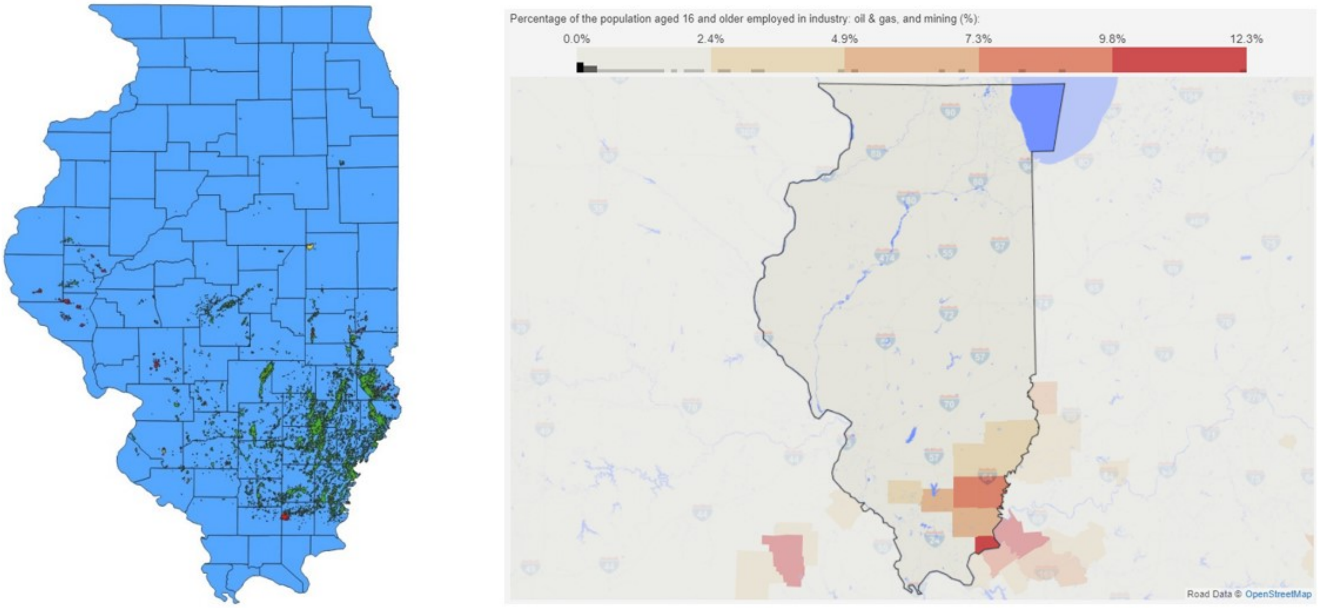


**Figure 20. Graph. Oil, gas, and mining in Illinois.**

***Source: Data for left-side map from Illinois Geospatial Data Clearinghouse (2023) and right-side map from Statistical Atlas (2018)***

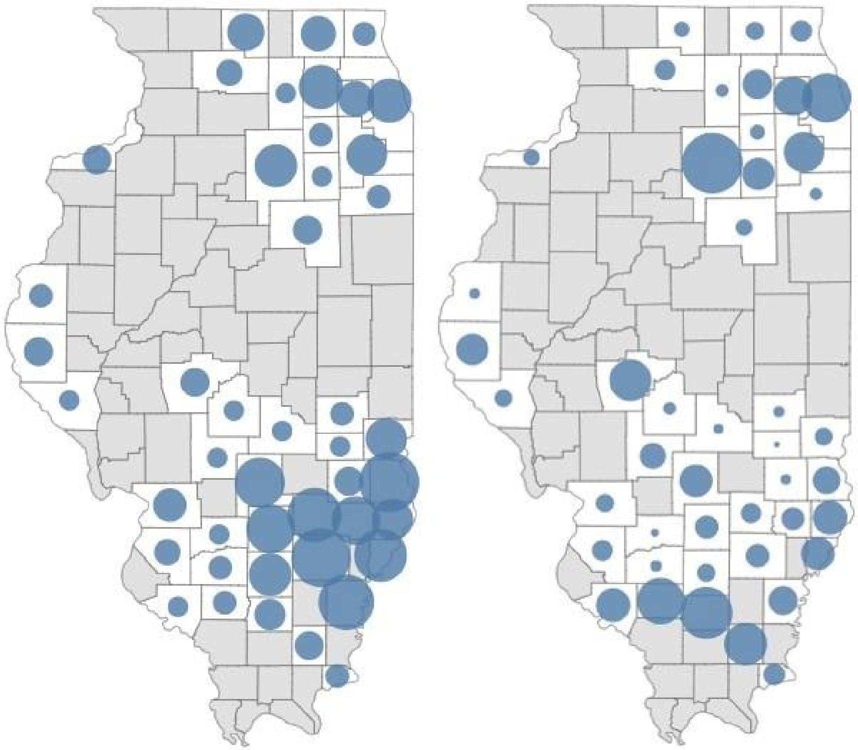


**Figure 21. Graph. Number of establishments (left) and the number of employees (right) in the industry of mining, quarrying, oil, and gas extraction.**

***Source: US Census Bureau (2021a)***

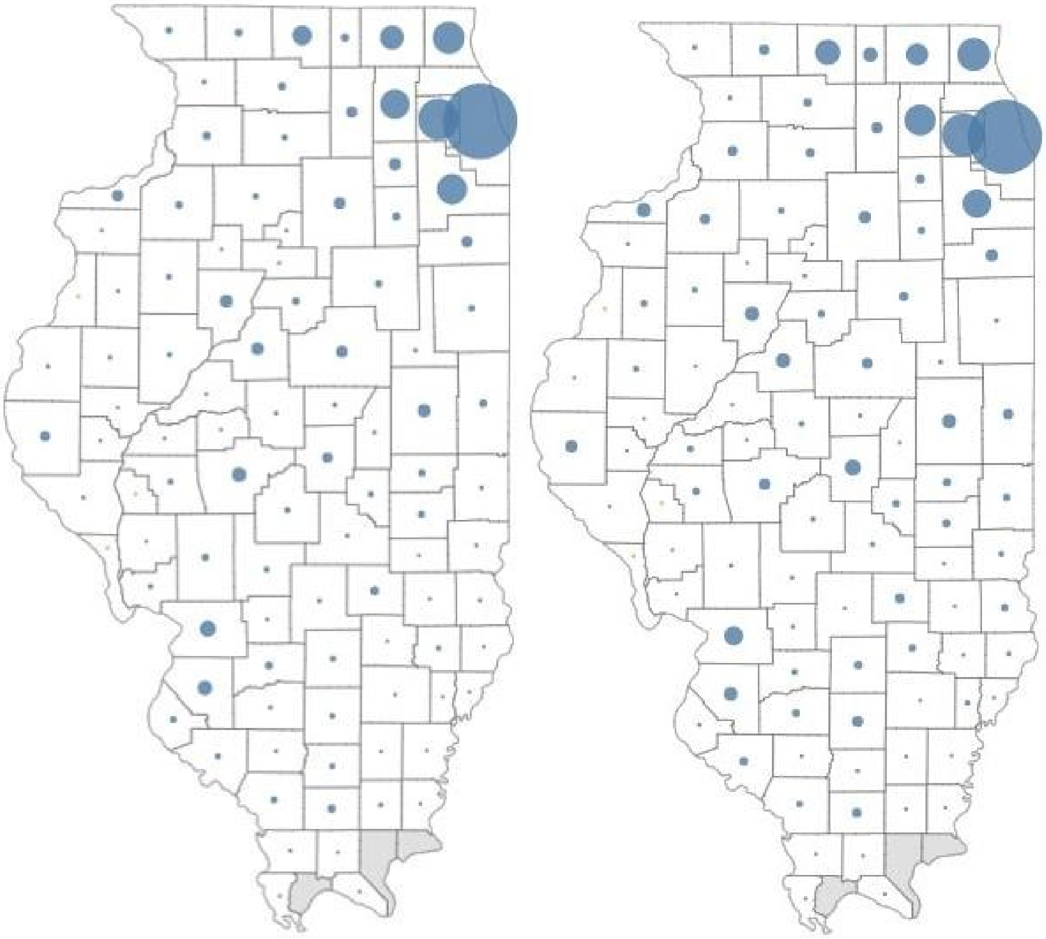


**Figure 22. Graph. Number of establishments (left) and the number of employees (right) in the industry of construction and manufacturing.**

***Source: US Census Bureau (2021a)***

Appendix B presents additional graphical representations (Figures 64–67) with respect to percentage of the population employed in certain industries and median income at the county level, which can provide a wider image of the diversity between different industries in Illinois.

## ECONOMIC GROWTH

In order to get an aggregate picture of the economic growth distribution across Illinois, a heat map of gross domestic product per county normalized by the area of each county was developed (data from [Illinois Geospatial Data Clearinghouse, 2018; Fred Economic Data, 2021]), in 2021 U.S. dollars values), and Figure 23 demonstrates that Cook, DuPage, and Lake Counties have the highest GDP values.

Based on data from the US Census Bureau (2021b), Figure 24 presents the mean travel time for work commuting purposes per county (data between 2017 and 2021). Several counties (Cook, Will, DuPage, Lake, McHenry, Marshall, Greene, Calhoun, Pope) have mean travel times between the range of 29–59.5 minutes, with others having high travel times as well. This could be a helpful source in identifying potential candidate areas for AAM operations as a commuting transportation mode, since the travel time savings of AAM can be significant after a certain threshold of ground travel time, as mentioned in Chapter 2. Additionally, because AAM commuting operations will be of a certain cost (at least during its initial years), combining data regarding travel times and economic growth could give us an even better understanding and forecasting ability of anticipating where and who would be using AAM more in Illinois.

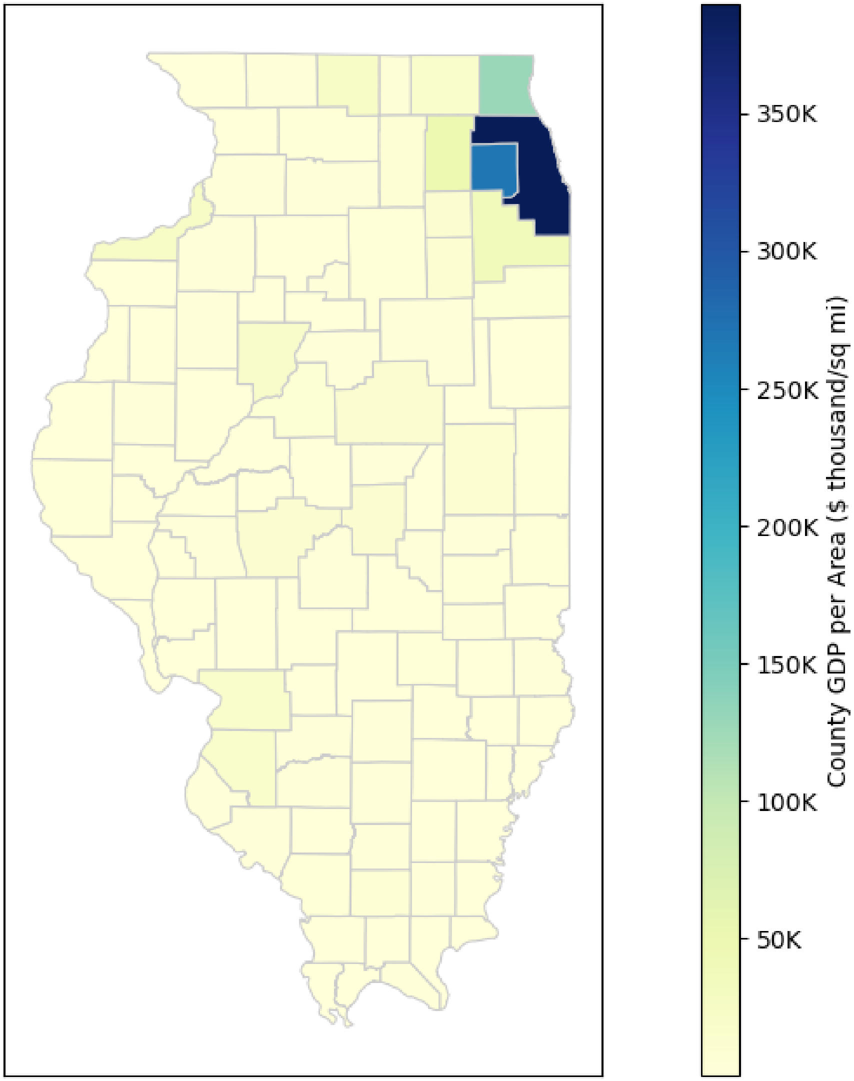


**Figure 23. Graph. Illinois GDP per county.**

***Source: Data from Illinois Geospatial Data Clearinghouse (2018) and Fred Economic Data (2021)***

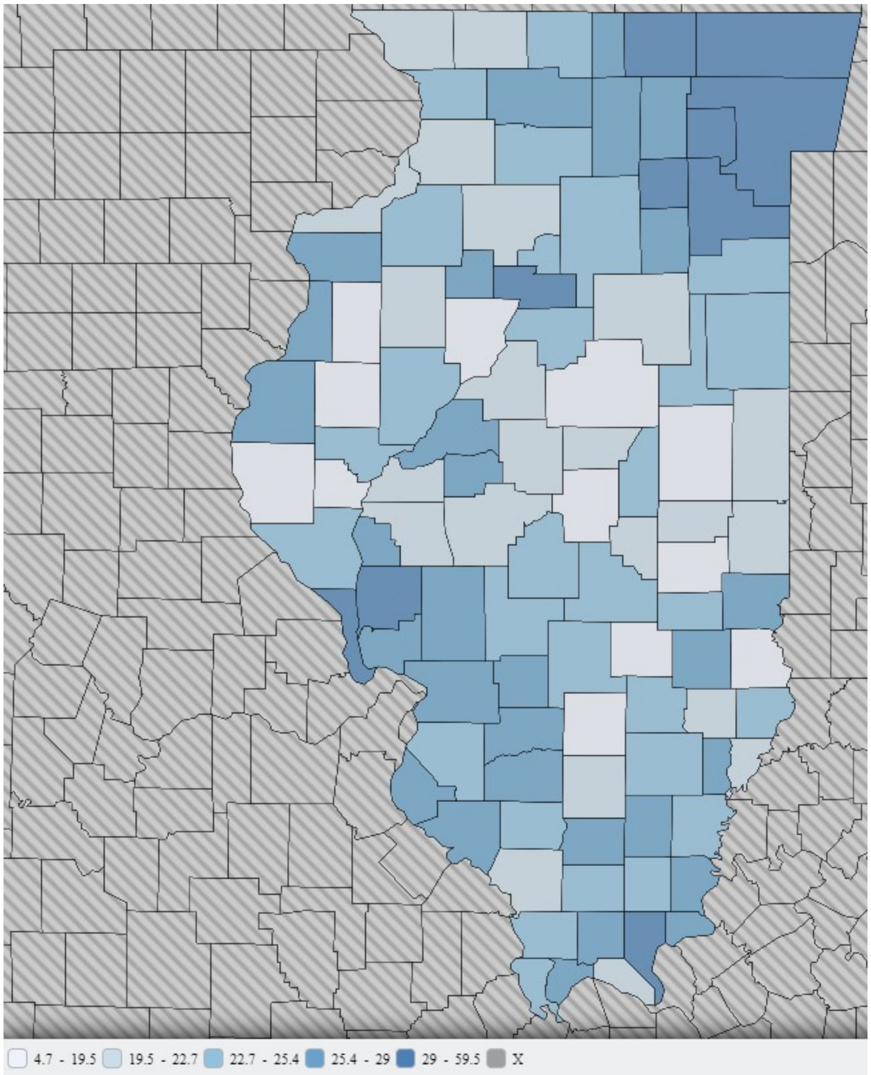


**Figure 24. Graph. Mean travel time to work.**

***Source: US Census Bureau (2021b)***

## ILLINOIS AIRSPACE

Moving into the airspace realm, the different classes of airspace are briefly mentioned per the *Pilot's Handbook of Aeronautical Knowledge*, Chapter 15 (FAA, 2016a):

- Class A Airspace: This is the highest airspace class, extending from 18,000 ft above mean sea level to flight level 600 (FL600). Class A airspace is generally reserved for instrument flight rules operations in controlled airspace.

- Class B Airspace: This airspace surrounds the busiest airports and major terminal areas. It is designed to accommodate high-density traffic and requires specific clearance from air traffic control (ATC) to operate within its boundaries. Class B airspace has multiple layers, with each layer expanding outward from the airport surface.

- Class C Airspace: This class encompasses the airspace around airports with a moderate level of commercial activity. It typically extends from the surface to a specified altitude, and it requires two-way radio communication with ATC and a transponder with altitude reporting for aircraft operating within it.

- Class D Airspace: This class covers the airspace around smaller airports with control towers. It extends from the surface to a specified altitude and requires two-way radio communication with the control tower to operate within its boundaries.

- Class E Airspace: This class includes controlled airspace that is not classified as Class A, B, C, or D. It typically extends from the surface or a designated altitude and accommodates various types of aircraft operations. Class E airspace may exist at various altitudes.

- Class G Airspace: This class is uncontrolled airspace and is often found in rural or sparsely populated areas. It has no specific requirements for communication or clearances but is subject to certain regulations for VFR operations.

In terms of allowable flying altitudes, from FAA (2021a), with the exception of necessary takeoff or landing maneuvers, individuals are prohibited from operating an aircraft at altitudes below the specified thresholds:

- General Areas—The altitude must allow for an emergency landing, should a power unit failure occur, without endangering individuals or property on the ground.

- Congested Areas—When flying over congested areas such as cities, towns, settlements, or open-air gatherings of people, the aircraft must maintain an altitude of 1,000 ft above the highest obstacle within a horizontal radius of 2,000 ft from the aircraft.

- Non-Congested Areas—In areas that are not congested, the aircraft must maintain an altitude of 500 ft above the ground, except when flying over open water or sparsely populated regions. In such cases, the aircraft must not operate within a distance closer than 500 ft to any individual, vessel, vehicle, or structure.

- Helicopters have the option to operate at altitudes below the minimums prescribed for congested or non-congested areas if the operation does not pose a risk to individuals or property on the ground. Additionally, helicopter operators must comply with routes or altitudes specifically designated by the Administrator for helicopter operations.

Various airspace classes can be observed in Figure 25 for different parts of Illinois (zoomed in on northern Illinois since most major airports are located there). Figures 62 and 63 in Appendix B present the state as a whole along with all private and commercial aircraft landing locations. The green and red areas represent altitude limits above and around each facility, not classes of airspace, and they define the various altitudes that aircraft are allowed to fly above these airspace locations. Airspace above major airports (e.g., O’Hare International Airport) is classified as Class B airspace, with airports of lower magnitude like Midway Airport categorized as Class C and Rockford Airport categorized as Class D. The rest of the airspace is classified as Class E, represented with a light purple color, where aircraft and pilots are still inside the controlled airspace realm. There are certain designated areas named “Recreational Flyer Fixed Sites,” which can be found around the perimeter of airspace sections around airports. These recreational sites are classified as Class G airspace, which is uncontrolled. Here, aircraft can navigate for recreational purposes up to 400 ft vertically, and aircraft/pilots are in charge of maintaining safe and smooth operations. To assess and quantify the congested airspace sectors of Illinois, data regarding flight routes and airports were taken from OpenFlights (2018), and by focusing on flight routes only toward and from Illinois airports, Figure 26 depicts the parts of Illinois’ airspace that are highly congested (airports above a certain size are marked in red, while the rest of the black points are landing areas and/or airports of smaller size). The blue trajectories are not individual aircraft trajectories, but, rather, designated flight routes that are followed by aircraft. As expected, the airspace sections around Illinois’ major airports are the most heavily visited by aircraft, with other segments of Illinois’ airspace having lower routes and less congestion. However, note that this is not a complete picture of the congestion levels of Illinois’ skies, since we have not accounted for helicopter, civilian and military aircraft, and UAVs, along with the fact that these are flight routes, not including the number of flights corresponding to them daily.

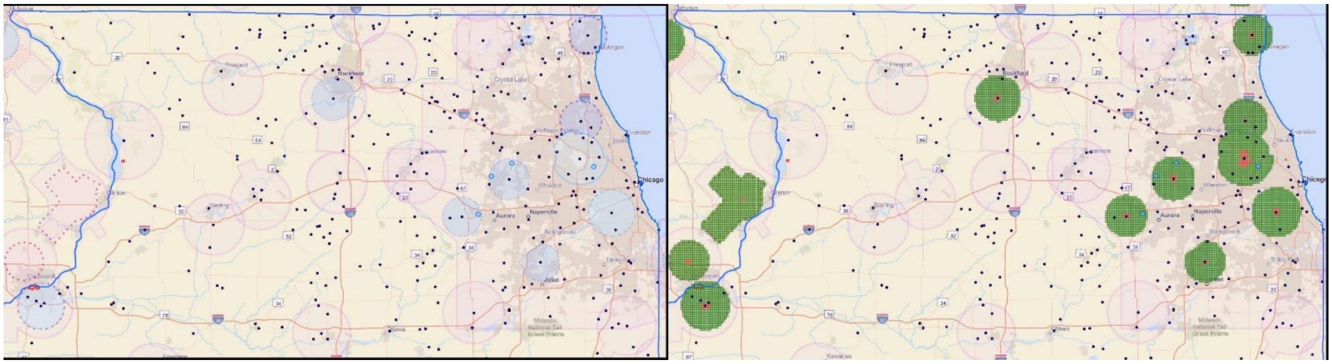


**Figure 25. Graph. Airspace classes across Illinois.**

***Source: Federal Aviation Administration (2020c)***

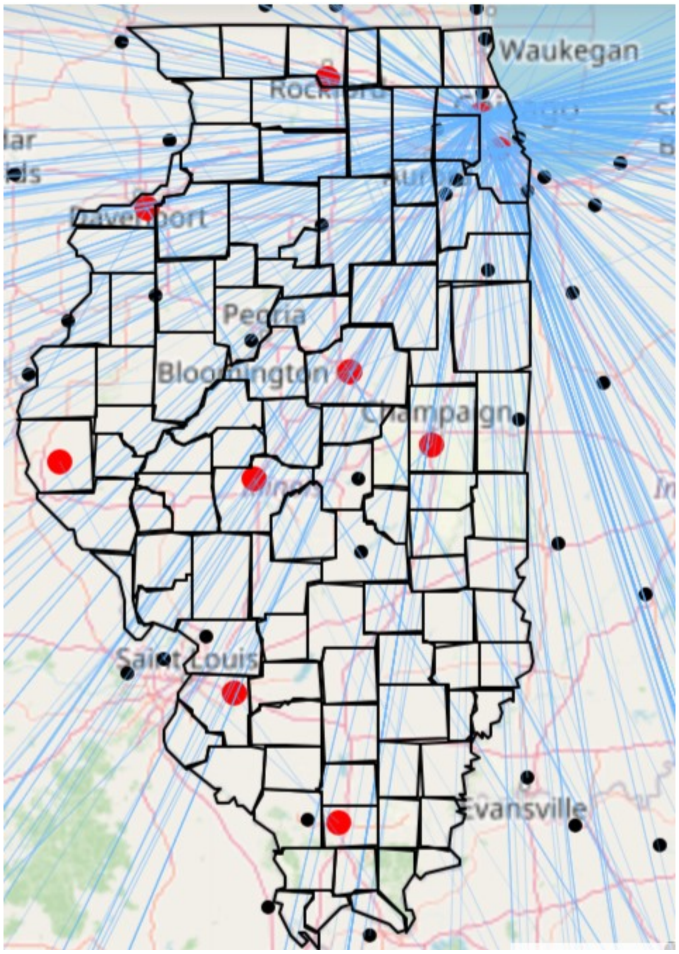


**Figure 26. Graph. Commercial aviation routes in Illinois.**

***Source: Data from OpenFlights (2018)***

Regarding existing infrastructure, Illinois has 12 primary, 10 reliever, and 67 general aviation airports, (Illinois Map, 2017) (their specific locations are in Figure 63, Appendix B) along with 243 heliports (AirNav, LLC., n.d.), from which a certain portion could be utilized by AAM aircraft.

# CHAPTER 4: POTENTIAL INFLUENCE OF AAM ON THE OVERALL ILLINOIS TRANSPORTATION SYSTEM

The introduction of AAM constitutes a transformative juncture in the realm of transportation, engendering multifaceted impacts on both ground and aviation transportation systems. AAM, encompassing innovative modes like UAM services, presents a paradigm shift in urban mobility by introducing aerial alternatives to conventional ground transportation. The integration of ground and aerial modes at the urban level entails a complex interplay of factors, shaping travel behavior, infrastructure utilization, and regulatory dynamics within ground and aviation systems alike. This chapter discusses the ramifications arising from the integration of AAM on both ground and air transportation systems.

## GROUND TRANSPORTATION SYSTEM

### General Overview

This section examines the potential impacts that AAM may exert on ground transportation systems, encompassing factors such as travel behavior, infrastructure development, urban planning, and regulatory frameworks. These include:

- Traffic reduction and decongestion: AAM can potentially alleviate traffic congestion in urban areas by offering an alternative mode of transportation that bypasses surface-level traffic. This could lead to reduced vehicular traffic, improved traffic flow, and a decrease in travel time for road users.

- Modal shift and integration: AAM may encourage a modal shift, where commuters opt for air travel over traditional ground transportation for shorter distances. This shift could reduce the demand on surface transportation systems and lead to a more integrated and efficient multimodal transportation network.

- Relief for high-density routes: AAM can provide an additional option for transportation on high-density routes, especially during peak hours. This could lead to the redistribution of passenger load from crowded roadways to the air, helping to ease strain on surface transportation systems.

- Last-mile connectivity for long-distance air travel: AAM could serve as a solution for last-mile connectivity, connecting transportation hubs and final destinations. This may reduce the need for extensive road/rail infrastructure and improve accessibility in underserved or overcongested areas.

- Emergency and rescue services: AAM could enhance emergency response and rescue services by providing rapid and direct aerial access to accident or disaster sites, leading to quicker response times and more efficient disaster management.

- Urban planning and land use: The integration of AAM into urban planning could influence land use patterns and urban development. It may lead to the creation of aerial landing infrastructure within city centers, affecting the design of transportation hubs and urban layouts.
- Environmental impact: The adoption of AAM may reduce carbon emissions from ground vehicles, especially if electric or low-emission aircraft are used. This could contribute to improved air quality and less pollution in densely populated areas.
- Congestion management strategies: State transportation authorities may need to develop new strategies and regulations to manage potential congestion at aerial landing sites and heliports. This could include coordinating flight schedules, managing air traffic, and ensuring safe coexistence with ground transportation.
- Infrastructure investment: The integration of AAM may necessitate investment in new infrastructure, such as vertiports and aerial corridors. Decisions regarding infrastructure development and investment will likely influence transportation planning and funding priorities.
- Regulatory framework: The introduction of AAM will require the establishment of comprehensive regulations and guidelines to ensure safe and efficient operation. These regulations may impact the interaction between aerial and surface transportation systems.
- Equity and accessibility: Considerations of equity and accessibility need to be addressed to ensure that new transportation options benefit all members of society, regardless of socioeconomic status.
- Transportation demand management: AAM could become a part of transportation demand management strategies, offering an alternative mode that reduces the demand on surface transportation during peak travel times.

## Conceptual Framework Development

To navigate effectively the transformative shift that AAM will bring to existing networks and systems, this section introduces a conceptual framework to facilitate a systematic analysis of the short- and long-term effects of AAM on various dimensions of travel behavior and demand as well as broader urban dynamics. The framework considers three distinct categories—first-order impacts, second-order impacts, and third-order implications.

### First-order Impacts

- Travel time efficiency
    - Reduction in travel time due to direct air routes and bypassing ground congestion
    - Increased accessibility to remote or congested areas

- Modal shift and choice
    - Potential shift from ground transportation to AAM for shorter journeys
    - Expanded modal choices for travelers, influencing travel mode preferences
- Traffic decongestion
    - Reduction of surface traffic congestion through aerial routes
    - Reduced ground traffic delays and gridlock
- Travel costs and value of time
    - Changes in travel costs due to AAM usage
    - Impact on the perceived value of travel time savings for different user groups
- Vehicle miles traveled
    - Potential reduction in ground vehicle miles traveled with increased AAM adoption
    - Influence on overall road usage and congestion
- Impact on other modes and infrastructure
    - Mitigation of road congestion and wear-and-tear due to reduced ground vehicle demand
    - Potential influence on public transport usage patterns and infrastructure

**Second-order Impacts**

- Land use and urban development
    - Potential alteration of urban spatial patterns due to new aerial corridors
    - Influence on land use planning around vertiports and AAM infrastructure
- Economic and business growth
    - Encouragement of economic growth in industries associated with AAM technology and services
    - Potential for new business models and services around AAM operations
- Environmental considerations
    - Impacts on air quality due to increased aerial activity

  - Potential shifts in greenhouse gas (GHG) emissions patterns from ground vehicles to aircraft
- Negative environmental aspects
  - Assessment of noise, visual annoyance, emissions, and safety concerns associated with AAM
  - Implications for public health and energy consumption in urban areas

**Third-order Implications**

- Equity and accessibility
  - Potential unequal access to AAM services based on location and socioeconomic factors
  - Disparities in affordability and accessibility for various segments of the population
- Infrastructure development
  - Need for specialized infrastructure, such as vertiports and charging stations, impacting urban planning and investment decisions
  - Interplay between existing ground infrastructure and newly developed AAM infrastructure
- Regulatory and safety frameworks
  - Evolution of regulations governing AAM operations, airspace management, and safety standards
  - Integration of AAM with existing air traffic control systems and safety protocols
- Public acceptance and behavior change
  - Evolution of public perceptions and attitudes toward AAM, impacting its adoption and societal integration
  - Potential changes in travel behavior patterns, influenced by the availability and convenience of AAM services
- Activity rescheduling and urban accessibility
  - Potential for changes in daily activity scheduling due to enhanced travel options
  - Altered accessibility to different parts of the urban area through AAM connections
- Urban sprawl

    - Influence on urban sprawl patterns as AAM provides access to previously less accessible areas
    - Consideration of land development in response to increased accessibility

### First-order Impacts

First-order impacts pertain to the immediate consequences of integrating AAM into existing ground transportation systems. These impacts directly influence travel behavior and demand, shaping the dynamics of urban mobility. Travel time efficiency stands as a pivotal consideration, addressing the potential reduction in travel time due to direct air routes, particularly in congested urban areas. Modal shift and choice examine how the introduction of AAM might influence travelers' decisions to shift from traditional ground transportation modes for shorter journeys. Traffic decongestion examines the potential relief from road congestion through the utilization of aerial routes, leading to potential reductions in ground traffic delays. Additionally, this category considers travel costs and the value of time, investigating alterations in travel costs and their influence on the perceived value of time savings for different user segments. The effects of AAM on vehicle miles traveled and its impact on other modes of transportation are also examined, analyzing potential changes in overall road usage patterns.

### Second-order Impacts

Second-order impacts extend beyond immediate travel changes, influencing urban development, economic growth, and environmental considerations. Key elements in this category include land use and urban development, addressing potential shifts in spatial patterns due to newly established aerial corridors and vertiports. Economic and business growth explores how AAM might stimulate economic opportunities, fostering new industries and business models. Environmental considerations analyze the ecological implications of AAM, evaluating its effects on air quality, noise, emissions, and public health. Furthermore, this category encompasses negative environmental aspects, scrutinizing potential drawbacks such as noise pollution, visual annoyance, and energy consumption associated with AAM operations.

### Third-order Implications

Third-order implications encompass the systemic and structural changes that arise from the integration of AAM into existing transportation systems. These implications extend to regulatory frameworks, equity considerations, and public acceptance. Key elements within this category include equity and accessibility, examining how AAM might impact equitable access to transportation services and potential disparities across different socioeconomic groups and geographic areas. Infrastructure development assesses the need for specialized infrastructure, such as vertiports, and their impact on urban planning and investment decisions. Regulatory and safety frameworks address the evolving regulations and safety standards necessary for the seamless integration of AAM operations with existing air traffic control systems. Moreover, this category explores public acceptance and behavior change, considering how AAM might shape societal attitudes, behaviors, and preferences toward transportation. Activity rescheduling and urban accessibility examine the potential for changes in daily routines and accessibility to different urban areas. Last, urban sprawl explores the interplay between AAM and urban development, assessing how AAM could influence urban and regional patterns.

## AAM and Ground Congestion Relation

Several studies have suggested that the introduction of AAM and UAM is going to help mitigate traffic congestion (Kellermann et al., 2020; Biehle, 2022; Neto & Baum, 2019; Park, 2021; Rajendran & Srinivas, 2020). AAM and UAM services can potentially lead to a decrease in congestion and emissions levels, but also to an increase in some instances, depending on how aircraft are used (e.g., traveling without passengers [deadheading], single passenger use, pooled use, length of trips, etc.). Latent demand is another aspect increasing the unpredictability of forecasts regarding the impact of removing a certain number of ground trips.

Results from a simulation study (Jiang et al., 2023) showed that UAM will reduce congestion in certain instances, while at the same time, it will create traffic on different sections of the network due to a number of parameters (such as access/egress trips to/from vertiports). In a similar study, stated preference survey data were used in a simulation method to evaluate a hypothetical UAM demand and how the network would react, considering the Upper Bavaria Area in Germany (Pukhova et al., 2021). The total vehicle kilometers travelled (VKT) were calculated for two scenarios, with and without (base case) a UAM service, with the consideration that automobile drivers, private autonomous vehicles (PAVs), and shared autonomous vehicles (SAVs) were contributing to ground traffic. The scenario with UAM available as a mode generated 0.3% more vehicle kilometers than the base scenario (corresponding to 140,000 VKT more). Even though the net impact on VKT is relatively small, UAM did not significantly reduce ground miles travelled nor auto use, and, therefore, it did not reduce prospective congestion. Figure 27 presents the mode shifting and changes from the introduction of the UAM service in the network.

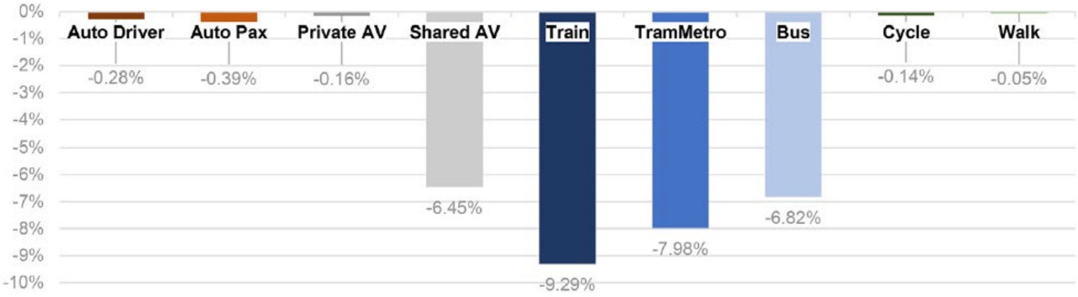


**Figure 27. Graph. Relative change in non-UAM modes.**

***Source: Pukhova et al. (2021)***

Opinions and estimates on both spectrums exist regarding the impact that AAM can have on ground traffic operations, with the majority of these opinions/estimations being based solely on forecasts due to the absence of actual data. Additionally, the difference in the structure and operations of different transportation networks increases the complexity and the uncertainty of estimates.

## Impacts Quantification Analysis

Leveraging an estimated mode choice model that incorporates UAM services as a distinctive mode, an analysis was conducted as part of this study to explore the potential shares of various transportation modes. A simulation approach was followed, focusing on the Chicago Metropolitan area, to forecast mode choice behavior with and without the integration of UAM services. Different simulation software was used: a transit assignment tool, NU-TRANS (Verbas et al., 2015), considers CTA and Metra services in the Chicago area, and a dynamic traffic network assignment tool, DYNASMART-P, regards private vehicle cost and time data for a given trip (Mahmassani, 1998). That data was used in a mode choice model, with parameters estimated based on CMAP's On To 2050 regional modeling plan (CMAP, 2018). The available modes considered are walking, personal vehicle, transit and walk combined (TRW), and park-n-ride (PNR), corresponding to the use of a car to the station, and from there use the transit mode of choice. Based on the aforementioned data and choice model, the mode shares can be estimated as shown in Figure 28.

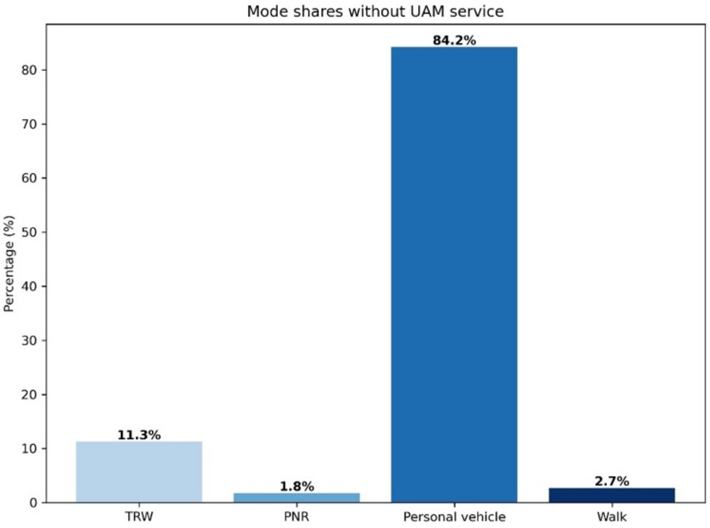
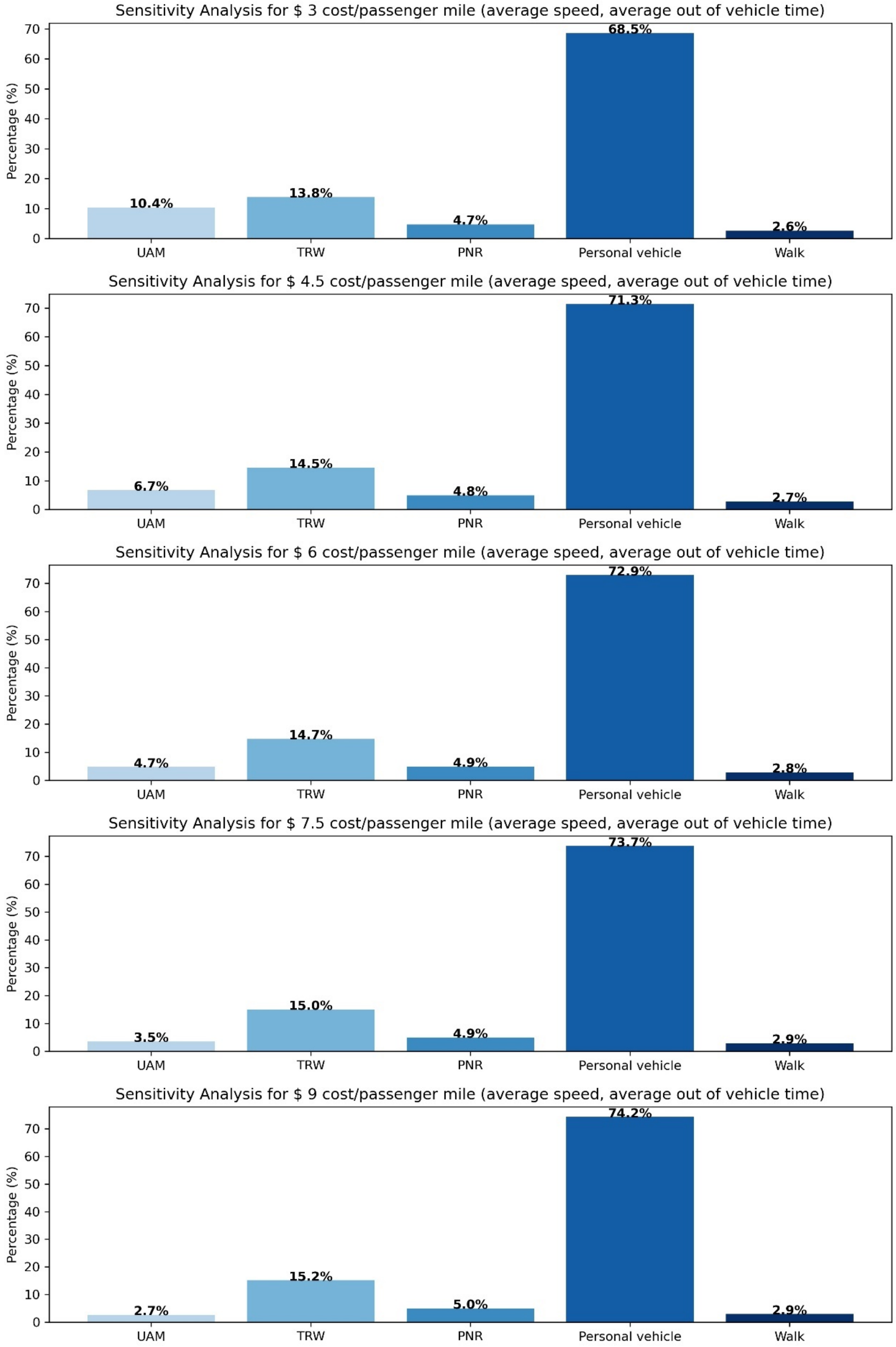


**Figure 28. Chart. Mode shares without a UAM service.**

To add a hypothetical UAM service, the incremental logit principle was followed, and by assuming that UAM is comparable with PNR and personal vehicle, among the available modes, their utility functions were adjusted in order to create one for UAM. In terms of UAM data, the calculation of trip distance was done by using Vincenty's formulae, since the origin and destination coordinates are known. Based on the distance and different aircraft speeds assumed, the travel times for each trip were calculated, with a congestion factor accounted in the calculations. Regarding travel times (through different aircraft values), cost, and out of vehicle times (waiting, boarding, and alighting times), a sensitivity analysis was done, with optimistic, pessimistic, and middle-case values. For each value investigated, the remaining two were assumed to be in a middle/average case. As seen in Figures 29, 30, and 31, the simulated population is more sensitive in terms of cost, with significant reductions in the UAM service share as the cost per mile increases, with out of vehicle and travel time following. Notable was the fact that changes in aircraft speeds, and therefore in travel times, created the smallest changes.

Since increased sensitivity was seen in the case of cost per mile, an even more pessimistic case was considered. The cost per mile (adjusted to 2021 U.S. dollar values) was assumed equal to $4.73 (based on the $6.5\ \$/mile$ from Goyal et al. [2018]), and an approximate cost of $0.49 - 2.1\ \$/mile$ [Holden et al., 2016]), with an additional base cost value of $20 assumed, based on Rimjha and Trani (2021), but rather making a more pessimistic estimation. The mode shares from Figure 32 verify that cost is indeed a catalyst parameter on the share that UAM services can take.


Sensitivity Analysis for $ 3 cost/passenger mile (average speed, average out of vehicle time)

Sensitivity Analysis for $ 4.5 cost/passenger mile (average speed, average out of vehicle time)

Sensitivity Analysis for $ 6 cost/passenger mile (average speed, average out of vehicle time)

Sensitivity Analysis for $ 7.5 cost/passenger mile (average speed, average out of vehicle time)

Sensitivity Analysis for $ 9 cost/passenger mile (average speed, average out of vehicle time)

**Figure 29. Chart. Sensitivity analysis for different cost per/passenger mile values.**

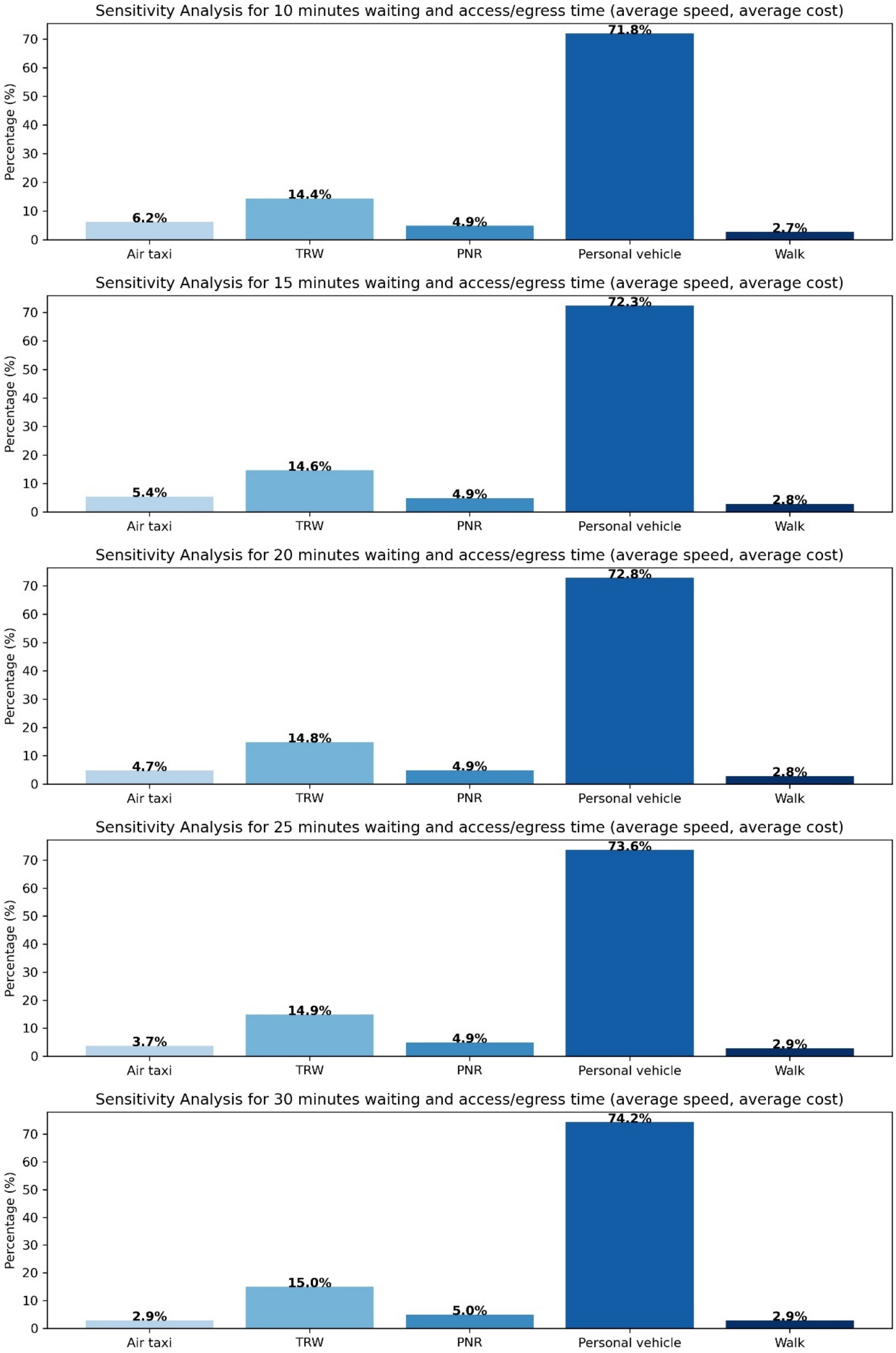


**Figure 30. Chart. Sensitivity analysis for different out of vehicle travel time values.**

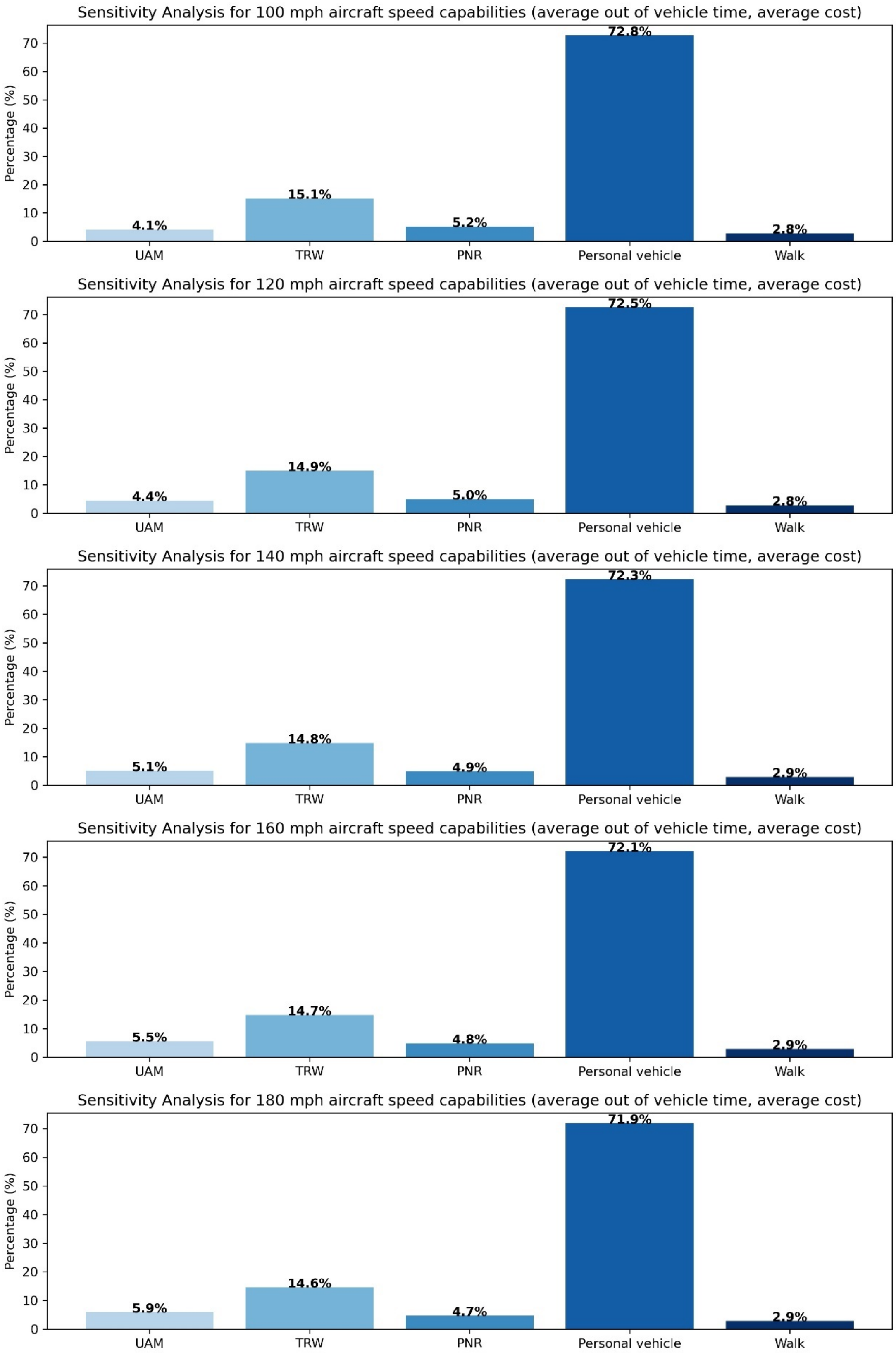


**Figure 31. Chart. Sensitivity analysis for different aircraft speed values.**

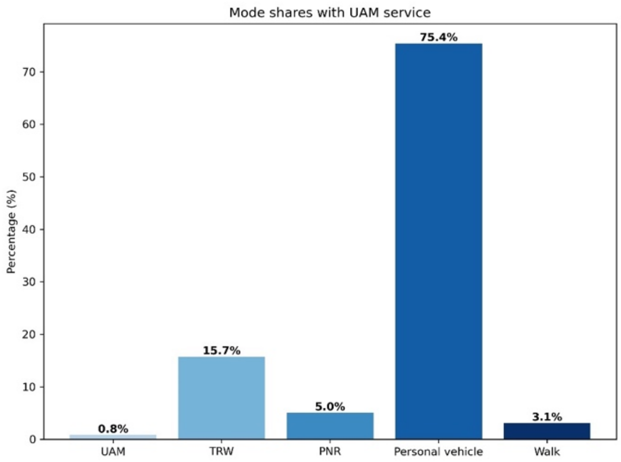


**Figure 32. Chart. Mode shares of a pessimistic UAM scenario.**

Additionally, AAM services and the travel time savings offered could lead to a shift from everyday physical presence in a particular workplace to hybrid and/or remote work, since people would have the opportunity to save their everyday commute time and invest some of these savings on faster access to their workplace when they need to. Therefore, an estimation of the percentage of jobs amenable to remote work within the state of Illinois was done to have a better understanding of savings in travel time and potential congestion averted. Occupational Employment and Wage Statistics survey data (US Bureau of Labor Statistics, 2022) was used to classify each occupation type as able or unable to be done remotely, based on a similar approach by Dingel and Neiman (2020). This classification is an upper bound on what might be feasible and greatly exceeds the share of jobs that have been performed entirely at home in recent years. It was found that 38% of all Illinois professions have the potential of hybrid or entirely remote working environments, with Table 24 in Appendix A presenting each occupation category. Assume that 80% of the 2,237,512 employees use ground transportation to access their workplace, with an average one-way distance of 18 miles (CMAP, n.d.), and that 77% of work trips are being done via personal vehicle (the rest accounts for public transit, walking, biking, etc.) (Active Transportation Alliance, 2020). We could save 44,619,066 VMT per day and 12,900,957,189 annual work-related VMT if the subset of employees using personal vehicles were to shift to fully remote work. This, however, is a strong assumption, so, assuming that three days shift to remote from a five-working week, we have 6,559,002,702 annual VMT saved, accounting roughly to 6.31% of the total annual 103.97 billion VMT in Illinois (Batty, 2021). However, the authors did not assume that the aforementioned amount of saved VMT would directly lead to reduced congestion, since there are various other parameters such as unobserved trips that could be generated in such a case (latent demand), region and network peculiarities, and so on.

## AVIATION TRANSPORTATION SYSTEM

### General Synopsis

The introduction of AAM will potentially impact airspace management and capacity. These new modes of transportation will add a layer of complexity to existing air traffic management systems. As aerial vehicles operate at lower altitudes and closer to populated areas, airspace structures and routing protocols may need to be reevaluated to ensure safe and efficient integration. Moreover, the increased volume of aerial traffic may require the development of new procedures for managing airspace congestion and avoiding conflicts with conventional aircraft. Additionally, such operations could potentially pose challenges to traditional air traffic control systems. The integration of unmanned aircraft, autonomous aircraft, eVTOLs, etc. will require the development of new communication and surveillance technologies. ATC protocols will need to be adapted to accommodate varying speeds, altitudes, and operational characteristics of AAM and UAM vehicles. Infrastructure requirements are an additional concern, as existing airports and heliports may be in need of modification or expansion to accommodate the infrastructure needed for takeoff, landing, and maintenance of aircraft. A summary of the identified potential impacts is presented below:

- Air traffic management and congestion
    - Increased air traffic from AAM and UAM operations may strain existing air traffic management systems.
    - Integrated airspace management is required to prevent congestion and ensure safe operations.
- Integration with airports and facilities
    - Adaptation of existing airports and heliports for AAM and UAM operations may be necessary.
    - Coordination between traditional aviation operations and AAM/UAM at airports is essential.
- Airspace management and deconfliction
    - Shared airspace mandates effective deconfliction systems to prevent collisions between traditional aircraft and AAM/UAM vehicles.
- Airspace integration and coordination
    - Effective coordination between AAM operators, traditional aviation stakeholders, and air traffic control will be essential to manage airspace congestion and ensure seamless integration while minimizing disruptions to existing aviation activities.
- Airspace design and segregation
    - As AAM operations expand, airspace designers and regulators may need to consider new airspace design concepts, including vertical corridors and dedicated routes for AAM vehicles. Proper segregation of AAM traffic from existing aviation operations will be crucial to ensure safety and minimize disruptions.

- Airport access and routing considerations
    - AAM could impact airport operations by introducing new access points for passenger pick-up and drop-off. This may require adjustments to airport layouts, infrastructure (e.g., need for charging infrastructure), and routing procedures to accommodate AAM operations without compromising traditional aviation activities.
- Regulatory framework and certification
    - Regulatory agencies must develop certification processes for AAM and UAM aircraft that ensure safety alongside traditional aviation.
    - Regulatory alignment is crucial for efficient operations and safety.
- Pilot training and workforce:
    - Specialized training is needed for pilots and operators of AAM and UAM vehicles, distinct from traditional aviation training.
    - Skilled workforce development must consider the unique requirements of AAM and UAM operations.
- Economic opportunities and challenges
    - Traditional aviation companies may face increased competition from new AAM and UAM providers.
    - Opportunities arise for economic growth through job creation and business development in the aviation sector.
- Insurance and liability
    - Insurance and liability frameworks must be adjusted to address the introduction of new AAM/UAM vehicles and their potential risks.

## Airspace-Related Impacts

According to FAA (2023c, July), airspace usage and route structure in the context of AAM operations is a critical consideration to ensure safe and efficient integration of AAM aircraft into the existing airspace system. AAM operators are expected to comply with established communication, navigation, and surveillance requirements for the airspace where they will operate. For the Innovate28 (I28) initiative, AAM aircraft are anticipated to operate from the surface to 4,000 ft above ground level, predominantly in or around Class B and C airspace, which necessitates adherence to specific regulations and equipment requirements. To operate within Class B airspace, pilots must receive ATC clearance and equip the aircraft with a two-way radio, Automatic Dependent Surveillance—Broadcast Out, suitable navigation capabilities, and an operable transponder with altitude reporting capability.

Initial AAM aircraft operations are expected to comply with visual flight rules (VFR) weather minima in visual meteorological conditions (VMC).

Charted routes will serve as the primary routing structure for AAM aircraft, designed to accommodate operator needs while leveraging existing design and charting processes. Adherence to these routes and recommended altitudes is voluntary for pilots, but ATC may assign them when compliance is necessary based on specific FAA-operator Letters of Agreement or safety considerations. The I28 AAM routes will be designed for VFR conditions, potentially incorporating VFR flyways, VFR corridors, VFR transition routes, and special flight rule areas to facilitate safe navigation through controlled airspace. Efforts will be made to minimize negative impacts on existing air traffic flows, but in some cases, operational efficiency may require consideration. According to FAA, the designated routes encompass the following options:

- VFR flyways: These are general flight paths that lack specific course definitions and are intended for pilots' use when planning flights that traverse complex terminal airspace, either entering, exiting, or passing near Class B airspace as a means to circumvent it. No ATC clearance is mandatory for flying along these routes.

- VFR corridors: These airspaces traverse Class B airspace and are characterized by explicit vertical and horizontal limits. Aircraft are permitted to operate within these corridors without necessitating an ATC clearance or establishing communication with ATC.

- VFR transition routes: These are distinct flight courses delineated on a terminal area chart to facilitate transit through specific Class B airspace. Each of these routes incorporates designated ATC-assigned altitudes, and pilots are mandated to secure an ATC clearance prior to entering the relevant Class B airspace along the route.

- Special flight rule areas: These encompass designated airspace regions of specified dimensions, situated above either land areas or territorial waters. Flight operations within these areas are subject to the regulations outlined in 14 CFR Part 93, unless a different authorization is conferred by ATC.

It is important to note that no unique AAM airspace structures or dedicated AAM airspace corridors are expected to be implemented by 2028. The responsibility for aircraft separation will continue to rely on the see-and-avoid principle. Addressing airspace usage and route structure is vital to ensure the successful integration of AAM operations, uphold safety standards, and promote efficient utilization of the airspace while accommodating the anticipated growth of AAM in the near future.

FAA (2023b), through their second Concept of Operations release, describes how gradually the airspace segmentation field could be developed, based on the demand for AAM and UAM services. As the volume and complexity of UAM operations continue to rise, the implementation of simplified UAM corridors may provide operational advantages for both airspace users and air traffic service providers. Initially, these UAM corridors will have straightforward designs, such as one-way corridors or a single track in each direction, as shown in Figure 33.

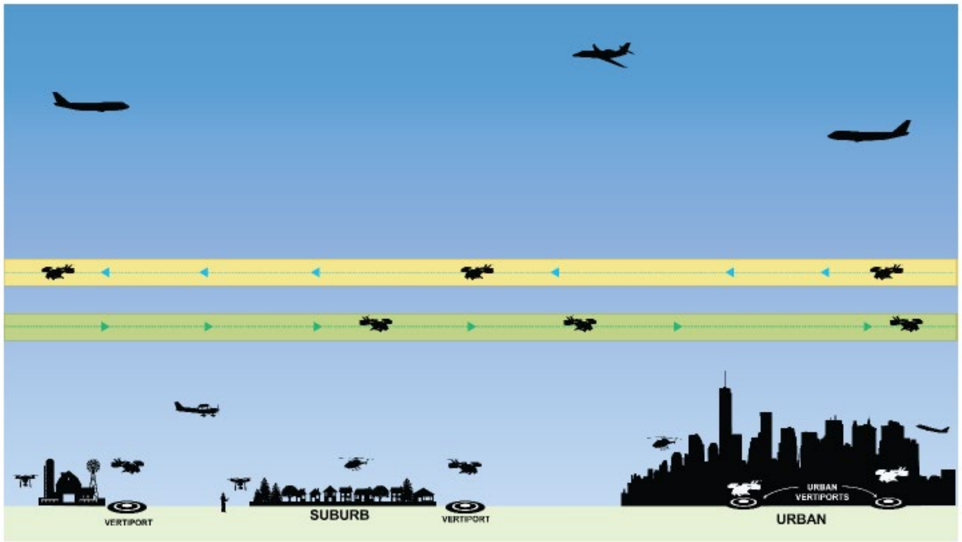


**Figure 33. Graph. Early stages of UAM operations.**

***Source: Federal Aviation Administration (2023b)***

As the demand for UAM continues to increase, it is possible that the operational requirements of UAM corridors may exceed their initial design capacity. To address specific challenges, alternative UAM corridor configurations, such as the inclusion of designated "passing zones" (as depicted in Figures 34 and 35), can be considered. Note that aircraft and operators that meet the performance criteria set for a UAM corridor, as well as those applicable to the surrounding airspace class, have the flexibility to choose the operational environment that offers the greatest operational benefits based on their discretion.

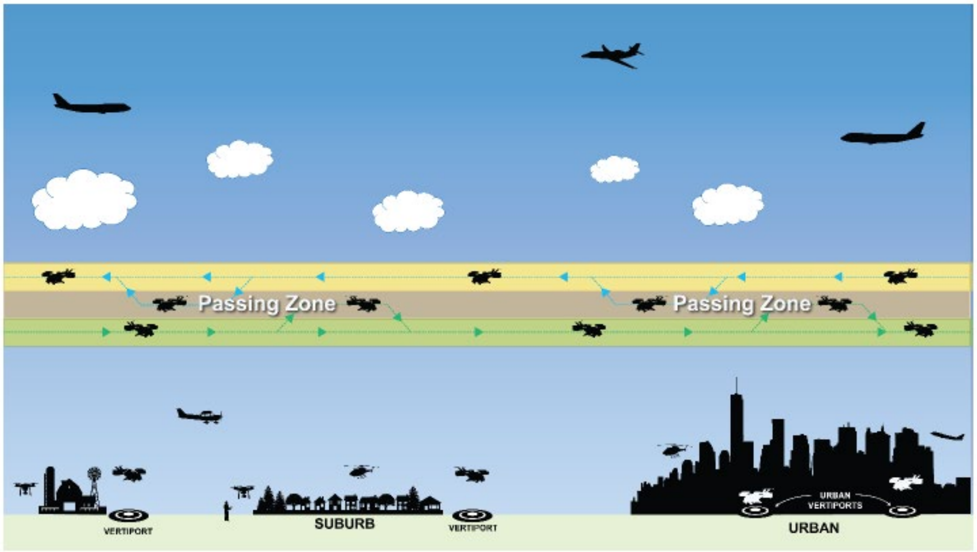


**Figure 34. Graph. Corridors with vertical passing zones.**

***Source: Federal Aviation Administration (2023b)***

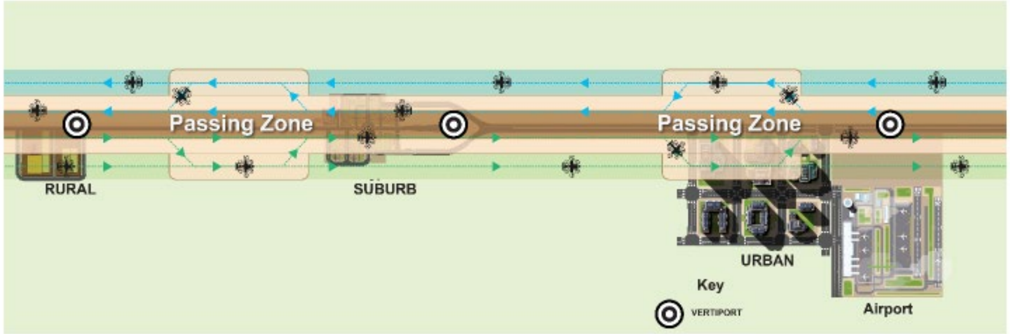


**Figure 35. Graph. Corridors with lateral passing zones.**

***Source: Federal Aviation Administration (2023b)***

With the increasing operational tempo and expanding physical capabilities of aircraft, such as enhanced speed, a conceptual depiction is presented in Figure 36. This illustration showcases an internal UAM corridor structure consisting of multiple "tracks" (i.e., air-traffic lanes). These tracks signify an enhanced internal framework that may require heightened performance criteria to accommodate the intensified operational tempo within the designated UAM corridor.

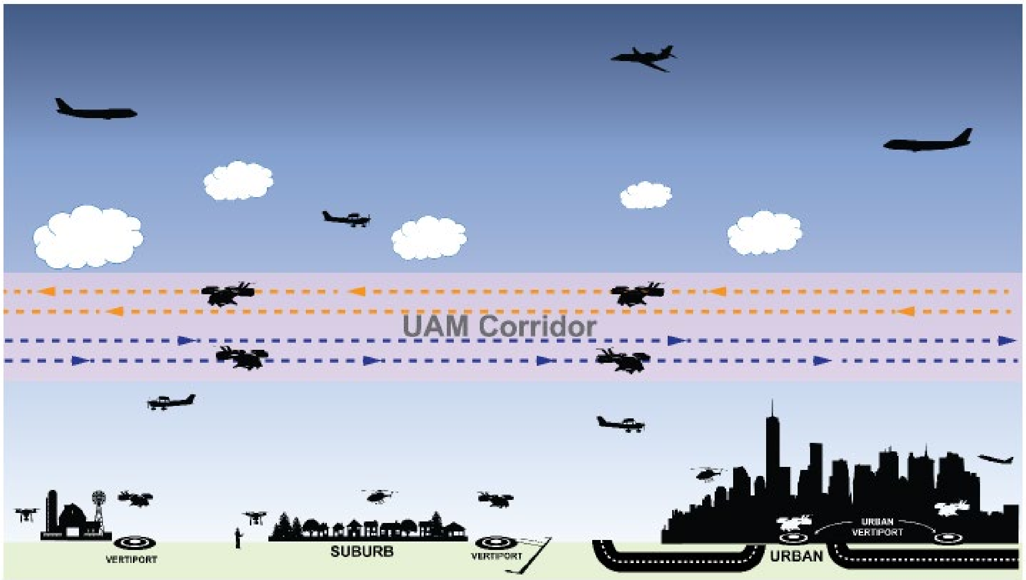


**Figure 36. Graph. Multiple tracks corridor framework.**

***Source: Federal Aviation Administration (2023b)***

The integration of UAM into the National Airspace System (NAS) is expected to exert substantial pressure on the current ATM systems in the foreseeable future (Goyal et al., 2018). Additionally, as different types of aircraft enter the domain of aviation, it becomes imperative to discern their distinctions and resemblances concerning established aircraft (Bauranov & Rakas, 2021). AAM vehicles are likely to exhibit diverse performance characteristics, particularly concerning cruise speed, which accentuates the impact of the traffic mix (Vascik et al., 2018).

In the context of airspace network design and management, a primary objective should be the reduction of concentrations of aircraft, particularly in proximity to congestion-prone locales like bottlenecks, intersections, or vertiports (Cummings & Mahmassani, 2023). It was duly observed that unconstrained networks offer routing efficiency and throughput advantages—accompanied by a heightened incidence of conflicts, however. As for restricted networks, the implementation of a free routing framework within corridors bolstered routing efficiency under low-density circumstances when juxtaposed with a fixed routing paradigm. However, at elevated densities, this approach exhibited a propensity for congestion. Thus, a trade-off arises between unrestricted free-routing and fixed-routing network configurations. Ultimately, under conditions of exceptionally high density, the most methodical network (the fixed-route corridors) can provide optimal capacity to sustain throughput, curtail conflicts, and mitigate increments in travel time. Tube airspaces exhibit a propensity to mitigate conflicts compared to unstructured airspace; however, restricted airspaces could also impose adverse repercussions on traffic flow dynamics (Cummings & Mahmassani, 2023). A restrictive airspace formation is characterized as a tube-related airspace volume, in which aircraft can only operate within predefined routes and altitudes. Notably, the transitional areas bridging unstructured and tube airspaces emerge as potential bottlenecks and congestion hotspots, warranting meticulous management should their deployment be pursued. An example of such an instance could be the airspace portion around vertiports, where bottlenecks would have an increased probability of forming.

Moreover, a critical objective is to ascertain how their integration with existing aviation influences the limitations of airspace. The integration of air-taxi services into conventional runway operations is advised primarily for low-traffic periods or at smaller single-runway airports, while for high-traffic airports, significant effects of AAM aircraft on conventional traffic delays are expected (Ahrenhold et al., 2021). During peak hours, it is recommended to conduct integration at distinct vertiports, separate from the main runway. Therefore, airports with medium to high traffic volumes are encouraged to establish at least two viable vertiport locations for ATC operations, allowing for flexible switching based on current traffic loads and runway conditions. The density and pace of UAM will not be able to be sustained by the prevailing ATM procedures and practices, with ATC workload limitations posing constraints on scaling UAM operations to the required traffic levels necessary to meet the projected demand (Patterson et al., 2021).

A recent Transportation Research Board report on airport integration with AAM and UAM (Mallela et al., 2023) mentions the following positive impacts:

- Expansion of air travel for both passengers and freight
- Initiatives aimed at enhancing the efficiency of airspace management in the United States
- Rising availability of extensive consumer data

Airports might face the following potential implications:

- Financial resources

- Infrastructure for vertiports
- Electric charging infrastructure
- Support equipment for ground operations
- Streamlining cargo handling
- Modifications to lease contracts
- Enhanced last-mile transportation connectivity
- Meteorological systems
- Utilization of land for designated purposes

Accommodating on-demand traffic of a conceptual UAM service will necessitate upgrades or construction of additional facilities to ensure that existing airports can handle the demand without becoming overloaded, considering traditional and UAM aviation services (Smith et al., 2012). This simulation-based study estimated that in 2035, under current airport capacities, 16,668 “traditional” aviation flights will witness a delay above 1 hour. However, under the case of scaled capacities, according to the assumed increased volume of flights, 1,019 delayed flights were found. The majority of on-demand traffic operated in less congested airspace and at significantly lower altitudes compared to commercial airline traffic. Notably, certain low-altitude level sectors experienced peak counts of over 500 aircraft simultaneously. However, it is essential to emphasize that the on-demand traffic operational concept relies on autonomous separation assurance, negating the need for explicit permission to cross sector boundaries and, consequently, imposing no direct additional burden on ATM systems. The on-demand traffic’s responsibility lies in maintaining safe clearance from other air traffic.

# CHAPTER 5: AAM INFRASTRUCTURE AND FACILITY NEEDS

To facilitate the operation of AAM services, a range of technologies and infrastructure will be needed. This chapter presents an overview of AAM support infrastructure requirements, specifications, and assessments of infrastructure scope, followed by managerial and planning recommendations.

## ELECTRIC POWER NEEDS, INFRASTRUCTURE IMPACTS, AND CHANGES NEEDED

### AAM Operations' Estimated Impacts and Infrastructure Needs

The number of eVTOLs able to charge simultaneously on the three interconnections in the United States (i.e., Eastern, Western, and Texas) was estimated, with the results suggesting that the electrical grid will have sufficient power capacity to support approximately 595,000 aircraft charging simultaneously, while 991,00 aircraft are aloft (Thipphavong, 2022). Electric vehicles (EVs) are expected to rise from 0.5% in 2021 to 40% in 2050. Therefore, AAM operations' access to the electrical grid's power capacity will decrease as ground EVs increase in number. The maximum number of AAM operations in the CONUS was predicted to be 20% lower in 2050 than it will be in its early stages of adoption. The Eastern Interconnection has the biggest reduction in the highest number of AAM aircraft charging (78,000 aircraft) and aircraft aloft (130,000).

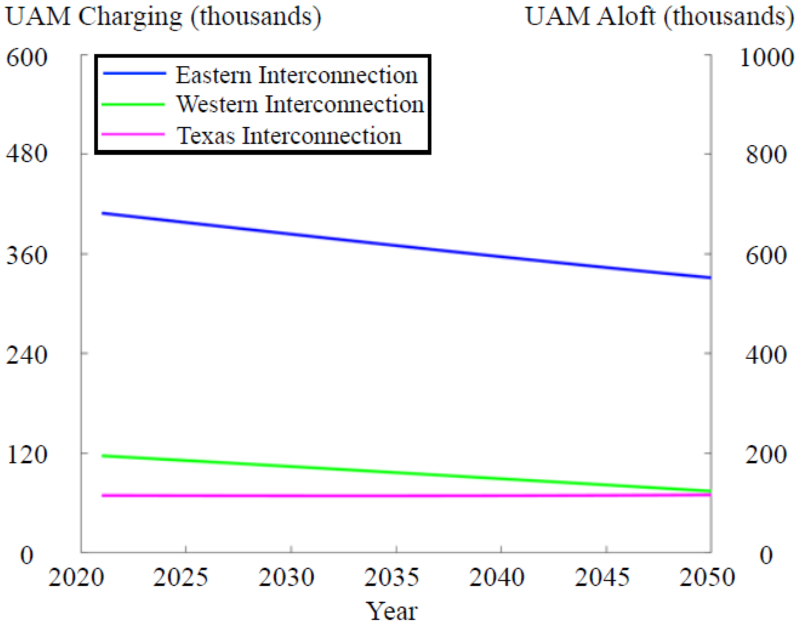


**Figure 37. Graph. Projections of maximum number of UAM operations by interconnection.**

***Source: Thipphavong (2022)***

Illinois has a 44,500 MW capacity through all its power plants, accounting for approximately 6% of the total capacity of the Eastern Interconnection (Wikimedia Foundation, 2023). Assuming the number of AAM aircraft in Illinois will be correlated to the percentage of the capacity, there would be available capability for 35,700 aircraft charging simultaneously and 59,460 aloft.

In the absence of existing data from electric aircraft flights, relating EVs with electric aircraft is a way to assess up to a certain level the impact of electric AAM operations in electric grids. From a study initiated by the Sacramento Municipal Utility District (SMUD, 2019), a scenario of 240,000 EVs in the network suggested a significant effect on the electricity distribution grid through 2030. Voltage violations would occur in almost 26% of SMUD's substations. In the high penetration scenario, between 11% and 17% of the utilities' transformers will need to be replaced (total cost: $89 million; each transformer costs $7,400, in 2019 U.S. dollars). Donateo and Ficarella (2022) compared the energy needs per unit time of an UAM aircraft flight under three different settings: conventional (i.e., ICE), hybrid, and electric. Figure 38 presents the differences in power needs in different segments of an aircraft's flight (ascending, descending, cruise), with technologies of today and 2035 (estimated).

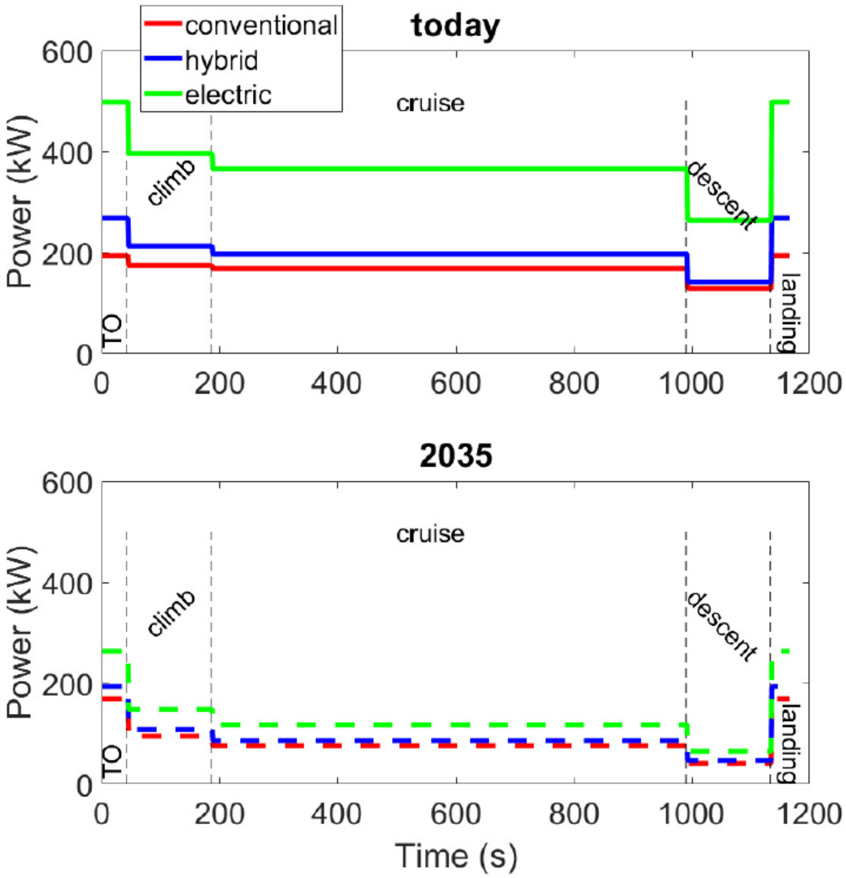


**Figure 38. Graph. Power request of three configurations with current and 2035 technology.**

***Source: Donateo & Ficarella (2022)***

Additionally, Figure 39 shows a comparison between ground and air EVs regarding cruise power needs in different speeds, with ground EVs having a significant advantage over eVTOLs. For a speed of 60 km/h (37.2 m/h), a value that approximates the average speed of a ground vehicle, an EV needs 4–5 kW, while an eVTOL would need 35 kW, corresponding to a 700% difference.

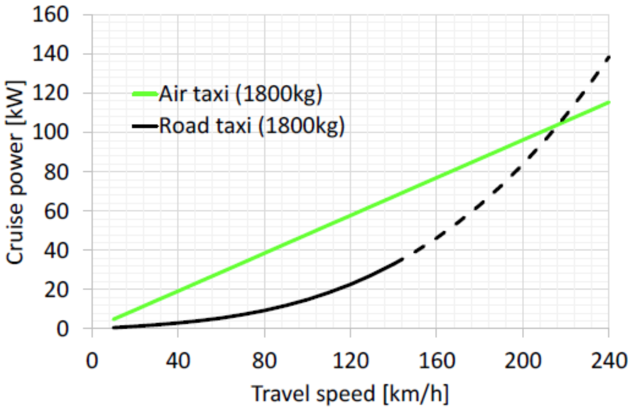


**Figure 39. Graph. Cruise power vs. travel speed for an air vehicle and a road taxi.**

***Source: Donateo & Ficarella (2022)***

In 2019, Pipistrel (2020) created the first US aircraft charger able to accommodate two aircraft at 20 kW or one at 40 kW. It takes an hour to fully charge a small electric plane with two seats. However, commercial flight schedules cannot be met at this charging rate. Cox et al. (2023) examined charging infrastructure requirements for electric aircraft, focusing on regional aviation aircraft, however. Despite the differences between AAM, this study can provide useful insight in terms of electric grids' capabilities. Three charging cases were introduced and compared with a base case of no electric aircraft.

- Case 1: Unlimited number of chargers, intended to represent charging batteries at the slowest rate that the flight schedule would permit.
- Case 2: Chargers with a maximum power draw limit. The aircraft was placed on a charger and charged fully within 30 minutes.
- Case 3: Chargers with guaranteed time-of-charge. The aircraft was placed on a charger and charged fully within 15 minutes.

The two airports chosen for the analysis were Colorado Springs Airport (COS) and Newport News/Williamsburg International Airport (PHF). Table 7 presents the changes that each electric grid will witness for each scenario, with significant increases in both annual and peak demand.

**Table 7. Charging Case Overview**

| Case Considered | Charging Time Limit | COS | | PHF | |
|---|---|---|---|---|---|
| | | Peak kW | Annual MWh | Peak kW | Annual MWh |
| Baseline airport | N/A | 1,752 | 7,413 | 743 | 3,640 |
| Baseline + Charging Case 1 | None | 25,265 | 26,981 | 938 | 4,919 |
| Baseline + Charging Case 2 | 30 minutes | 19,161 | 28,176 | 1,549 | 4,995 |
| Baseline + Charging Case 3 | 15 minutes | 21,580 | 28,425 | 1,574 | 4,995 |

***Source: Cox et al. (2023)***

Tables 8–10 present the cost for a 3, 6, and 10 MW infrastructure installation, respectively (in 2022 U.S. dollars).

**Table 8. Cost Analysis for 3 MW Plant**

| Component | Cost |
|---|---|
| Overhead-to-underground riser | $45,000 |
| New primary meter | $15,000 |
| New on-site underground 0.5-mile, 900-A, 6,840-kVA feeder | $2,006,047 |
| Total | $2,066,047 |

***Source: Cox et al. (2023)***

**Table 9. Cost Analysis for 6 MW Plant**

| Component | Cost |
|---|---|
| Overhead-to-underground riser | $45,000 |
| New primary meter | $15,000 |
| New overhead feeder back to utility distribution substation | $1,395,000 |
| New on-site underground 0.5-mile, 900-A, 6,840-kVA feeder | $2,877,507 |
| 5 × 1.5-kVA and 1 × 500-kVA transformers | $206,600 |
| Total | $4,125,907 |

***Source: Cox et al. (2023)***

**Table 10. Cost Analysis for 10 MW Plant**

| Component | Cost |
|---|---|
| 10-MW distribution substation | $5,000,000 |
| New on-site underground 0.5-mile, 10-MVA feeder | $3,000,000 |
| 6 × 1.5-MVA and 1 × 1-MVA transformers | $252,100 |
| Total | $7,747,900 |

***Source: Cox et al. (2023)***

In all cases, adding even a few planes made the demand for electric aircraft charging quickly become the most important demand for electricity on the airport site. Even a modest deployment of electric aircraft could quickly overshadow even larger airports' baseline electricity demand, because each flight necessitates megawatt-level charging for the majority of flight schedules.

## GROUND INFRASTRUCTURE

### Spatial Requirements

Several studies focused on the way that existing infrastructure could be reshaped and leveraged to serve the needs of AAM aircraft as well as the specifications and requirements of newly introduced infrastructure. Yedavalli and Cohen (2022) conducted an overview of the functionality and cost of different landing and take-off infrastructure types, information that IDOT would potentially find useful toward assessing infrastructure utility and costs, summarized in Table 11 (in 2022 U.S. dollars).

**Table 11. Taxonomy and Definitions of Urban Air Mobility Infrastructure**

| Type of Infrastructure | Description |
|---|---|
| Vertihub | A larger facility (possibly with multiple floors) to accommodate numerous landing pads with parking for multiple aircraft. Yedavalli and Cohen (2022) estimated that vertihubs would be approximately 70,000 ft$^2$, spread across multiple floors, and cost between \$6 and \$7 million to build. |
| Vertiport/vertibase | A medium-sized facility intended to accommodate up to three landing pads and up to six parked aircraft. Yedavalli and Cohen (2022) estimated that vertiports/vertibases would be approximately 23,000 ft$^2$ and cost between \$500,000 and \$800,000 to construct. |
| Vertipad/vertistation | A single landing pad and parking stall intended to accommodate one or two parked aircraft. Yedavalli and Cohen (2022) reported that vertipads would be approximately 6,000 ft$^2$ and cost between \$200,000 and \$400,000 to construct. |

***Source: Yedavalli & Cohen (2022)***

Various elements of a heliport—approach-departure paths, taxiways, safety zones, touchdown and lift-off areas (TLOF), final approach and take-off areas (FATO)—are described by FAA (2023a), with more details observed in Figure 40.

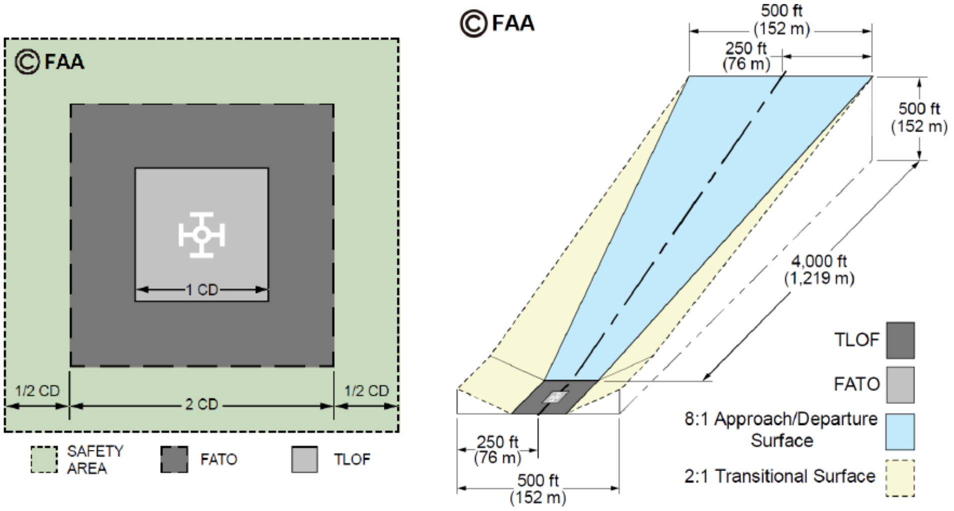


**Figure 40. Graph. Dimensions of pad and approach/departure slope according to an FAA engineering brief on vertiport design.**

***Source: Federal Aviation Administration (2023a)***

Space requirements of a vertiport were presented by Brusberg et al. (2021), with the corresponding (minimum) diameters for TLOF, stand, FATO, and safety areas being 11.3, 13.6, 17, and 23 m, respectively. Therefore, the complete structure would correspond to a 529 m$^2$ (5,694.11 ft$^2$) area, accommodating one aircraft at a time. Figure 68 in Appendix B presents graphically the dimensions.

A small-sized vertiport for 10 vehicles and a daily passenger demand of 5,400 passengers was estimated to require 4,160 m$^2$, while a large vertiport able to accommodate 50 vehicles and 130,000 passengers needs an area of 20,000 m$^2$ (Schweiger & Preis, 2022; Ploetner et al., 2020). Electric STOL (short take-off and landing aircraft) operations may offer advantages over VTOL operations in terms of vehicle performance, with runway lengths needed between 100 and 300 ft (Courtin et al., 2018). To accommodate an additional vehicle per hour, a vertiport's land area will need to be increased by 420 m$^2$ (Taylor et al., 2020). Regarding vertiport safety specifications and design guidance, Figure 69 in Appendix B illustrates the discretization of the obstacle restriction terrain (Brusberg et al., 2021).

There are two distinct vertiport configuration designs suggested by NASA (2021) apart from a single-pad vertiport: hybrid surface and linear process configurations. The hybrid configuration encompasses a larger spatial extent compared to single pad design, featuring a single TLOF pad alongside multiple staging areas, as depicted in Figure 41. These staging areas, situated beyond the perimeter of the FATO, serve various purposes (parking, refueling, maintenance, passenger, and cargo handling), and they enhance operational efficiency. However, the inclusion of staging areas results in increased costs and a larger physical footprint compared to the single-pad configuration.

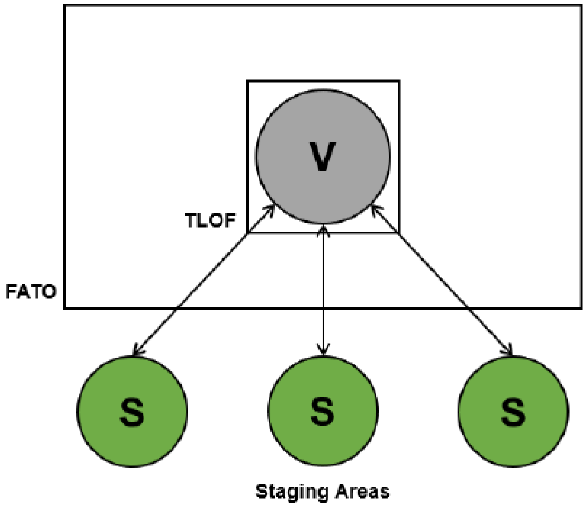


**Figure 41. Graph. Hybrid surface configuration.**

***Source: NASA (2021)***

In the linear process configuration (Figure 42), aircraft follow a sequential pattern, commencing with landing on an arrival TLOF pad situated on one side. Subsequently, they proceed to designated staging areas for necessary servicing before progressing to a separate TLOF pad dedicated to departures from the vertiport. Notably, the linear process design excels in facilitating a high volume of traffic compared to other configurations, at a higher cost and occupying a larger physical space. These configurations are best suited for vertihubs located on the outskirts of urban areas, where substantial passenger and cargo movement can be accommodated.

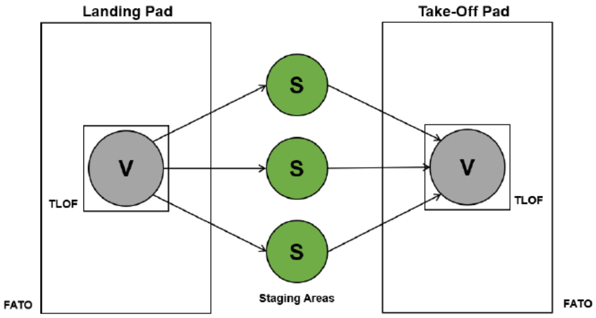


**Figure 42. Graph. Linear process configuration.**

***Source: NASA (2021)***

## Cost Overview

In terms of ground infrastructure costs, a network of five vertiports and 500 vehicles each will cost a total of $72 million to operate, in 2018 U.S. dollar values, considering only electric aircraft (Kohlman, 2018). The estimated cost for a vertiport that provides a single multi-function pad with a dimension of 127 × 226 m (2019 U.S. dollar values) is $350,000 (Taylor et al., 2020). If two or three extra parking spaces are connected to the single FATO, respectively, the cost rises to $750,000–$950,000. A vertiport with a linear design, one takeoff pad, one landing pad, and two disembarking, maintenance, and embarking station areas per pad is anticipated to cost $1,600,000 and have a 226 × 551 m spatial output. An initial expenditure of $1–2 million is anticipated for the smallest configuration of Lilium's vertiports, which will be ground-based with modest terminal areas and a constrained number of charging stands (Lilium GmbH, 2021). Elevated vertiports with bigger spans and capabilities require investments between 7 to 15 million euros ($7,542,850–$16,163,250), in 2020 U.S. values. A cost analysis of the necessary new or updated components of an airport vertiport construction for a 20-year time frame is presented in Table 12 (Guo et al., 2020), in 2020 U.S. dollar values.

**Table 12. Parameters of Airport Charging Infrastructure System**

| Factor | Action | Cost (£) | Cost ($ - adjusted) | Cost Units |
|---|---|---|---|---|
| PV (solar photovoltaic) | Installation cost | 1,500 | 1,834.5 | £/$/kWp |
| Transformer | | 25,000 | 30,575 | £/$/MVA |
| Battery | | 150,000 | 183,450 | £/$/each |
| Charger for battery swap | | 10,000 | 12,230 | £/$/each |
| Charger for plug-in charge | | 100,000 | 122,300 | £/$/each |
| Energy storage | | 150,000 | 183,450 | £/$/MWh |
| Energy storage system | | 100,000 | 122,300 | £/$/MW |
| 0:00–7:00, 21:00–24:00 | Electricity price | 0.1 | 0.1223 | £/$/kWh |
| 7:00–21:00 | | 0.2 | 0.2446 | £/$/kWh |
| 0:00–7:00, 21:00–24:00 | Feed-in tariff | 0.05 | 0.06115 | £/$/kWh |
| 7:00–21:00 | | 0.08 | 0.09784 | £/$/kWh |
| CO2 | Emission cost | 20 | 24.46 | £/$/t |

***Source: Guo et al. (2020)***

The concept of “megaports” was also introduced, identified as multiple landing pads, charging stations, and other necessary infrastructure constricted together as a whole (the largest was assumed to have 31 landing pads and 186 parking stalls) (Tarafdar, 2020). One obstacle for these enormous landing destinations is cost and spatial availability (e.g., a total of 2,036,430 ft$^2$ would be needed for a large megaport, something that seems to be infeasible).

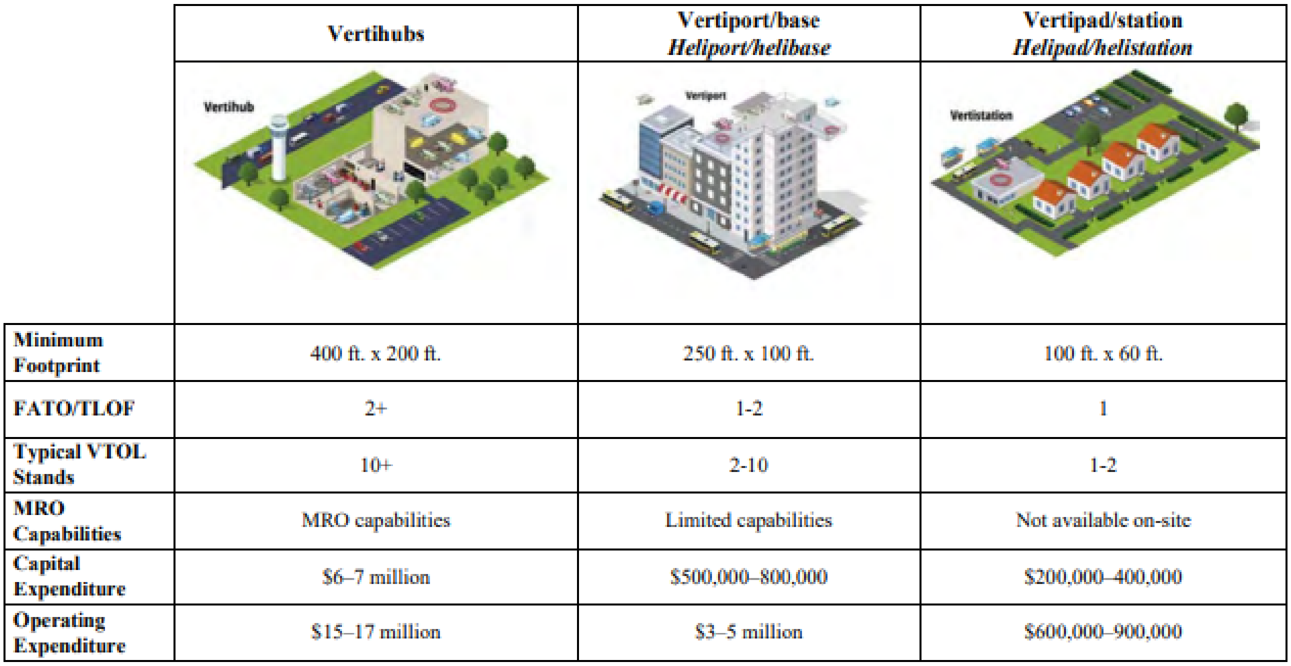
A site with six 600 kW chargers containing two pads can have equipment arranged into an area occupying approximately 1,400 ft$^2$, with Table 13 presenting different vertiport schemes (Black & Veach, 2018). The costs and spatial needs identified by Mallela et al. (2023) are depicted in Figure 43.

While serving as valuable reference points, it is important to note that the above cost estimates for vertiport construction and operation were formulated in 2018, while currently, an increase in the interval of 25%–35% have been observed in construction costs for aviation-related development. The last column on Table 13 corresponds to an estimate of 2023 U.S. cost values, based on a 28% cost increase factor, accounting also for inflation rate differences. However, further assumptions and underlying parameters which have not been taken into consideration might apply as well.

**Table 13. Overview of Different Infrastructure Settings**

| Infrastructure type | Number of landing pads | Number of charging stations | Generalized cost ($) | Implementation time frame (months) | 2023 – adjusted generalized cost ($) |
|---|---|---|---|---|---|
| Landing Site without Charging Stations | – | 3 | 350,000 | N/A | 505,389 |
| Rooftop Existing Landing Site (with Charging Station) | 1 | 1 | 883,000 | 9–12 | 1,275,024 |
| Ground Landing Site | 3 | 3 | 2,630,000 | 9–12 | 3,797,638 |
| Existing Parking Garage | 3 | 9 | 1,876,000 | 6–12 | 2,708,885 |
| Ground Landing Site Central Charging Station Only | 3 | 3 | 2,560,000 | 9–12 | 3,696,560 |
| Airport Station | 3 | 9 | 2,630,000 | 9–12 months | 3,797,638 |

***Source: Black & Veach (2018); author calculations***



| | Vertihubs | Vertiport/base<br>*Heliport/helibase* | Vertipad/station<br>*Helipad/helistation* |
|---|---|---|---|
| **Minimum Footprint** | 400 ft. x 200 ft. | 250 ft. x 100 ft. | 100 ft. x 60 ft. |
| **FATO/TLOF** | 2+ | 1-2 | 1 |
| **Typical VTOL Stands** | 10+ | 2-10 | 1-2 |
| **MRO Capabilities** | MRO capabilities | Limited capabilities | Not available on-site |
| **Capital Expenditure** | \$6–7 million | \$500,000–800,000 | \$200,000–400,000 |
| **Operating Expenditure** | \$15–17 million | \$3–5 million | \$600,000–900,000 |

**Figure 43. Graph. AAM infrastructure requirements.**

***Source: Mallela et al. (2023)***

## COMMUNICATIONS

Low-altitude UAV information exchange could be possible over 4G and 5G-NR networks (Shrestha et al., 2021). At greater altitudes (beyond 500 to 6,500 ft) communication problems start to be significant. Table 14 provides an overview of 4G, 5G, and a proposed 6G model as well as their capabilities and limits. Certain limitations in terms of speed, data rate, and integration capabilities between the different technologies exist. Additionally, UAV communication networks are assumed to be different in capabilities and needs compared to AAM passenger and cargo aircraft.

In terms of cost, telecommunication systems upgrades could cost up to $40 million annually, according to Goyal et al. (2018), along with capital costs of $60–80 million (for a life span of 40–60 years) for beacon placement, flight exception locations creation accounting for $10–20 millions, as well as battery replacement costs, noise barriers installment costs, among others, adjusted to 2018 U.S. dollar values. Similarly, these cost values should be seen as reference points, since costs for telecommunication-related projects are subject of fluctuations that reflect prevailing market trends.

**Table 14. Comparison of Different Cellular Communication Networks**

| Features | 4G Network | 5G Network | Proposed 6G Network |
|---|---|---|---|
| Peak data rate | 1 Gbps | 10 Gbps | 1 Tbps |
| Mobility support | up to 350 km/hr | up to 500 km/hr | >1000 km/hr |
| Satellite integration | No | No | Fully |
| Artificial intelligence | No | Partial | Fully |
| Extended reality | No | Partial | Fully |
| End-to-end latency | 100 ms | 10 ms | <1 ms |
| Autonomous aircraft | No | Partial | Fully |
| High precision positioning | 10 m | 1 m | cm level |
| Connection density | 100,000/km$^2$ | >1 million/km$^2$ | >10 million/km$^2$ |
| Reliability | <99% | About 99.9% | >99.999% |
| THz communication | No | Very limited | Extensive |

***Source: Shrestha et al. (2021)***

With the use of existing helicopter communication infrastructure and procedures as a base, and by assuming that a certain portion (if not all of them) will be applicable to AAM operations, useful information can be gathered from Moreno et al. (2019). In airports that are technologically advanced, helicopters can use precision navigation aids such as lighting elements (e.g., landing direction lights, perimeter lighting for TLOF and FATO, illumination for taxiway centerlines, windsock equipped with lighting, and a beacon in a rotational motion), if they are capable of Instrument Landing System (ILS) approaches. ILS, in combination with high-intensity lighting arrays, allows for safe landing. Airports that support ILS approaches at runways include a separate ILS for each runway direction. An example is O'Hare, which has separate ILS coupled with distance measuring equipment on each runway end (FAA, 2023e).

The FAA (2023d) is developing a program known as Next Generation Air-to-Ground Communications (NEXCOM), which is responsible for supporting the radio communications equipment used by air traffic controllers and pilots for air-to-ground communications. It operates continuously throughout all regions within the National Airspace System and also facilitates ground-to-ground communications necessary for servicing airfield equipment. Furthermore, it serves as crucial communication infrastructure for all phases of flight. An alternative communication solution, called the Aeronautical Mobile Airport Communication System (AeroMACS, 2022), offers extensive support for a wide range of applications, enhances security capabilities, and optimizes air traffic management operations.

In terms of potential communication barriers that AAM operations could face, the effective utilization of voice communications within urban environments is hindered by obstacles such as multipath interference, line of sight limitations, and co-channel interference resulting from the increased density of operations (NASA, 2021). To enable effective operation and cooperation, it is imperative to establish standardized data communications methods and protocols. Currently, FAA and industry stakeholders utilize data models such as the Aeronautical Information Exchange Model, the Weather Information Exchange Model, the Flight Information Exchange Model, and the Flight and Flow Information for a Collaborative Environment.

Regarding weather impacts that could interfere with aircraft communications, an average of 6.1 hours per day in the winter, 7.3 hours per day in the spring, 2.2 hours per day in the fall, and 2.9 hours per day in the summer could be impacted from weather impacts, reducing operational capabilities (Reiche, 2018).

## SAFETY RISKS AND CYBERSECURITY

AAM services are going to be heavily dependent on the existence of safe internet connections in order to accomplish many of the necessary actions that need to take place throughout a successful flight. In the UAV realm, Tang (2021) identified and summarized a number of potential ways that security of an aircraft could be compromised, which are briefly presented in Table 15.

Tang (2021) proposed a resilient system to counteract security threats, which includes the following:

- Fully independent flying is allowed, and flight chart plans are physically loaded
- Asymmetrically encrypted automatic dependent surveillance-broadcast (ADS-B) system and remote frequency identification (RFID) tags for air traffic controllers and law enforcement
- Multiple inter-validating navigation systems
- Symmetric encryption for combined video transmission, secondary control, and navigation data link
- Blockchain-based PKI for key management
- Exclusion of in-flight internet use or usage with a VPN

**Table 15. Potential Cybersecurity Vulnerabilities Overview**

| **Vulnerability** | **Threat Overview** | **Countermeasures** |
|---|---|---|
| RF Jamming | Using a device to physically disrupt a specific RF signal. | • A "failsafe" function that will either force the UAV to hover in position, go back to a prearranged designated location, or automatically descend and land.<br>• Direct prevention |
| Spoofing | Spoofing is an assault where a close wireless broadcaster tricks the recipient by sending it false information, like incorrect GPS coordinates. | Standard encryption |
| Man-in-the-middle | An unauthorized person capturing and changing video broadcast from a UAV. | – |
| De-authentication | After cutting off the wireless connection, the attacker will identify themselves as that UAV's owner and eventually take full control of all data links. | Standard encryption, GPS encryption |
| Eavesdropping | Spying on talks about flights or video feeds. The host might not even be conscious of the violation in either situation. | Standard encryption |
| Denial of Service | Impair a UAV's control or video transmission. Its effects can range from complete control of the UAV to leaving it open to a subsequent attack. | Blockchain, encryption |

***Source: Tang (2021)***

# CHAPTER 6: REGULATORY CONTEXT AND RECOMMENDATIONS FOR ILLINOIS

This chapter considers advanced air mobility (AAM) and urban air mobility (UAM) operations from a regulatory and policy perspective at the federal level with samples from state and regional levels along with international perspectives. These are synthesized to develop policy and regulatory recommendations for the state of Illinois that are consistent with federal rules and regulations, state statutes, and the Illinois Aviation System Plan. The extent to which existing regulations and policies were appropriate considered the following criteria.

- **Safety Risk Management:** AAM involves new technologies that include inherent risks, known and unknown. Developing comprehensive regulations identifying and mitigating risks ensures the safety of passengers, pedestrians, and other aircraft in the airspace.

- **Operational Integration:** Integrating AAM into existing airspace systems requires coordination with air traffic control, airports, and other aviation stakeholders. Proper regulations help prevent congestion and ensure smooth integration.

- **Public Acceptance:** Effective regulations build public trust and acceptance. Addressing concerns about noise, privacy, and safety enhances public support for AAM initiatives.

- **Innovation and Economic Growth:** A supportive regulatory environment attracts investment and promotes the growth of AAM industries, leading to job creation and economic benefits. Balancing innovation with public safety and environmental concerns is also essential.

- **Environmental Impact:** AAM technologies have the potential to be more environmentally friendly than traditional aviation. Regulations can set standards for emissions, noise levels, and energy efficiency.

- **Infrastructure Planning:** Policymakers need to plan for AAM infrastructure, including vertiports, charging stations, and maintenance facilities. Proper regulations facilitate efficient infrastructure development.

- **Transportation System Connectivity**: Regulations must consider the interconnectedness of AAM with urban planning, transportation networks, and other modes of transit.

These topics were addressed previously in this report from an engineering perspective. They are further explored from a policy perspective in this chapter.

## REVIEW OF US FEDERAL POLICIES AND REGULATORY ENVIRONMENT

In the United States, the Federal Aviation Administration is the primary regulatory body responsible for certificating, regulating, and providing air navigation services. In accordance with those duties, FAA is responsible for providing a regulatory framework for permitting AAM and UAM operations, including elements that govern the design, manufacture, and operation of eVTOL aircraft. That framework continues to evolve as aircraft and infrastructure technologies improve, demand and market forecasts shift, and system engineering details mature. FAA (2023b) recently reiterated that, at the federal level, it holds exclusive and authoritative jurisdiction over all safety aspects pertaining to the integration of AAM. This authority encompasses operational regulations, aircraft certification, and pilot certification. The agency is responsible for developing and executing certification processes, policies, procedures, rulemaking, and regulatory activities, all aimed at ensuring the safety of flight operations within the AAM sector.

Additionally, FAA is partnering with various government agencies to expedite the seamless integration of AAM into the NAS such as the National Aeronautics and Space Administration, Department of Defense, Department of Homeland Security, and other modal agencies in the US Department of Transportation. Notably, FAA collaborates extensively with NASA’s AAM Program and the National Campaign as well as engages with the US Air Force AFWERX Prime program to leverage valuable research, data, and testing experience toward the shared mission of safely incorporating AAM aircraft into the airspace (FAA, 2023b). Moreover, apart from federal-level cooperation, FAA is engaging with local, state, tribal, and territorial governments in formulating decisions and ensuring the secure and successful operation of AAM on a local and regional scale.

## FAA Regulations Impacting AAM/UAM Airworthiness Certification

Aviation regulations are built on three basic notions: certification of aircraft, certification of airmen, and regulations governing flight operations (Perritt & Sprague, 2015). The certification processes for aircraft and airmen are important mechanisms for enforcing detailed requirements on the design and manufacturing of aircraft as well as on the skills of personnel responsible for operating and maintaining them. FAA has a well-established history of safely certifying and integrating new and innovative design features, aircraft, and safety-enhancing technologies into the NAS. The type certification of AAM aircraft requires implementing FAA’s existing regulatory framework, which allows for the development of project-specific requirements tailored to accommodate the distinctive characteristics of novel designs. FAA has continued to evolve certification requirements for eVTOL manufacturers and operators, which include demonstrating compliance with safety standards, conducting flight testing, and obtaining appropriate permits. Some of the key regulations and guidance documents are shown in Figure 44.

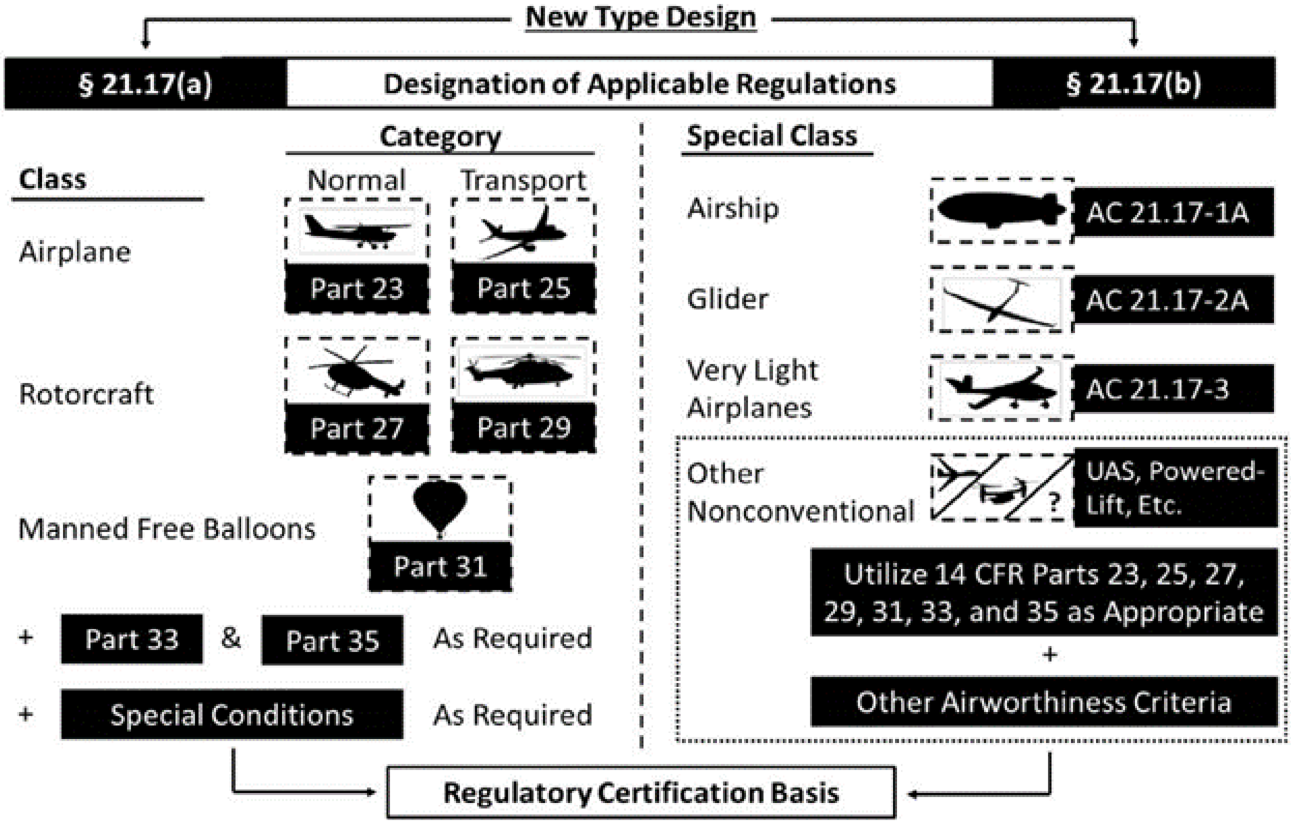


**Figure 44. Graph. FAA certification path decision tree.**

***Source: FAA***

- **Part 23—Aircraft Airworthiness Standards**: This regulation outlines the airworthiness standards for normal, utility, acrobatic, and commuter category airplanes and covers a range of areas, including structural integrity, systems and equipment, and flight performance.

- **Part 25—Aircraft Airworthiness Standards**: This regulation outlines the airworthiness standards for transport category airplanes. The standards cover a range of areas, including structural integrity, systems and equipment, and flight performance.

- **Part 27—Rotorcraft Airworthiness Standards**: This regulation sets out airworthiness standards for utility helicopters, which certain types of eVTOL aircraft may be classified as. The regulation covers areas such as structural design, powerplant installation, and systems and equipment.

- **Part 29—Rotorcraft Airworthiness Standards**: This regulation sets out airworthiness standards for transport helicopters, which certain types of eVTOL aircraft may be classified as. The regulation covers areas such as structural design, powerplant installation, and systems and equipment.

- **Part 31—Manned Free Balloons Airworthiness Standards**: This regulation sets out airworthiness standards for manned free balloons.

- **Part 33—Airworthiness Standards for Aircraft Engines**: This regulation sets out airworthiness standards for aircraft engines, which impacts eVTOL aircraft depending on design.

- **Part 35—Airworthiness Standards for Propellers**: This regulation sets out airworthiness standards for propellers, which also may impact eVTOL aircraft depending on design.

If the proposed new aircraft design follows the decision paths outlined in Figure 44 and does not fit into the existing definitions and airworthiness standards, FAA applies Advisory Circular (AC) 21.17(b) to designate it as a special class aircraft. This typically refers to airships, gliders, very light aircraft, etc. FAA also designated a category “Powered-Lift” within AC 21.17(b), which refers to heavier-than-air aircraft capable of vertical takeoff, vertical landing, and low-speed flight that depends principally on engine-driven lift devices or engine thrust for lift during these flight regimes and on nonrotating airfoil(s) for lift during horizontal flight.

In June 2023, the US DOT released a report of an investigation into FAA’s progress in establishing the basis for certification of AAM aircraft, which included ensuring the provision of safety surrounding novel features on vehicles and infrastructure as well as providing guidance to applicants for certification. The investigation found that FAA regulations are “still primarily intended for traditional small aircraft, creating challenges for the FAA” (US DOT, 2023). The report further pointed out that given their unique features, many AAM aircraft designs do not quite fit into FAA’s existing airworthiness standards and that FAA has made limited progress regarding this over the past four years. One issue surrounds the Powered-Lift category (applicable to some AAM aircraft designs), for which FAA never established corresponding airworthiness standards and regulations leading to significant internal debates on how to proceed with AAM certification. However, in April 2022, FAA communicated to applicants that it would begin to certify fixed-wing AAM aircraft as Powered-Lift, special-class aircraft.

However, at this time none of the AAM aircraft models considered has received airworthiness certification from an aviation regulator (Bushey et al., 2023). Companies operating in the US and Europe are required to obtain a “type certificate” for the design of the aircraft and its components as well as certification to demonstrate that the design can be mass-produced. Table 16 lists Aviation Week’s choice for top AAM aircraft developers and compares assessments of their success potential (in 2022 U.S. dollars).

**Table 16. Comparison of Top AAM Aircraft Developers**

| | 2023 Rank | 2022 Rank | Change |
|---|---|---|---|
| Joby | 1 | 1 | Service entry delayed to 2025. Pilot production begun. Delta Airlines partnership. |
| Archer | 2 | 5 | Service entry on track for 2025. Stellantis investment. |
| Volovopter | 3 | 3 | +$382 million raised. Certification flight tests underway. Service entry slipped to 2024. |
| EHang | 4 | 7 | Certification expected early in 2023. China market only at first. |
| Beta | 5 | 2 | +$375 million raised. Flight test progress. Certification and production plans TBD. |
| Eve | 6 | 8 | +$377 million special-purpose acquisition company. Engineering support from Embraer. United Airlines investment. |
| Lilium | 7 | 4 | Shift to premium private market for launch. More funding needed. |
| Vertical | 8 | 6 | Full-scale tethered hover test performed. More funding needed. |
| Airbus | 9 | 9 | Certification in 2025 doubtful. Air medical service initial market focus. |
| Wisk | 10 | 10 | Unveiled production four-seat autonomous eVTOL. No entry date yet. |
| AutoFlight | 11 | – | Full scale proof-of-concept flights. |
| Overair | 12 | 12 | +$145 million from Hanwha (total $175 million). Plan to fly prototype in 2023. |
| Supernal | 13 | 11 | Collaborating with BAE Systems, EPS, Microsoft. |

***Source: Warwick (2023)***

## FAA Regulations Impacting AAM/UAM Operator Certification

The following are operating certifications, as outlined by the Code of Federal Regulations Title 14, I-G. All potentially may apply to eVTOL aircraft operations, depending on their intended use.

- Part 91—General Operating and Flight Rules: This regulation establishes general operating and flight rules for all aircraft. It typically refers to general aviation pilots and some corporate pilots. The regulation covers areas such as pilot certification, aircraft maintenance, and operational procedures.

- Part 121—Air Transport Operations: This regulation outlines the requirements for operating domestic, flag, and supplemental transport category operations.

- Part 135—Air Taxi and Commuter Operations: This regulation outlines the requirements for operating air taxi, commuter, and on-demand flight services. Rotorcraft operators typically fall under this certification (as well as Part 133 for External Load Rotorcraft).

- Part 107—Small Unmanned Aircraft System (sUAS): While this refers to small remotely piloted aircraft weighing less than 55 lb, the framework can also provide additional context for UAM/AAM regulations.

- Part 137—Chemical/Agricultural Product Dispensing: This part governs the use of all aircraft, including sUAS, to dispense or spray substances (including disinfectants).

Finally, one additional regulation is included to address the environment of AAM aircraft design and operation: Advisory Circular 90-116—Noise Considerations for the Evaluation of Aircraft. This guidance document provides information on how to evaluate the noise impact of eVTOL aircraft operations. The document covers areas such as noise measurement, noise modeling, and noise abatement procedures.

## Regulating the Commercial Use of UAS

As listed above, Part 107 regulates the commercial use of UAS operations using vehicles with a gross take-off weight of less than 55 lb. However, there are additional regulations that are required for specific types of commercial use, specifically package delivery and dispensing chemical/agricultural products. In general, Part 107 operations, specified in §107.205, may be subject to an applicable waiver:

- Operation from a moving vehicle or aircraft—§107.25
- Operation at night—§107.29(a)(2) and (b)
- Visual line of sight aircraft operation—§107.31
- Visual observer—§107.33
- Operation of multiple small unmanned aircraft systems—§107.35
- Yielding the right-of-way—§107.37(a)
- Operation over human beings—§107.39
- Operation in certain airspace—§107.41
- Operating limitations for small unmanned aircraft—§107.51
- Operations over moving vehicles—§107.145

For package delivery operations, sUAS aircraft are currently subject to modified certification regulations under Part 135. These modifications mostly pertain to elements that are not applicable to these vehicles based on size and weight (e.g., requirements to carry flight manuals on board). For operations involving dispensing chemical/agricultural products, operational certification would be obtained through Part 137.

To encourage innovation in partnerships with industry and state, local, tribal and territorial (SLTT) governments, FAA conducted a pilot program to explore the benefits of sUAS usage and inform future rules and regulations. From 2017 through 2020, the UAS Integration Pilot Program and the current continuation program, UAS BEYOND, focused on testing and evaluating civil and public drone operations integration into the NAS (listed in Table 17). Challenges of UAS integration include issues related to beyond visual line of sight (BVLOS) operations, societal and economic benefits of UAS operations, and community engagement strategies.

**Table 17. FAA UAS Integration Pilot Program Participants**

| Participating Entity | Location | Govt Entity | Program Focus |
|---|---|---|---|
| Choctaw Nation (OK) | Durant, OK | Tribal | Monitoring Forest Fires via Extended BVLOS Flights |
| Innovation & Entrepreneurship Investment Authority | Herndon, VA | State | Package Delivery |
| Mid-Atlantic Aviation Partnership (MAAP) | Blacksburg, VA | State | Utility inspection/Public perception of deliveries |
| Kansas DOT | Topeka, KS | State | Energy Transmission Infrastructure Inspection |
| Memphis-Shelby County Airport Authority | Memphis, TN | County | FedEx Multi-Mission—airport inspection/payload delivery |
| North Carolina DOT | Raleigh, NC | State | Healthcare deliveries to sparsely populated areas |
| North Dakota DOT | Bismarck, ND | State | Infrastructure Inspection/Network Operations Center/Weather Sensing |
| City of Reno | Reno, NV | City | Operations Reliability & Durability/Search & Rescue |
| City of San Diego | San Diego, CA | City | Situational Awareness support for Emergency Response |
| University of Alaska–Fairbanks (UAF) | Fairbanks, AK | State | Pipeline Inspection/Alaskan Flight Operations Integration |

## Major Federal Activities on the AAM/UAM Regulatory Environment

While FAA's Concept of Operations (2020a, 2023b) are expressly not policy statements, they are inter-related and do reveal the current perspective of UAM/AAM operations evolution and assessment. As a collaborative effort between FAA, NASA, and industry, FAA (2023b) includes conceptual descriptions of aircraft, vertiports, and vertistops (i.e., take-off/landing zones with minimal supporting infrastructure), supporting infrastructure, air traffic operations, and integration within the existing NAS environment.

The change in FAA's (2020a, 2023b) perspective on UAM operations between successive ConOps illustrates that over the past three years, the anticipation of how these vehicles are expected to operate and integrate continues to increase in scope and detail. However, as there is uncertainty surrounding the forecasted operational tempo, the structure for operational detail has evolved to be more accommodating across the range of traffic levels (Figure 45). Note that specific details regarding this reference (Corridor Operations) were described in more detail in Task 4.

As the operational tempo of AAM increases within the NAS, the infrastructure, automation, and traffic management methodologies related to AAM will need to evolve progressively to accommodate increased demands. The UAM ConOps includes designs to seamlessly integrate AAM aircraft on a larger scale with commercial and general aviation traffic as well as other users of low-altitude airspace, such as recreational and commercial small-unmanned aircraft systems (sUAS) or drones. FAA's AAM Implementation Plan, also referred to as Innovate28 or I28, was developed to respond to the "Advanced Air Mobility Coordination and Leadership Act" (P. L. 117–203).

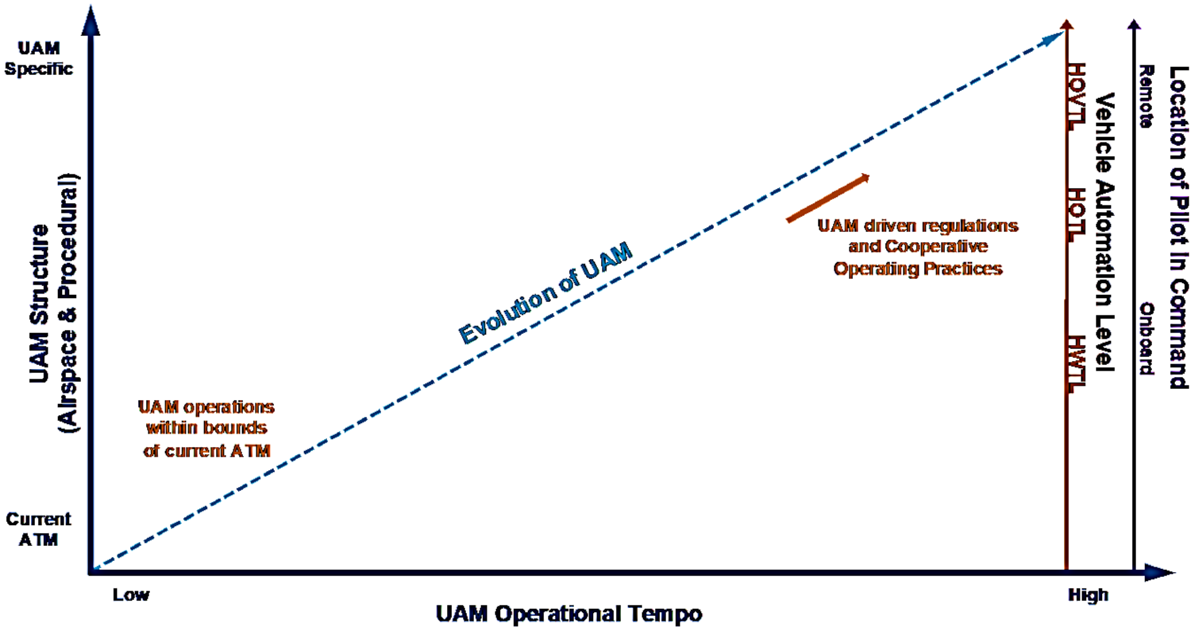


**Figure 45. Graph. Evolution of UAM operational tempo and associated environment.**

***Source: Federal Aviation Administration (2023b)***

According to Innovate28 (FAA, 2023c, July), the initial phase of AAM operations will seek to minimize interactions between AAM aircraft and existing air traffic, managed using currently available ATC infrastructure, procedures, and protocols. Piloted AAM aircraft are envisioned to operate under visual flight rules (VFR) in visual meteorological conditions (VMC) to be treated comparably to fixed-wing aircraft or rotorcraft operating under VFR conditions according to performance characteristics. The notion of VFR-only operations deviates from FAA (2023b), which suggests initial operations will operate under VFR and instrument flight rules. Additionally, the following rulemaking actions were specified in Innovate28:

- Proposed Amendment to Air Carrier Definitions
    - Encompass powered lift within these definitions, ensuring that the appropriate regulatory frameworks apply to the operations of aircraft classified as powered lift under FAA regulations, revisiting the contents of operations specifications and reevaluating the qualifications relevant to certain management personnel.
- Integration of Powered Lift: Pilot Certification and Operations
    - The goal is to identify the appropriate operational regulations that should temporarily apply to powered lift aircraft.
- Recognition of Pilot in Command Experience from Military and Air Carrier Operations
    - The rule extends the privilege of utilizing the 500-hour credit previously available to military pilots of fixed-wing airplanes to powered lift aircraft operations.
- Incorporation by Reference: Airman Certification Standards and Practical Test Standards for Airmen
    - Refine the existing regulations governing airman certification.

### Federal Perspectives Relevant to State Policy Development

One area that FAA (2023b) specifically references state and local governments is the suggestion to actively plan for UAM infrastructure to ensure transportation equity, market choice, and accommodation of demand for communities. This includes ensuring that vertiports and vertistops are sited properly to integrate into existing surface transportation, have zoning protections in place to protect operational airspace, and to account for growth based on FAA evaluated forecasts. In addition, FAA recommends that metropolitan planning organizations incorporate UAM infrastructure planning into larger transportation and utility planning efforts to ensure seamless coverage and capacity.

Last, it is important to consider the role that IDOT plays in the overall national context of critical infrastructure. The Department of Homeland Security defined Transportation Systems, which includes aviation, as one sector of the national critical infrastructure (CI), which includes identifying and mitigating vulnerabilities.

Some examples of vulnerabilities to consider: cybersecurity, global positioning system (GPS), power grid resilience, and space weather impacts.

## LAWS AND POLICIES FROM US STATES AND INTERNATIONAL CONTEXTS

FAA (2020a) released a set of regulations for the general use of UAVs. The new regulations permit operators to fly over people and during night hours, subject to specific conditions, on the condition that they have a remote identification (ID) for their drones. FAA stated that at the time of the announcement, over 203,000 remote pilots who had obtained FAA certification were registered in the system, controlling over 1.7 million drones. To enable SLTT governments to promote and collaborate with private industry to develop and test new UAM technologies, FAA (2017) created the Unmanned Aircraft Systems Integration Pilot Program, described earlier. The program allows participants to test innovative new technologies in real-world environments, while also helping FAA to develop regulations that can enable safe and efficient UAM operations. Within each participating state, laws were developed to support the planned operations, including defining legally associated terms.

Despite providing clear guidance and predictability on commercial UAV operations (FAA, 2016b), the 107 Rule still raises various uncertainties according to Kohler (2016). In 2018, FAA collaborated with the US DOT to release the ConOps for UTM as part of the NextGen initiative. The proposed operations for UTM in airspace Class G below 400 ft AGL introduces several principles and ensures equal access to airspace for all participants. In order to enable the use of commercial UAVs in the NAS, three actions should be taken according to Olsen (2017):

- Congress amendment of the 2012 Reform Act, provision of specific directives to the FAA.
- Establishment of regulations by FAA that indicate levels of safety rather than solely prohibiting activities such as pilot and line-of-sight requirements, drone automation, and flight over humans.
- Drone manufacturers should take the initiative to prove their drones' safety and reliability by conducting tests in FAA's six drone flight test areas. Amazon and DHL have already tested drone delivery systems successfully (similar to the way that Waymo has done with autonomous cars on public roads, tests for drone reliability and safety could be conducted by private firms).

However, laws and regulations can be different between UAS and AAM/UAM aircraft due to variations in size, flight range and speed, operational capacities, human presence, etc., which could lead to unique impacts in different domains (safety, privacy, environmental output, etc.). Nevertheless, the above does not prohibit the possibility of coexisting regulations for both categories and/or usage of one as a basis for the development of the other.

At the state level, several states have passed legislation aiming to promote AAM and UAM development. However, states do not regulate or control manned aviation. State policies influence the amount, location, and timing of air commerce it attracts. In addition, the operation of airports and heliports and the agreements for their services are made at the local level, not the federal level. A synopsis of the laws and regulations established by different government settings is summarized in Table 25 at state-level legislations, while categorizing them according to the verticals introduced earlier. All states not listed defer to FAA regulations for UAS operations. Table 26 lists a compilation of regulations in major cities (Drone Laws, 2023), with Table 27 presenting international laws and legislation. These tables can be found in Appendix A.

NASA formulated a set of principles based on prior work concerning UAM airspace integration concepts, technologies, and procedures that could change as NASA collaborates and learns with the UAM community and broader aviation community (Ravich, 2019). These principles consist of the following:

- UAM must require minimal additional ATC infrastructure (for instance, radar systems, controller positions) and minimal modifications to FAA automation systems employed for ATC.
- UAM should not impose any additional workload on controllers beyond their present responsibilities for existing airspace users.
- UAM should not impose additional requirements or burdens on existing airspace users beyond fair access to airspace resources.
- UAM should fulfill regulatory safety and security requirements for vehicle-level and system-level safety and security, including timely and guaranteed data exchange and the elimination of single points of failure and common failure triggers.
- UAM should be robust against a wide range of disruptions, such as weather and localized sub-system failures (e.g., single vehicle or software tool) to widespread disruptions (e.g., GPS failure).
- UAM should economically scale to high-demand operation with a minimal amount of fixed costs.
- UAM should support user flexibility and decision-making to the greatest extent possible.

EASA is currently the only regulator that has published dedicated technical specifications for eVTOLs. Under their “special condition for VTOL” specification, EASA has mandated that developers planning commercial passenger flights adopt a safety standard similar to that applied to commercial jetliners: a probability of just one catastrophic failure in one billion flight hours. EASA envisions air taxis operating with a high frequency and not solely from existing airports. FAA has not yet specified a target safety level but is likely to set the threshold at one catastrophic failure every 100 million flight hours, or 10 million flight hours. FAA’s approach to safety is philosophically different from EASA’s, as it places greater emphasis on redundancy and regards the pilot as an additional safeguard against disaster, especially considering that air taxis are mechanically simpler than jetliners.

## REGULATORY AND POLICY CONTEXT FOR ILLINOIS

At the state level, the Illinois General Assembly laws that are relevant to the AAM/UAM context begins with those laws pertaining to air transportation. Table 28 in Appendix A presents the list of Acts along with an estimation of potential relevancy to AAM/UAM operations and integration, with the caveat that the authors of this document do not have the legal credentials to fully determine relevancy. The assessment provided here is intended to provide an initial filter for applicable legislation for AAM/UAM operations and would require a more comprehensive legal review by qualified professionals. The following laws apply only to specific municipalities, cities, or counties within the state of Illinois and were created by various authorities across the state.

- **City of Evanston—2016**. This city ordinance establishes a moratorium on drone use until reasonable state and federal regulations are enacted.

- **Crystal Lake Park District—2015**. This park ordinance prohibits the operation of drones within any of the Park District properties, except when and where such use has been permitted by the special Parks Districts program or in designated areas.

- **McHenry County Ordinance.** This county ordinance prohibits drones from operating within any property owned by the district without prior written permission of the Executive Director.

- **Village of Schaumburg—2016**. This city ordinance prohibits the use of drones within 100 ft of the perimeter of any village property or on any village right-of-way during a special event.

### Connections with the Illinois Aviation System Plan

The Illinois Aviation System Plan (IASP), while very comprehensive across the many facets of the state's aviation system, only references AAM or UAM operations in a small set of sections rather than included within the plan holistically. Table 29 in Appendix A lists the sections of the IASP that contain content related to AAM/UAM operations, along with detailed descriptions. The current IASP references AAM/UAM vehicle technology, infrastructure needs, and a possible future air traffic scenario that requires consideration. The IASP should be modified to accommodate AAM vehicles and infrastructure needs more centrally into the system plan, if but for one reason alone: United Airlines, one of the world's largest air carriers and one of Illinois' largest employers, stated in their 2022 Annual Report that investing in eVTOL aircraft is one of their three major strategies for "redefining the future of air travel with environmental sustainability at the forefront" (United Airlines, 2023).

In support of their commitment, in 2021 United announced investments in eVTOL aircraft development at Archer Aviation, electric aircraft (Heart Aerospace), and hydrogen–electric engines (ZeroAvia) to advance technologies with a potential to help decarbonize air travel in the future once regulatory approvals are obtained. In 2022, they announced an addition to their eVTOL investment portfolio with Eve Air Mobility developing an electric four-seater aircraft. Along with the investment, United entered into a conditional purchase agreement for 200 aircraft with Eve, with expected first deliveries as early as 2026, once regulatory approvals are obtained.

## SYNTHESIS AND RECOMMENDATIONS

The federal, state, and local laws and policies presented in this section culminate in the following recommendations (in no particular order):

- **Recommendation #1: Continue to monitor the evolution of FAA/federal regulations on AAM and UAM.** FAA continues to evolve their thinking on the operational and regulatory environment for this aviation subdomain. Illinois policies should include methods to ensure alignment with future changes in federal regulations.

- **Recommendation #2: Develop flexible policies to account for the uncertainty of UAM/AAM adoption rates.** Due to the inherent uncertainty in the overall demand for these vehicles and the progressive adoption rates, it is recommended that Illinois policies are designed with the breadth of demand in mind.

- **Recommendation #3: Develop policies that enable AAM/UAM to easily integrate with existing transportation systems.** A well-integrated transportation system encourages use and supports economic growth. This includes both enabling UAM/AAM aircraft to integrate into the Illinois Aviation System (as well as surrounding states within operational range) and connecting to surface transportation systems to enable doorstep-to-doorstep trip-making by UAM/AAM segments.

- **Recommendation #4: Modify the Illinois Aviation System Plan to include integration of AAM/UAM and eVTOL aircraft operations throughout all aspects.** Currently the IASP is written referencing AAM/UAM as a possible future air-traffic scenario that requires consideration. The IASP should be modified to accommodate AAM vehicles and infrastructure needs more centrally into the plan.

- **Recommendation #5: Append the IL Aviation System Plan to address vulnerabilities throughout the system.** Currently the IASP does not consider identifying and addressing Critical Infrastructure disruption vulnerabilities such as cybersecurity, electrical grid, natural disasters. A burgeoning AAM/UAM system would be particularly vulnerable.

- **Recommendation #6: Develop strategies to educate and notify local jurisdictions across the state of Illinois on statewide strategies, policies, and relevant laws.** Developing a strategy to inform and educate local jurisdictions on AAM/UAM-related laws and policies will help to ensure the success of statewide strategies. Failure to adequately include local jurisdictions may result in counterproductive local ordinances that limit the ability to successfully implement AAM or UAM plans or strategies.

# CHAPTER 7: ECONOMIC, ENVIRONMENTAL, AND SOCIETAL IMPACTS OF AAM

This chapter is devoted to identifying the potential economic, environmental, and societal impacts of AAM services in Illinois. A quantitative analysis based on time series models was formulated in order to express economic and environmental impacts with a monetized value, following the concept developed for the state of Ohio by Dulia et al. (2021). However, due to the complexity of the social aspects of AAM, quantification was done through a different path, emphasizing a noise pollution analysis, with further aspects analyzed at a conceptual level. Appendix C presents the methodological paths in detail.

## ECONOMIC IMPACTS

The advent of AAM holds substantial promise for engendering noteworthy economic impacts on both federal and state scales, with some impacts briefly presented below:

- Increased accessibility
- Health-related quality of life
    - A potential reduction of gas emissions by using fewer combustion engine vehicles
    - Faster response times in remote areas to potential accidents and/or provision of access in areas that current modes cannot provide such a service
- Reduction in travel times, leading to increased productive time, increased number of trips
- Increased employment opportunities
- Opening of new markets
- Federal and state revenue increase (e.g., through taxes)
- Domestic manufacturing opportunities
- Competition between existing markets
- Reduction in transportation cost
- Increased quality of service due to competition
- Land value increase
- Land availability reduction
- Increase of prices in batteries and materials related to battery charging
- Investment hazard due to the uncertainty of how the market will be shaped eventually

To estimate the economic impacts of AAM in Illinois, time series approaches were used, with two different methods being considered: a deep learning model and an auto-regressive integrated moving average (ARIMA) model. While historical data offers valuable insights into potential cost savings, the existence of impacts stemming from the evolving landscape of technology, regulatory frameworks, market conditions, and others, should be taken into account in such forecasts, and thus the various cost estimates should be used as benchmarks. The cost values and factors used in all the following formulations and calculations were adjusted to 2022 U.S. dollar values.

## Passenger Travel Time Benefits

Focusing on the ability of AAM services to provide reduced travel times, a cost-savings analysis was conducted, forecasting the annual savings that Illinois could achieve. Figure 46 presents different AAM market-share scenarios, with the magnitude of benefits in cost and travel time savings varying. Notable savings can be achieved even at the worst-case scenario.

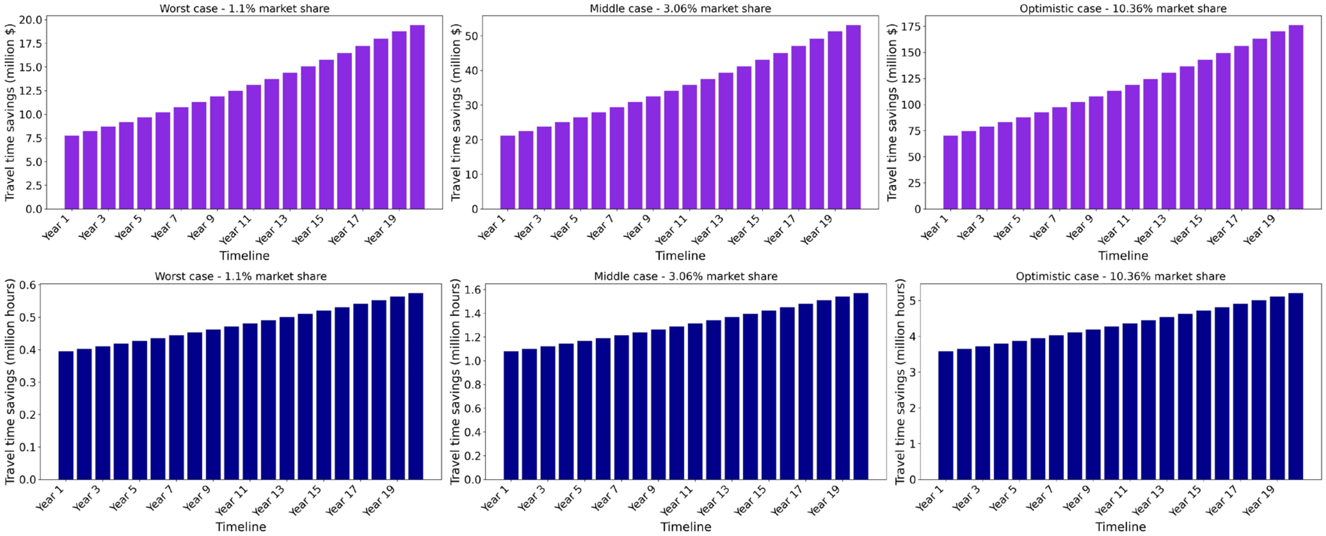


**Figure 46. Chart. Annual monetary and unit time passenger travel time savings.**

## Medical Emergency Benefits

Benefits from people surviving outside of hospital cardiac arrest (OHCA) episodes due to faster delivery of medical equipment and faster medical support in Illinois can be observed in Figures 47 and 48. The decline from Year 1 to Year 19 is due to the reduction in the forecasted Illinois population, from the historical data used.

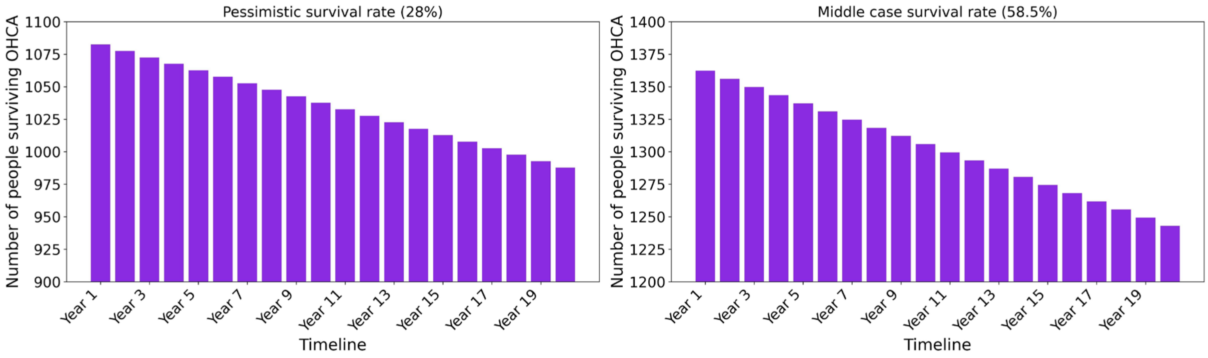


**Figure 47. Chart. Number of individuals surviving OHCA due to UAV support.**

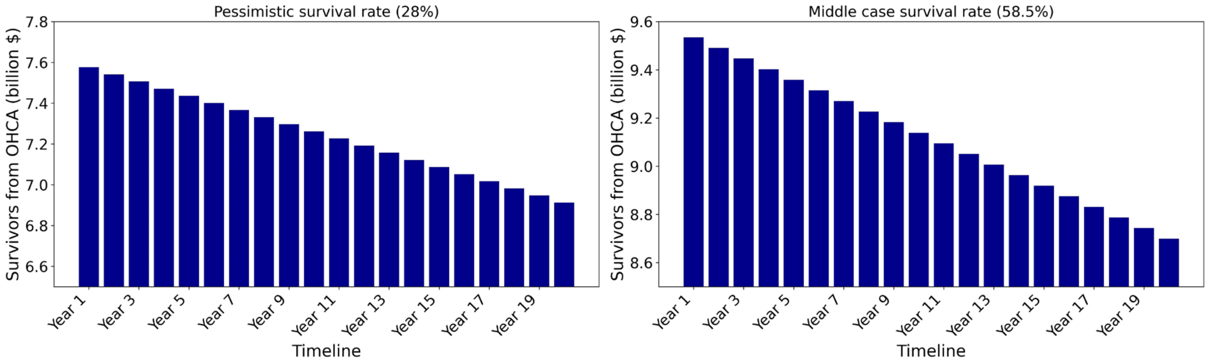


**Figure 48. Chart. Monetary gains from OHCA survivors due to UAV support.**

## Driving-Related Accident Benefits

Travelling with VTOLs and STOLs is projected to be a safer mode than ground transportation (Dulia et al., 2021; Oakey et al., 2022; Ackerman et al., 2021). Based on that assumption, the monetary benefits from reduced injuries and fatalities from the use of AAM aircraft instead of ground vehicles were forecasted, as shown in Figure 49.

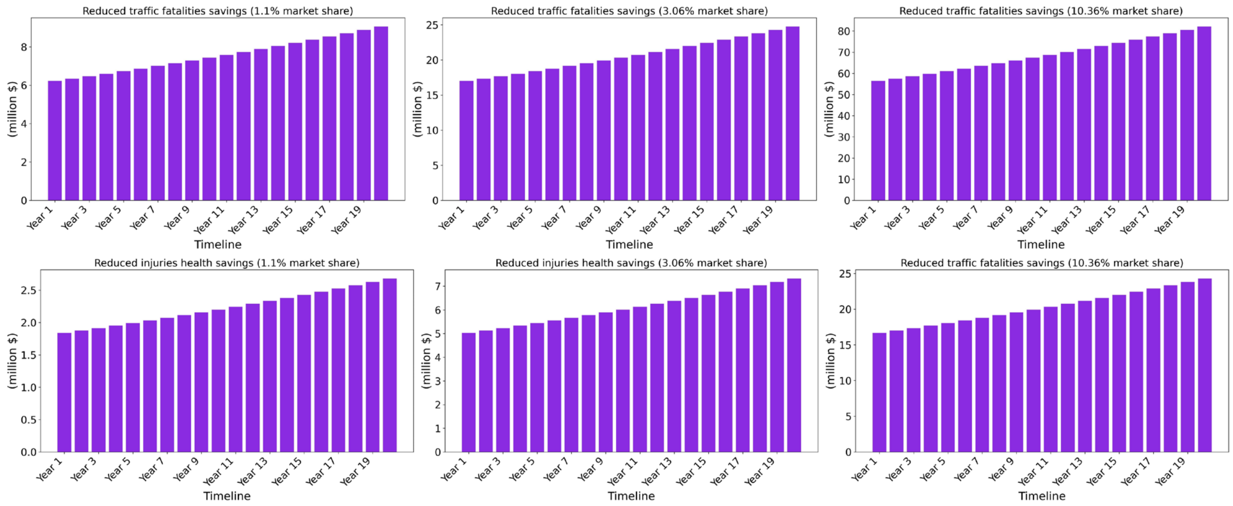


**Figure 49. Chart. Savings from reduced injuries and fatalities.**

## Cargo Delivery Benefits

Last-mile package delivery is a prominent AAM concept, with various companies already implementing it in an effort to reduce delivery cost and times as well as have a milder environmental footprint, etc. Figure 50 presents the drone delivery market size forecast in Illinois. Additionally, by shifting 53.5% of the total parcels delivered by UAVs, $194,140,800 annual operational cost savings, along with $8,474,400 on travel time cost savings, can be achieved.

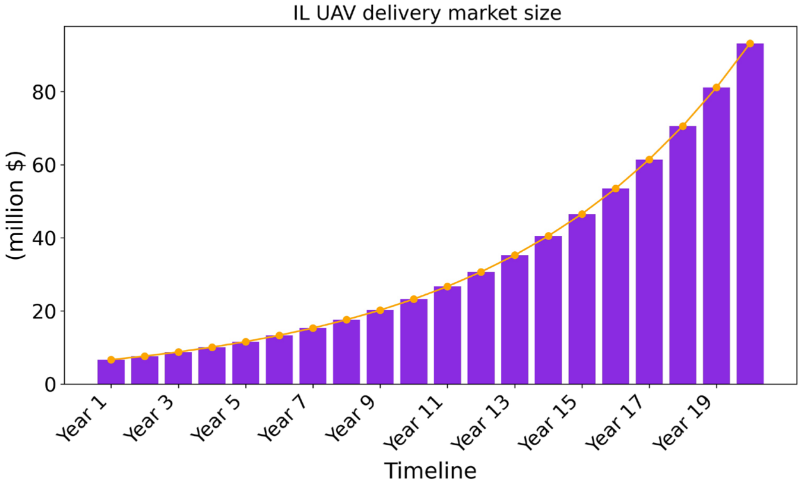


Figure 50. Chart. Package delivery gains from UAV usage.

## Bridge Inspection Benefits

With almost 27,000 bridges and a third-place national ranking for structurally defective bridges, Illinois could potentially witness notable benefits from adopting inspection AAM services. Due to more efficient bridge inspections with the usage of UAVs, 920,266 hours lost in traffic could be saved annually in Illinois. Figure 51 presents the annual forecasted operational savings from bridge inspections.

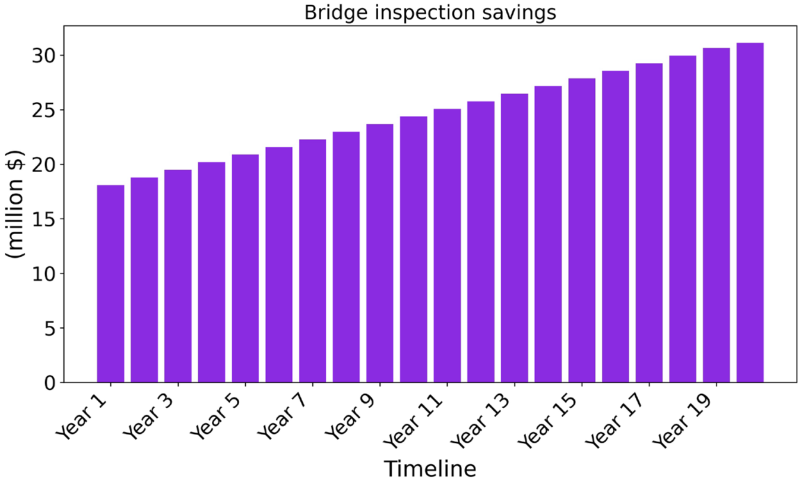


Figure 51. Chart. Bridge inspection operational savings from UAVs usage.

## Agriculture Benefits and Cost Savings

The two main crops grown in the state, and for which Illinois is a major US producer, are corn and soybeans (Stovall, 2016). Additionally, wheat and livestock have a strong presence, so they were also accounted for in the forecasting. Figure 52 presents the monetary gains from the introduction of UAVs in the agricultural domain. Wheat and soybeans have a steady savings profile, with corn, however, having an increasing annual profile. The decline in livestock labor savings comes from the fact that a significant reduction in livestock population was forecasted over the studied period.

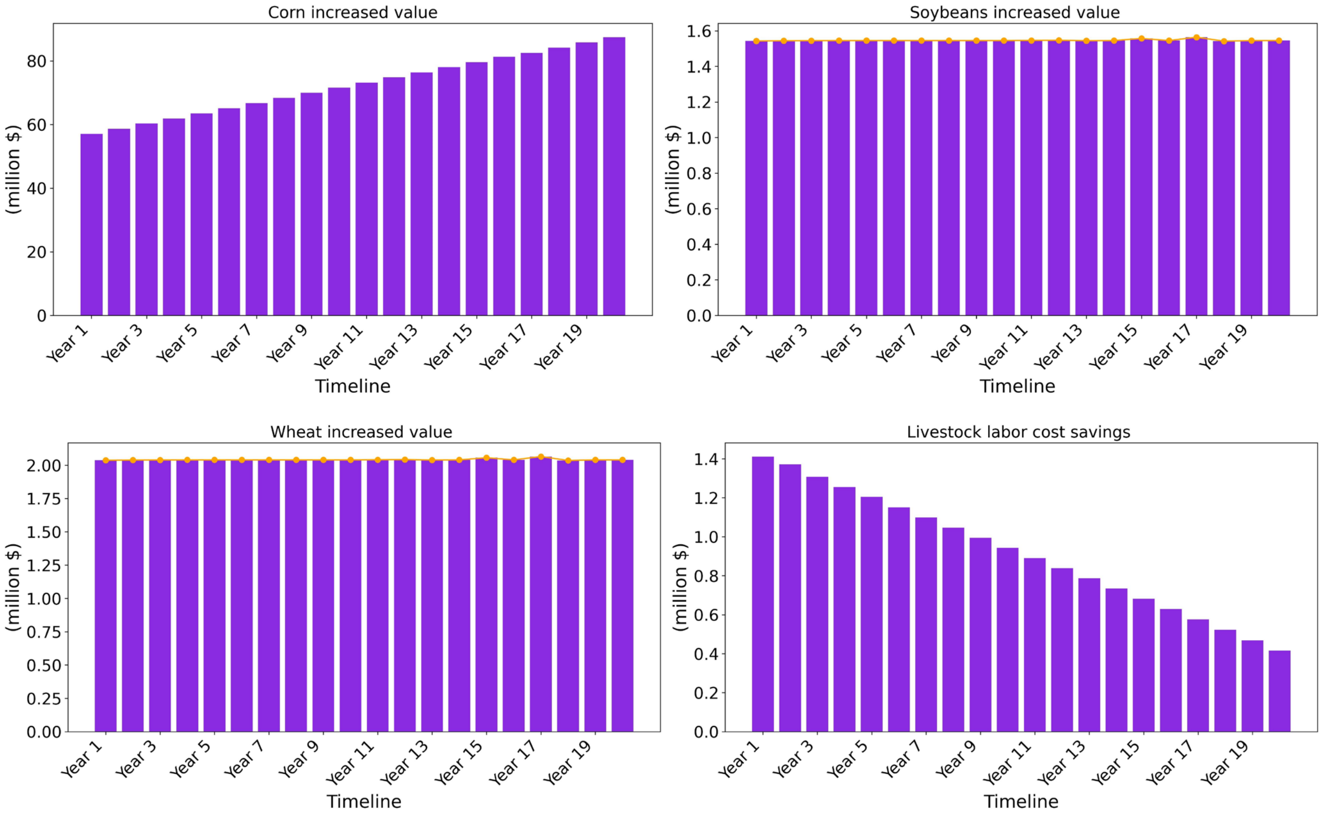


**Figure 52. Chart. Agriculture-related monetary projections.**

## Tax Revenue

AAM services would potentially have to follow tax policies at the federal, state, and county level, similar to ground and aviation transportation tax policies. In the state of Ohio, based on a 25-year forecast, the amount of tax revenue is going to be at the scale of billions, with $2.5 billion being the approximation, from which $1.5 billion would go to the federal government and $1 billion to the state government (Del Rosario, 2021). Based on the methodology followed, Illinois was estimated to have an annual state revenue of $157,263,600 from AAM operations taxes.

## Benefits from Employment Opportunities

Direct benefits in terms of job opportunities can account to over 9,000 jobs, with a total benefit impact (combining direct, indirect, and induced benefits) accounting to 16,967 jobs by 2040, in that

20-year span, for the Greater Vancouver region (Herman et al., 2020). In monetary value, that number accounts for an incremental gross domestic product of $2,168,411,000. According to the authors, industries with higher job growth will be:

- Transportation
- Retail trade
- Finance (insurance, real estate, rental, leasing and holding companies)
- Professional, scientific, and technical services
- Accommodation and food services

The main occupation categories that will witness higher growth levels are as follows (Del Rosario, 2021):

- Engineering and Intelligent Transportation Systems
  - Safety Engineering
- Advanced Air Mobility Operations
  - Advanced Air Mobility Operational Support
- Quality Control
- Vehicle Design and Manufacturing
- Medical and Emergency Services
- Travel Support Services
- Business and Financial Operations
- Hospitality

## ENVIRONMENTAL IMPACTS

As AAM services are not yet deployed, environmental impacts will be estimated for future possible scenarios under a range of assumptions. As in previous sections, it is essential to consider the implications of various factors on these forecasts and acknowledge that these cost figures should be used as a benchmark and not specifically as actual monetary values. Similarly to the economic impacts section, all monetary values here were adjusted to 2022 U.S. dollar values.

Before delving into findings specific to Illinois, a broader review was conducted to convey a broader picture of the potential environmental outputs of AAM. A number of AAM aircraft are going to depend on electric energy, and, therefore, the amount of carbon dioxide produced depends on the energy mix. The more renewable energy is included in the mix, the less carbon dioxide is produced overall (Liberacki et al., 2023). Regarding the operator's cost for emitted GHG emissions, and $CO_2$ in particular, 18% of the total $CO_2$ emitted needs to be paid by the operator. However, from the Office of Energy Efficiency and Reliable Energy (2022), Illinois does not have (so far) a carbon dioxide tax (only a few states such as California have already implemented such actions).

Battery electric vehicles (BEVs) consume less energy than eVTOLs and also discharge less GHG emissions, even though the ground travel time and milage are higher than the ones in the air (Pukhova, 2019). AAM flight emissions rise compared to the equivalent ground distance travelled, given that commuters would have to travel longer to access and egress a vertiport. However, when internal combustion engine vehicles (ICEVs) are considered, an AAM-based trip has a lower carbon footprint than the equivalent ground trip.

Donateo and Ficarella (2019) presented the potential benefits of an electrified air taxi over a hybrid-electric road taxi using current technology. Figures 53 and 54 compare eVTOL emissions related to travel distance, different technology states, and other transportation modes.

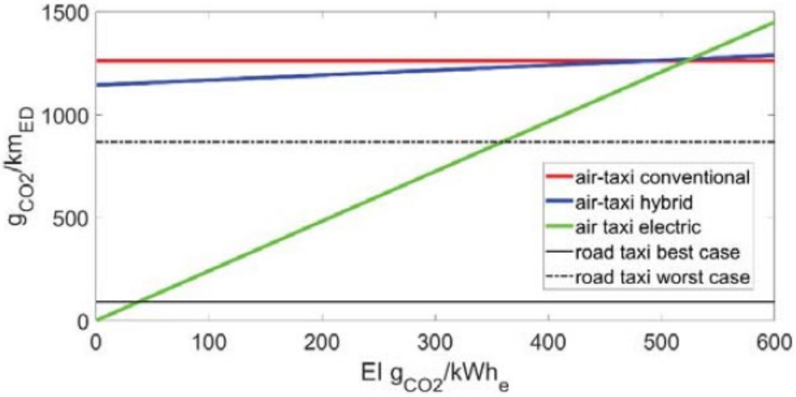


**Figure 53. Chart. Comparison of $CO_2$ per km with today's technology.**

*Source: Donateo & Ficarella (2019)*

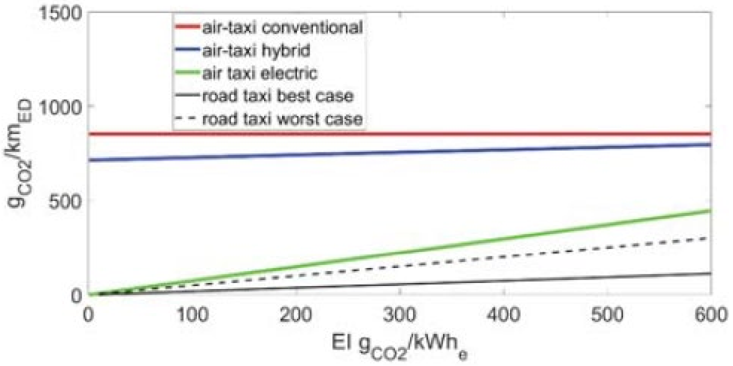


**Figure 54. Chart. Comparison of $CO_2$ per km with 2035 technology.**

*Source: Donateo & Ficarella (2019)*

The comparison with a fully electric road car in the case of 2035 technology was unfavorable, but the wheel-to-wheel emissions with an anticipated emission intensity of 90 g/kWe were quite low (67 g/km). That value is equal to 107.78 g/mile of GHG. While eVTOLs seem to be unable to compete with ground EVs (yet), the case is slightly different when compared with ICEVs, since light-duty vehicles emit 348 g/mile on average (Office of Energy Efficiency and Reliable Energy, 2022), meaning that the amount of gases emitted by eVTOLs is 69% lower than those emitted by ICEVs.

ICEVs outperform VTOLS up to 35 km, where aerial flying is dominated by the energy-demanding hover mode (Kasliwal et al., 2019). For trips greater than 50 km, VTOL emissions fall sharply below those from ICEVs. A VTOL has GHG emissions that are 35% lower than those of an ICEV, but 28% higher than those of a BEV, for a 100 km trip. Figure 55 presents how different passenger loads can make a VTOL trip more eco-friendly by distributing the emissions per individual and comparing it with BEVs and ICEVs.

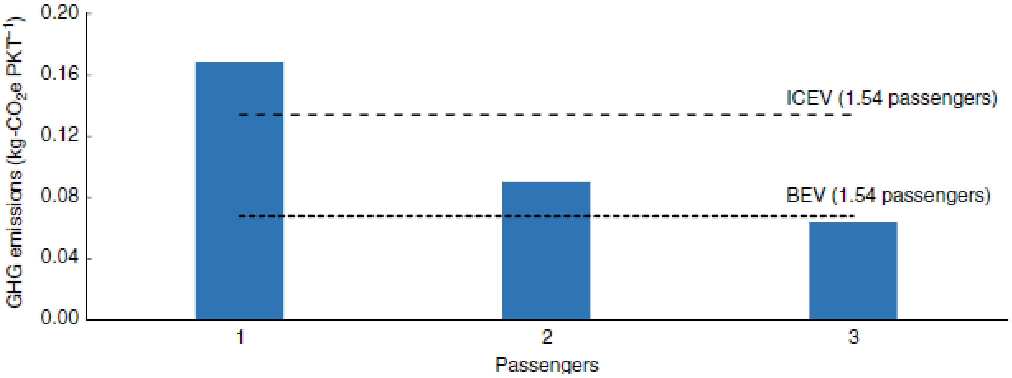


**Figure 55. Chart. GHG emissions over different pax loads.**

***Source: Kasliwal et al. (2019)***

Pukhova (2019) introduced a specific eVTOL aircraft type (denoted as MC Heavy), which was compared in terms of GHG emissions with other ground transportation modes. Figure 56 shows that when MC Heavy travels its maximum distance of 47.25 km, it produces the same amount of $CO_2$ emissions per kilometer as conventional diesel- and gasoline-powered vehicles. When considering a distance of 20 km or more, the amounts of NOx emissions released by an eVTOL are lower than those released by diesel-powered vehicles (Figure 57).

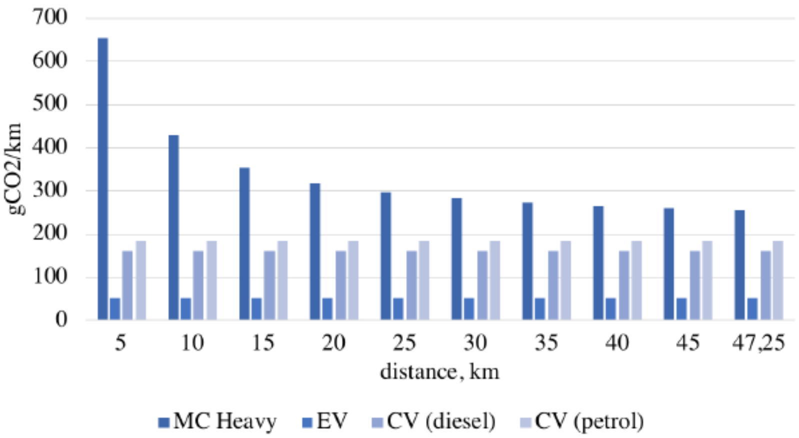


**Figure 56. Chart. Amount of $CO_2$ gases released per kilometer travelled from different transportation modes depending on the trip distance.**

***Source: Pukhova (2019)***

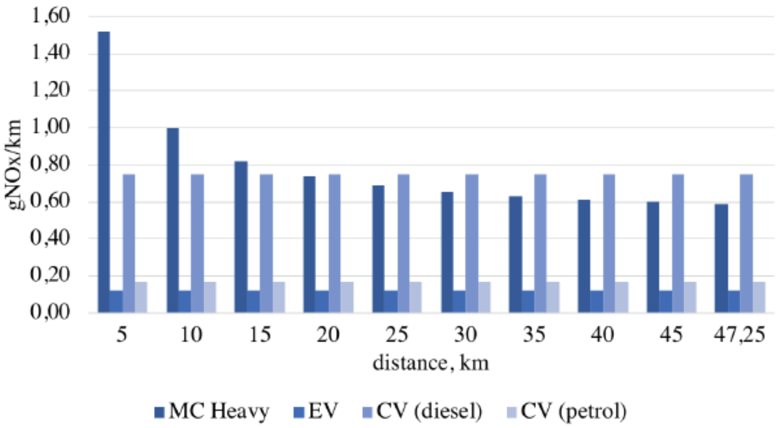


**Figure 57. Chart. Amount of NOx pollutants released per kilometer travelled from different transportation modes depending on the trip distance.**

***Source: Pukhova (2019)***

Figure 58 presents the yearly health social cost savings in Illinois from reduction in GHG emissions due to a portion of total trips being satisfied with AAM services.

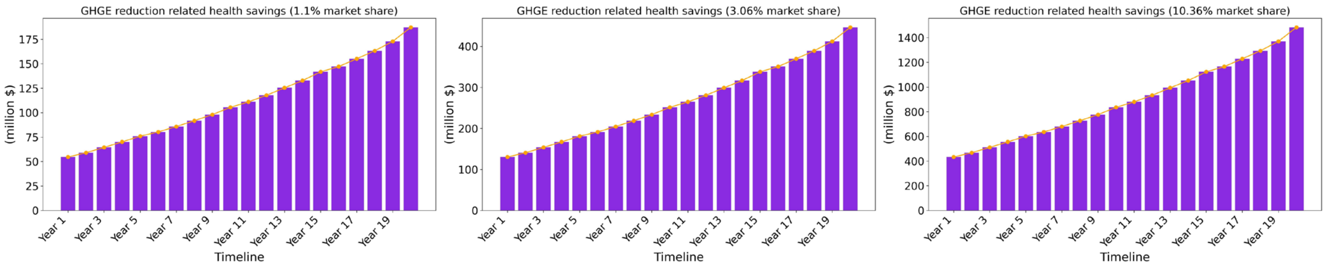


**Figure 58. Chart. GHG emissions reduction related health savings.**

## SOCIAL IMPACTS

As society witnesses the convergence of technological innovation, urbanization, and environmental consciousness, the potential societal impacts of AAM are of paramount significance. This section delves into a comprehensive exploration of the social consequences stemming from the integration of AAM into modern life. The social acceptance of AAM will depend on addressing six key areas of social impact: safety, noise reduction, emissions, privacy, land use, and visual pollution. By examining the multifaceted dimensions of accessibility, urban planning, economic dynamics, environmental stewardship, and cultural transformation, this section seeks to elucidate the potential societal impacts engendered by AAM.

### Social Impacts Summary

The primary obstacles for potential users of AAM services are safety concerns, cost, and infrastructure limitations. Among these, addressing safety concerns is of utmost importance in enhancing the acceptability of AAM. Experts have emphasized the need for a safety assurance process to create a positive perception of AAM and convince the public of its safety. For instance, conducting pilot tests to directly demonstrate the safety aspect of such services would be beneficial. Additionally, establishing government systems that manage UAM safety and setting standards are critical steps toward ensuring safe AAM operations. In order to offer a satisfactory level of service and substantial time savings that justify the selection of urban air transportation (UAT), the operator commits to minimizing the delays caused by waiting times and passenger relocations (Ale-Ahmad & Mahmassani, 2023). The findings demonstrate that the ability to provide expedient service while efficiently relocating passengers on the ground heavily relies on the speed and dependability of ground-based transportation. Key factors influencing the acceptance of AAM across all phases are the affinity for AAM and willingness to pay. As safety concerns are addressed, cost becomes the second most important factor, and those who see UAM as a viable alternative mode of transportation are more inclined to use the service. These findings align with those of Reiche et al. (2018), who emphasized the significance of familiarity with the AAM concept. Moreover, early adopters are more likely to use UAM, as observed in the initial stages of AV adoption. However, studies conducted in the United States (Reiche et al., 2018) as well as in other locations including Europe (Park, 2021) show that young people or high-income groups are more likely to use UAM.

Biehle (2022) examined the potential impact of passenger AAM services on the socially sustainable aspects of urban transportation. In summary, the introduction of AAM is likely to have a negative impact on the social sustainability of European urban mobility systems. The cost is expected to be too high for many people without public subsidies, and demand for added value must be present in the local community before such subsidies are granted. The inclusivity of urban transportation systems may also suffer if mobility-impaired groups are not considered in planning authorities’ standards. While vertiport operation in developed urban areas may not improve accessibility, mobility hubs in suburbs and rural areas could positively impact the access indicator. Finally, the overall quality of urban public spaces may be negatively affected, but legal competences for urban airspace planning and civil society participation at the local level could mitigate that impact.

Park (2021) studied the willingness of both the public and experts to use AAM services, including traditional helicopters, eVTOLs, remotely piloted aviation systems (RPAS), and a completely autonomous system. Results of a stated preference survey showed that experts exhibit a more positive attitude toward using AAM services compared to the public. This could be attributed to their superior knowledge of autonomous and electric technology as well as higher expectations of achieving related goals. However, the public does not exhibit significant resistance toward AAM, possibly because of prior exposure to electrification following the emergence of electric cars. While experts' willingness to use AAM services does not decrease when switching to unmanned vehicles, the public tends to become more hesitant due to safety concerns and a lack of understanding about the technology. In particular, the absence of a pilot is a significant factor that affects the public's willingness to use RPAS.

The identified social impacts related to AAM are briefly presented as follows:

- Social equity
    - Affordability of service
    - Inclusivity of different groups
    - Equitable land use regarding AAM ground infrastructure
- Uncertainty regarding flight safety
- Job displacement in the traditional transportation industry, particularly in sectors such as taxi and ride-sharing services. It is important to consider the potential impact on workers and provide support for those who may be impacted.
- Noise pollution
- Visual pollution
- Privacy concerns
- Infrastructure requirements that could lead to land use–related issues
- Potential electric grid limitations (increased energy prices, regulations, etc.)
- Increased accessibility to transportation, particularly in urban areas where traffic congestion is a significant problem, reduced commuting time, easier for people to access essential services (health care services)
- Potential to be more environmentally friendly than traditional modes of transportation
- Increased mobility for people in areas with limited transportation options. This can be particularly beneficial for people with disabilities or those living in rural areas.

- Support emergency services, such as medical evacuation or rescue operations
- Significant economic impact, creating new job opportunities and driving innovation. This can lead to economic growth and increased competitiveness in the global market.
- Could play a critical role in disaster response and relief efforts. They can help deliver supplies and personnel to disaster-stricken areas quickly and efficiently, reducing the time it takes to provide aid.
- Could help improve public safety by reducing the risk of accidents caused by overcrowded roads or poor infrastructure.
- Improved and increased connectivity between cities and rural areas. This can help bridge the gap between urban and rural communities, improving access to jobs, healthcare, and education.

## Accessibility and Affordability

One of the primary equity issues with AAM is access. If AAM services are accessible only to a specific portion of individuals, it could lead to increased disparities in transportation options and mobility. The “logical” path would be to follow the market and focus on locating vertiports in areas with high demand. This strategy, however, could create uneven distribution of accessibility in a network, leaving a significant number of people without easy access to such services. Inclusivity of groups with mobility restrictions and affordability regarding low-income groups are also important parameters to consider (Biehle, 2022).

Due to the higher energy efficiency of eVTOLs compared to helicopters, AAM is predicted to become affordable and suitable for large-scale operations using eVTOLs (Holden et al., 2016). Based on Grote et al. (2022), concerns about shared airspace exist, such as costs allocation and equitable access. Funding AAM infrastructure will start with private investments before involving public investments until later stages of the mode. Air taxis are expected to be operated by third-party operators rather than be privately owned by individuals. Integrating UAM in multimodal transportation systems is one of the goals of operators to ensure the overall comfort of passengers (Holden et al., 2016). This integration could increase coverage in certain networks and accessibility, especially between suburban cities and the central business district. Travelers on regional trips could benefit in particular from AAM, as these trips typically include either a few hours by car/public transportation or an expensive flight on commercial airlines. Operators like Uber also mentioned that accessibility to all riders’ needs might not be targeted in the initial phase of AAM but is planned to be addressed in the development of the system (Holden et al., 2016). Social equity implications are also mentioned by Cohen and Shaheen (2021) as highly important, with current aviation services having an average of $150–300 per seat, which makes it not affordable for an increased portion of the population (2020 U.S. dollar values). Air taxis would cost $8–18 per minute of flight (2021 U.S. dollar values), showing there is a high uncertainty of how the cost of such services will be shaped (Sider, 2021).

## Privacy

Privacy and how AAM is going to operate without crossing the line of violating people's privacy is a consideration, with individuals being skeptical as passengers as well as non-users of the service (Goyal et al., 2018). Data privacy concerns could be a reason that people will be skeptical about AAM, due to collection, storage, and management of data that could violate somebody's privacy (Cohen & Shaheen, 2021). A requirement for clearance above residential properties is needed to protect privacy of individuals and gain public trust (Holden et al., 2016). UAVs will redefine the concept of privacy, as traditionally it is defined as the right to not be observed or disturbed within one's private property or not be observed in public beyond the eye-sight limit.

On the other hand, in case of personal injury or collision, insurance companies would need enough information to make a judgement such as flight path, take-off and landing takeoff and location, and the intent of flight (Rao et al., 2016). This means that storing some data might be crucial for judgement of liability in case of accidents. But authorities should control who accesses this data and limit it to the UTM system. Another strategy could be to limit data collection capabilities to only certain AAM operations as needed while denying or limiting these capabilities for other operations such as for package delivery and eVTOLs used for passenger or cargo delivery.

## Safety Issues

One of the primary safety concerns with AAM is the risk of collisions. This includes the safety of passengers as well as any residents who may be affected by a collision between two aircraft. The risk of collisions mainly arises due to errors in perception and sensory equipment, cyberattacks on the control system of an autopilot-run UAV, or pilot errors. The last of these causes concerns regarding public trust, but the stringent training and certification programs for pilots over the past decades have instilled confidence in them. The development of reliable sense-and-avoid technology will be essential to mitigating this risk. Another safety concern is the potential for human error. Pilots will still be required to fly AAM aircraft, and there is always the potential for human error in any form of transportation. The implementation of automated systems and artificial intelligence could help to reduce the potential for human error, but this must be balanced with the need for human oversight.

In addition to these concerns, safe AAM operations will also depend on the development of appropriate infrastructure. This includes the design and construction of landing pads and other infrastructure as well as the integration of AAM with existing air traffic control systems. Coordination between multiple aircraft in a small airspace is a critical safety issue that will need to be addressed. Furthermore, AAM introduces new challenges for emergency response. While traditional emergency services are well-equipped to deal with accidents on the ground, the infrastructure and procedures for dealing with accidents in the air will need to be developed. This includes the development of rapid response teams capable of dealing with mid-air emergencies and the establishment of protocols for coordinating emergency responses with traditional ground-based services.

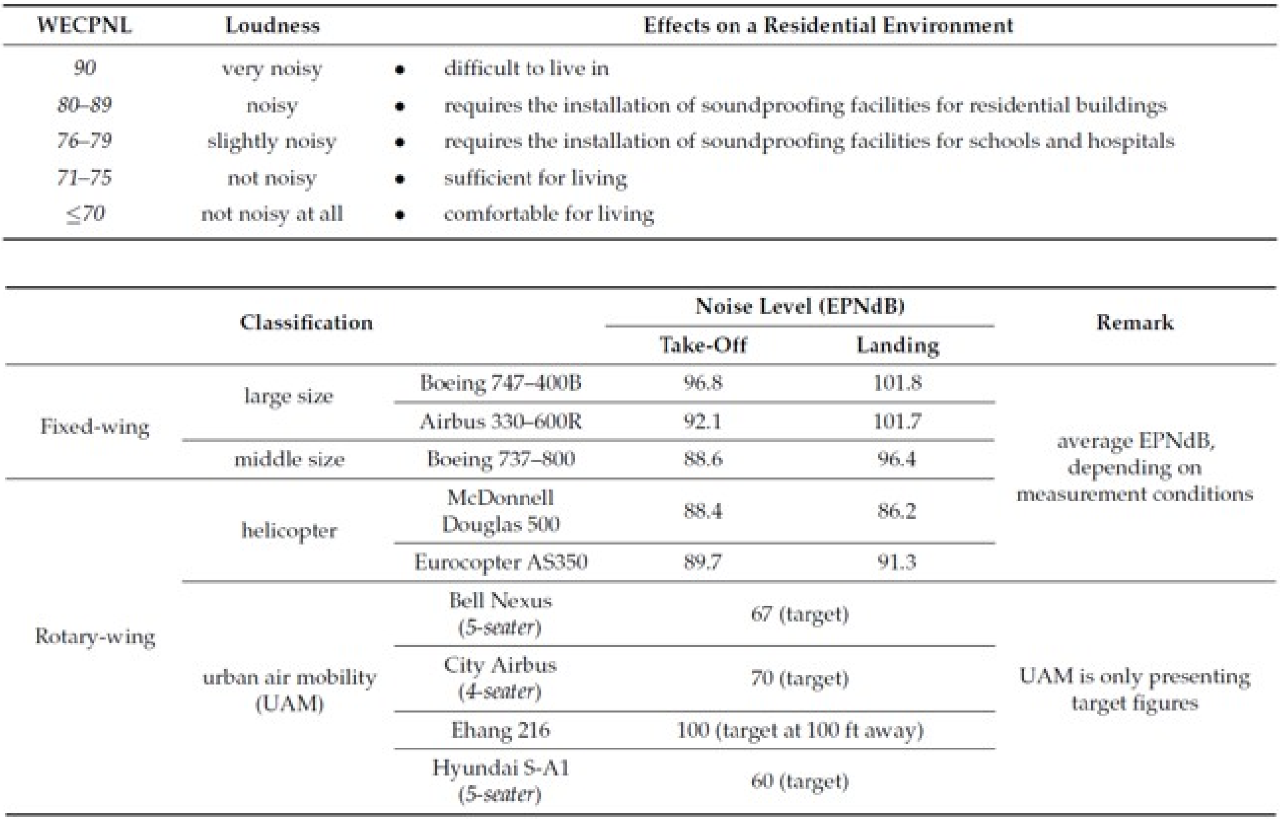
## Noise Pollution and Societal Impacts from AAM Aircraft Operations

eVTOLs have the potential to be quieter than traditional helicopters and fixed-wing aircraft, but they are still likely to generate a significant amount of noise. The impact of noise pollution from AAM aircraft could be significant, particularly in urban areas where noise is already a major issue. According to the World Health Organization, excessive noise can have a range of negative impacts on human health, including hearing impairment, cardiovascular disease, sleep disturbance, and annoyance. In urban areas, noise pollution is already a significant problem, with traffic, construction, and industrial activities all contributing to high noise levels. The addition of AAM aircraft to the mix could exacerbate these issues and lead to further negative impacts on health and well-being.

### *Community Thresholds*

Li and Lee (2021) studied noise generation from VTOLs, considering different scenarios regarding altitude of the aircraft, passengers on board, aircraft type, and more. They found that when carrying an equivalent payload at an altitude of 250 ft, the broadband noise generated by a multirotor AAM aircraft is roughly 10 dB lower than that of a traditional single rotor helicopter. Nevertheless, a 10 dB decrease in noise may not be adequate to satisfy public acceptance of AAM.

Noise pollution is generated both during take-off and landing as well as during the flight of aircraft in the designated altitude (300–600 m is an average altitude of operation) (Kim, 2022). Figure 59 shows a comparison between current aircraft of different types in terms of noise pollution.



| WECPNL | Loudness | Effects on a Residential Environment |
|---|---|---|
| *90* | very noisy | • difficult to live in |
| *80–89* | noisy | • requires the installation of soundproofing facilities for residential buildings |
| *76–79* | slightly noisy | • requires the installation of soundproofing facilities for schools and hospitals |
| *71–75* | not noisy | • sufficient for living |
| *≤70* | not noisy at all | • comfortable for living |

| Classification | | | Noise Level (EPNdB) | | Remark |
|---|---|---|---|---|---|
| | | | Take-Off | Landing | |
| Fixed-wing | large size | Boeing 747–400B | 96.8 | 101.8 | average EPNdB, depending on measurement conditions |
| | | Airbus 330–600R | 92.1 | 101.7 | |
| | middle size | Boeing 737–800 | 88.6 | 96.4 | |
| Rotary-wing | helicopter | McDonnell Douglas 500 | 88.4 | 86.2 | |
| | | Eurocopter AS350 | 89.7 | 91.3 | |
| | urban air mobility (UAM) | Bell Nexus (*5-seater*) | 67 (target) | | UAM is only presenting target figures |
| | | City Airbus (*4-seater*) | 70 (target) | | |
| | | Ehang 216 | 100 (target at 100 ft away) | | |
| | | Hyundai S-A1 (*5-seater*) | 60 (target) | | |

**Figure 59. Graph. Noise comparison between different aircraft.**

***Source: Kim (2022)***

Addressing early the concerns of the impacts of noise pollution and successful initial flight operations could have negative impacts if communities are not prepared in advance (Rizzi, 2020). The future electrification of ground transportation will lead to a reduction of ground transportation–generated noise, which would make UAM noise more intense for communities (Cohen et al., 2021).

Glaab et al. (2019) discussed the outcomes of systems-level simulations for UAM aircraft in New York. With 32 operations per hour, nearly all of Manhattan is exposed to noise levels over 60 dB, with some areas in Queens and Brooklyn also exceeding 60 dB. In the case of 128 operations per hour, most of Manhattan will experience noise levels over 65 dB, with certain areas reaching 70 dB. Although the 128 vehicle per hour case exceeded the 50 dB target for the work shown, the noise level results comply with FAA regulations. In this case, the noise levels were 55 dB in the interior of Manhattan and 65 dB in the vicinity of the vertiports.

There are no clear regulations for the noise-level thresholds for AAM aircraft yet, and while they are expected to have less noise levels than helicopters, assessing the accepted threshold of noise levels is dependent on people’s tolerance. Although people have accepted noise generated by trains, one could argue that trains are relatively accessible to everyone. Schomer et al. (2012) studied the influence of community tolerance level (CTL) in noise annoyance, and the results showed that the average CTL among communities is 73.3 dB for an aircraft, which is perceived to be more annoying than road traffic or rail (without vibration) and also showed that duration of exposure to loud noise affects the annoyance level. Kalakou et al. (2023) recognized the importance of noise impacts as one of the most significant AAM barriers. Assessing noise levels from different aircraft and communities’ tolerance levels will play an important role in vertiport placement, especially due to the higher noise levels at departure and arrival corridors (Neuman, 2016).  Uber reports that the noise caused by eVTOLs will not be higher than background noise even at take-off and landing (Holden et al., 2016). Historically, communities have had higher tolerance to noise caused by activities that serve the public good or are deemed important such as for medical transportation and lower tolerance for less important and private noise sources (Holden et al., 2016).

### *Quantification of Noise Impacts*

One of the challenges of assessing the potential impact of UAM noise pollution is the lack of data on the topic. There are currently few studies or measurements of the noise generated by UAM aircraft, and the available data are often based on simulations or estimates. However, some initial data suggest that the noise levels from UAM aircraft could be similar to those produced by helicopters, which are already a significant source of noise pollution in many urban areas. For example, a study by NASA found that a small eVTOL aircraft could generate noise levels up to 80 dB at 244 m, which is similar to the noise level of a helicopter at the same distance. According to a report by the World Health Organization, noise pollution can have negative impacts on human health, including cardiovascular disease, cognitive impairment, and sleep disturbance. The report also notes that noise levels above 55 dB can be harmful to health and that noise levels above 75 dB can cause hearing damage. Currently, there are no widely adopted noise standards specifically for UAM aircraft. However, FAA has established noise standards for other types of aircraft that could be used as a reference for future UAM noise standards. For example, FAA’s Stage 4 noise standard for large commercial aircraft limits the noise level to 75 dB during takeoff and landing.

Ground noise metric data regarding a specific helicopter type (MD-902) were used (Greenwood, 2018) in a 1500 ft altitude above ground level, at a 60 knot, 950 fpm descent to create a potential UAM route based on Archer's and United Airlines' announcement of connecting O'Hare Airport with Vertiport Chicago. Additionally, a population density map of the Chicago area was created as well as the following noise contour maps (Figures 60 and 61) to quantify the potential noise impacts that UAM routes could have (data from ArcGIS Hub, 2022; Wikimedia Foundation, 2023).

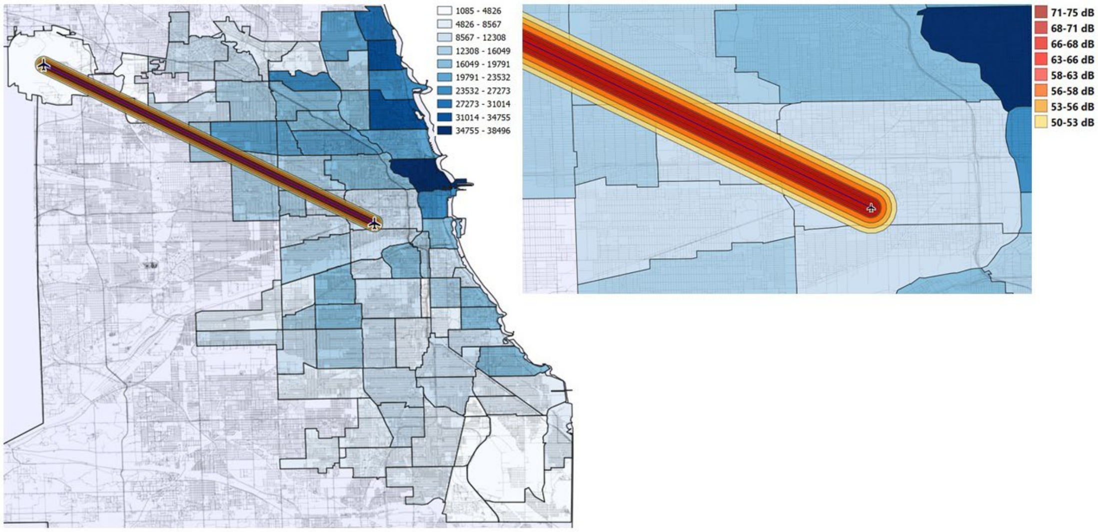


**Figure 60. Graph. UAM potential route connecting O'Hare Airport with Vertiport Chicago.**

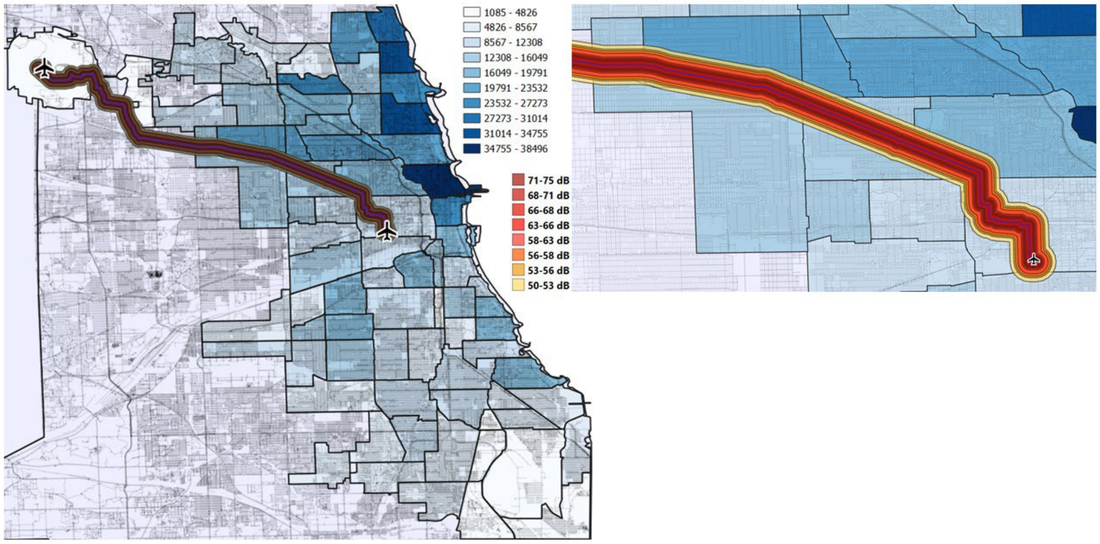


**Figure 61. Graph. UAM potential route connecting O'Hare Airport with Vertiport Chicago.**

Only two different routes (for the same origin and destination pair) are included in the report for space and time reasons. However, more routes were considered in an effort to investigate the different impact levels in terms of noise and the number of people affected, by different route choices. The dB levels considered based on the helicopter data mentioned above are in a close scale with those of an eVTOL (Jia & Lee, 2022). The second route affects approximately 14,778 people (accounting for 68–75 dB “zones” only), and the first route affects 12,863 people. These results, however, are for one specific route at a specific time of day, a fact that generates questions such as what will happen in the case of having multiple routes per day at different times. Also, the surrounding areas of the two vertiports considered were assumed to be equally impacted from noise as the rest of the areas of the routes, something that is not close to reality, since noise levels in close proximity of a vertiport will be more intense—80 dB noise levels around final approach and takeoff areas (Taylor et al., 2020). Therefore, the aforementioned number could be higher for these specific routes. Another important aspect is the altitude of the aircraft, since noise propagates in certain ways for different altitude levels, and noise levels are higher as the aircraft gets closer to ground level. Additionally, accounting for the effect of buildings on how sound propagates is also important as well as the number of passengers (Jia & Lee, 2022).

Uber estimated the noise level of 100 eVTOLs to be acceptable if it is less than half of noise of a truck (75–80 dB(A) at 50 ft proximity). The day-night average sound level (DNL) is defined as the 24-hour period average sound pressure level for a neighborhood, with 10 dB less offset for nighttime. The DNL guidelines vary depending on the neighborhood, and as expected, residential neighborhoods have higher restrictions. The report also suggests that defining noise thresholds should be considered for each landing site separately, with the ultimate goal of not increasing the long-term DNL average by more than 1 dB, by setting a maximum number of allowed aircraft landings for a specific model (Holden et al., 2016).

## Visual Pollution

Visual pollution is the term used to describe the presence of intrusive visual elements that detract from the overall aesthetic of a particular environment. In the context of urban air mobility, visual pollution could be a consequence of the increase in the number of aircraft that may be regarded as noisy, obtrusive, and disruptive to the visual landscape of cities. This visual pollution, caused by aircraft, can have a significant negative impact on the quality of life of people residing or working in the affected areas. For instance, the presence of a large number of hovering or low-flying aircraft over urban regions could cause distractions and reduce the quality of life of people nearby.

The visual impact of AAM operations is expected to be the highest during take-off and landing of eVTOLs, and less during the flight path. Uber has suggested conducting tests to identify acceptable densities as perceived by people on the ground as well as creating air corridors above existing highways to reduce visual pollution (Holden et al., 2016). Based on the results of such simulations, regulations regarding the threshold of acceptable frequency of operations in each route and area must be established. Certain areas, such as tourist and natural locations, require more attention to visual impacts because they depend on the view offered to visitors, and visual pollution could negatively impact their monetary return. Additionally, visual pollution caused by aircraft could negatively impact tourism and the attractiveness of cities as a destination for business and investment. The presence of intrusive and noisy aircraft, especially when used extensively in densely populated urban areas, may deter visitors.

# CHAPTER 8: CONCLUSION

This study delved into the multifaceted realm of advanced air mobility (AAM) within the context of Illinois' transportation landscape. It examined the current and projected states of the AAM industry, analyzing aircraft specifications, infrastructure requirements, energy consumption, operational concepts, and potential demand scenarios. This foundational investigation set the stage for a deeper understanding of the technological and operational nuances inherent in AAM. Building upon this groundwork, the study transitioned into an exploration of the operational aspects of AAM and UAM. This involved not only uncovering potential benefits and challenges, but also examining the implications of integrating these innovative modes into the existing transportation fabric. The study further extended its scope to estimate the demand for air taxi services, unraveling the underlying drivers and market dynamics that influence travelers' choices. By addressing safety concerns and risk factors, the study completed the framework for the integration of AAM services into the existing transportation and mobility landscape of the state.

An analysis of the geographic and operational diversity spanning across Illinois was presented. The study delved into the distinct characteristics of urban, suburban, and rural areas, while also assessing varying operational environments within the state. This assessment enabled an understanding of the diverse contexts within which AAM would operate. Guided by the insights garnered from previous chapters, the study then turned its attention to the interplay between AAM and existing transportation systems. This transformative juncture introduced paradigm shifts in both ground and air transportation. The integration of aerial modes within urban mobility frameworks was examined, shedding light on the intricate relationships between travel behavior, infrastructure utilization, and regulatory dynamics.

The realm of infrastructure requirements was considered as well, outlining the technological and operational support necessary for AAM services. A detailed overview of infrastructure specifications, scope assessments, and managerial recommendations provided a blueprint for the successful implementation of AAM within the transportation ecosystem. The study also directed attention to related policy and regulatory considerations. Synthesizing insights from federal, state, regional, and international levels, the study developed a cohesive set of policy recommendations aligned with established rules and statutes. This policy framework facilitated the harmonious integration of AAM, ensuring a seamless transition into existing aviation systems. Last, an exploration of AAM's potential broader impacts—economic, environmental, and societal—on the Illinois landscape was performed. A quantitative analysis estimated these impacts, shedding light on the broader implications of AAM within the state.

While this study adopted a broad perspective of the wide range of impacts of the full scope of AAM services and application sectors ("verticals"), each vertical merits more detailed study, given the widely different types of uses, likely demand patterns, service supply models, and infrastructure requirements. Accordingly, this work opens the door for several important areas for additional investigation. Methodologically, the development of a system-level network modeling platform would enable more comprehensive and detailed assessment of impacts, especially for UAM services, which are likely to most directly impact roadway congestion. To better understand the demand side, targeted surveys using state-of-the-art techniques can provide more robust insight and estimates of future demand, and the design factors that ultimately impact adoption and usage. Such information will help in further shaping a strategy for infrastructure planning and development as well as the respective roles of the public and private sectors in this regard.

## RECOMMENDATIONS

### Impact on the Existing Transportation Systems

- Consider zoning regulations and land use planning that integrate AAM and UAM services.
    - Delve into a detailed assessment of the current zoning regulations and land use planning frameworks to identify potential gaps and opportunities for the seamless integration of AAM and UAM services. This should involve a thorough analysis of spatial constraints and the identification of suitable areas for the development of necessary infrastructure.
    - Foster proactive engagement with urban planners and policymakers to advocate for the development of adaptable zoning regulations that can accommodate the evolving needs of AAM and UAM services. This includes the implementation of flexible zoning policies that facilitate the establishment of dedicated take-off and landing zones, as well as the integration of vertiports and helipads within urban landscapes.
- Invest in the expansion and upgrade of existing aviation and ground infrastructure.
    - Conduct a comprehensive assessment of the current aviation and ground infrastructure to identify areas that require expansion and modernization to accommodate the projected surge in demand for AAM and UAM services. This should involve a detailed analysis of the capacity constraints and the identification of key infrastructure elements that necessitate immediate upgrades.
    - Collaborate with relevant stakeholders, including aviation authorities and transportation agencies, to formulate a comprehensive investment strategy that prioritizes the expansion and enhancement of critical infrastructure components. This involves the allocation of resources for the construction of state-of-the-art vertiports, the development of advanced air traffic control systems, and the enhancement of ground transportation networks to facilitate seamless multimodal connectivity.
- Foster collaboration between local, regional, and federal authorities to develop harmonized policies.
    - Initiate a collaborative dialogue among local, regional, and federal authorities to foster a coordinated approach towards the development of harmonized policies that effectively address the multifaceted impacts of AAM and UAM on ground and aviation systems. This necessitates the establishment of a platform for regular communication and information sharing to ensure a cohesive regulatory framework.

  - Facilitate the development of comprehensive policy guidelines that prioritize regulatory coherence and streamline the implementation of AAM and UAM services. This should involve the formulation of standardized operating procedures, safety protocols, and airspace management regulations that account for the diverse operational requirements of AAM and UAM services while ensuring the overall efficiency and safety of the transportation ecosystem.

## AAM Infrastructure

- Establish a comprehensive framework for the development of landing pads, vertiports, and charging stations, while ensuring integration with existing transportation infrastructure.
  - It is imperative to establish a comprehensive framework for the development of essential AAM infrastructure, such as landing pads, vertiports, and charging stations. This framework should prioritize strategic placement to ensure accessibility and connectivity, thereby optimizing the efficiency of urban air mobility networks. Moreover, integration with existing transportation infrastructure, such as roads and public transit systems, is crucial. This integration will foster a seamless and interconnected transportation ecosystem, allowing passengers and goods to smoothly transition between various modes of transportation.
- Develop and implement rigorous safety and certification standards for the infrastructure, vehicles, and related technologies, in line with the evolving aviation safety regulations.
  - To promote public confidence and safety, it is essential to develop and implement rigorous safety and certification standards for the AAM infrastructure, vehicles, and related technologies. These standards should align with the evolving aviation safety regulations and encompass robust testing and certification processes. Furthermore, they should adapt to the unique operational characteristics and challenges of urban air mobility. Ensuring safety at all levels is paramount for fostering trust among users and stakeholders.
- Coordinate with aviation authorities to integrate advanced air mobility into existing air traffic management systems, ensuring smooth coordination and minimizing airspace congestion.
  - Collaborative efforts with aviation authorities are pivotal for the successful integration of advanced air mobility into existing air traffic management systems. This collaboration should focus on establishing efficient coordination mechanisms to minimize airspace congestion. Additionally, it should address regulatory aspects, such as air traffic routes, altitude restrictions, and communication protocols, to ensure the harmonious coexistence of traditional and AAM traffic in the airspace. The integration should facilitate the seamless transition of AAM vehicles from the ground to the airspace and back, ensuring safe and efficient operations.

- Further examine land use and spatial requirements, and how necessary infrastructure can be integrated in urban networks and dense areas.
    - A comprehensive examination of land use and spatial requirements is imperative to understand how AAM infrastructure can be seamlessly integrated into urban networks and dense urban areas. This analysis should consider factors such as available real estate, environmental impacts, and the potential for repurposing existing infrastructure. Identifying optimal locations for landing pads and vertiports within urban landscapes is essential for minimizing travel times and enhancing the convenience of AAM services for users. Furthermore, such considerations should align with urban planning and zoning regulations, taking into account the need for minimal disruptions to existing urban activities and maximizing the utilization of available urban space.

## Economic, Social and Environmental Impacts

- Develop public health and safety standards for AAM and UAM operations to minimize risks to public safety (with emphasis on noise pollution).
    - In the context of AAM and UAM operations, it is crucial to establish comprehensive public health and safety standards. This includes a specific focus on noise pollution mitigation. Noise pollution is a critical concern, especially in urban environments, and standards should be designed to minimize disturbances to residents and communities. These standards will contribute to the safety and well-being of the public and ensure that AAM and UAM operations are conducted in a responsible and socially acceptable manner.
- Foster community engagement initiatives to address any social concerns and ensure equitable access to AAM and UAM services, particularly in underserved communities, while promoting inclusivity and accessibility for all segments of society.
    - Addressing Social Concerns: To build public trust and acceptance of AAM and UAM, fostering community engagement initiatives is essential. These initiatives should proactively address any social concerns that communities may have regarding the implementation of these technologies. By facilitating open dialogues and addressing community feedback, it becomes possible to create a more supportive and informed environment for the introduction of AAM and UAM. This approach is crucial for ensuring that these technologies are welcomed and do not disrupt the social fabric of the areas in which they operate.
    - Ensuring Equitable Access: Inclusivity and equitable access are central goals. Communities, particularly underserved ones, must be included in the planning and implementation of AAM and UAM services. Promoting inclusivity and accessibility for all segments of society is paramount. This approach helps ensure that the benefits of these technologies are distributed fairly and that no community is left behind, thereby fostering social equity.

- Consider economic incentives, such as tax breaks and subsidies, to encourage the adoption of AAM and UAM technologies, thereby fostering innovation, job creation, and economic growth in the aviation and related industries.
    - Economic incentives, such as tax breaks and subsidies, should be explored as tools to encourage the widespread adoption of AAM and UAM technologies. By reducing the financial barriers associated with these innovations, businesses and individuals are more likely to invest in and adopt them. Such incentives can catalyze innovation and job creation within the aviation and related industries, contributing to overall economic growth. However, these incentives should be subject to further analysis to determine their feasibility and potential impact on the economy.

## Regulatory Framework

The federal, state, and local laws and policies presented in Chapter 6 are reflected in the following recommendations (in no particular order):

- Continue to monitor the evolution of FAA/federal regulations on AAM and UAM. FAA continues to evolve their thinking on the operational and regulatory environment for this aviation subdomain. Illinois policies should include methods to ensure alignment with future changes in federal regulations.

- Develop flexible policies to account for the uncertainty of UAM/AAM adoption rates. Due to the inherent uncertainty in the overall demand for these vehicles and the progressive adoption rates, it is recommended that Illinois policies are designed with the breadth of demand in mind.

- Develop policies that enable AAM/UAM to integrate easily with existing transportation systems. A well-integrated transportation system encourages use and supports economic growth. This includes both enabling UAM/AAM aircraft to integrate into the Illinois aviation system (as well as surrounding states within operational range) and connecting to surface transportation systems to enable doorstep-to-doorstep trip-making by UAM/AAM segments.

- Adapt the Illinois Aviation System Plan to include integration of AAM/UAM and eVTOL aircraft operations throughout all aspects. Currently the IASP is written referencing AAM/UAM as a possible future air traffic scenario that requires consideration. The IASP should be modified to accommodate AAM vehicles and infrastructure needs more centrally into the plan.

- Append the Illinois Aviation System Plan to address vulnerabilities throughout the system. Currently the IASP does not consider identifying and addressing critical infrastructure disruption vulnerabilities such as cybersecurity, electrical grid, natural disasters. A burgeoning AAM/UAM system would be particularly vulnerable.

- Develop strategies to educate and notify local jurisdictions across the State of Illinois on statewide strategies, policies, and relevant laws. Developing a strategy to inform and educate local jurisdictions on AAM/UAM-related laws and policies will help to ensure the success of statewide strategies. Failure to adequately include local jurisdictions may result in counter-productive local ordinances that limit the ability to successfully implement AAM or UAM plans or strategies.

## Major Uncertainties and Areas of Additional Research

- The demand side:
    - Recommend additional demand-side research to better understand user perceptions and adoption and develop a clearer pathway for adoption and system integration.
    - Need for integrating air mobility alternatives in strategic regional planning tools and network models to capture impacts at finer granularity.
- The air traffic management side:
    - Need to better understand the congestability of air space under different air management and routing approaches (e.g., Cummings & Mahmassani, 2023a, 2023b).
- The business models:
    - Each of the verticals considered (urban mobility, agriculture, package delivery) can be expected to have different business models for deployment at scale, with varying public-private arrangements.

Firstly, with regards to the demand side, it is imperative to conduct additional research that delves in greater depth than possible under the present study into critical aspects of user perceptions and adoption patterns. This should encompass a multifaceted examination of factors influencing user preferences and the potential barriers to adoption. Moreover, a more robust exploration is needed to delineate a clear trajectory for the integration of these innovative systems within existing infrastructures. This entails a nuanced understanding of the intricate pathways that can facilitate the seamless assimilation of advanced air mobility solutions into contemporary transportation networks. Furthermore, the incorporation of air mobility alternatives into strategic regional planning tools and network models is indispensable. This integration must be able to capture the multifaceted impacts of these solutions at a granular level, thereby enabling a more informed and comprehensive assessment of their potential role in shaping future urban landscapes.

On the air traffic management side, there exists a pressing need to enhance our understanding of the dynamic nature of airspace congestion under varying air management and routing approaches. Building upon the seminal work of Cummings and Mahmassani (2023a, 2023b), a comprehensive exploration of the congestability of airspace is essential. This should encompass an analysis of the implications of diverse air traffic management strategies on the overall efficiency and safety of the airspace, with a specific focus on the scalability and adaptability of these approaches within the evolving urban air mobility ecosystem.

Moreover, the multifaceted nature of the business models associated with different verticals within the advanced air mobility domain necessitates separate examination of the business case for each of them. Considering the diverse sectors such as urban mobility, agriculture, and package delivery, it is imperative to recognize the intrinsic variations in the business models required for their large-scale deployment. This entails a thorough analysis of the unique operational intricacies and regulatory frameworks specific to each vertical. Additionally, a comprehensive evaluation of the potential public-private arrangements and partnerships that can foster the effective implementation and sustainability of these diverse business models is essential. Such an investigation is vital for developing a holistic understanding of the intricate interplay between business models and the broader ecosystem of advanced air mobility.

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# APPENDIX A: ADDITIONAL TABLES

**Table 18. AAM/UAM Market Size Estimation Studies**

| Study | Location of Study | Services Considered | Prices Assumed | Market Share | Job Opportunities | Market Size ($) |
|---|---|---|---|---|---|---|
| Garrett-Glaser (2020) | – | short-range on-demand air-taxi, airport shuttle services, inter-city transportation | – | – | – | $80 billion/year |
| Goyal et al. (2021) | – | air-taxi, airport shuttle | $2.0 per mile | 82,000 daily passengers | – | $2.5 billion/year |
| Mayor & Anderson (2019) | – | – | – | 12 million passengers/year by 2030, 400 million passengers/year by 2050 (globally) | – | – |
| Holden, et al. (2016) | US | Air-taxi | $0.50–$2.34 per mile | – | – | – |
| Lineberg et al. (2021) | – | – | – | – | 280,000 people employed by 2035 | $115 billion/year |
| (Mayakonda et al., 2020) | – | – | $0.93 per passenger kilometer | 327 million passenger trips/year by 2035 | – | – |
| Goyal et al. (2018) | Houston, Los Angeles, New York, the San Francisco Bay Area, Washington, DC | air-taxi, airport shuttle, air ambulance | $6.25 per passenger mile | 82,000 daily passengers | – | $500 billion (unconstrained case), $2.5 billion/year (constrained case) |

## Table 19. AAM/UAM Survey-Based Studies

| Study | Location of study | Sample size | Services considered | Prices assumed | VOT |
|---|---|---|---|---|---|
| Fu et al. (2019) | Munich metropolitan region (Germany) | 248 | Autonomous ground taxi (AT), Autonomous flying taxi (AFT) | (9, 11, 13) euros/km (AT), (15, 25, 75) euros/km (AFT) | 32.57 euros/h, 44.68 euros/h (AFT) |
| Yedavalli & Mooberry, (2018) | Los Angeles, Mexico City, Switzerland, New Zealand | 385 | Air taxi | – | – |
| Holden et al. (2019) | US | – | Air-taxi | $21 for the equivalent of a 60-mile automobile trip | – |
| Sivak & Schoettle (2017) | US (majority from the Pacific, South Atlantic, North Central) | 508 | Air-taxi, commercial UAM vehicles | – | – |
| Eker et al. (2020) | US | 584 | UAM vehicles | – | – |
| Al Haddad et al. (2020) | Europe (majority in Munich), US | 221 | Air-taxi, airports U.Shuttle | 90 euros for a trip corresponding to a 30–40 min ground taxi trip, 53 euros for euros for a trip corresponding to a 35–55 min ground taxi trip | $9.7–75.4/hour |
| Boddupalli (2020) | Atlanta, Boston, Dallas-Ft. Worth, San Francisco, and Los Angeles | 2,500 | Air-taxi | $5–$10 (for trips corresponding to automobile trips of 40–60 min) | – |
| Rimjha et al. (2021) | Los Angeles International airport (LAX) | 15,000 (existing airport-airline services survey data) | Airport air-taxi | $2 per passenger mile, plus $15 base cost, plus $20 landing cost | $22/hour for no business trips, $52/hour |

**Table 20. Risk Map Categories Description**

| Risk category | Infrastructure type |
|---|---|
| Critical infrastructure | Airport, Hospital, School |
| Urban and industrial environments | General building, Mine, Oilfield, Populated area, Post Office, Church |
| Infrastructure with potential human presence area | Locale, Military (Historical), Crossing, Civil, Cemetery, Park |
| Infrastructure with relatively low human presence area | Dam, Reservoir |
| Environmental terrain | Ridge, Summit, Stream, Valley, Woods, Swamp, Lake, Island |

**Table 21. Concept of Operations**

| Operation | Description |
|---|---|
| Urban Air Taxi | eVTOL aircraft between 1 and 5 passengers flying between vertiports in a dense urban area. Operations between 400 and 4000 ft AGL. Speeds generally between 60 mph and 200 mph. Operations generally 60 miles or less. Operations within airspace corridors that separate traffic directionally and establish a point-to-point network. Navigation and deconfliction controlled by interaction with an automated UTM controller. |
| Regional Air Taxi | Tilt-rotor eVTOL or small fixed-wing aircraft flying between regional airports and major airport hubs for between 2 and 6 passengers. Operations around 5000 ft AGL at speeds of around 200 mph. Trips of generally 200 miles or less. Navigation and deconfliction services provided by an automated UTM controller. |
| Package Delivery | Small multi-rotor UAVS aircraft carrying small packages of several pounds or less. Operations below 400 ft AGL, at speeds of 60 mph or less and generally 20 miles or less. Drones operate within small delineated airspaces. Vertiports located at stores or warehouses with deliveries to consumers' yards. Operations fly within urban and suburban areas, including residential neighborhoods. |
| Cargo and Freight Distribution | VTOL aircraft with several hundred pounds payload used to rapidly redistribute high-value goods around a distribution network within a region. Ranges of a few hundred miles or less with speeds of 200 mph or less. Operations coordinated with UTM and navigation services. Vertiports located at warehouses or stores, but operations may overfly busy urban and suburban areas. |
| Agriculture – Spraying Crops | Heavy drone aircraft carrying several hundred pounds in payload operating from small rural vertiports and airports. Remote-control or automated operations using precision instruments for precise guidance over a field. Operations at several hundred feet or less, application speed of 75 mph or less. In general avoids populated areas and high demand airspaces. Varying range capability depending on fuel or battery power. |

| Operation | Description |
|---|---|
| Agriculture – Evaluating Crops / Animals | Smaller observation drones mounted with cameras. Remote or automated control. Operations at several hundred feet or less, speeds of 200 mph or less. Generally short range of a few dozen miles or less. Operations at low altitude over private properties with minimal interaction with other aircraft or flyovers of populated areas. |
| Infrastructure Inspection | Smaller unmanned aircraft designed for observation missions at low altitude. Equipped with cameras. Speeds of 200 mph or less. For pipeline missions long ranges and faster speeds versus other infrastructure, which may use small, short-range multirotor aircraft for small spaces and precise control. Coordination with UTM to create block of exclusionary airspace for operations. Operations in sensitive industrial or infrastructure places but away from populated areas. |
| Emergency Services – Air Ambulance | Emergency medical transit involving both crew and patient on board a larger VTOL aircraft. Operations at several thousand feet, with speeds of 200 mph or less. Ranges of 100 miles or less. Coordinates operations with UTM to clear airspace for the aircraft. VTOL aircraft capable of landing in remote ground spaces and at hospital heliports. Generally operating in populated areas. |
| Emergency Services – Medical Supplies | Small drones with remote or automated control. Multirotor or fixed wing configurations with payloads of several pounds. Speeds ranging from 60 mph to 200 mph. May involve landing at remote sites or winch to lower supplies to ground. Ranges of several dozen miles to 100 miles or more. Operations may be focused in remote areas that would otherwise be without medical access. |
| Emergency Services – Disaster Areas | Reconnaissance operations in disaster hit areas. Unmanned aircraft capable of flying into or near dangerous conditions. Low altitude operations with cameras for observation. Speeds of 200 mph or less. Remote control or automated control. Unlikely to operate in airspaces with other aircraft interactions. |

**Table 22. AAM Operations Risks and Risk Classes**

| Operation | Air Risk Class (ARC) |
|---|---|
| Urban Air Taxi | ARC-d - Not in individual airspace, operations may be in airport environment and within class B, C or D airspace near urban areas |
| Regional Air Taxi | ARC-d - Not in individual airspace, operations extend to airport environments within controlled airspace |
| Package Delivery | ARC-c - Not in individual airspace, operates outside of airport environments and below 500 ft AGL within controlled airspace or uncontrolled urban airspace |
| Cargo and Freight Distribution | ARC-c - Not in individual airspace, operates outside of airports, above 500 ft AGL in uncontrolled airspace over urban or rural areas. |
| Agriculture – Spraying Crops | ARC-b - Not in individual airspace, operates outside of airport environments, below 500 ft AGL in uncontrolled airspace over rural areas. |
| Agriculture – Evaluating Crops / Animals | ARC-b - Not in individual airspace, operates outside of airport environments, below 500 ft AGL in uncontrolled airspace over rural areas. |
| Infrastructure Inspection | ARC-b - May be in individual airspace, but operates below 500 ft AGL in uncontrolled airspaces over sparsely-populated areas. |
| Emergency Services – Air Ambulance | ARC-a - Will be segregated from other aircraft strategically and assigned its own airspace along its route. |
| Emergency Services – Medical Supplies | ARC-c - Not in individual airspace with operations below 500 ft AGL and in uncontrolled urban airspaces. |
| Emergency Services – Disaster Areas | ARC-b - Not in individual airspace with operations below 500 ft AGL and uncontrolled airspace over sparsely-populated areas. |

## Table 23. AAM Operations Risks and Mitigations

| Operation | GRC | ARC | Ground risks | Air risks | Mitigations |
|---|---|---|---|---|---|
| Urban Air Taxi | 9 | ARC-d | - The ground risk is high (9) because of operations in dense urban areas. However, re-routing aircraft to avoid highly populated neighborhoods without vertiports may be possible to a limited extent to mitigate the ground risk. Flight paths may also follow existing infrastructure routes (roads and highways) to mitigate the risk to neighborhoods. | - The air risk classification (ARC-d) is high because of operations in dense areas with other airspace restrictions and service to airports. Measures to strategically separate air taxi operations from existing forms of aviation will be needed (especially near airports) and may take the form of designated corridors. | - Even with strategic mitigation a robust UTM system for detecting and resolving conflicts at the tactical level will be necessary. A service provider to operate the UTM system will be needed. Aircraft may also carry their own sensors and deconfliction capabilities on board in the event of communications failures.<br>- Because of the high risk for both ground and air classifications other mitigations to verify the safety procedures and capabilities of operators and crew should be verified through certification, training and inspection. |
| Regional Air Taxi | 9 | ARC-d | - The ground risk is high (9) because of some operations in dense urban areas. However, re-routing aircraft to avoid highly populated neighborhoods without vertiports may be possible to a limited extent to mitigate the ground risk. Flight paths may also follow existing infrastructure routes (roads and highways) to mitigate the risk to neighborhoods. | - The air risk classification (ARC-d) is high because of service to airports. Measures to strategically separate air taxi operations from existing forms of aviation will be needed (especially near airports) and may take the form of designated corridors. | - Even with strategic mitigation a robust UTM system for detecting and resolving conflicts at the tactical level will be necessary. A service provider to operate the UTM system will be needed. Aircraft may also carry their own sensors and deconfliction capabilities on board in the event of communications failures.<br>- Because of the high risk for both ground and air classifications other mitigations to verify the safety procedures and capabilities of operators and crew should be verified through certification, training and inspection. |

| Operation | GRC | ARC | Ground risks | Air risks | Mitigations |
|---|---|---|---|---|---|
| Package Delivery | 5 | ARC-c | - The ground risk classification (5) was moderate because of the small and light nature of most package delivery vehicles combined with the populated areas in which the aircraft will operate. Some limited strategic re-routing of aircraft to avoid dense or sensitive ground areas may be possible. Obstacle avoidance will be an issue for very low altitude operations, which may be mitigated by certification of the capability of aircraft to detect and avoid obstacles even in poor weather conditions. | - The air risk classification (ARC-c) was moderate to high because of operations in urban controlled airspaces, although this was somewhat mitigated by low altitude operations. | Both strategic and tactical mitigations will be needed to manage the risk of aircraft collision. An effective UTM system for routing aircraft strategically will be needed in addition to individual aircraft capabilities to detect and avoid other aircraft. |
| Cargo and Freight Distribution | 8 | ARC-c | - The ground risk classification (8) was high because of the larger and heavier nature of the aircraft along with anticipated operations near urban areas. With anticipated origins and destinations near warehouses and away from neighborhoods, however, it may be possible to utilize strategic re-routing of aircraft to avoid the most densely populated areas. | - The air risk classification (ARC-C) was moderate to high because of operations above 500 ft AGL in or near urban and controlled airspaces. Both strategic and tactical mitigations should be used to manage aircraft trajectories via a UTM service and robust detect and avoid capabilities on individual aircraft should be certified. | - Because of the high risk for both ground and air classifications other mitigations to verify the safety procedures and capabilities of operators and crew should be verified through certification, training and inspection. |
| Agriculture – Spraying Crops | 6 | ARC-b | - The ground risk classification (6) was moderate on the basis of the large size of aircraft and heavy payload. However, anticipated aircraft operations are away from populated and sensitive areas, providing an effective strategic mitigation for the ground risk. | - The air risk classification (ARC-b) was low to moderate due to operations in uncontrolled airspaces and away from high-demand areas. Within uncontrolled airspaces strategic deconfliction via UTM may or may not be available, placing greater emphasis on the tactical capabilities of individual | |

| Operation | GRC | ARC | Ground risks | Air risks | Mitigations |
|---|---|---|---|---|---|
| | | | | aircraft to detect and avoid conflicts. | |
| Agriculture – Evaluating Crops / Animals | 3 | ARC-b | - The ground risk classification (3) was low because of the small size of the aircraft and operations in uncontrolled and low altitude airspaces. With operations away from populated areas no extra mitigations for ground risk may be necessary. | - The air risk (ARC-b) was low to moderate due to the operations in uncontrolled airspaces in rural areas. Tactical mitigations to verify the capability of aircraft for individual detect and avoid may be a sufficient mitigation. | |
| Infrastructure Inspection | 4 | ARC-b | - The ground risk (4) is low because of the small size of the aircraft. However, operations may occur in active and sensitive locations with obstacles near the ground. Some ground risk can be strategically mitigated with route planning. Obstacle avoidance mitigations should be taken to certify that aircraft have the requisite capabilities to sense and avoid obstacles. | - The air risk classification (ARC-b) is low to moderate based on the low altitude of the operations which will not intersect with other forms of aviation. However, operators must still maintain the capabilities to detect and avoid other air risks with aircraft in the airspace. | - The safety mitigations for infrastructure inspection can vary widely based upon the actual operation. Determining factors include the sensitivity of the infrastructure, the activity level of the infrastructure, the location and nearby populated areas, and the mission requirements which may occur in airspaces small or large. |
| Emergency Services – Air Ambulance | 10 | ARC-a | - The ground risk classification (10) is very high, due to likely operations in densely populated areas. Strategic ground mitigations (routing away from densely populated areas) may not be possible. | - The low air risk classification (ARC-a) is based upon the supposition that air ambulances will operate in separated airspaces. Sufficient communications and systems must be implemented to clear sufficient airspace for air ambulance operations when and where they occur. This strategic mitigation should result in a clean airspace for air ambulances. | - Because of the high ground risk and highly-sensitive nature of air ambulance operations extensive operational safety mitigations should be taken to certify safe operations and procedures from the operating group, crew, and service provider systems they rely upon. These mitigations likely take the form of rigorous processes for certification, training, and inspection. |

| Operation | GRC | ARC | Ground risks | Air risks | Mitigations |
|---|---|---|---|---|---|
| Emergency Services – Medical Supplies | 8 | ARC-c | - The ground risk classification (8) was high because of the larger size of the aircraft and the populated areas in which it will operate at low altitudes. Obstacle avoidance will be an issue for very low altitude operations, which may be mitigated by certification of the capability of aircraft to detect and avoid obstacles even in poor weather conditions. | - The air risk classification (ARC-c) was moderate to high because of operations in urban controlled airspaces, although this was somewhat mitigated by low altitude operations. Both strategic and tactical mitigations will be needed to manage the risk of aircraft collision. An effective UTM system for routing aircraft strategically will be needed in addition to individual aircraft capabilities to detect and avoid other aircraft. | |
| - Emergency Services – Disaster Areas | 6 | ARC-b | - The ground risk (6) was moderate because of the larger size of the aircraft although the operations in disaster zones will likely be away from currently populated areas. Further ground risk mitigation could be done strategically by routing the aircraft away from known populated areas or sensitive infrastructure. | - The air risk (ARC-b) was low to moderate because of the low altitude nature of the operations and the anticipated low air traffic in disaster areas. However, the aircraft may still need to cope with other emergency services air traffic and therefore a tactical ability to sense and avoid conflicts should be required. | - Disaster areas may also present challenging environments for aircraft operations depending on the conditions, and therefore robust aircraft capable of handling challenging weather or visibility conditions should be utilized. |

### Table 24. Percentage of Professions Which Have Remote Capabilities

| OCC_CODE | Occupational title | Total employment | Percentage of professions with remote capabilities | Number of professions with remote capabilities |
|---|---|---|---|---|
| 11-0000 | Management Occupations | 514,390 | 0.87 | 447,519 |
| 13-0000 | Business and Financial Operations Occupations | 391,090 | 0.88 | 344,159 |
| 15-0000 | Computer and Mathematical Occupations | 187,150 | 1.00 | 187,150 |
| 17-0000 | Architecture and Engineering Occupations | 80,110 | 0.61 | 48,867 |
| 19-0000 | Life, Physical, and Social Science Occupations | 38,340 | 0.54 | 20,704 |
| 21-0000 | Community and Social Service Occupations | 81,790 | 0.37 | 30,262 |
| 23-0000 | Legal Occupations | 50,820 | 0.97 | 49,295 |
| 25-0000 | Educational Instruction and Library Occupations | 357,260 | 0.98 | 350,115 |
| 27-0000 | Arts, Design, Entertainment, Sports, and Media Occupations | 73,250 | 0.76 | 55,670 |
| 29-0000 | Healthcare Practitioners and Technical Occupations | 362,000 | 0.05 | 18,100 |
| 31-0000 | Healthcare Support Occupations | 218,390 | 0.02 | 4,368 |
| 33-0000 | Protective Service Occupations | 142,530 | 0.06 | 8,552 |
| 35-0000 | Food Preparation and Serving Related Occupations | 454,770 | 0.00 | 0 |
| 37-0000 | Building and Grounds Cleaning and Maintenance Occupations | 168,880 | 0.00 | 0 |
| 39-0000 | Personal Care and Service Occupations | 100,520 | 0.26 | 26,135 |
| 41-0000 | Sales and Related Occupations | 486,390 | 0.28 | 136,189 |

| OCC_CODE | Occupational title | Total employment | Percentage of professions with remote capabilities | Number of professions with remote capabilities |
|---|---|---|---|---|
| 43-0000 | Office and Administrative Support Occupations | 746,560 | 0.65 | 485,264 |
| 45-0000 | Farming, Fishing, and Forestry Occupations | 6,390 | 0.01 | 64 |
| 47-0000 | Construction and Extraction Occupations | 176,280 | 0.00 | 0 |
| 49-0000 | Installation, Maintenance, and Repair Occupations | 205,740 | 0.01 | 2,057 |
| 51-0000 | Production Occupations | 409,860 | 0.01 | 4,099 |
| 53-0000 | Transportation and Material Moving Occupations | 631,420 | 0.03 | 18,943 |
| | | | | |
| | Total | 5,883,930 | | 2,237,512 |
| | Percentage of all IL professions with remote capabilities | | | 38% |

## Table 25. UAM/AAM-related Laws and Policies across US States

| Laws and Policies from US States | | | | | | |
|---|---|---|---|---|---|---|
| *States* | *Public Safety Risk Management* | *Operational Integration* | *Public Acceptance* | *Innovation & Economic Growth* | *Environmental Impact* | *System & Infrastructure Planning* |
| Alaska (Alaska Statutes, 2022) | | Law enforcement usage | | | Prohibit usage for hunting or fishing | |
| Arizona (Serrao et al., 2018) | Prohibits reckless operations | Prohibit operations interfering w/ first respondents | | | | Prohibits operating near a critical facility for crime |
| Arkansas (State of Arkansas, 2015) | Prohibits reckless operations | | Prevents privacy violations, private surveillance | | | Prohibits ciritical infrastructure overflights |
| California (Serrao et al., 2018; Advanced Air Mobility and Aviation Electrification Committee, 2023) | Prohibit operations interfering w/ first respondents | Prohibit operations interfering w/ first respondents | Prohibits private surveillance, permitted in State parks | Univ of CA - Santa Barbara: Process for permitting operations | Aviation industry electrification & Carbon Fuel standards | Promoting equity of access to advanced air mobility infrastructure |
| Colorado (Serrao et al., 2018) | Emergency response systems integration | Integrating UAS operations with existing transportation systems | Prevents privacy violations | Govt study on operations for firefighting, wildfires, search & rescue, crime scene & crash investigation, emergency management. | Prohibits usage for hunting or fishing | |

| **Laws and Policies from US States** | | | | | | |
|---|---|---|---|---|---|---|
| *States* | *Public Safety Risk Management* | *Operational Integration* | *Public Acceptance* | *Innovation & Economic Growth* | *Environmental Impact* | *System & Infrastructure Planning* |
| Connecticut (State of Connecticut, 2017) | Prohibits operations in State parks w/o special authorization | Prohibits municipalities from enacting regulations | Prohibits operations on Federal lands w/o authorization | | | |
| Delaware (The Delaware Code Online, 2019) | Prohibits private operations over popular events, first responders | Usage by law enforcement | | | | Prohibits operations over critical infrastructure; contraband into prisons |
| Florida (Serrao et al., 2018) | Prohibits lethal weapons; operations near space ports | Usage by law enforcement | Prevents law enforcement/state agents from privacy violations with exceptions | | | Prohibits over or near critical infrastructure facilities |
| Georgia (Georgia General Assembly, 2018) | | Prohibits municipalities from enacting regulations | | | | |
| Hawaii (Serrao et al., 2018) | | Law enforcement usage | | | | |
| Idaho | | | Prevents privacy violations, private surveillance | | Prohibits usage for hunting or fishing | |

| **Laws and Policies from US States** | | | | | | |
|---|---|---|---|---|---|---|
| *States* | *Public Safety Risk Management* | *Operational Integration* | *Public Acceptance* | *Innovation & Economic Growth* | *Environmental Impact* | *System & Infrastructure Planning* |
| Illinois (Illinois Compiled Statutes, 2020) | | Prohibits law enforcement uses w/o search warrant unless for terrorist or imminent threats, search & rescue, disaster surveys, crime scene/crash investigation; prohibits municipalities (< 1M residents) from enacting regulations | Private data capture for govt use | | Prohibits interfering w/ lawful hunting & fishing | |
| Indiana (Indiana General Assembly, 2023) | Prohibits operations interfering w/ first respondents | Limits law enforcement uses w/o search warrant unless for crash investigation | Prohibits sex offenders from surveilling, following, or contacting w/o consent | | Prohibits usage for hunting or fishing | |
| Iowa (General Assembly of the State of Iowa, 2017) | | Prohibits law enforcement uses w/o search warrant; prohibits operations for traffic law enforcement | | | | |

| **Laws and Policies from US States** | | | | | | |
|---|---|---|---|---|---|---|
| *States* | *Public Safety Risk Management* | *Operational Integration* | *Public Acceptance* | *Innovation & Economic Growth* | *Environmental Impact* | *System & Infrastructure Planning* |
| Kansas (Legislature of the State of Kansas, 2016) | | | Prevents privacy violations | Can carry (lethal and non-lethal) payloads | | Prevents operations around correctional facilities |
| Kentucky (General Assembly of the Commonwealth of Kentucky, 2017) | Prohibits reckless operations | | | | | Prohibits operations in "restricted airspace" near airports |
| Louisiana (Article III, Section 2(A)(4)(b)(i) of the Constitution of Louisiana, 2017) | Prohibit operations interfering w/ first respondents | Prohibits municipalities from enacting regulations | Prevents privacy violations, private surveillance | Promotes commercial, agricultural, or educational uses with registration, licensing | | Prevents surveillance of correctional facilities or schools |
| Maine (Maine Legislature, 2015) | | Prohibits law enforcement use w/o approval; operations investigating crimes requiring search warrant | | | | |
| Maryland (Serrao et al., 2018) | | Prohibits municipalities from enacting regulations | | Promotes research & economic development | | |

| Laws and Policies from US States | | | | | | |
|---|---|---|---|---|---|---|
| *States* | *Public Safety Risk Management* | *Operational Integration* | *Public Acceptance* | *Innovation & Economic Growth* | *Environmental Impact* | *System & Infrastructure Planning* |
| Michigan (State of Michigan, 2016) | Prohibit operations interfering w/ first respondents | Prohibits municipalities from enacting regulations | Prevents privacy violations, restraining order violations; prohibits sex offenders from surveillance on victims | | Prohibits interfering w/ lawful hunting & fishing; usage for hunting or fishing | |
| Minnesota (State of Minnesota, 2020) | | Prohibits law enforcement uses w/o search warrant unless for imminent threats, disaster surveys, training, crash investigation | Private data capture for govt use investigating crime or if requested; state operator license, registration, insurance requirement | | Currently evaluating UAS operations for monitoring moose population | |
| Mississippi (Mississippi Legislature, 2015) | | | Prevents privacy violations, private surveillance | | | |
| Montana (Legislature of the State of Montana, 2017) | | Prohibits law enforcement uses w/o search warrant | | | Prohibits operations interfering w/ fighting wildfires | |

| Laws and Policies from US States | | | | | | |
|---|---|---|---|---|---|---|
| *States* | *Public Safety Risk Management* | *Operational Integration* | *Public Acceptance* | *Innovation & Economic Growth* | *Environmental Impact* | *System & Infrastructure Planning* |
| Nevada (Nevada Legislature, 2015) | Prohibits reckless operations; operate under influence of drugs/alcohol; operations overpopulated areas (except parks) incl. low level operations, dropped objects; prohibits lethal weapons | Prohibits law enforcement uses w/o search warrant unless for imminent threats, disaster surveys | Prohibits operations < 250 ft over private property | | | State registry of operations by public bodies; prohibits critical infrastructure overflights; < 5 mi from airports w/o consent |
| New Hampshire (State of New Hampshire, 2015) | | | | | Prohibits interfering w/ lawful hunting & fishing | |
| New Jersey (State of New Jersey, 2017) | Prohibits reckless operations; operations under influence of drugs/alcohol | Prohibit operations interfering w/ first respondents; limits municipalities from regulating | Prohibits specific parks only | | | Prohibits operations near prisons; Enable critical infrastructure owners to apply to FAA for restrictions |

| Laws and Policies from US States | | | | | | |
|---|---|---|---|---|---|---|
| *States* | *Public Safety Risk Management* | *Operational Integration* | *Public Acceptance* | *Innovation & Economic Growth* | *Environmental Impact* | *System & Infrastructure Planning* |
| New Mexico (State of New Mexico, 2017) | | | Prevents privacy violations; Operations prohibited at Navajo Lake State Park & White Sands Natl Park | | Prohibit usage for hunting, except for wildlife management | |
| North Carolina (North Carolina General Assembly, 2014), (North Carolina, 2017) | Prohibits crimes with UAS; interfering w/ manned aircraft; lethal weapons | Enables municipalities enact regulations on launch/ recovery sites | Permits not required, state operator license required; Prevents privacy violations | | | Prohibits delivering contraband into prisons; no operations from state- or private property w/o permission |
| North Dakota (64th Legislative Assembly of North Dakota, 2015) | Prohibits lethal weapons | Deployment of testing operations | Registration not required; Prevents privacy violations | | | |
| Ohio (Ohio Department of Transportation, 2022), (General Assembly of the State of Ohio, 2014) | Develop safety management systems | | Policies consider AAM benefits for the public | Related workforce & economic rewards | Evaluation of environmental impact | Land use planning criteria |

| Laws and Policies from US States | | | | | | |
|---|---|---|---|---|---|---|
| *States* | *Public Safety Risk Management* | *Operational Integration* | *Public Acceptance* | *Innovation & Economic Growth* | *Environmental Impact* | *System & Infrastructure Planning* |
| Oklahoma (State of Oklahoma, 2015, 2021) | | | | Promotion, development, & safe integration of UAS | | Prohibits ciritical infrastructure overflights |
| Oregon (Oregon Administrative Rules, 2018a,b) | Prohibits reckless operations; lethal weapons | Prohibits law enforcement uses w/o search warrant unless for search & rescue, or crime scene reconstruction | Prohibits interfering or controlling another's UAS or private property overflights | | Prohibit usage for hunting or fishing | State registry of operations by public bodies; prohibits critical infrastructure overflights |
| Pennsylvania (Pennsylvania General Assembly, 2018) | Prohibits reckless operations | Prohibits municipalities from enacting regulations | Prevents privacy violations, private surveillance | | | Prohibits operations delivering contraband into prisons |
| Rhode Island (State of Rhode Island, 2016) | | Prohibits municipalities from enacting regulations | | | | |
| South Carolina (South Carolina General Assembly, 2018) | | | | | | Prohibits operations around correctional facilities |
| South Dakota | | Enables use by law enforcement; first responders | Registration not required; Prevents privacy violations, | | | Prohibits operations around critical |

| **Laws and Policies from US States** | | | | | | |
|---|---|---|---|---|---|---|
| *States* | *Public Safety Risk Management* | *Operational Integration* | *Public Acceptance* | *Innovation & Economic Growth* | *Environmental Impact* | *System & Infrastructure Planning* |
| (South Dakota Legislature, 2017a, b) | | | private surveillance | | | infrastructure or delivering contraband into prisons |
| Tennessee (State of Tennessee, 2015, 2016, 2017a, 2017b, 2018) | Prohibits operations over fireworks displays or open-air events | Prohibits law enforcement uses w/o search warrant unless for search & rescue/anti-terrorism | Prevents privacy violations, private surveillance of hunters | Permits use by colleges & universities | | Prohibits operations around critical infrastructure |
| Texas (Serrao et al., 2018) | | Usage by law enforcement; integration with existing trans. systems | Prevents privacy violations; Operations in specific parks only | | | Prohibits operations around critical infrastructure; Enables use for air quality sampling |
| Utah (UTAH State Legislature, 2014, 2015) | Prohibits reckless operations; lethal weapons | Prohibits law enforcement use w/o search warrant unless for search & rescue/data capture testing | Prevents privacy violations | | Prohibits harassing livestock; operations near wildfires | Implement AAM strategies; Vertiport locations and infrastructure |
| Vermont (State of Vermont, 2017a,b) | Prohibits lethal weapons | Prohibits law enforcement for criminal investigation; Must | | | Prohibit usage for hunting or fishing | |

| **Laws and Policies from US States** | | | | | | |
|---|---|---|---|---|---|---|
| *States* | *Public Safety Risk Management* | *Operational Integration* | *Public Acceptance* | *Innovation & Economic Growth* | *Environmental Impact* | *System & Infrastructure Planning* |
| | | log all use and data capture | | | | |
| Virginia (Serrao et al., 2018) | | Prohibits law enforcement use w/o search warrant unless for pursuit/search & rescue/fires | Prevents privacy violations; Operations in specific State parks ok | Promote usage from public, private, and educational entities | | |
| Washington (Washington State, 2019) | | | Operations in State parks requires permit | | | Prohibits operating around State Capitol campus |
| West Virginia (West Virginia Legislature, 2015,2018a,b) | Prohibits lethal weapons | | Registration not required; Prevents privacy violations; Operations in State parks require permission | | Prohibit usage for hunting or fishing | |
| Wisconsin (Serrao et al., 2018) | | | Prohibits operations in State parks beyond designated areas | | Prohibits interfering w/ lawful hunting & fishing | Prohibits operating over a correctional facility |
| Wyoming (64th Legislature of the State of Wyoming, 2017) | | | Prohibits low alt operations over state parks | | | |

**Table 26. UAM/AAM-related Laws and Policies across US Cities**

| Laws and Policies from Major US Cities/Metro Areas | | | | | | |
|---|---|---|---|---|---|---|
| *Urban Area* | *Safety Risk Management* | *Operational Integration* | *Public Acceptance* | *Innovation & Economic Growth* | *Environmental Impact* | *Infrastructure Planning* |
| Boston, MA (Drone Laws, 2023) | Prohibits reckless operations | | | | | Prohibits operations in city parks, around Boston-Logan Int'l Airport |
| New York, NY (Drone Laws, 2023), (Serrao et al., 2018) | Prohibited operations, flight permit requirement | Use in limited areas for recreational and commercial use only, subject to NYPD authorization | | | | Prohibits operations in close proximity to specific areas and infrastructure |
| Orlando, FL (Drone Laws, 2023), (City of Orlando, 2020) | Prohibits operations near city property, schools, parks or near populated events, flight regulations | Use in limited areas for recreational and commercial use only | Public acceptance actions | Studied potential job generation | | Infrastructure related actions |
| Los Angeles, CA (Drone Laws, 2023) | Use for recreational and commercial use only, subject to restrictions based on CA legislation | Prohibits every potential act that could lead to interference with existing aviation | | | | Prohibits operations within a 5-mile proximity of airports |
| Miami, FL (Serrao et al., 2018) | Bans operations < 0.5 mi from large venues/events | Use in limited areas for recreational and commercial use only | | | | |

| Laws and Policies from Major US Cities/Metro Areas | | | | | | |
|---|---|---|---|---|---|---|
| *Urban Area* | *Safety Risk Management* | *Operational Integration* | *Public Acceptance* | *Innovation & Economic Growth* | *Environmental Impact* | *Infrastructure Planning* |
| Phoenix, AZ (Drone Laws, 2023) | Prohibits reckless operations | | Prohibits operations in regional parks except designated areas | | | |
| San Diego, CA (Drone Laws, 2023) | Flight rules and conditions definition, request permission before flight | | | | | Prohibits operations in close proximity to specific areas and infrastructure |
| San Francisco, CA (Drone Laws, 2023) | UAV test and certification before flight | Use in limited areas for recreational and commercial use only | | | | Prohibits operations in close proximity to specific areas and infrastructure |
| Washington DC (Drone Laws, 2023), (Serrao et al., 2018) | | Law formulation, allowed in limited areas for recreational and commercial use | | | | Prohibits operations in close proximity to specific areas and infrastructure |

**Table 27. International Laws and Policies**

| Laws and Policies from International Contexts | | | | | | |
|---|---|---|---|---|---|---|
| | *Safety Risk Management* | *Operational Integration* | *Public Acceptance* | *Innovation and Economic Growth* | *Environmental Impact* | *Infrastructure Planning* |
| European Union (European Union Aviation Safety Agency, 2018), (Iker, 2016) | Safety regulations | Operational categories definition | Mitigate risks to privacy, protection of personal data | Identification of economic operators | Security and environmental protection | Infrastructure supporting the command and control |
| Canada (Serrao et al., 2018) | Flight & operational instructions | Flight instructions | | | | |
| United Kingdom (Serrao et al., 2018) | Assess competence of drone pilots | Assess competence of drone pilots | | | | |
| Ireland (Serrao et al., 2018) | Safety distance & flight altitude specs | Safety distance & flight altitude specs | | | | |
| New Zealand (Serrao et al., 2018) | Safety distance & flight altitude specs | Safety distance & flight altitude specs | | | | |
| United Arab Emirates (Serrao et al., 2018) | Safety, certification, privacy | Safety, certification, privacy | Safety, certification, privacy | | | |
| Germany (Serrao et al., 2018) | | Certification of aircraft | | | | |

| **Laws and regulation from major international cities** | | | | | | |
|---|---|---|---|---|---|---|
| | *Safety Risk Management* | *Operational Integration* | *Public Acceptance* | *Innovation and Economic Growth* | *Environmental Impact* | *Infrastructure Planning* |
| Tokyo (Drone Laws, 2023) | Restricted to fly below 150 m | | | | | Prohibit operations, need of specific permit to fly above Densely Inhabited Districts (DID) defined and published by the Ministry of Internal Affairs and Communications, around airports |
| Dubai (Drone Laws, 2023) | UAVs cannot near public and/or private property | The minimum age to fly UAS/drones weighing more than 25Kg is 21 years | | | | UAVs cannot be flown within an airport's 3.1-mile radius |
| Hong Kong (Drone Laws, 2023) | Definition of UAV categories based on weight, specific permits | Registration of pilots, training | | | | UAVs cannot be flown within an airport's 3.1-mile radius |

### Table 28. Illinois Compiled Statutes on Air Transportation

| Index | Name | Potentially Relevant |
|---|---|---|
| 620 ILCS 5/ | Illinois Aeronautics Act. | Yes |
| 620 ILCS 10/ | Military Emergency Aircraft Restriction Act. | No |
| 620 ILCS 15/ | Aircraft Landing and Taking Off Restriction Act. | Yes |
| 620 ILCS 20/ | Joint Airports Act. | Yes |
| 620 ILCS 25/ | Airport Zoning Act. | Yes |
| 620 ILCS 30/ | Zoning to Eliminate Airport Hazards Act. | Yes |
| 620 ILCS 35/ | Permanent Noise Monitoring Act. | Yes |
| 620 ILCS 40/ | General County Airport and Landing Field Act. | Potentially |
| 620 ILCS 45/ | County Airport Law of 1943. | No |
| 620 ILCS 50/ | County Airports Act. | No |
| 620 ILCS 52/ | County Air Corridor Protection Act. | Potentially |
| 620 ILCS 55/ | East St. Louis Airport Act. | No |
| 620 ILCS 60/ | Meigs Field Airport Act. (Repealed by P.A. 90-6) | No |
| 620 ILCS 65/ | O'Hare Modernization Act. | No |
| 620 ILCS 70/ | Aircraft Crash Parts Act. | Potentially |
| 620 ILCS 75/ | Public-Private Agreements for the South Suburban Airport Act. | No |
| **Additional relevant Illinois legislation** | | |
| IL Public Act 102-1094 | IDOT is able to use the design-build project delivery method subject to budgetary limits on capital costs for transportation facilities. | Potentially |
| IL Public Act 102-0313 | Amends the Illinois Aeronautics Act to include provisions of financial assistance to municipalities and others for the planning, development, and improvement of air navigation facilities including land acquisition, easements including navigation easements necessary for clear zones or clear areas, costs of obstruction removal and airport approach aids for the benefit of the public. | Potentially |

**Table 29. AAM/UAM-Related Content within the Technical Report Chapters of the IL Aviation System Plan (source: IL Aviation System Plan)**

| Chapter | Title | AAM/UAM-Related and -Relevant Content Sections | Content Description |
|---|---|---|---|
| 1 | System Goals and Performance Measures | – | |
| 2 | Airport Classifications | – | |
| 3 | Existing and Future System Adequacy | – | |
| 4 | Aviation System Issues | 4.5: Drones and Commercial Airspace | Section 4.5.1: UAS, the IASP recognizes that unmanned aerial vehicles (UAVs) are already being used by state agencies including the Illinois State Police and may be adopted by other state agencies in the coming years.<br>Section 4.5.3: Next Steps, the IASP In addition to UAS and the privatization of space, the aviation industry is burgeoning with other cutting-edge technologies promising a future where flight is cheaper, more sustainable, and/or faster than ever before. |
| 5 | Multimodal Integration and Airport Access | – | |
| 6 | Land Use Evaluation and Environmental Considerations. | – | |

| Chapter | Title | AAM/UAM-Related and -Relevant Content Sections | Content Description |
|---|---|---|---|
| 7 | Aviation Activity Forecasts | 7.2.2: Emerging Technologies | Section 7.2.2: Emerging Technologies. The IASP proposes that the emerging AAM/UAM technologies may radically alter demand for parking garages, consolidated rental car facilities, electricity and charging stations, ground access, terminal buildings, and management of airspace. |
| 8 | Future Aviation Scenarios. | 8.3: General Aviation | Section 8.3.3: Charging Station and Power Generation, the IASP suggests developing legislation to promote-adopt infrastructure for electric aircraft |
| 9 | Cost Estimates | – | |
| 10 | System Considerations | 10.3: IASP Project Considerations | Section 10.3.4: Heliport and Vertiport System Plan, the IASP recommends planning for heliports (including vertiports/vertistoperations) separately from IL Aviation System airports to allow for AAM integration as it emerges. The IASP recognizes that integration of AAM into the current aviation system will need to consider novel aircraft and aircraft technology, operational framework, airspace access, infrastructure retrofitting and development, and policy. |

# APPENDIX B: ADDITIONAL FIGURES

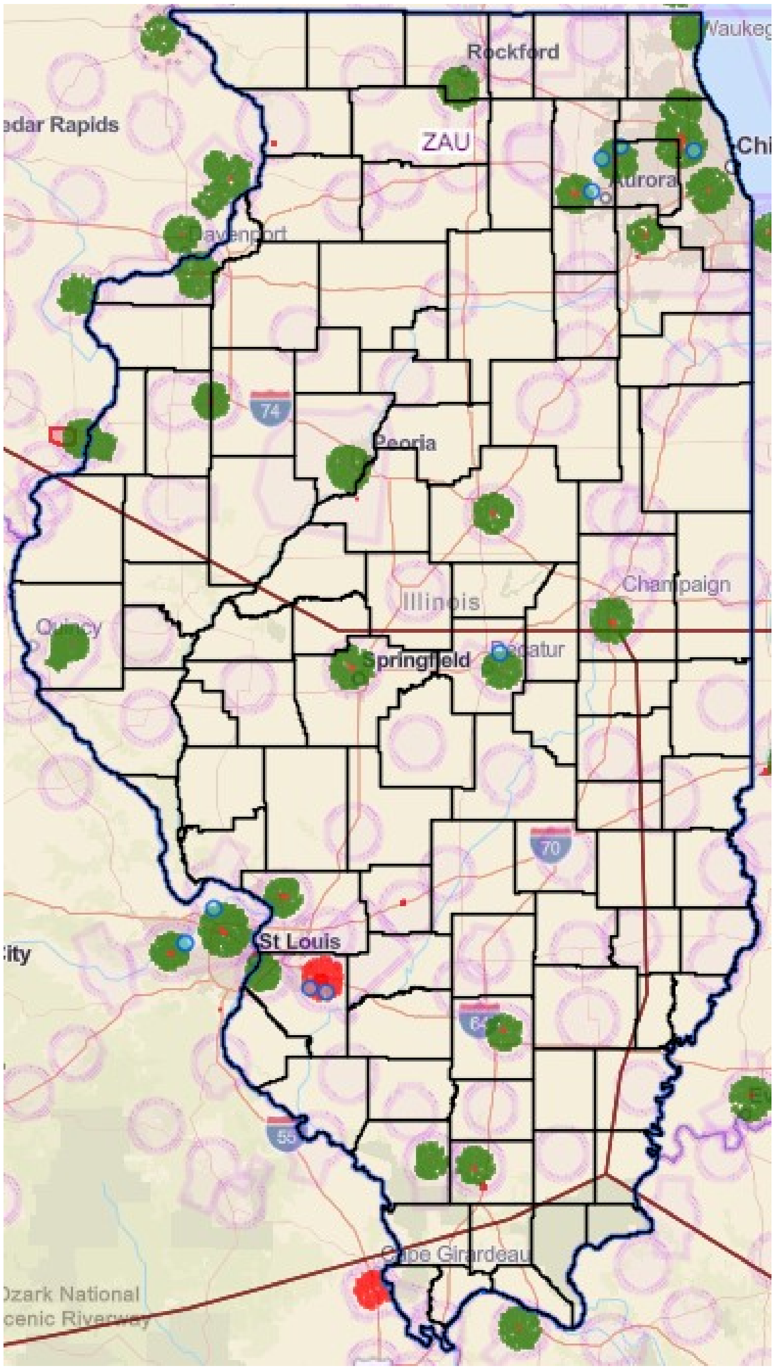


Figure 62. Graph. Airspace classes across Illinois.

*Source: Federal Aviation Administration (2020c)*

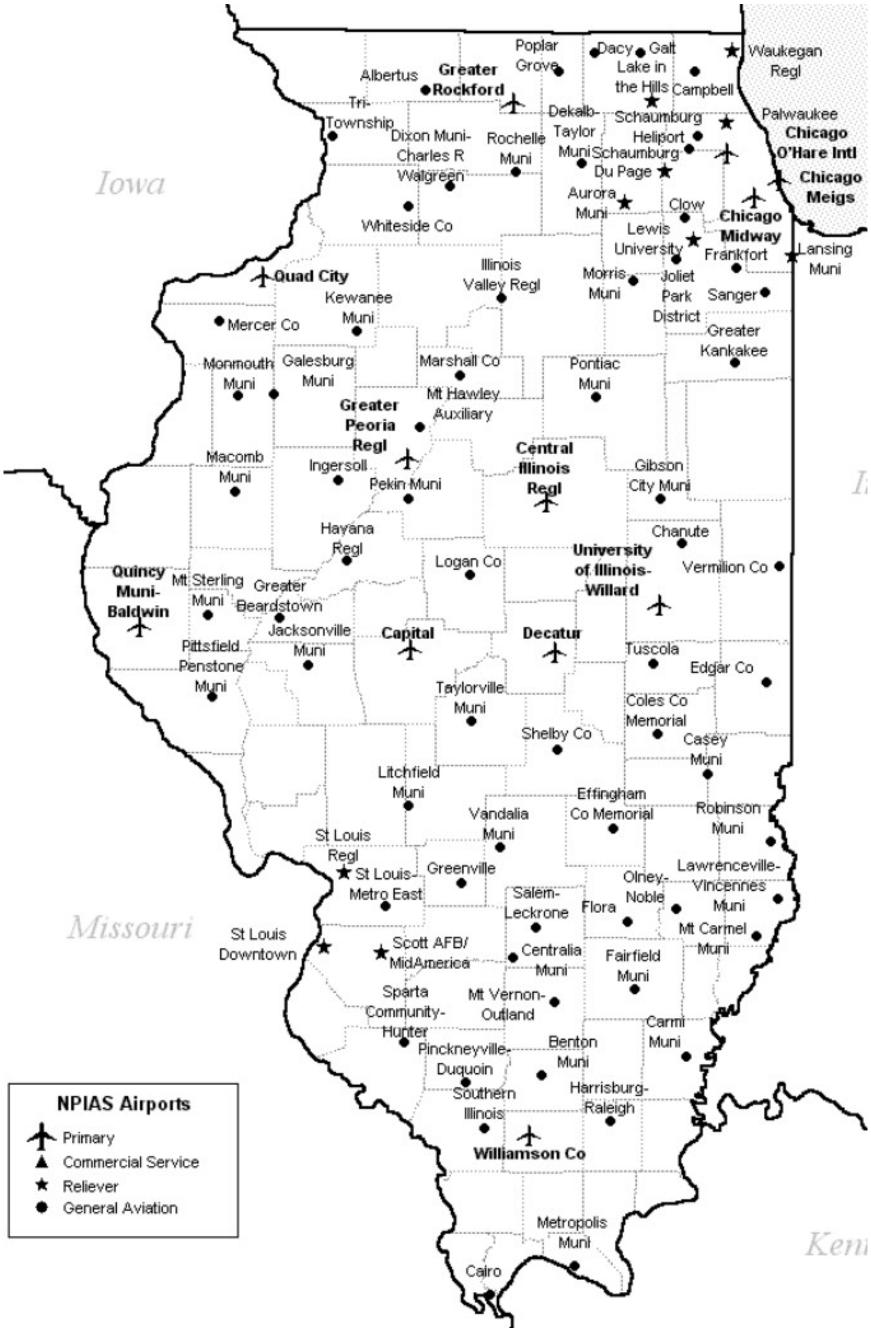


**Figure 63. Graph. Airports and landing locations in Illinois.**

***Source: Illinois Map (2017)***

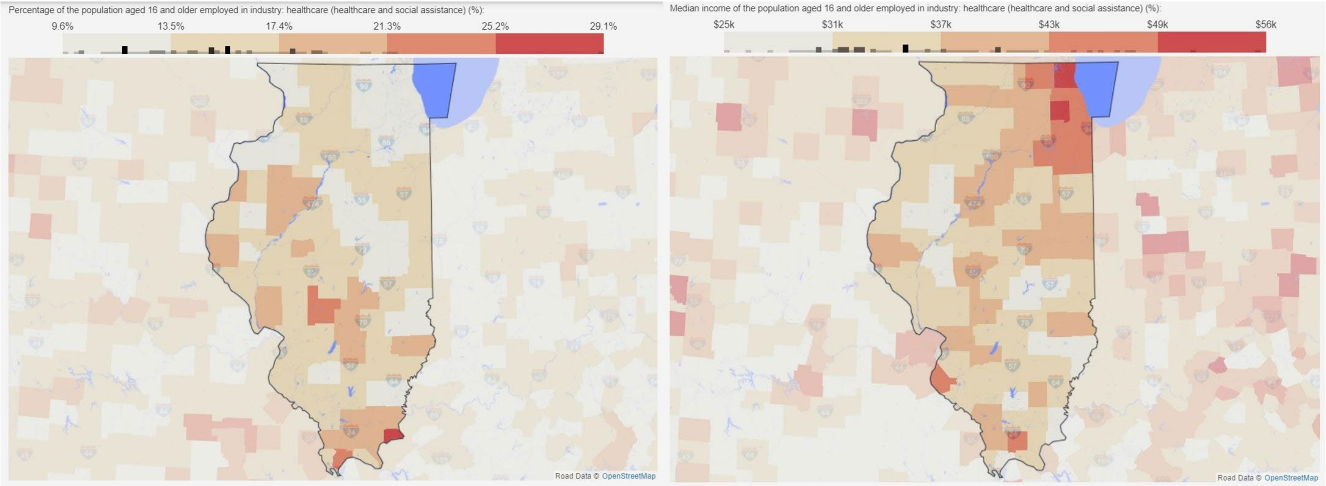


**Figure 64. Graph. Percentage of people employed in the health industry (left), median income of people employed in the health industry (right).**

***Source: Statistical Atlas (2018)***

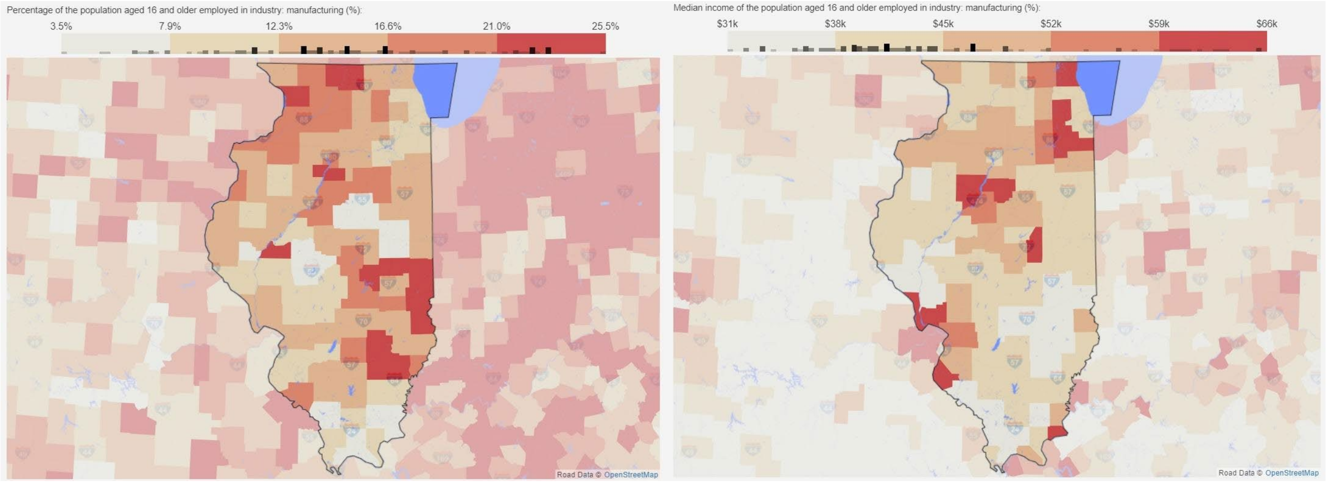


**Figure 65. Graph. Percentage of people employed in the manufacturing industry (left), median income of people employed in the manufacturing industry (right).**

***Source: Statistical Atlas (2018)***

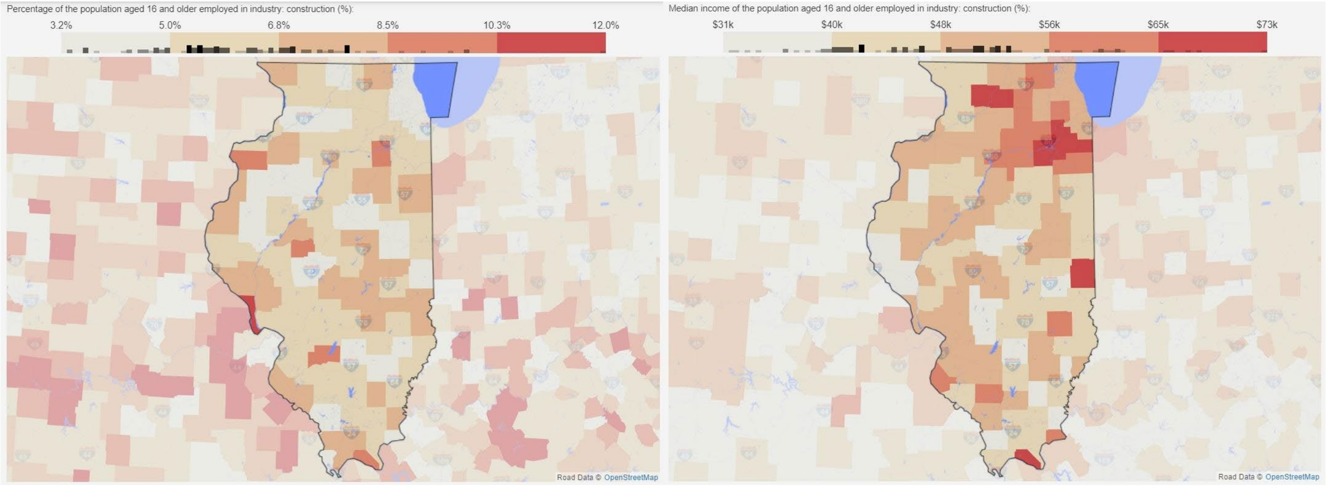


**Figure 66. Graph. Percentage of people employed in the construction industry (left), median income of people employed in the construction industry (right).**

***Source: Statistical Atlas (2018)***

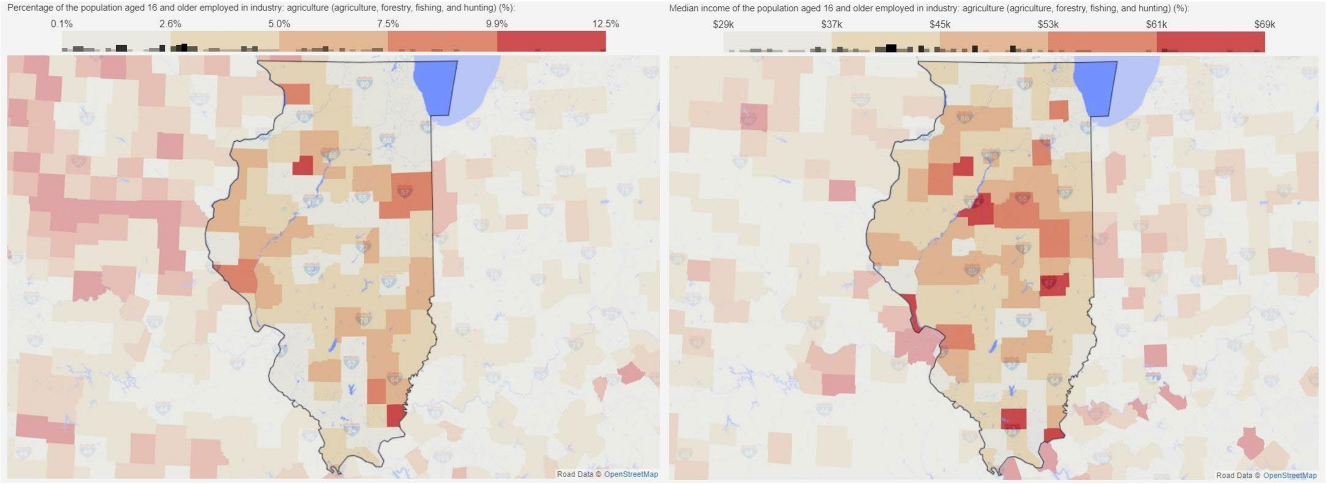


**Figure 67. Graph. Percentage of people employed in the agriculture industry (left), median income of people employed in the agriculture industry (right).**

***Source: Statistical Atlas (2018)***

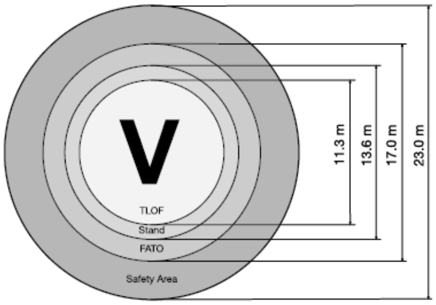


**Figure 68. Graph. Calculated dimensions based on the legally required areas for heliports.**

***Source: Brusberg et al. (2021)***

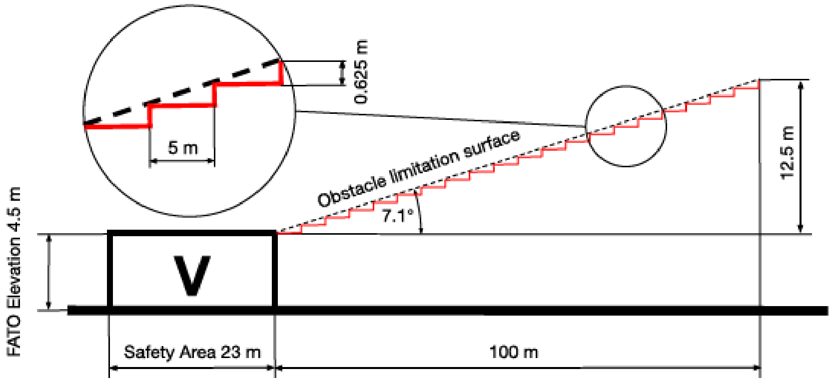


**Figure 69. Graph. Discretized obstacle limitation surface (red) for the vertical spatial analysis.**

***Source: Brusberg et al. (2021)***

# APPENDIX C: METHODOLOGY ANALYSIS

## GROUND RISKS

In terms of the number of people that could potentially be affected by aircraft incidents, Su and Xu (2022) derived a mathematical formulation in order to quantify the impact of an aircraft falling into a populated area after a failure, mechanical or other nature. The authors calculated the circular area inside which the risk of being affected severely by the falling aircraft is relatively high. The diameter of this area is given as $\left(2 * R_p + \frac{H_p}{tan\gamma} + L_{aircraft}\right) * 2$, where $L_{aircraft}$ is the length of the aircraft from rotor to rotor, $H_p$ the average height of a person, $\gamma$ the aircraft falling angle without power, and $R_p$ the radius of a person. This was used in order to calculate the number of pedestrians affected in a potential incident, and based on that various injury and fatality indexes were formulated, as well as the probabilities of sustaining different injuries (different by level of severity).

## FORECASTING MODELS

Deep Learning models primarily consist of three layers, despite the fact that specific model architectures may vary based on various problem requirements: input, output, and hidden. The quantity of neurons in each layer and the quantity of layers are the hyperparameters of the organization. In general, the terms input (x), weight (w), and bias (b) are present in each hidden layer neuron.

$$y_i = \sigma(\sum_i W_i x_i + b_i)$$

**Figure 70. Equation. Output of a single neuron in a Neural Network (NN).**

***Source: Anderson (1995)***

$$\sigma(z) = \frac{1}{1 + e^{-z}}$$

**Figure 71. Equation. Nonlinear activation functions.**

***Source: Anderson (1995)***

$$\tanh(z) = \frac{e^{z} - e^{-z}}{e^{z} + e^{-z}}$$

**Figure 72. Equation. Hyperbolic tangent function.**

***Source: Anderson (1995)***

$$R(z) = \max(0, z)$$

**Figure 73. Equation. Rectified linear unit.**

***Source: Anderson (1995)***

However, due to the model's fully connected nature, the parameter size in the network will grow in proportion to the number of input features, which will compromise computational performance and cause storage issues. But since the data used here are only going back several years, this model can be used without worrying extensively for the above.

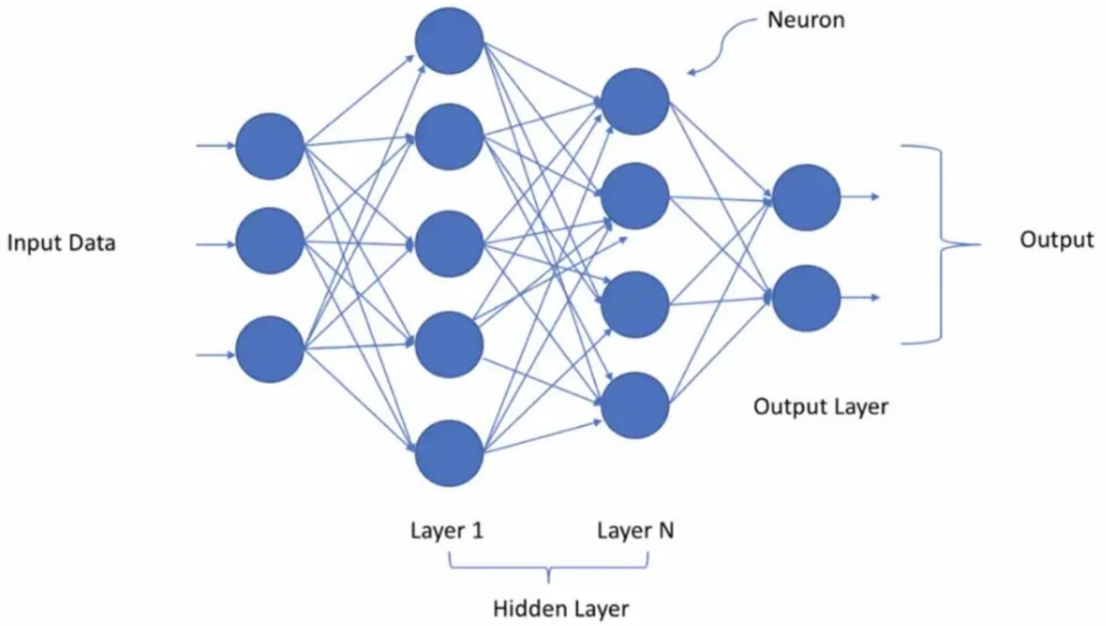


**Figure 74. Deep neural network with N hidden layers.**

***Source: (Moolayil, 2020)***

Regarding the ARIMA model (Newbold, 1983; Ho & Xie, 1998) in the statistical literature, the Box-Jenkins ARIMA method is well established. However, there isn't much use for it in the reliability field. To determine whether the proposed model is adequate, an iterative three-stage procedure involving model identification, parameter estimation, and a diagnostic check is required.

$$X_t = \Psi_0 + \varphi_1 X_{t-1} + \varphi_2 X_{t-2} + \cdots + \varphi_p X_{t-p} - \theta_1 \varepsilon_{t-1} - \theta_2 \varepsilon_{t-2} - \cdots - \theta_q \varepsilon_{t-q} + \varepsilon_t$$

**Figure 75. Equation. ARIMA model.**

***Source: Anderson (1995)***

where $p$ and $q$ are the order of the autoregressive model and moving average model, respectively, $\varphi_1, \varphi_2, \ldots, \theta_1, \theta_2, \ldots$are the regression weights to be estimated, $\Psi_0$ represents the trend component, and $\varepsilon_1, \varepsilon_2, \ldots$ are the random errors. The ARIMA modeling method is primarily an exploratory data-oriented strategy that can be tailored to an appropriate model based on the data's structure. The stochastic nature of the time series can be roughly modeled using the autocorrelation function and the partial autocorrelation function; which can be used to discover information like a trend, random variations, a periodic component, cyclic patterns, and serial correlation. Consequently, it is simple to make predictions of the series' future values with some degree of accuracy. Both models were implemented in Python (using Keras and Arima libraries [Attri et al., 2020; Khodadadi, 2021]). Table 30 presents the variables forecasted via the aforementioned models.

**Table 30. Forecasted Variables**

| Variable notation | Forecasted variable explanation |
|---|---|
| $MHI_{f_i}$ | Median Household Income |
| $VOT_{f_i}$ | Value of Time |
| $V_i$ | Volume of passengers |
| $P_{f_i}$ | Illinois Population |
| $FVMT_i$ | Vehicle Miles Traveled |
| $yd_{j_i}$ | Yield, $j = \{corn, soybeans, wheat\}$ |
| $ac_{j_i}$ | Area harvested |
| $pr_{j_i}$ | Value of production |
| $fl_i$ | Livestock count (sheep, cattle) |

# ECONOMIC IMPACTS

## Passenger Travel Time

The value of travel time (VOT) is evaluated as the half of hourly median household income in 2019 in the US (US Census Bureau, 2020; US Department of Transportation, 2016), and a value of $VOT = \$16.5/\text{hour}$ will be used. In order to forecast the value of travel time for the time-span of 20 years that it was mentioned above, the following equation has adapted from Dulia et al. (2021):

$$VOT_{f_i} = VOT \frac{MHI_{f_i}}{MHI_{2021}}$$

**Figure 76. Equation. Forecasted value of travel time.**

***Source: Adapted from Dulia et al. (2021)***

where as $MHI_{2021} = \$72{,}563$, the median household income in Illinois for 2021 was used, [299] and $MHI_{f_i}$ corresponds to the forecasted value for the median household income in Illinois for each one of the years considered in the forecast, $i = (2023{,}2024, \dots, 2042)$.

Using estimated data from Chapter 2, and assuming middle-case daily trip volume for both air-taxi and airport shuttle services ($a_s = 4{,}100$), $V_i$ was estimated for $\forall i \in \{2023{,}2024, \dots, 2042\}$. Not all 365 days of a year were considered as the same, with the 260 workdays being non-weighted, but the other 105 being weighed by a factor of 0.33 ($f_{nw} = 0.33$), trying to roughly account for a trip reduction of 1/3 of usual demand, due to the absence of work trips. Accounting for a conservative 2% yearly demand increase, a value that was based on the reduction on the cost/passenger mile that Uber Elevate estimated in their long-term scenario (10–20 years), from \$0.84 to \$0.34 (Holden et al., 2016). Consequently:

$$V_i = (260 + 105 * f_{nw}) * a_s * (1 + 0.02)^{1*i}, i = (1, 2, \dots, n), n = 20\ years$$

**Figure 77. Equation. Volume of passengers.**

The following equation was derived for calculating time saved by users using UAM services:

$$TT_{s_i} = V_i * \frac{TT_{avg}}{60}$$

**Figure 78. Equation. Time saved by users using UAM.**

where $V_i$ corresponds to the volume of passengers that was estimated for each year considered, and $TT_{avg}$ equals to 52.5 minutes, which is the average time of a UAM trip that would lead to considerable travel time savings. The literature so far shows that in order for AAM services to achieve significant travel time savings, the distance of these trips has to be above a certain threshold (50–55 minutes and up of ground transportation time in a pessimistic scenario [Rothfeld et al., 2021]). Following, Figure 79 corresponds to the monetary value of the calculated time saved from passengers using UAM services, based on the value of time that was introduced and calculated above.

$$TT_{m_{S_i}} = TT_{s_i} * VOT_{f_i}$$

**Figure 79. Equation. Monetary value of the calculated time saved from passengers using UAM.**

## Medical Emergency

Response-time reductions achieved by UAVs delivering medical equipment were associated with between a 42% and 76% higher survival rate and up to 144 additional lives saved each year ($ls_T$), with data from Toronto, Canada, in Out of Hospital Cardiac Arrest Episodes (OHCAE, Boutilier & Chan, 2022). Illinois has a population of approximately 12,670,000 people, and the Greater Toronto Area has approximately 6 million people, so the number of lives saved in Illinois will be estimated as $ls_C = 2.11 ls_T$. According to Cleveland Clinic (2021), 74 out of 100,000 people suffer of a cardiac arrest related incident in the United States (2017 data), and 1 out of 7 passed away. Based on the Illinois population forecast ($P_{f_i}$), the estimated number of people suffering from OHCAE in Illinois ($i = (2023,2024,\ldots,2042)$):

$$ca_i = P_{f_i}\left(\frac{74}{100{,}000}\right)$$

**Figure 80. Equation. Estimated number of people suffering from OHCAE in Illinois.**

Considering the middle case of the estimated increase in the survival rate by supplying automated external defibrillators (AEDs), (Boutilier & Chan, 2022), which corresponds to 58.5%, between a 41% and a 76% increase. For the survival rate, $sr = 1.585 * sr_{init}$, where the survival rate before the drone-delivered AEDs option was 9.9% ($sr_{init}$), according to [308], Figure 81 corresponds to the number of survivors due to the existence drone-delivered AEDs ($i = (2023,2024,\ldots,2042)$):

$$Tls_i = ca_i * (sr - sr_{init})$$

**Figure 81. Equation. Number of survivors due to the existence drone-delivered AEDs.**

To compute the monetary value of lives saved, first the annual cost for each drone ($c_d = \$3750 + \$3000$), costs for purchase and maintenance for a life span of 4 years). It was assumed initially that 150 drones per station will be sufficient to serve Illinois, since from Miller (2018), Rwanda is more than five times smaller in size (10,169 mi$^2$ compared to 57,915 mi$^2$ of Illinois), was served by 25 stations of 30 UAVs each. Assuming one third of the number of UAVs to be needed (since in Rwanda Zipline was continuously delivering vaccines, blood products, medication, etc., with the "demand" in the Chicago Area being significantly less due to the different nature of the provided service), the total annual cost would be estimated from Figure 82:

$$Tc_d = c_d * (5 * 50)$$

**Figure 82. Equation. Total annual cost.**

Regarding the monetary value of lives saved, a middle range value of the different Values of Life that were reported by the authors based on different occupation sectors will be assumed, where $VLS = \$7\ million$ (2021 values) (Keller et al. 2021). Therefore, Figure 83 gives the total monetary savings for each forecasted year, from the availability of medical first aid drone delivery ($i = (2023,2024,\ldots,2042)$):

$$TS_i = Tls_i * VLS - Tc_d$$

**Figure 83. Equation. Total monetary savings.**

## Driving-Related Accidents

The annual VMT for Illinois were forecasted, denoted as $FVMT_i$, using the time series models that were introduced above. From Injury Facts (2022a), the death rate per 100 million passenger miles accounts for 0.56 people, while from IIHS (2021), Illinois in 2020 had a fatality rate from motor traffic accidents of 1.27 people per 100 million passenger miles driven, leading to the usage of $dr_c = 1.128$ (using a higher weight for the 1.27 value and a lower one for the 0.56 value for passenger vehicles, while for aviation $d_a = 0.002$ (the assumption that similar levels of safety will exist between today's aviation and AAM services is being made). So, the number of ground transportation fatalities for each one of the forecasted years in Illinois is calculated from Figure 84, for $i = (2023,2024, \ldots ,2042)$:

$$gf_i = \frac{FVMT_i}{10^8}(dr_c - d_a)$$

**Figure 84. Equation. Number of ground transportation fatalities.**

Considering that $TT_{avg}$ corresponds to approximately a 35-mile distance covered ($gd = 35\ miles$), and considering a middle case value of 2 passengers per trip, the miles flown by the total number of passengers for each forecasted year is calculated from Figure 85, for $i = (2023,2024, \ldots ,2042)$:

$$Mt_i = \frac{V_i}{2} gd$$

**Figure 85. Equation. Miles flown by the total number of passengers for each forecasted year.**

To calculate the estimated number of reduced fatalities due to the use of eVTOLs:

$$F_{R_i} = \frac{Mt_i}{FVMT_i} gf_i$$

**Figure 86. Equation. Estimated number of reduced fatalities due to the use of eVTOLs.**

with Figure 86 being the ratio of forecasted miles flown and ground VMT, multiplied by the ground fatalities estimate for each year $i$. The Value of Life is denoted as a constant and wasn't forecasted, due to the high number of economic-related and other variables affecting such a number (inflation, monetary values changes, etc.), therefore the savings from the fatalities reduction can be obtained from Figure 87:

$$S_{f_i} = F_{R_i} * VLS$$

**Figure 87. Equation. Savings from the fatalities reduction.**

Injury-related savings are also considered in this work, with data from Illinois Department of Transportation (2021) indicating that in 2021, there were 295,604 total crashes, from which 60,991

($n_{inj_g}$) had injuries (but non A-type injuries) as a consequence, and 7,576 (of the total) led to A-type injuries, i.e., disability-related injuries ($n_{inj_a}$). From (Injury Facts, 2022b), the cost of an A-type injury was set to be $j_a = \$101{,}000$, and an average cost was set to as $j_r = \$26{,}550$, based on different values regarding types B and C injuries. In order to calculate injury rates per 100 million passenger miles driven, (Illinois Department of Transportation, 2021) there were 102.22 billion miles driven in Illinois in 2021, so a factor corresponding to accidents per 100 million miles driven that had injuries (but non A-type injuries) as a consequence was defined as $dj_{n_a} = 59.7$, and a factor corresponding to accidents that had A-type injuries as a consequence was defined as $dj_a = 7.4$ (i.e., 7.4 A-type injury related accidents per 100 million miles driven). Therefore, the number of ground transportation injuries non-type A and type A, for each one of the forecasted years in Illinois is calculated from Figures 88 and 89, respectively, for $i = (2023, 2024, \dots, 2042)$:

$$gj_{na_i} = \frac{FVMT_i}{10^8}(dj_{n_a} - d_a)$$

**Figure 88. Equation. Non-A-type ground transportation injuries.**

$$gj_{a_i} = \frac{FVMT_i}{10^8}(dj_a - d_a)$$

**Figure 89. Equation. A-type ground transportation injuries.**

To calculate the estimated number of reduced injuries due to the use of eVTOLs:

$$F_{na_i} = \frac{Mt_i}{FVMT_i} gj_{na_i}$$

**Figure 90. Equation. Estimated number of reduced non-A-type injuries due to the use of eVTOLs**

$$F_{a_i} = \frac{Mt_i}{FVMT_i} gj_{a_i}$$

**Figure 91. Equation. Estimated number of reduced A-type injuries due to the use of eVTOLs**

with Figure 90 corresponding to the estimated number of reduced non-A-type injuries, and Figure 91 corresponding to the estimated number of reduced A-type injuries from ground traffic accidents. The savings from the injuries avoidance due to the use of AAM aircraft can be obtained from Figure 92:

$$S_{j_i} = F_{na_i} * j_r + F_{a_i} * j_a$$

**Figure 92. Equation. Savings from injuries avoidance.**

## Package Delivery

From Markets and Markets (2021), the global drone package delivery market is projected to reach the levels of $5.6 billion by the end of 2030, at a CAGR (Compound Annual Growth Rate) of 49%. From (Markets and Markets, 2020), the 2021 US UAV package delivery market size was $402.4 million ($D_{US_{2021}}$), with the global market corresponding to $945 million ($D_{g_{2021}}$), and by using that value, the global UAv package delivery market size can be estimated based on Equation 93, and consequently from Equation 94, the US market size for each forecasted year can be estimated as well, with $t \in \{2,3, \dots ,20\}$:

$$D_{g_i} = D_{g_{2021}} * (1 + CAGR)^t$$

**Figure 93. Equation. Global UAV package delivery market size.**

***Source: Adapted from Dulia et al. (2021)***

$$D_{US_i} = D_{g_i} * D_{US_{2021}} / D_{g_{2021}}$$

**Figure 94. Equation. US UAV package delivery market size.**

***Source: Adapted from Dulia et al. (2021)***

From Placek (2022), 83% of parcels weighed less than 2 kilograms (4.4 lb), and 67% weighed less than 1kg (2.2 lb). Additionally, the weather has a big impact on drone delivery. Based on Chicago hourly weather data from 2010 NCEI, the weather alone cuts total flyable time by 25%. Regarding the annual UAV operational hours based on various restrictions, in order to adjust the forecasted US market sizes from Figure 94 to the Illinois market, a factor $f_{ad} = 0.72$ was used (package delivery restrictions have already been accounted for in the numbers provided by Markets and Markets (2021) since they refer to actual UAV delivery services, but considering the fact that in Illinois a 48-59% of the total package volume can be serviced via UAV due to the aforementioned limitations, the above factor was introduced to account for a conservative case).

From Statista (2021), the Illinois industry revenue of couriers and express delivery services in 2021 was approximately equal to $3.85 billion, and from Placek (2022), the US 2021 parcel delivery revenue were at $188 billion. So an approximation of Illinois drone delivery market size would be at the scale of 2% ( $dr_{IL_{2021}} = 0.02$). Consequently, an estimation of the Illinois market size for each forecasted year can be estimated from Figure 95:

$$D_{IL_i} = D_{US_i} * dr_{IL_{2021}} * f_{ad}$$

**Figure 95. Equation. US drone package delivery market size.**

In the US there were 21.6 billion parcels shipped (Placek, 2022), and by assuming that an approximation of 2% corresponds to Illinois (based on the above calculations and assumptions), that could correspond to 432 million parcels, from which a 53.5% could be delivered via drone ($pg_{IL} = 231.12$ million units). Garcia et al. (2019) found that the cost of a package delivered by UAV is approximately equal the one third of the cost of a package delivered by truck ($c_{drone} = \$0.36/\text{unit}$, compared to $c_{truck} = \$1.20/\text{unit}$, accounting for capital, maintenance, costs of UAVs, etc. Figure 96 corresponds to cost-savings from shifting parcels delivered by trucks to UAVs. Important to mention is the fact that a deterministic value for each year is considered, due to the inability of evaluating properly the speed under which technology will allow for more drone delivered packages each year.

$$cs_{l_{static}} = pg_{IL} * (c_{truck} - c_{drone})$$

**Figure 96. Equation. Cost-savings from shifting parcels delivered by trucks to UAVs.**

In the realm of travel time savings, a drone (under 2016 technology specifications) can finish a 15-mile roundtrip delivery in 24 minutes (7.5 miles which is the average last-mile delivery trip in 12 minutes, accounting for ascending, descending, loading and unloading time), corresponding to an 8-minute trip for a 5-mile distance ($tt_{drone} = \frac{8}{5}\frac{minutes}{mile}$), (Garcia et al., 2019). A truck driven 5-mile distance for delivery is going to take approximately 19 minutes ($tt_{truck} = \frac{19}{5}\frac{minutes}{mile}$). Figure 97 gives the travel time cost savings for Illinois (again deterministically considered for each year due to the same reasons as in Figure 96):

$$cs_{tt_{static}} = pg_{IL} * \frac{tt_{truck} - tt_{drone}}{60}$$

**Figure 97. Travel time cost savings for Illinois.**

## Bridge Inspections

The traditional bridge inspection approach needs on average 8 hours per inspection ($it_t$), while UAV inspection needs approximately 4 hours per inspection ($it_d$). From Batty (2021), data for Illinois bridges annual average daily traffic volume where used, in order to find an hourly average estimate of traffic in an Illinois bridge, with that estimate being $bt_{IL_{2021}} = 580$ vehicles/hour per lane, for the year 2021. Figures 98 and 99 will give the number of annual vehicles facing delays due to bridge closing in Illinois in the cases of traditional and drone inspections, respectively:

$$vd_t = nb_{IL} * bt_{IL_{2021}} * it_t$$

**Figure 98. Equation. Number of annual vehicles facing delays due to bridge closing in Illinois, traditional inspection.**

$$vd_d = nb_{IL} * bt_{IL_{2021}} * it_d$$

**Figure 99. Equation. Number of annual vehicles facing delays due to bridge closing in Illinois, UAV inspection.**

According to Colorado Department of Transportation (2020), an average delay from the closing of a lane due to the congestion created in the rest of the network is approximately 10 min per vehicle ($ad_{lc} = 10/60$), and based on Dulie et al. (2021), the average vehicle occupancy is assumed to be $a_{vo} = 1.7$ passengers/vehicle. Figure 100 gives the travel time savings for every forecasted year (using VOT calculated in previous sections). Figure 101 provides the value of the aforementioned travel time savings:

$$t_{tss} = (vd_t - vd_d) * a_{vo} * ad_{lc}$$

**Figure 100. Equation. Value of the aforementioned travel time savings.**

$$vt_{tts_i} = VOT_i * (vd_t - vd_d) * a_{vo} * ad_{lc}$$

**Figure 101. Equation. Travel time savings for every forecasted year.**

According to the Department of Transportation, using UAVs can reduce costs by 40% without sacrificing quality (Intelligent Transportation Systems, 2019). Additionally, traditional bridge inspection calls for the closure of lanes, the use of heavy machinery, and the presence of at least two people (West Virginia Department of Transportation, 2020; Wells, J., & Lovelace, B., 2021. While minor bridges may only require a single day of inspection, major bridges may need many weeks (Brittingham, 2021). Highway technicians, inspectors, traffic coordinators, or those willing to put in about 48 hours in dangerous, dark settings, are all needed (Facade Ordinance Inspections, 2019). In contrast, drones would only need two field personnel and cost $45 for each bridge inspection ($bc_d$). Ohio DOT predicts annual savings of $400,000, with Ohio having an average of 400 bridges for imminent inspection (out of 14,500 bridges), while Illinois has 3.5 times more bridges for imminent inspection.

## Agriculture

Assuming that farms which could adopt AAM are the ones with revenue greater or equal $100,000 annually, according to United States Department of Agriculture (2017), from a total of 72,651 agricultural farms in Illinois (2019 data), there are 23,710 is this revenue category, estimating in that way a 33% adoption factor ($a_f = 0.33$). Data from 1980 until 2019 were used in order to forecast different values regarding different products, which are corn, soybeans, wheat, and data from 1990 until 2019 regarding livestock (sheep and cattle) (United States Department of Agriculture, 2017, 2020). The choice of these commodities was done based on Stovall (2016), regarding the top agricultural commodities in Illinois. The forecasted time-period was defined from 2020 until 2039.

Wheat yields can potentially increase up to 3.3% ($y_w = 0.033$), and yields regarding soybeans and corn up to 2.5% ($y_{cs} = 0.025$) with the use of UAVs (Doering, 2015). Equations 20, 21 and 22 account for the annual value of the increased production for corn, soybeans and wheat, respectively, for each of the forecasted years (with $yd$, $ac$, and $pr$ corresponding to yield (bushels) per acre, acres, and price, respectively, for each one of the considered products):

$$Vpd_{c_i} = \left(yd_{c_i} * y_{cs}\right) * \left(\frac{pr_{c_i}}{yd_{c_i}}\right) * ac_{c_i} * a_f$$

$$Vpd_{s_i} = \left(yd_{s_i} * y_{cs}\right) * \left(\frac{pr_{s_i}}{yd_{s_i}}\right) * ac_{s_i} * a_f$$

$$Vpd_{w_i} = \left(yd_{w_i} * y_w\right) * \left(\frac{pr_{w_i}}{yd_{w_i}}\right) * ac\_w_i \; * a_f$$

**Figure 102. Equation. Annual value of the increased production for corn, soybeans and wheat.**

***Source: Adapted from Dulia et al. (2021)***

In terms of labor cost savings, \$11.58/acre can be saved ($ls$), by the use of UAVs (Doering, 2015). The annual cost savings for each commodity (\$ saved/acre) can be calculated from Figure 103:

$$lcs_{i_j} = ac_{j_i} * ls * a_f$$

**Figure 103. Equation. Annual cost savings for each commodity.**

where $j = \{corn, soybeans, wheat\}$

From a case study in Scotland, labor cost reductions could stem from reduced times for grassland checks (one and a half hours on foot, compared to 30 minutes by UAVs), as well as hill checks (30 minutes by UAVs compared to 40 minutes by truck), which can lead to a reduction of 104 and 26 hours per year, respectively ($mhs = 130$), by using a UAV twice per week, for a herd of 980 sheep in total ($hs$), (Farm Advisory Service, 2021). The average farmer salary in Illinois \$29/hour ($fe_{avg}$), (Economic Research Institute, 2020), with Figure 104 providing labor cost savings from the use of drones in agricultural activities (regarding livestock):

$$llcs_i = \frac{mhs * fe_{avg}}{hs} * fl_i * a_f$$

**Figure 104. Equation. Labor cost savings from the use of UAVs in livestock related activities.**

where $fl_i$ corresponds to the forecasted livestock count for each year $i$.

## State Taxes

A study in the Greater Vancouver Area, Canada, stated that the Province of British Columbia can potentially acquire a cumulative \$167 million in new tax revenues from income and value-added sales tax activities (Herman et al., 2020). Federal taxes are assumed to be \$34.38 million, while total provincial and municipal revenues equal \$92.562 and \$40.1 million, respectively. The above numbers correspond to a four-year life-span, in the final phase of the forecast (years 2036–2040). Previous phases have cumulative levels of approximately \$18 million, \$50 and \$105 million for each of the previous four-year phases. As a point of reference, the State of Illinois has a size of 57,915 mi$^2$, while the Greater Vancouver Area corresponds to 1,113 mi$^2$, with populations of 12,670,000 and 2,632,000 people, respectively. Turning that into Illinois numbers, the annual Greater Vancouver Area tax revenue from AAM services would potentially be \$33.15 million ($t_{r_{vanc}}$), account for state taxes, with Illinois annual tax revenue being estimated from Equation 25, with $f_{size} = 52.03$ being a factor corresponding to the size difference, and $f_{pop} = 4.81$ a population difference size, and $a_{weight} = 0.3$, $\beta_{weight} = 0.7$ being weight factors regarding the magnitude of the effect each variable has:

$$t_{rev} = ((f_{size} * a_{weight} + f_{pop} * \beta_{weight}) * t_{r_{vanc}})/4$$

**Figure 105. Equation. Illinois annual tax AAM revenue.**

Population was weighed with a higher factor than the spatial differences of the compared areas.

## ENVIRONMENTAL IMPACTS

Various researchers (Le Varlet et al., 2020; Philippot et al., 2019; Majeau-Bettez et al., 2011) have estimated that a range of 200–250 kgCO$_2$e/kWh$_c$ produced by EV battery manufacturing. However, Illinois doesn't have an existing EV (nor eVTOL) battery manufacturing plant, nor it belongs among the States that have planned to host such infrastructure (Schoeck, 2023). By making the (strong perhaps) assumption that ground EV battery manufacturing will have a similar GHG emissions output with eVTOL battery manufacturing plants, and also by assuming that Illinois will host such infrastructure in the future, but at the lowest level among the existing candidates (due to the so far absence of Illinois from the candidate States), Figure 106 can provide the annual kg of CO$_2$ in terms of GHG emissions from such activities in Illinois.

$$b_m = a_{ev_{ghg}} * (10^{-6}) * f_{IL}$$

**Figure 106. Equation. Annual kg of CO2 in terms of GHG emissions from EV battery manufacturing activities in Illinois.**

As $a_{ev_{ghg}}$, an average value of 225 kgCO$_2$e/kWh$_c$ produced is assumed, and as $f_{IL}$ a semi-conservative value of 2 GW/year in battery energy produced in Illinois (since the lowest capacity produced of the candidate States is below or equal to 4 GW/year, from Schoeck [2023]).

From Dulia et al. (2021), the concept and the basis of their formulation was adapted and used here, with data for Illinois, in an effort to assess the environmental impact of AAM in Illinois, regarding greenhouse gas emissions (gases considered are carbon dioxide ($CO_2$), methane ($CH_4$), and nitrous oxide ($N_2O$)). Instead of a 3% or a 7% discount rate, based on the Biden and Trump administrations respectively, a 2% discount rate ($r = 0.02$) is considered based on Löffler (2021), Rennert et al. (2022) and Prest et al. (2021). From Rennert et al. (2022), the Social Cost of Carbon is monetized at \$185 per metric ton ($c_{CO_2}$), and from (Technical Support Document: Social Cost of Carbon, Methane, 2021) the Social Cost of methane is \$2,000 ($c_{CH_4}$), and the Social Cost of nitrous oxide is \$27,000 ($c_{N_2O}$) (all values are per metric ton). Figure 107 will provide the forecasted values for each of the mentioned pollutants for each of the years considered:

$$sc_{i_{CO_2}} = c_{CO_2} * (1+r)^t, i \in (2023,2024,\dots,2042), t \in (2,3,4,\dots,20)$$

$$sc_{i_{CH_4}} = c_{CH_4} * (1+r)^t, i \in (2023,2024,\dots,2042), t \in (2,3,4,\dots,20)$$

$$sc_{i_{N_2O}} = c_{N_2O} * (1+r)^t, i \in (2023,2024,\dots,2042), t \in (2,3,4,\dots,20)$$

**Figure 107. Equation. Forecasted values of gas pollutants.**

***Source: Adapted from Dulia et al. (2021)***

From Economic Research Institute (2020), the average US light duty vehicle fuel efficiency (mpg) for 2020 was calculated to be equal to $mpg_{2020} = 22.9$. Using that value along with the forecasted vehicle miles travelled in Illinois, we can compute the gallons burned for each one of the forecasted years (Figure 108), in order to reach on the calculation of the annual metric tons of greenhouse gas emissions in Illinois.

$$f_{b_i} = \frac{FVMT_i}{mpg_{2020}}$$

**Figure 108. Equation. Gallons of gasoline burned from ground vehicles, for each one of the forecasted years, in Illinois.**

***Source: Adapted from Dulia et al. (2021)***

From United States Environmental Protection Agency (2014), 8,887 grams $CO_2$/gallon are the $CO_2$ emissions from a gallon of gasoline ($gem_{gasoline_{CO_2}}$), and 10,180 grams $CO_2$/gallon are the $CO_2$ emissions from a gallon of diesel ($gem_{diesel_{CO_2}}$), and from Bureau of Transportation Statistics (2015) the percentage of diesel-powered light trucks and passenger cars in the US is approximately 4%, so there are 8,938.72 grams $CO_2$/gallon emitted ($p_{CO_2} = avg_{gem_{CO_2}}$), considering both diesel and gasoline emissions, from Figure 109.

$$avg_{gem_{CO_2}} = gem_{gasoline_{CO_2}} * 0.96 + gem_{diesel_{CO_2}} * 0.04$$

**Figure 109. Equation. Average of CO2/gallon grams emitted in Illinois.**

Regarding the remaining two gases, from United States Environmental Protection Agency (2014) again, $CH_4$ is considered to have 25 times the impact of $CO_2$ ($p_{CH_4} = 25 * p_{CO_2}$), and $N_2O$ 298 times ($p_{N_2O} = 298 * p_{CO_2}$). However, since this difference is taken under consideration in the monetary "pricing" of the social cost for Methane and Nitrous Oxide, from (Pradeep & Wei, 2018)it was found that 0.375 grams of $CH_4$ per gallon of gasoline are emitted ($p_{CH_4}$), and an average emission factor (g of N2O/g of CO2) = (6 ± 2) × $10^{-5}$ ($p_{N_20}$), from Becker et al. (1999). Following, from Figure 110 the yearly emitted GHG in Illinois are calculated, for each of the forecasted years.

$$e_{i_{CO_2}} = p_{CO_2} * f_{b_i} * 10^{-6}\ metric\ tons$$

$$e_{i_{CH_4}} = p_{CH_4} * f_{b_i} * 10^{-6}\ metric\ tons$$

$$e_{i_{N_2O}} = p_{N_2O} * f_{b_i} * 10^{-6}\ metric\ tons$$

**Figure 110. Equation. Yearly emitted GHG in Illinois, for each of the forecasted years.**

***Source: Adapted from Dulia et al. (2021)***

In order to calculate the cost savings from introducing eVTOLs, we need to know the percentage of difference between eVTOLs and ground vehicles in terms of gas emissions. In terms of ground vehicles, both ICEVs and BEVs are going to be considered, with the market share of BEVs being 5.8% of the US automobile market, according to Nedelea (2023). Therefore, Figures 111 and 112 are constructed accordingly (with $cs_{ghg_{IL_i}}$ being the total cost savings from the reduced amount of GHG emissions due to the introduction of Urban Air mobility):

$$r_f = 0.058 * (-f_{BEV_{ghg}}) + 0.942 * f_{ICEV_{ghg}}$$

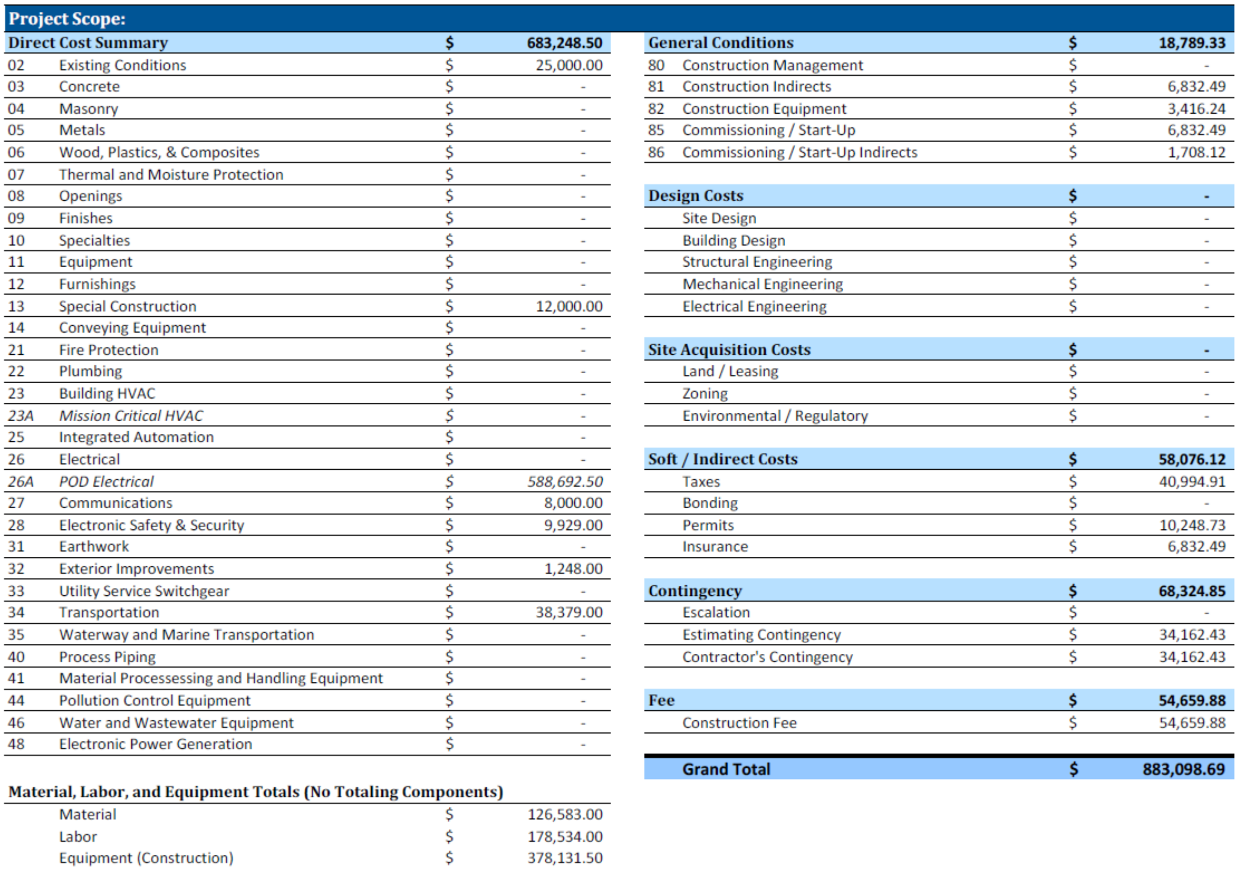
**Figure 111. Equation. Parameter accounting for the increase in GHG emissions that eVTOLs presented compared with BEVs.**

Figure 111 is constructed in that way in order to account for the increase in GHG emissions that eVTOLs presented compared with BEVs, and not only account for the reduction in emissions that eVTOLs have compared to ICEVs. BEV related emissions comparison is presented by a factor $f_{BEV_{ghg}} = 0.245$, corresponding to the average value of 21% lower emissions than eVTOLs, from Mudumba et al. (2021), and 28% lower emissions (Kasliwal et al., 2019). Minus sign is used since eVTOLS behave worse than BEVs, so they are having a negative effect. $f_{ICEV_{ghg}}$ is the factor corresponding to the reduction in emissions that eVTOLs have compared to ICEVs, which will be assumed to be equal to 52%, the average value of 35% reduction from Kasliwal et al. (2019), and 69% calculated by the authors based on Office of Energy Efficiency and Reliable Energy (2022) and Donateo and Ficarella (2022), since the calculated value of eVTOL emissions was found to be 67 grams/km (≅ 108 grams/mile), and the emitted emissions per mile of an ICEV is equal to 348 grams. Figure 112 corresponds to the generalized social cost savings from the reduction in GHGE for each of the forecasted years ($d_{fUAM} = \{0.011, 0.031, 0.103\}$ is a demand factor of the number of trips that AAM services will take from ground transportation related trips, based on the market shares introduced before) can be observed from Figure 112:

$$cs_{ghg_{IL_i}} = \left(e_{i_{CO_2}} * sc_{i_{CO_2}} + e_{i_{CH_4}} * sc_{i_{CH_4}} + e_{i_{N_2O}} * sc_{i_{N_2O}}\right) * r_f * d_{fUAM}$$

**Figure 112. Equation. Generalized social cost savings from the reduction in GHGE for each of the forecasted years.**

# APPENDIX D: INFRASTRUCTURE COST-RELATED ADDITIONAL FIGURES AND ANALYSIS



**Project Scope:**

| | **Direct Cost Summary** | **$** | **683,248.50** |
|---|---|---|---|
| 02 | Existing Conditions | $ | 25,000.00 |
| 03 | Concrete | $ | - |
| 04 | Masonry | $ | - |
| 05 | Metals | $ | - |
| 06 | Wood, Plastics, & Composites | $ | - |
| 07 | Thermal and Moisture Protection | $ | - |
| 08 | Openings | $ | - |
| 09 | Finishes | $ | - |
| 10 | Specialties | $ | - |
| 11 | Equipment | $ | - |
| 12 | Furnishings | $ | - |
| 13 | Special Construction | $ | 12,000.00 |
| 14 | Conveying Equipment | $ | - |
| 21 | Fire Protection | $ | - |
| 22 | Plumbing | $ | - |
| 23 | Building HVAC | $ | - |
| *23A* | *Mission Critical HVAC* | $ | - |
| 25 | Integrated Automation | $ | - |
| 26 | Electrical | $ | - |
| *26A* | *POD Electrical* | $ | *588,692.50* |
| 27 | Communications | $ | 8,000.00 |
| 28 | Electronic Safety & Security | $ | 9,929.00 |
| 31 | Earthwork | $ | - |
| 32 | Exterior Improvements | $ | 1,248.00 |
| 33 | Utility Service Switchgear | $ | - |
| 34 | Transportation | $ | 38,379.00 |
| 35 | Waterway and Marine Transportation | $ | - |
| 40 | Process Piping | $ | - |
| 41 | Material Processessing and Handling Equipment | $ | - |
| 44 | Pollution Control Equipment | $ | - |
| 46 | Water and Wastewater Equipment | $ | - |
| 48 | Electronic Power Generation | $ | - |

| **Material, Labor, and Equipment Totals (No Totaling Components)** | | |
|---|---|---|
| Material | $ | 126,583.00 |
| Labor | $ | 178,534.00 |
| Equipment (Construction) | $ | 378,131.50 |

| | **General Conditions** | **$** | **18,789.33** |
|---|---|---|---|
| 80 | Construction Management | $ | - |
| 81 | Construction Indirects | $ | 6,832.49 |
| 82 | Construction Equipment | $ | 3,416.24 |
| 85 | Commissioning / Start-Up | $ | 6,832.49 |
| 86 | Commissioning / Start-Up Indirects | $ | 1,708.12 |

| **Design Costs** | **$** | **-** |
|---|---|---|
| Site Design | $ | - |
| Building Design | $ | - |
| Structural Engineering | $ | - |
| Mechanical Engineering | $ | - |
| Electrical Engineering | $ | - |

| **Site Acquisition Costs** | **$** | **-** |
|---|---|---|
| Land / Leasing | $ | - |
| Zoning | $ | - |
| Environmental / Regulatory | $ | - |

| **Soft / Indirect Costs** | **$** | **58,076.12** |
|---|---|---|
| Taxes | $ | 40,994.91 |
| Bonding | $ | - |
| Permits | $ | 10,248.73 |
| Insurance | $ | 6,832.49 |

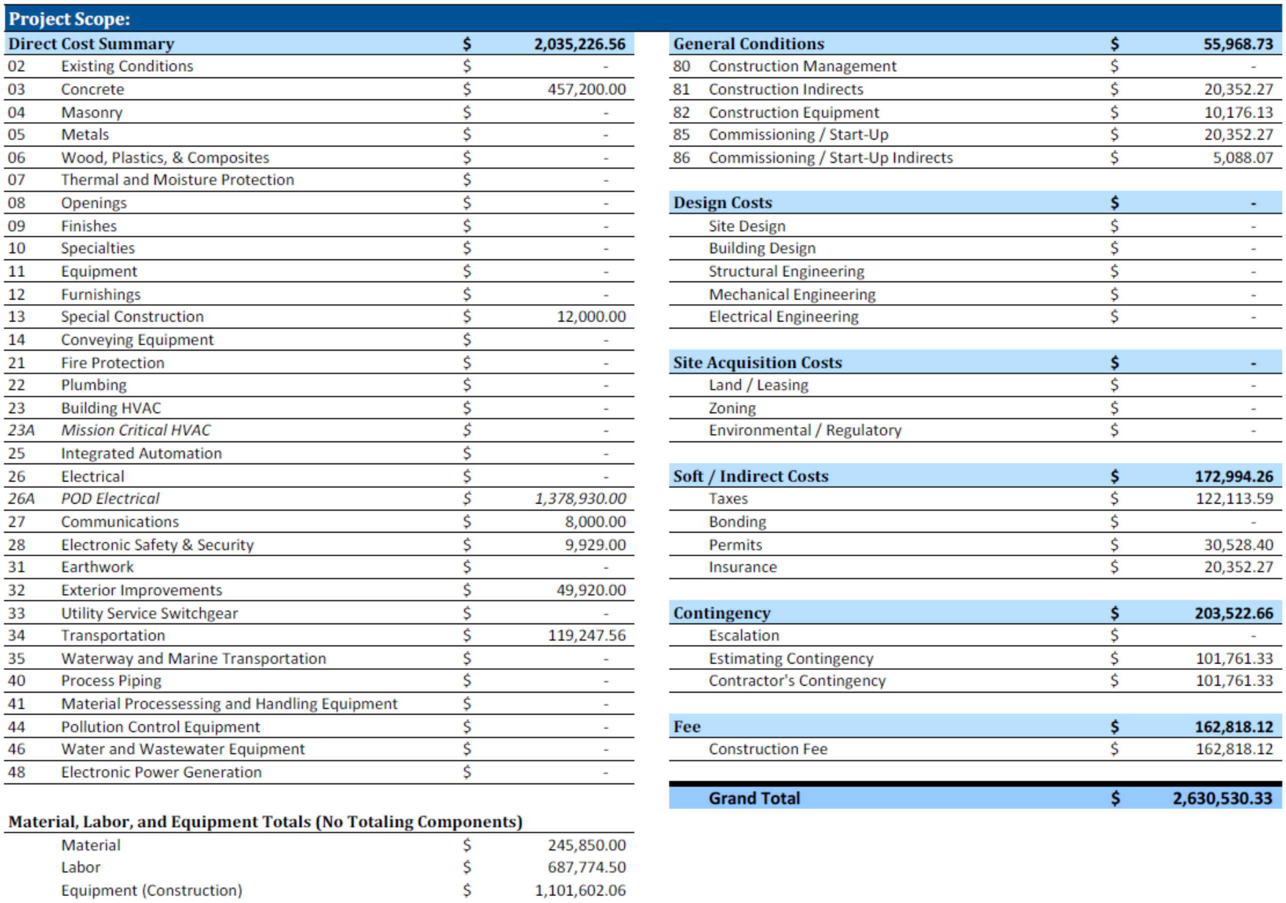
| **Contingency** | **$** | **68,324.85** |
|---|---|---|
| Escalation | $ | - |
| Estimating Contingency | $ | 34,162.43 |
| Contractor's Contingency | $ | 34,162.43 |

| **Fee** | **$** | **54,659.88** |
|---|---|---|
| Construction Fee | $ | 54,659.88 |

| **Grand Total** | **$** | **883,098.69** |
|---|---|---|

**Figure 113. Graph. NASA eVTOL Existing Building Landing Single Charging Station, Five Story Building cost analysis.**

***Source: Black & Veatch (2018)***



**Project Scope:**

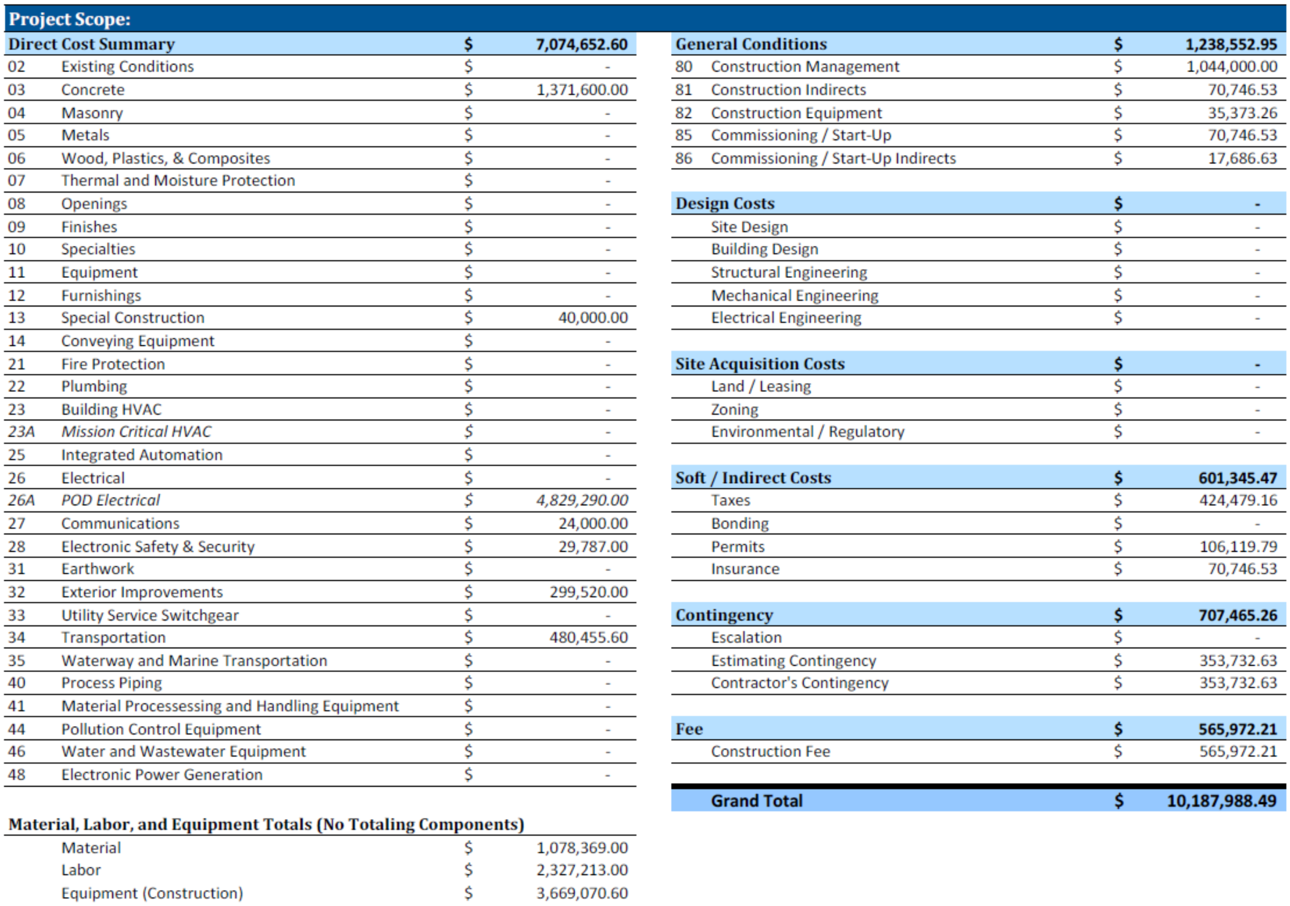
| | **Direct Cost Summary** | **$** | **2,035,226.56** |
|---|---|---|---|
| 02 | Existing Conditions | $ | - |
| 03 | Concrete | $ | 457,200.00 |
| 04 | Masonry | $ | - |
| 05 | Metals | $ | - |
| 06 | Wood, Plastics, & Composites | $ | - |
| 07 | Thermal and Moisture Protection | $ | - |
| 08 | Openings | $ | - |
| 09 | Finishes | $ | - |
| 10 | Specialties | $ | - |
| 11 | Equipment | $ | - |
| 12 | Furnishings | $ | - |
| 13 | Special Construction | $ | 12,000.00 |
| 14 | Conveying Equipment | $ | - |
| 21 | Fire Protection | $ | - |
| 22 | Plumbing | $ | - |
| 23 | Building HVAC | $ | - |
| *23A* | *Mission Critical HVAC* | $ | - |
| 25 | Integrated Automation | $ | - |
| 26 | Electrical | $ | - |
| *26A* | *POD Electrical* | $ | *1,378,930.00* |
| 27 | Communications | $ | 8,000.00 |
| 28 | Electronic Safety & Security | $ | 9,929.00 |
| 31 | Earthwork | $ | - |
| 32 | Exterior Improvements | $ | 49,920.00 |
| 33 | Utility Service Switchgear | $ | - |
| 34 | Transportation | $ | 119,247.56 |
| 35 | Waterway and Marine Transportation | $ | - |
| 40 | Process Piping | $ | - |
| 41 | Material Processessing and Handling Equipment | $ | - |
| 44 | Pollution Control Equipment | $ | - |
| 46 | Water and Wastewater Equipment | $ | - |
| 48 | Electronic Power Generation | $ | - |

| | **Material, Labor, and Equipment Totals (No Totaling Components)** | | |
|---|---|---|---|
| | Material | $ | 245,850.00 |
| | Labor | $ | 687,774.50 |
| | Equipment (Construction) | $ | 1,101,602.06 |

| | **General Conditions** | **$** | **55,968.73** |
|---|---|---|---|
| 80 | Construction Management | $ | - |
| 81 | Construction Indirects | $ | 20,352.27 |
| 82 | Construction Equipment | $ | 10,176.13 |
| 85 | Commissioning / Start-Up | $ | 20,352.27 |
| 86 | Commissioning / Start-Up Indirects | $ | 5,088.07 |
| | | | |
| | **Design Costs** | **$** | **-** |
| | Site Design | $ | - |
| | Building Design | $ | - |
| | Structural Engineering | $ | - |
| | Mechanical Engineering | $ | - |
| | Electrical Engineering | $ | - |
| | | | |
| | **Site Acquisition Costs** | **$** | **-** |
| | Land / Leasing | $ | - |
| | Zoning | $ | - |
| | Environmental / Regulatory | $ | - |
| | | | |
| | **Soft / Indirect Costs** | **$** | **172,994.26** |
| | Taxes | $ | 122,113.59 |
| | Bonding | $ | - |
| | Permits | $ | 30,528.40 |
| | Insurance | $ | 20,352.27 |
| | | | |
| | **Contingency** | **$** | **203,522.66** |
| | Escalation | $ | - |
| | Estimating Contingency | $ | 101,761.33 |
| | Contractor's Contingency | $ | 101,761.33 |
| | | | |
| | **Fee** | **$** | **162,818.12** |
| | Construction Fee | $ | 162,818.12 |
| | | | |
| | **Grand Total** | **$** | **2,630,530.33** |

**Figure 114. Graph. Three Charging Stations Ground cost analysis.**

***Source: Black & Veatch (2018)***



**Project Scope:**

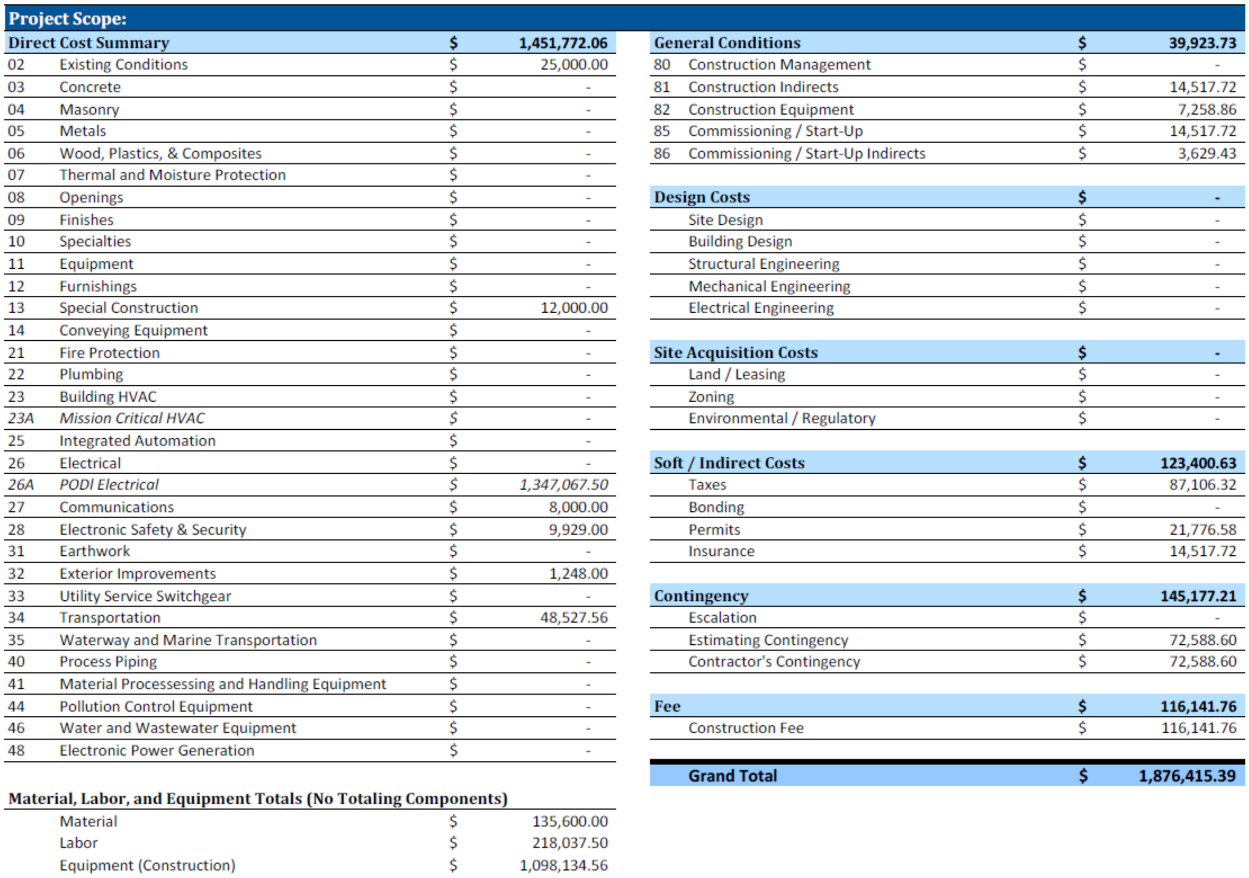
| **Direct Cost Summary** | | **$** | **7,074,652.60** |
|---|---|---|---|
| 02 | Existing Conditions | $ | - |
| 03 | Concrete | $ | 1,371,600.00 |
| 04 | Masonry | $ | - |
| 05 | Metals | $ | - |
| 06 | Wood, Plastics, & Composites | $ | - |
| 07 | Thermal and Moisture Protection | $ | - |
| 08 | Openings | $ | - |
| 09 | Finishes | $ | - |
| 10 | Specialties | $ | - |
| 11 | Equipment | $ | - |
| 12 | Furnishings | $ | - |
| 13 | Special Construction | $ | 40,000.00 |
| 14 | Conveying Equipment | $ | - |
| 21 | Fire Protection | $ | - |
| 22 | Plumbing | $ | - |
| 23 | Building HVAC | $ | - |
| *23A* | *Mission Critical HVAC* | $ | - |
| 25 | Integrated Automation | $ | - |
| 26 | Electrical | $ | - |
| *26A* | *POD Electrical* | $ | *4,829,290.00* |
| 27 | Communications | $ | 24,000.00 |
| 28 | Electronic Safety & Security | $ | 29,787.00 |
| 31 | Earthwork | $ | - |
| 32 | Exterior Improvements | $ | 299,520.00 |
| 33 | Utility Service Switchgear | $ | - |
| 34 | Transportation | $ | 480,455.60 |
| 35 | Waterway and Marine Transportation | $ | - |
| 40 | Process Piping | $ | - |
| 41 | Material Processessing and Handling Equipment | $ | - |
| 44 | Pollution Control Equipment | $ | - |
| 46 | Water and Wastewater Equipment | $ | - |
| 48 | Electronic Power Generation | $ | - |

| **Material, Labor, and Equipment Totals (No Totaling Components)** | | |
|---|---|---|
| Material | $ | 1,078,369.00 |
| Labor | $ | 2,327,213.00 |
| Equipment (Construction) | $ | 3,669,070.60 |

| **General Conditions** | | **$** | **1,238,552.95** |
|---|---|---|---|
| 80 | Construction Management | $ | 1,044,000.00 |
| 81 | Construction Indirects | $ | 70,746.53 |
| 82 | Construction Equipment | $ | 35,373.26 |
| 85 | Commissioning / Start-Up | $ | 70,746.53 |
| 86 | Commissioning / Start-Up Indirects | $ | 17,686.63 |
| | | | |
| **Design Costs** | | **$** | **-** |
| | Site Design | $ | - |
| | Building Design | $ | - |
| | Structural Engineering | $ | - |
| | Mechanical Engineering | $ | - |
| | Electrical Engineering | $ | - |
| | | | |
| **Site Acquisition Costs** | | **$** | **-** |
| | Land / Leasing | $ | - |
| | Zoning | $ | - |
| | Environmental / Regulatory | $ | - |
| | | | |
| **Soft / Indirect Costs** | | **$** | **601,345.47** |
| | Taxes | $ | 424,479.16 |
| | Bonding | $ | - |
| | Permits | $ | 106,119.79 |
| | Insurance | $ | 70,746.53 |
| | | | |
| **Contingency** | | **$** | **707,465.26** |
| | Escalation | $ | - |
| | Estimating Contingency | $ | 353,732.63 |
| | Contractor's Contingency | $ | 353,732.63 |
| | | | |
| **Fee** | | **$** | **565,972.21** |
| | Construction Fee | $ | 565,972.21 |
| | | | |
| | **Grand Total** | **$** | **10,187,988.49** |

**Figure 115. Graph. Ten vertiport ground cost analysis.**

***Source: Black & Veatch (2018)***



**Project Scope:**

| **Direct Cost Summary** | | **$** | **1,451,772.06** |
|---|---|---|---|
| 02 | Existing Conditions | $ | 25,000.00 |
| 03 | Concrete | $ | - |
| 04 | Masonry | $ | - |
| 05 | Metals | $ | - |
| 06 | Wood, Plastics, & Composites | $ | - |
| 07 | Thermal and Moisture Protection | $ | - |
| 08 | Openings | $ | - |
| 09 | Finishes | $ | - |
| 10 | Specialties | $ | - |
| 11 | Equipment | $ | - |
| 12 | Furnishings | $ | - |
| 13 | Special Construction | $ | 12,000.00 |
| 14 | Conveying Equipment | $ | - |
| 21 | Fire Protection | $ | - |
| 22 | Plumbing | $ | - |
| 23 | Building HVAC | $ | - |
| *23A* | *Mission Critical HVAC* | $ | - |
| 25 | Integrated Automation | $ | - |
| 26 | Electrical | $ | - |
| *26A* | *PODI Electrical* | $ | *1,347,067.50* |
| 27 | Communications | $ | 8,000.00 |
| 28 | Electronic Safety & Security | $ | 9,929.00 |
| 31 | Earthwork | $ | - |
| 32 | Exterior Improvements | $ | 1,248.00 |
| 33 | Utility Service Switchgear | $ | - |
| 34 | Transportation | $ | 48,527.56 |
| 35 | Waterway and Marine Transportation | $ | - |
| 40 | Process Piping | $ | - |
| 41 | Material Processessing and Handling Equipment | $ | - |
| 44 | Pollution Control Equipment | $ | - |
| 46 | Water and Wastewater Equipment | $ | - |
| 48 | Electronic Power Generation | $ | - |

| **General Conditions** | | **$** | **39,923.73** |
|---|---|---|---|
| 80 | Construction Management | $ | - |
| 81 | Construction Indirects | $ | 14,517.72 |
| 82 | Construction Equipment | $ | 7,258.86 |
| 85 | Commissioning / Start-Up | $ | 14,517.72 |
| 86 | Commissioning / Start-Up Indirects | $ | 3,629.43 |
| | | | |
| **Design Costs** | | **$** | **-** |
| | Site Design | $ | - |
| | Building Design | $ | - |
| | Structural Engineering | $ | - |
| | Mechanical Engineering | $ | - |
| | Electrical Engineering | $ | - |
| | | | |
| **Site Acquisition Costs** | | **$** | **-** |
| | Land / Leasing | $ | - |
| | Zoning | $ | - |
| | Environmental / Regulatory | $ | - |
| | | | |
| **Soft / Indirect Costs** | | **$** | **123,400.63** |
| | Taxes | $ | 87,106.32 |
| | Bonding | $ | - |
| | Permits | $ | 21,776.58 |
| | Insurance | $ | 14,517.72 |
| | | | |
| **Contingency** | | **$** | **145,177.21** |
| | Escalation | $ | - |
| | Estimating Contingency | $ | 72,588.60 |
| | Contractor's Contingency | $ | 72,588.60 |
| | | | |
| **Fee** | | **$** | **116,141.76** |
| | Construction Fee | $ | 116,141.76 |
| | | | |
| | **Grand Total** | **$** | **1,876,415.39** |

**Material, Labor, and Equipment Totals (No Totaling Components)**

| | | | |
|---|---|---|---|
| | Material | $ | 135,600.00 |
| | Labor | $ | 218,037.50 |
| | Equipment (Construction) | $ | 1,098,134.56 |

**Figure 116. Graph. Three charging station garage cost analysis.**

***Source: Black & Veatch (2018)***

Illinois Department of Transportation

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