Open Framework Standards for Combined Aircraft Sensor Network for the State of Ohio to Detect and Track Lower Altitude Aircraft

Volume 1 of 1

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16. Abstract

As research, development and overall investment continues to accelerate the integration of Uncrewed Aircraft Systems (UAS or drones) into our skies, it is becoming ever more critical to develop supporting systems and services that are based on sound engineering and strategic planning. Reliable and robust airspace surveillance for the lower altitude airspace, which currently is not addressed by existing Air Traffic Management (ATM) systems, but where smaller UAS will operate, is still a major technical challenge for the industry. This research paired comprehensive information gathering with a rigorous systems engineering activity to define the high-level functional, performance and design requirements for a scalable, low-altitude airspace surveillance service (LAASS), utilizing industry standard interfaces. This system has the potential to enable safe UAS operations and generate positive net present value and return on investment, providing strong justifications for investment in airspace surveillance infrastructure in Ohio.

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1 Problem Statement

Communications, Navigation and Surveillance (CNS) are the pillars of the existing Air Traffic Management (ATM) system managing our National Airspace System (NAS), and this will be the case for the emerging Uncrewed Traffic Management (UTM) and Advanced Air Mobility (AAM) systems. Today's telecommunications companies are charging ahead with our next generation of terrestrial communication systems with 5G, which promises to support dedicated services (e.g., dedicated UAS Command & Controls services) for a whole host of new automation technologies such as driverless cars and Uncrewed Aircraft Systems (UAS). Likewise, navigation services continue to improve beyond even the extreme precision and availability of GPS, with at least four functioning Global Navigation Satellite Systems (GNSS) now operating, providing layers of robustness for our utilization. However, as much progress as we continue to make in the communications and navigation domains, our ability to provide accurate, robust, and scalable surveillance services, particularly for lower altitude airspace, has quickly become the biggest obstacle and impediment for wide-use operationalization of UAS.

Ohio has begun to address this gap by investing in the SkyVision Ground-Based Detect and Avoid (GBDAA) system, and more recently the Ohio Department of Transportation (ODOT) UTM Corridor. However, these are isolated systems with no data sharing, and both have challenges in scaling beyond their current installations. Additionally, there are no common interface requirements and/or formats for future systems to leverage for seamlessly integrating and extending coverage to new areas. Finally, even if these systems could communicate, there is no organized data archival and retrieval system to make use of all this data for post real-time utilization.

The challenges associated with lower altitude surveillance are not just technical ones. In a recent study Ohio is ranked 30th in terms of market embracing UAS legislation, with North Dakota ranked 1st. The challenge to Ohio, however, may be even greater than just determining how or whether to legislate on the topic of UAS or drones. For Ohio, the greater question may be, are there laws or regulations that inhibit innovation? Are these laws, or the lack of appropriate laws, either intentionally or unintentionally creating barriers to the operation of non-traditional and emerging transportation technologies? There is no question that the development of laws and the foundational policy necessary to guide their creation is not an easy process, especially when it comes to technologies like those associated with UAS or electric Vertical Take Off/Landing (eVTOL) aircraft. The regulatory balancing of public interests associated with privacy, property rights, safety, and that of Ohio's goal to develop a commercial market that will sustain and grow technology, logistics, aviation, and related service jobs in this new age of UTM/AAM is critical and must be immediately undertaken. This endeavor will be challenging for our elected officials, business leaders, and our citizenry.

2 Research Background

The CAL team's goal in this research effort was to define the requirements for a low-altitude airspace surveillance service. To achieve this, a series of objectives was established to provide a complete roadmap for a low-altitude airspace surveillance service (LAASS) system implementation. This included a review of the current state-of-practice for lower altitude surveillance, determination of the attributes and functional requirements for the system, key design considerations specific to Ohio, development of a legal framework for future implementation, a cost-benefit analysis, and a top-to-bottom requirements analysis.

The current state-of-practice was identified by first performing a market survey of surveillance sensors in use today or projected in the near future. Next, the prevalent data interface standards were examined to ease adoption concerns, and a comprehensive catalog of required data items for each class of sensors was formulated for varying levels of service. This information is contained in the Surveillance Survey Report included in the appendix.

The attributes and functional requirements for the system started with an outreach/survey involving potential end-users, input providers, technology providers, and other stakeholders of the surveillance framework. These included local and state government agencies, federal government agencies, and relevant industry stakeholders. Potential use cases were developed to inform the desired features of the end-state system, and then the real-time functional and performance requirements were defined via discussions with ODOT, the Sensor Source Study, and the stakeholder analysis. This resulted in a set of threshold and objective requirements for the real-time aspects of the lower altitude surveillance framework along with appropriate critical performance requirements.

In addition to real-time aspects of the system, the functional and performance requirements associated with the offline aspects of the framework were defined, including data archival attributes, analysis capabilities, access levels, and privacy concerns.

Using the developed functional requirements, a Functional Design was developed that focuses on how to represent the new framework and its data and access flows. This activity focused on visualization through workflows, example data specifications, security access considerations, and other aspects of the framework. The result is a set of implementation-agnostic design considerations and restraints based on Ohio's unique infrastructure and existing ODOT data philosophies. The Functional Requirements Document is included in the appendix.

To assist in the development of Ohio's regulatory framework for safe lower altitude UAS operations in Ohio, a policy position and roadmap was developed by the team's lawyers and policy leaders. This included an extensive analysis of existing law regarding issues of privacy, trespass, land use, property rights and easements, zoning laws, and air rights. In addition to studying Ohio law, this task included research into how other states and local governments developed, created, and implemented laws that regulate or control UAS operations. This information was leveraged to identify concerns among industry stakeholders in response to laws and policy regarding UAS development, manufacturing, and operations. The Legal Framework Analysis is provided in the appendix.

A cost payback analysis was performed that identifies, quantifies, and evaluates benefits and costs of the proposed statewide air traffic monitoring center with a centralized data clearinghouse, based on the desired project objectives, system architecture, functional requirements, and capabilities. The cost estimates associated with this analysis were compared to the base case to provide justification for investments in the proposed system. The analysis considered the cost of planning, constructing, and maintaining the system (including labor costs), as well as equipment, services, tools, and the costs associated with the risk of system malfunctions. Potential payback was considered in tandem, including the benefits associated with attracting new companies and products to Ohio, revenue from taxes and fees imposed on system users, reduction in cost and time of package delivery, surveys and inspections, and many other monetary gains and societal benefits. The Cost Payback Analysis Report is included in the Appendix.

Taken together, the research objectives achieved by the research team form a top-to-bottom requirements analysis for future ODOT development of a lower altitude surveillance monitoring system.

3 Research Approach

This report is largely a summary of the four key work products this project developed, and which are captured in their entirety in the four appendices:

1. Appendix A – Surveillance Source Survey Report
2. Appendix B – Functional Requirements Document
3. Appendix C - Legal and Policy Analysis Report
4. Appendix D – Cost-Benefit Analysis Report

These products are intended be utilized in tandem to guide ODOT through the deployment of a LAASS that will serve as a key digital building block for developing an AAM transportation modality.

Appendix A lays out the various airspace surveillance sensor technologies that are likely to be leveraged to provide the source of data for this service, including key data elements from these sensors for various aircraft types. Additionally, the appendix defines some key interface standards to be leveraged by the LAASS.

Appendix B defines the key requirements that the LAASS ("The System") is expected to satisfy to meet the expected needs of down-stream AAM services. This appendix is intended to be the key product for ODOT to leverage to go to a procurement Request for Proposal for building this service.

Appendix C lays out some of the key legal aspects ODOT needs to consider to ensure statutory authority for development and operation, as well as revenue considerations for sustainment of such a system. Although this is not official legal advice, the appendix does identify some key local, state, and federal legal references that ODOT can leverage to build out any required legislation to ensure comprehensive legal authority for this service.

Appendix D captures the various cost-benefit analysis for ODOT to consider for developing this system. This appendix is intended to inform ODOT and the state of Ohio about some of the expected cost for deploying the required sensor networks, the costs associated with hosting and managing the service, and to provide various options for the state to finance the building and deployment for this system, including both government and private sources.

The remaining sections are a more detailed description of the project activities that went into the development of these key products, including additional insights.

3.1 Surveillance Source Survey Report and Open Interface Standard

The Surveillance Source Survey Report and Open Interface Standard is a multi-faceted analysis of the potential sensors comprising the ODOT sensor network and was completed in three parts as described below. The report includes a market survey analysis, a data and interface standard analysis, and data item definitions.

3.1.1 Surveillance market survey update

A surveillance market analysis was first performed to identify sensors that might feed the ODOT sensor network. The sensors were categorized depending on their use for crewed vs. uncrewed applications, as well as cooperative vs non-cooperative types. Most crewed surveillance sensors are well-known, and most sensors used for nominal uncrewed operations are of the cooperative type based on current airspace philosophy. This implies that most sensors used for uncrewed, non-cooperative functionality are associated with non-compliant UAS. The survey conducted a review of aircraft surveillance sensors likely to be used for low-altitude airspace surveillance, including background, technical descriptions, and a listing of known manufacturers.

3.1.2 Surveillance Data Item Definition Requirements

Data item requirements were determined in terms of varying levels of service requested. At the highest level is Radio Navigation Quality, and this level was used to develop the most stringent list of required data. This level would include safety critical services such as detect-and-avoid (DAA). Subsets of this list may be acceptable for the two lower levels: Informational Only, and Radio Location Quality. This report only identifies a data list for Radio Navigation utilization based on Airborne Collision Avoidance System sXu (ACAS sXu) requirements for each surveillance type (cooperative and non-cooperative).

3.1.3 Surveillance Data and Interface Standard Analysis

An analysis of existing aircraft surveillance standards was performed based on the required data items. The goal was to leverage existing, widely used interface standards if possible. For this study, the emphasis was on identifying required data items for radio navigation applications, such as DAA, and the all-purpose structured EUROCONTROL surveillance information exchange (ASTERIX) data formats with the goal of identifying the appropriate ASTERIX message and the associated message-elements needed to provide or calculate the associated data items.

3.2 Functional Requirements Analysis

The functional requirements analysis was motivated by the current gap in open framework standards for detecting and tracking lower altitude aircraft. The requirements developed here are the product of a robust systems engineering approach conducted by local industry experts and have been informed by local and national stakeholder outreach and feedback.

3.3 High-Level Functional Design

The team reviewed existing ODOT Information Technology (IT) requirements and Event Streaming Platform (ESP) documentation along with International Civil Aviation Organization (ICAO) documentation. This enabled a focus on building upon what ODOT already has and is continuing to develop. The IT requirements documentation enabled conformation to ODOT's IT and data protection policies and standards. Another decision that was made early on was to utilize ODOT's Event Streaming Platform (ESP). This provided an existing data platform to build upon for archiving and disseminating the data feed that had real-time scalability at its heart. Using this system of systems approach allowed the team to focus on a system that can receive and process the incoming feeds. ICAO UTM Framework documentation provided guidance on standardized data feeds, allowing for interoperability between networks and feeds.

3.4 Financial & Legal Analysis

3.4.1 Cost-Benefit Analysis

The cost payback analysis of the lower altitude surveillance network for the state of Ohio was driven by data on AAM traffic projections, survey responses of AAM stakeholders, and cloud computing pricing policies, as well as findings of other studies conducted as part of this project (e.g., AAM Stakeholder Outreach, Legal Framework Analysis). The analysis period was considered to be the next 10 years (2024-2033). The yearly net present values (NPVs) produced by various suitable sensor types for AAM surveillance were estimated for the six major cities of Ohio (SMCO) with the largest AAM market potential: Columbus, Cleveland, Cincinnati, Akron, Toledo, and Dayton.

A survey of AAM stakeholders was first carried out to determine the stakeholder preferences and expectations concerning LAASS services, features, and pricing. The survey responses revealed the willingness of potential LAASS subscribers to pay for the services offered by it. The range of suitable subscription fees for the LAASS services was set based on these responses. This was used in the computation of the revenue generated from the LAASS. It is also evident from the survey responses that private entities are open to considering investing in surveillance equipment for integration with Ohio's LAASS through Private-Public Partnerships (PPP) with an expectation of 10%-20% annual return on investment (ROI). Therefore, a PPP model was considered in the analysis based on the findings of the survey to allow sharing of the AAM surveillance sensor cost and revenue between the state of Ohio and private entities.

The surveillance data interface standards, surveillance data types, and LAASS functional and performance requirements obtained from the LAASS system requirements study were used to identify and determine the cloud computing costs associated with surveillance data storage and processing. The performance characteristics and costs of these sensors were collected from the corresponding sensor vendors. The estimated yearly AAM passenger and cargo traffic was obtained from previous AAM market studies. For other AAM use cases, the potential future AAM traffic was estimated through forecasting. Using the AAM traffic projections data, the amount of surveillance data that would be generated from the surveillance network and its corresponding data storage and computing requirements was determined. Using the Microsoft Azure cloud computing pricing policies, the total cloud computing cost was then estimated.

For evaluating the minimum required sensor cost to set up the surveillance network, an optimization model was developed to find the optimal location and number of sensors needed to be placed in the SMCO. After estimating the cost and benefit factors, the NPVs of different sensor types were calculated over the analysis period to determine whether an investment in AAM surveillance for Ohio is financially viable. Then, a sensitivity analysis was performed to evaluate the effect of key parameters — such as subscription fee, number of subscribers, and PPP cost-sharing percentage — on the NPVs generated. Lastly, the results were analyzed to generate relevant insights for government and private investors and policymakers.

3.4.2 Legal Framework Analysis

A comprehensive survey of Constitutional Authority, both federal and the state of Ohio, Statutory Laws, Regulations and Case law were conducted. A key word search was developed to appropriately conduct research to find, analyze and support this project. Legal research was conducted utilizing resources such as Westlaw, LexisNexis, the Code of Federal Regulations, and the United States Code Annotated to find materials on point to this project. LexisNexis® is a preeminent legal research tool.

Upon researching various related cases identified through the survey, a further test of the validity or reliability was applied by Shepardizing® the search results. Shepardizing® determines whether or not the law is still relevant or good law, and results in a detailed citation history and if other jurisdictions or courts have actually used the cases. Westlaw® is an online, proprietary legal research tool that is similar to LexisNexis, but provides some novel information and in some instance some different cases that LexisNexis may not have found. Both Westlaw and LexisNexis were used to find case law, statutory and regulatory laws concerning any of the key words that were identified in the course of this project. The law was then collated and collected into one library and used in the creation of the final report.

Public Record requests were made to local municipalities to determine how many UAS operations were reported across the Northeast Ohio Region. This was done to see if this method of collecting police reports and court records could determine how active UAS operations were in each community sampled. Lastly, outreach events with stakeholders were publicly held and accomplished during the course of this project with the Ohio State Bar Association Aviation Law Committee, the Florida Bar Association Aviation Law Committee, the Ohio Department of Transportation, and the John Glenn Center for Public Policy. All feedback became a part of this study and part of our analysis.

4 Research Findings and Conclusions

4.1 Surveillance Source Survey Report and Open Interface Standard

The central result of the market survey update is the Surveillance Equipment Matrix (SEM) included as Table 1 in the Surveillance Source Survey Report. The sensors identified as likely data sources include automatic dependent surveillance-broadcast (ADS-B), multilateration (MLAT), ground radar, remote identification, radio frequency and acoustic sensors, and bispectral cameras. The SEM includes specifications for each data source such as range, scan type, and target size range. Each of the data sources are described in the report, and a discussion of how they would contribute to the LAASS is included.

The full list of data items was constructed following ACAS-sXu requirements for providing DAA services. Referencing the ACAS-sXu Minimum Operational Performance Standard (MOPS), a subset of items was identified for each sensor-type: Crewed/Uncrewed Cooperative, and Crewed/Uncrewed Non-cooperative. The complete list of data items is provided as Tables 2-4 in the Surveillance Source Study.

The recommended interfaces that would be used to input data to the LAASS are based on FAA and ASTERIX data formats. In particular, the CAT-033 data interface, which is designed for ADS-B data, would be leveraged for all cooperative crewed aircraft sensors. The CAT-129 message is designed for UAS Remote ID and would provide the interface standard for all cooperative UAS. For all non-cooperative traffic, whether crewed or uncrewed, the CAT-062 interface would be utilized.

4.2 Functional Requirements Analysis

The functional requirements analysis was largely based on the functions and services necessary to support Radio Navigation Quality surveillance data. Using ACAS-sXu as a model for a collision avoidance system requiring such data and providing general services to provide a positive and manageable user experience, requirements in categories such as User Registration, Service Querying, Data Format, and Live Data

Streaming were identified and described. In addition, specific requirements for Supplemental Data Service Provider (SDSP) performance such as correlation and maximum latency were considered.

4.3 High-Level Functional Design

The functional design activity found that ODOT digital infrastructure already exists to aid in the development and deployment of this system (i.e., ESP) and should be leveraged as much as possible to prevent duplication of efforts and save taxpayers money. ODOT IT already has policies in place for IT security and possesses experience in deploying infrastructure in the cloud.

4.4 Financial & Legal Analysis

4.4.1 Cost-Benefit Analysis

Throughout the 10-year analysis period (2024-2033), a lower altitude surveillance network in Ohio has the potential to enable safe AAM operations and generate positive NPV and ROI, providing strong justifications for investment in the surveillance infrastructure. Within the analysis period and among the six sensor types considered, ADS-B, remote ID, and RF sensor types produce positive NPVs, ADS-B generates the largest NPV ($18.50M), followed closely by remote ID ($18.38M), while RF brings the third largest NPV ($13.91M). ADS-B, remote ID, and RF sensor types were found to achieve break-even points (BEPs) within the 10 year analysis period, with both ADS-B and remote ID sensor types reaching BEPs in 2024, and RF in 2029. Based on these results, if tracking only cooperative aircraft is sufficient, then ADS-B and remote ID are the most financially viable sensor types for AAM surveillance. If tracking both cooperative and non-cooperative aircraft is required, then RF is the most profitable sensor type.

The different sensor types listed in ascending order of total sensor acquisition cost to set up a surveillance network are: ADS-B ($0.027M), remote ID ($0.145M), RF ($4.62M), radar ($157.29M), optical camera ($714.30M), and acoustic ($964.64M). Ohio's investments are lower for all sensor types when Ohio is pursuing the project implementation through PPP. Pursuing PPP allows the state of Ohio to generate a greater net profit and NPV and obtain an earlier attainment of BEP compared to the case of self-financing only.

4.4.2 Legal Framework Analysis

ODOT has the authority under existing laws to develop and implement the LAASS with potential funding through the Ohio General Fund as long as the specific statutory requirements are met, as discussed above (O.R.C. §5531.09 & 5531.10). To secure additional funding beyond its normal budgetary process, ODOT can consider a registration/subscription fee arrangement. However, if ODOT intends to generate revenue from LAASS users through registration and subscription fees, it would require a specific enabling statute and regulatory framework for collecting subscription fees for the LAASS. Additionally, careful attention must be given to potential conflicts with federal regulations regarding the registration of LAASS users compared to the registration of UAS with the FAA.

Ohio could become a leading authority on how to enable policy influenced legislation that invites commercial market growth, but also protects rights and duties of its citizenry. Through the course of aviation history, disruptive technology has been the forerunner to the advent of regulations. In addition, Ohio has been the global leader for aviation innovation. The goal of this section is to provide the legislature with information to help formulate the policy foundation of our highways in the sky. Ohio can be the first entity to place a LAASS that is safe, active, and successful into the stream of commerce, and as usual other states will follow. The FAA will listen and craft Federal Regulations to embrace Ohio's innovation.

5 Recommendations for Implementation

5.1 Surveillance Source Survey Report and Open Interface Standard

By utilizing the goal of tactical deconfliction or collision avoidance as the most demanding from a data requirements perspective, requiring full position/velocity states and associated uncertainty information, the Surveillance Source Survey identified the data requirements that would be needed for each sensor type (cooperative crewed aircraft, cooperative uncrewed aircraft, and non-cooperative aircraft). It is recommended that the ASTERIX standard be adopted as described in the report, specifically CAT-033, CAT-129, and CAT-062 respectively.

5.2 Functional Requirements Analysis

The functional requirements Analysis provided in the appendix recommends a range of functions and services to support lower altitude surveillance and tracking. The intended functions, operational goals, and appropriate assumptions are specified in the report, and include user and sensor registration, service querying, and recommendations for surveillance data formats. Recommendations on live data streaming are provided, as well as details on processing surveillance data from various sources. Integration of data sources is also discussed, and the standards set forth by Ohio's Information Technology Office as they apply to the SDSP given. In addition, ODOT's Event Streaming Platform is proffered as a scalable platform for ingestion, processing, and dissemination of real time surveillance data.

5.3 High-Level Functional Design

ODOT should utilize existing Commercial Off-the-Shelf (COTS) solutions where viable. ODOT's existing efforts in developing ESP should be leveraged by utilizing it as the client facing platform, focusing on data visualization, data dissemination, and data archiving. Most, if not all, of the data capturing and initial cleansing should be taken care of within a COTS solution or custom developed application.

5.4 Financial & Legal Analysis

5.4.1 Cost-Benefit Analysis

Based on the cost-benefit analysis results, ODOT is recommended to make investments toward Ohio's lower altitude surveillance network and LAASS as the investment is expected to be profitable, given that positive NPVs and ROIs were generated for various sensor types within the analysis period. If tracking only cooperative aircraft is sufficient, then ODOT should consider ADS-B and/or remote ID sensor types for lower altitude surveillance as they are found to be the most financially viable sensor types. In this case, ODOT should set the monthly subscription fees at no less than $100 to ensure profitability within the next 10 years. If tracking both cooperative and non-cooperative aircraft are required in certain security-sensitive areas, then ODOT should consider the RF sensor type for those areas as this was found to be the most profitable sensor type for this purpose. In this case, ODOT should set the monthly subscription fees at no less than $250 to ensure profitability within the next 10 years. To minimize the total sensor cost, ODOT is recommended to use a mixture of ADS-B, remote ID, and RF sensor types to set up the surveillance network.

ODOT should pursue project implementation with PPP as it allows to generate a greater NPV and obtain an earlier attainment of BEP compared to the case of self-financing only. To maximize ODOT's NPV and return, ODOT should strive to negotiate a minimum PPP cost-sharing percentage which specifies lower investment from their side and higher from the private entities' side, and a revenue sharing percentage with the private entities which is as low as possible while keeping them still interested in the PPP.

5.4.2 Legal Framework Analysis

Future LAASS-related legislation should include provisions stipulating that prospective LAASS users must first comply with federal regulations. Specifically, FAA regulations mandate the registration of all UAS weighing between 0.55 pounds and 55 pounds. Furthermore, operating a UAS requires obtaining an FAA sUAS Part 107 Certificate, unless it is solely used for recreational and hobby purposes. Consequently, LAASS legislation should require full compliance with federal requirements as a prerequisite for LAASS registration. It is essential that any state LAASS legislation includes references to these federal requirements to ensure alignment and adherence to both state and federal laws.

Lastly, to develop further PPP relationships after the Government is satisfied with the development and implementation of the LAASS, statutory provisions for Public Private Partnerships are in existence in the O.R.C. These provisions can be used effectively to include further investment, development, maintenance, and expansion of the LAASS.

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7 Acronyms

.NET	Network Enabled Technologies
100M	100 Megabytes Per Second
AAM	Advanced Air Mobility
AC	Alternating current
ACAS	Airborne Collision Avoidance System
ADD	Algorithm Description Document

ADS-B	Automatic Dependent Surveillance-Broadcast
AF/AT	Ampere Rating of Breaker Frame/Breaker Trip Rating in Ampere
AGT	Absolute Geodetic Track
APNT	Alternate Position, Navigation and Timing
ASTERIX	All-purpose structured EUROCONTROL Surveillance Information exchange
ASTERIX CAT	ASTERIX Category
ATC	Air Traffic Control
BEP	Break-Even Point
BI	Business Intelligence
COTS	Commercial Off-the-Shelf
DB	Database
EO	Electro-Optical
EO/IR	Electro-Optical/Infrared
ESP	Event Streaming Platform
eVTOL	Electric Vertical Takeoff and Landing Aircraft
EY	Entry Year
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FRIA	FAA Recognized Identification Area
GCS	Ground Control System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HDTV	High-definition Television
Hz, Hz, GHz	Hertz, Megahertz, Gigahertz
I/O	Input/Output
IFF	Identification Friend of Foe
IP	Ingress Protection
KSQL	SQL for Apache Kofka
L x W x H	Length x Width x Height
LAN	Local Area Network
LAASS	Low-Altitude Airspace Surveillance Service
MB	Mega Byte
MIL-STD	Military Standard
MLAT	Multilateration
MOPS	Minimum Operational Performance Standard
NEMA	National Electrical Manufacturers Association
NPRM	Notice of Proposed Rulemaking
NPV	Net Present Value
ODOT	Ohio Department of Transportation
POE	Power-Over-Ethernet
POE	Power-Over-Ethernet
PPP	Public-Private Partnership
PTZ	Pan, Tilt, and Zoom

RCS	Radar Cross-Section
REST	Representational State Transfer
RF	Radio Frequency
RF	Radio Frequency
RID	Remote Identification/ Remote ID
ROI	Return on Investment
SAND Model	Surveillance for AAM Network Design Model
SDSP	Supplemental Data Service Provider
SMCO	Six Major Cities of Ohio
SQL	Structured Query Language
SSR	Secondary Surveillance Radar
sUAS	Small Uncrewed Aircraft System
TDOA	Time Difference of Arrival
TRACON	Terminal Radar Approach Control
UAS	Uncrewed Aircraft Systems
UAT	Universal Access Transceiver
UTM	Uncrewed Traffic Management

8 Appendix A – Surveillance Source Survey Report

Open Framework Standards for Combined Aircraft Sensor Network

for the State of Ohio to Detect and Track Lower Altitude Aircraft

Surveillance Source Survey Report

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1 Introduction

One of the most critical steps in the development of an Open Framework to Detect and Track Lower Altitude Aircraft is developing a common data interface to enable sensor systems connectivity. This study is a fact-finding activity to ensure that a holistic view of current and future aircraft surveillance sensors, their capabilities, and outputs from a data perspective are understood and captured for requirements development and design. The net result of this study will be a recommendation to define a set of sensor interface standards to feed into the LAASS, Figure 1, and to enable seamless integration and build-out throughout the state.

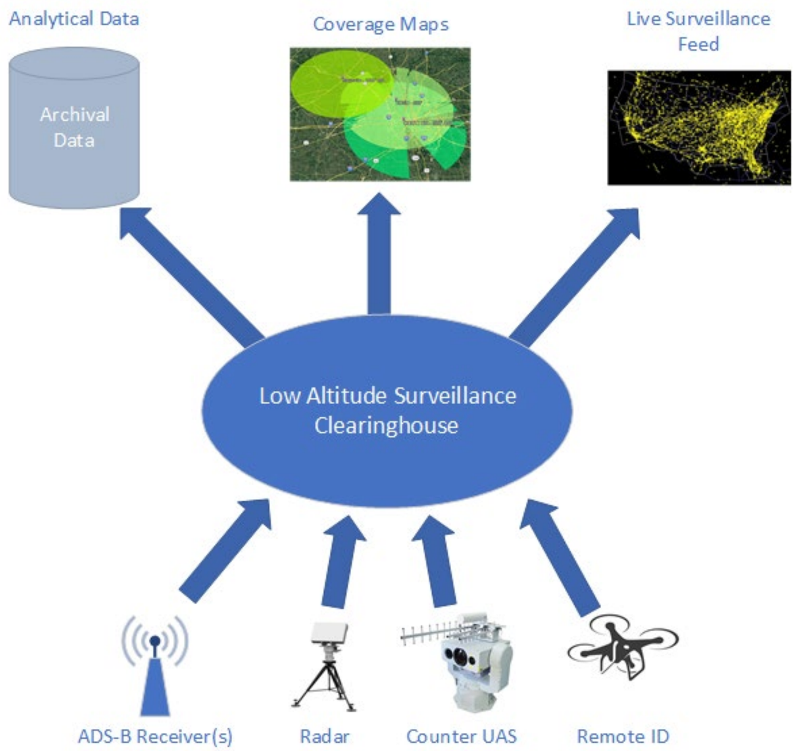

Figure 1: Lower Altitude Aircraft Surveillance Service

The aircraft surveillance source study is comprised of three primary parts including: (a) a surveillance market analysis, (b) an analysis of the surveillance data item requirements, and (c) a surveillance data and interface standard analysis.

2 Surveillance Market Study

In the first phase of this effort, the team completed a market analysis of potential sensors which may feed the ODOT sensor network. To inform the data requirements, interface standards, and eventual requirements for the sensor network, we want to ensure that all facets of sensors are considered during the research and development phase of this program (see Table 1).

To perform this market analysis, our team decomposed the various possible surveillance sensors into groups, dictated by (1) existing crewed aviation surveillance sources and (2) uncrewed aviation surveillance approaches. Each of these two groups were then subdivided into cooperative and non-cooperative aviation surveillance types. Most of the crewed surveillance sensors are well known, as they form the basis of the existing Air Traffic Management (ATM) system used by the aircraft today.

For uncrewed aircraft, the current approach by federal and international regulators is to ensure all Uncrewed Aircraft Systems (UAS) or drones are cooperative in nature and provide their location information, either by request or by regular periodic broadcast. Hence, non-cooperative UAS surveillance is likely to be geared towards non-compliant UAS as part of a counter-UAS surveillance system. Given that these UAS are not adhering to cooperative surveillance requirements, it's also likely they are not adhering to any Uncrewed Traffic Management (UTM) structure either, but nonetheless must be tracked and managed as part of this overall lower altitude surveillance system.

The following sections are a comprehensive review of applicable aircraft surveillance sensors that are likely to be utilized as part of any encompassing lower altitude surveillance system. For each sensor type, a short background and technical description is given as well as a list of known manufacturers of these sensors.

Table 1: Surveillance Equipment Matrix

Sensor Type	Coverage Range(m)	Scan Type	Target Size Range (m sq)	Detection Limitations	Application Type
ABS-B	450000	RF	NA	Size of Equip.	Crewed Aircraft
MLAT	1500 - 3000	RF	NA	Range	Crewed Aircraft
Ground Based Radar – Crewed Aircraft	110000	Radar	> 1	Target Size	Crewed Aircraft
Remote ID	8800*	RF	NA	Drone Only	UAV
Radio Frequency	2200	RF	NA	Range	UAV
Acoustic Beacon	300	Acoustic	2	Range	Crewed Aircraft & UAV
EO/IR PTZ Camera	4500	Optical	>.3	Water Vapor	UAV
Ground Based Radar - UAS	2500	Radar	> .5	Transmit Power	UAV

*Using Cellular LTE/5G for communication

2.1 Cooperative Crewed Aircraft Surveillance

2.1.1 Automatic Dependent Surveillance-Broadcast (ADS-B)

ADS-B is a surveillance technology in which an aircraft determines its position via satellite navigation or other sensors and periodically broadcasts its latitude and longitude, altitude, velocity, aircraft identification, and other information, enabling the aircraft to be tracked. ADS-B is now recognized by the FAA and industry as an important enabler for future trajectory-based air traffic management. ADS-B data (from ADS-B Out equipped aircraft) is already used for separation in FAA Air Traffic Control (ATC) systems and is being received by ADS-B In systems onboard equipped aircraft today. ADS-B is dependent on a position source (e.g., global navigation satellite system [GNSS]) of required quality and requires additional information from other on-board systems. Every ADS-B message includes an indication of the quality of the position and velocity data. This allows ADS-B recipients to determine whether the data is adequate to support the intended use.

ADS–B is "automatic" in that it requires no pilot or external input. It is "dependent" in that it depends on data from the aircraft's navigation system. ADS-B is a technology that enhances safety and efficiency, and directly benefits pilots, controllers, airports, airlines, and the public. It forms the foundation for NextGen by moving from ground radar and navigational aids to precise tracking using satellite signals.

Product Providers:

- Garmin - GNX™ 375 https://www.garmin.com/en-US/
- Appareo Systems https://appareo.com/
- Aventech Research Inc. https://aventech.com/
- AVIONIX SOFTWARE S.L. – Ping Station https://www.astronics.com/
- BECKER AVIONICS https://www.becker-avionics.com/
- Bendix/King by Honeywell https://www.becker-avionics.com/sar-gLAASSses/
- Caledonian Airborne Systems Ltd http://www.caledonian-airborne.com/
- COPPERCHASE LIMITED https://www.copperchase.co.uk/

2.1.2 Multilateration (MLAT)

MLAT takes advantage of the fact that many aircraft are equipped with some form of a transponder (e.g., Mode A, C, and S) to support secondary surveillance radars (SSR) to manage the airspace in and around high-density areas like airports. MLAT employs several ground stations, which are placed in strategic locations around an airport, its local terminal area, or a wider area that covers the larger surrounding airspace. These ground station units listen for “replies,” typically to interrogation signals transmitted from a local SSR or another MLAT ground station. Since individual aircraft will be at different distances from each of the ground stations, their replies will be received by each station at fractionally different times. Using advanced computer processing techniques, these individual time differences allow an aircraft’s position to be precisely calculated. MLAT ground stations receive replies from all transponder-equipped aircraft, including those with legacy radar and ADS-B avionics, and determine aircraft position based on the time difference of arrival (TDOA) of the replies.

The FAA in 2017 included MLAT as a contract option for the ADS-B program. MLAT can provide a backup and/or replacement for SSR. This makes MLAT a major contender for the Alternative Positioning, Navigation, and Timing (APNT) program.

MLAT requires no additional avionics equipment, as it uses replies from Mode A, C and S transponders, as well as military Identification Friend or Foe (IFF) and ADS-B transponders. Depending on the number of ground stations deployed, the MLAT system can provide very accurate location (<100 meters) of aircraft.

Product Providers:

- SAAB - https://www.saab.com/
- Comsoft Solutions – https://www.comsoft.aero

2.2 Non-Cooperative Crewed Aircraft Surveillance

2.2.1 Ground Radar

Ground radar is a method whereby radio waves are transmitted and are then received back when they have been reflected by an object in the path of the beam. Range is determined by measuring the time it takes (at the speed of light) for the radio wave to go out to the object and then return to the receiving antenna. The direction of a detected object from a radar site is determined by the position of the rotating antenna when the reflected portion of the radio wave is received.

Ground radar was developed during World War II as a military air defense system. The primary surveillance radar (PSR) consists of a large parabolic "dish" antenna mounted on a tower so it can scan the entire airspace unobstructed.

The primary radar displays a "return" indiscriminately from any object in its field of view, and cannot distinguish between aircraft, drones, weather balloons, birds, and some elevated features of the terrain (called "ground clutter"). Primary radar also cannot identify an aircraft. Prior to secondary radar being utilized; aircraft were identified by the controller asking the aircraft by radio to waggle its wings. Another limitation is that primary radar cannot determine the altitude of the aircraft.

An airport surveillance radar (ASR) is the radar system used at airports to detect and display the presence and position of aircraft in the terminal area (i.e., the airspace around airports). It is the main air traffic control system for the terminal area. At large airports it typically controls traffic within a radius of 60 miles (96 km) and below an elevation of 25,000 feet. The sophisticated systems at large airports consist of two different radar systems, the primary and secondary surveillance radar [6]. The primary radar typically consists of a large rotating parabolic antenna dish that sweeps a vertical fan-shaped beam of microwaves around the airspace surrounding the airport. It detects the position and range of aircraft by microwaves reflected back to the antenna from the aircraft's surface. The secondary surveillance radar consists of a second rotating antenna, often mounted on the primary antenna, which interrogates the transponders of aircraft, transmits a radio signal back containing the aircraft's identification, barometric altitude, and an emergency status code that is displayed on the radar screen next to the return from the primary radar.

The positions of aircraft can be displayed on a screen. At large airports, multiple screens are used in an operations room called the Terminal Radar Approach Control (TRACON) and are monitored by air traffic controllers who direct the traffic by communicating with aircraft pilots by radio. The radar system is used to maintain a safe and orderly flow of traffic and adequate aircraft separation to prevent midair collisions.

Ground radar sensors can be susceptible to radio interference that can cause, in some cases, dramatic impairments to the performance of these sensors. As a result, the FAA and the Federal Communications Commission (FCC) have allocated certain protected frequency bands for the use of radar-based radio navigation services (47 CFR Part 87), where aircraft are able to make changes in their flight based on the surveillance provided from radar sensors. Other radar sensors that operate in unprotected frequency ranges (47 CFR Part 90) only enable aircraft operators to have very limited use of such systems, such as situational awareness, due to the frequency interference issue. Therefore, it is critical to consider the operating frequency of these sensors and their intended function when considered within the context of this lower altitude open framework.

Product Providers:

- L3 Harris https://www.l3harris.com/
- Raytheon https://www.rtx.com/
- General Atomics https://www.ga.com/
- SRC Inc https://www.srcinc.com/

2.3 Cooperative Uncrewed Aircraft Surveillance

2.3.1 Remote ID

Remote ID is the ability of a drone in flight to provide identification and location information that can be received by other parties. In recent years, the FAA has been evaluating the challenges of identifying potentially millions of commercial drones operating in the national airspace. Previous efforts at generating consensus around Remote ID have hit a variety of roadblocks in the past few years. Throughout 2017, the FAA gathered industry stakeholders and experts in a series of meetings and working groups to discuss and inform future rulemaking, leading to the December 2017 Remote ID and Tracking Aviation Rulemaking Committee.

The FAA's Notice of Proposed Rulemaking (NPRM) on Remote Identification of Uncrewed Aircraft Systems was published on December 31, 2019. The FAA received over 53,000 comments on the NPRM during the 60-day comment period following publication. In May of 2020, the FAA announced eight companies that will work with the FAA in setting up a framework of technology requirements for future suppliers of remote ID technology. The eight companies chosen are: Airbus, AirMap, Amazon, Intel, OneSky, Skyward, T-Mobile, and Wing.

The final rule on remote ID (14 CFR Part 89) will require most drones operating in US airspace to have remote ID capability. Remote ID will provide information about drones in flight, such as the identity, location, and altitude of the drone and its control station or take-off location. Authorized individuals from public safety organizations may request the identity of the drone's owner from the FAA. The final rule was effective April 21, 2022, with the addition of subpart C in September 2022, and applies to operations of unmanned aircraft within the airspace of the United States after September 16, 2023.

There are three ways drone pilots can meet the identification requirements of the remote ID rule:

1. Operate a Standard Remote ID Drone (§89.110) that broadcasts identification and location information of the drone and control station. A standard remote ID drone is one that is produced with built-in remote ID broadcast capabilities.

2. Operate a drone with a remote ID broadcast module (§89.115a) giving the drone's identification, location, and take-off information. A broadcast module is a device that can be attached to a drone, or a feature (such as a software upgrade) integrated with the drone. Persons operating a drone with a remote ID broadcast module must be able to see their drone at all times during flight.

3. Operate (without remote ID equipment) (§89.115b) at FAA-recognized identification areas (FRIAs) sponsored by community-based organizations or schools. FRIAs are the only locations uncrewed aircraft (drones and radio-controlled airplanes) may operate without broadcasting remote ID message elements.

Remote ID helps the FAA, law enforcement, and other federal agencies find the control station when a drone appears to be flying in an unsafe manner or where it is not permitted to fly. Remote ID also lays the foundation of the safety and security groundwork needed for more complex drone operations that will require detection and avoidance for BVLOS flights. Currently, it is recommended that drone ID equipment broadcast using a spectrum similar to Wi-Fi and Bluetooth devices to send flight data and messages. These spectra have limited range for direct vehicle to vehicle transmission but can be augmented with a ground receiver network to provide cooperative surveillance for a given region. The FAA wants to ensure that the public has the capability - using existing commonly available and FCC compliant devices, such as cellular phones, smart devices, tablet computers, or laptop computers- to send and receive these broadcast messages.

Product Providers (Component Vendors):

- Intel https://www.intel.com
- Kismet - https://www.kismetwireless.net/development/droneid/
- Aloft was KittyHawk - https://www.aloft.ai/air-control/
- Ubihere – Ubitrax 5G/LTE Remote ID Ultra Tag https://www.ubihere.com

2.4 Non-Cooperative Uncrewed Aircraft Surveillance

2.4.1 Ground Radar

Like primary radar surveillance used in the current ATM, ground-based radar systems can be utilized for detecting and tracking non-cooperative UAS as well. The technology is essentially identical to the systems used for current crewed aircraft surveillance systems; however, detecting and tracking UAS does present some unique challenges, particularly for small UAS and UAS operating at extremely low-altitudes.

Since small UAS have inherently smaller radar cross-sections, higher frequency radar systems are required. This results in smaller sensor ranges and more susceptibility to noise, in particular from weather. Additionally, the lower the altitude required for aircraft surveillance coverage, the more ground clutter is introduced, dramatically increasing the difficulty in providing a clean and reliable airspace picture. Since these ground radar sensors are used primarily within the context of lower altitude aircraft surveillance of uncrewed aircraft, FCC regulations found in 14 CFR Part 87 and 47 CFR Part 90 have currently not been applied.

Given these challenges and the inherent relatively high-cost of these ground-based radar systems, utilization is usually limited to sensitive sites, such as correctional facilities, airports, and government facilities.

Product Providers:

- Raytheon LPR/Skyler, ASR-11 https://www.rtx.com/
- General Atomics https://www.ga.com/
- SRC Inc LSTARv2 and R14x0 https://www.srcinc.com/
- Ainstein ULAB-D1 https://ainstein.ai/o-79-vehicle-imaging-radar/
- FLIR R8SS-3D https://www.flir.com/
- Fortem TrueView R20 https://fortemtech.com/
- Echodyne GB https://www.echodyne.com/

2.4.2 Radio Frequency (RF) Sensors

Most available drones on the market today use radio signals in the 915Mhz and 2.4Ghz frequency range for their primary means of command and control. The drone uses these radio signals to receive commands from their ground control system (GCS), whether directed by a remote pilot or automation computer, and the drones also send data back to the GCS, such as video images or telemetry (e.g., position or remaining battery power).

The radio frequency (RF) sensors receive and analyze these signals and are not only able to reliably detect and locate drones, but also to classify and identify them as to the manufacturer and/or model. This ability applies to almost all commercial, hobby and home-made drones, and the entire product line manufactured by DJI.

RF scanners use passive detection technology and provide a cost-effective solution for detecting, tracking, and identifying UAVs based on their communication signature. These scanners employ algorithms to scan known radio frequencies and to find and geolocate RF-emitting drones despite weather and day/night conditions, much like the MLAT system, using triangulation techniques.

The RF sensor system's main benefits are that it is inexpensive, simple to install, and can be easily integrated with multiple other sensors like cameras and radars. The challenge with RF sensors is that as more automation is brought to the UAS platform, the dependency on RF signals for command and control diminishes, bringing into question the long-term UAS reliance on RF and reliability of this tracking approach.

Product Providers:

- Dedrone – RF Sensors RF-160 and RF-360 https://www.dedrone.com/
- Converint – https://www.convergint.com
  SRC https://www.srcinc.com/
- Hidden-Level https://hiddenlevel.com/
- Fortem https://fortemtech.com/

2.4.3 Acoustic

Aircraft propellers transmit an audio pattern that can be detected and used for aircraft positioning and classification by acoustic sensors. Usually, a microphone detects the sound made by an aircraft and calculates the location using the time difference of arrival (TDOA) technique, while more sets of microphone arrays can be used for rough triangulation of aircraft. In most cases, acoustic sensors have a short detection range, less than 300 m. They are subject to interference limitations with other audible noise, which is quite significant around airports. For aircraft acoustic detection, researchers use microphone arrays with single board computers for performance evaluation of acoustic denoising algorithms. Acoustic fingerprint collection is a major issue for acoustic detection and identification; however, there are factors able to scatter sound waves, altering the direction of the sound, like wind, temperature, time of day, obstacles, and other emitted sounds. Some researchers propose methods to triangulate sounds captured from centralized and distributed microphone arrays in order to detect the location of low flying aircraft. Although acoustic sensors cannot be considered a primary detection source, they are often combined with other detection systems to enhance aircraft identification. A system with the combination of radar and audio sensors for identification of rotor-type of the aircraft can be a viable detection method.

Acoustic sensors can detect aircraft, with lower system costs and medium probability of detection with a higher false alarm or false positive rate (due to the increasing number of aircraft models), while geolocation of the operator is not provided. Finally, acoustic sensors rely on a database of sounds emitted by known aircraft and might be deaf to drones not covered by the library. Algorithms can also identify the type of aircraft and even differentiate between authorized and unauthorized aircraft. However, in high traffic airport environments where aircraft noise is enormous and overlapping, the use of acoustic sensors cannot be considered a reliable detection method. Additionally, these acoustic sensors likely will only provide 2-D lateral position information, without any clear information on the altitude.

Product Providers:

- Sara - https://sara.com/tasa -
- Dronedj – www.dronedj.com - DroneShield FarAlert Acoustic Sensor

2.4.4 Bispectral Electro-Optical/Infrared (EO/IR) PTZ Camera

A bispectral system is an electronic device that consists of both electro-optical and infrared (EO/IR) sensors that provide accurate optical information during the day or night. An electro-optical sensor can convert the light into the electrical signal. The infrared sensor can detect any structure in its surroundings by detecting infrared radiation. EO/IR systems can be used to enhance target identification, assess threats from a specific distance, or perform target monitoring of other aircraft tracks or ground obstacles that may need to be avoided.

The setup of an EO/IR system is inexpensive and relatively simple. The networking and power for the device is provided by Power Over Ethernet (POE) and is installed easily on top of any existing structure (i.e., buildings, towers, poles, etc.) The camera software allows for dynamic training for tracking targets of interest.

Similar to the limitations of the acoustic sensors, EO/IR struggles to provide a direct range measurement to the target, thus making the surveillance information somewhat limited. Techniques for range estimation have been explored over the years , but they have had very limited success.

Product Providers:

- Axis Communications - Q6215-LE PTZ Network Camera https://www.axis.com/en-us

- Axis Communications AXIS Q87 Bispectral PTZ Network Camera https://www.axis.com/en-us
- L3Harris WESCAM MX™-10 https://www.l3harris.com/

3 Surveillance Data Item Requirements

Data requirements are dependent on the level of service being requested: Informational Only, Radio Location Quality, or Radio Navigation Quality. In this analysis, to determine the most stringent data requirements, we based the data requirements on Radio Navigation level service that supports tactical deconfliction services (e.g., Detect and Avoid / Collision Avoidance). Radio Navigation level service should encompass the full breadth of potential data requirements, with the remaining two levels requiring only subsets of the full requirements.

Surveillance data must encompass both cooperative and non-cooperative sources as described in the ACAS sXu MOPS [6] and the associated Algorithm Description Document (ADD) [7]. This section identifies the data required by ACAS sXu for each surveillance type, along with the corresponding proposed all-purpose structured EUROCONTROL surveillance information exchange (ASTERIX) message elements that can be used either directly or to calculate those required inputs.

3.1 ASTERIX Specification

The ASTERIX interface standard was selected to form the basis of the open standard LAASS. The ASTERIX is a set of interface definitions and "documents defining the low level ('down to the bit') implementation of a data format used for exchanging a wide variety surveillance-related information for ATM applications" [8]. The ASTERIX standard library is comprised of over 70 actively managed message formats for different applications, and is currently grouped into three main applications:

ASTERIX Category Message Groupings

- 000 - 127: Standard Civil and Military Applications
- 128 - 240: Special Civil and Military Applications
- 241 - 255: Civil and Military Non-Standard Applications

A complete list of ASTERIX messages can be found at https://www.eurocontrol.int/asterix. As part of this effort, we have recommended utilizing three ASTERIX message categories to cover the span of various airspace surveillance requirements and associated sensor types.

1. CAT033 ADS-B Message
2. CAT062 System Track Data
3. CAT129 UAS Identification Report

The ASTERIX data specification is a widely used standard across the aerospace industry and should be well known to most airspace surveillance sensor providers.

3.2 Cooperative Data Sources

Table 2 is a list of required cooperative surveillance data elements for ACAS sXu. It is formed by combining Table 9 - Table 12 in [7]. Some elements in the table are required by multiple sXu data reports (e.g., *toa*). The first column is a notional requirement number, and the second describes the data requirement. The third column is the data description, and the last column provides the mapping to the ASTERIX CAT033 data element used to populate or calculate the required value.

Table 2. ACAS sXu Input Requirements for Cooperative (non-v2v) Intruders and CAT033 Data Items

Requirement Number	Requirement Description	Data Item Description	CAT033 Data Item
MC-001	Intruder ADS-B version	Identification of the MOPS version used by a/c to supply ADS-B information. One-octet fixed length Data Item	3
MC-002	Intruder altitude (nominally pressure altitude)	Flight Level from barometric measurements, not QNH corrected, in two's complement form. Two-Octet fixed length data item. -15 FL <= Flight Level <= 1500 FL (LSB) = 1/4 FL	8
MC-003	Intruder geodetic height-above-ellipsoid (HAE) altitude	Geometric Height: Minimum height from a plane tangent to the earth's ellipsoid, defined by WGS-84 Two-Octet fixed length data item	15
MC-004	Intruder pressure altitude	*see above*	8
MC-005	Intruder reporting geodetic height-above-ellipsoid (HAE) altitude	*see above*	15
MC-006	Flag to indicate message received on UAT 978MHz frequency	*see above*	3
MC-07	Intruder latitude	Target latitude	7

Requirement Number	Requirement Description	Data Item Description	CAT033 Data Item
MC-08	Intruder longitude	*Target longitude*	7
MC-09	Intruder 24-bit aircraft address	Target Address	5
MC-10	Intruder Navigation Accuracy Category for Position (NACp)	*This data item conveys the accuracy and integrity parameters reported by the ADS-B target.*	6
MC-11	Intruder Navigation Accuracy Category for Velocity (NACv)	*see above*	6
MC-12	Intruder Navigation Integrity Category (NIC)	*see above*	6
MC-13	Flag to indicate that the address is a non-ICAO 24-bit aircraft address (anonymous address)	see above	5
MC-14	Intruder altitude quantization	*see above*	8
MC-15	Intruder System Design Assurance (SDA) (0-3)	*see above*	21
MC-16	Intruder Source Integrity Level (SIL)	*see above*	6
MC-17	Time of applicability	Time of Applicability for Position, Velocity	4
MC-18	Intruder velocity in east-west direction, true east is positive	Velocity reported by aircraft relative to true north	9
MC-19	Intruder velocity in north-south direction, true north is positive	*see above*	9

Table 3 gives the ACAS sXu input data requirements for cooperative UAS (e.g. Remote ID) given in [6] and [7], along with the proposed elements of the ASTERIX CAT129 [10] message that correspond. The columns are defined as in the previous table.

Table 3 ACAS sXu Input Data Requirements for V2V Intruders and CAT129 Items

Reqt. Number	Requirement Description	Data Item Description	CAT129 Data Item
UC-01	Intruder latitude	Position in WGS-84 Coordinates. Eight-octet fixed length Data Item.	80
UC-02	Intruder longitude	*see above*	80
UC-03	Intruder pressure altitude		N/A
UC-04	Intruder geodetic height above ellipsoid (HAE) altitude	Altitude above Mean Sea Level (AMSL).	90
UC-05	Intruder east-west velocity	Horizontal velocity vector expressed in target centric Cartesian coordinate	185
UC-06	Intruder north-south velocity	*see above*	185
UC-07	Intruder Navigation Accuracy Category for Position (NACp)	GNSS Signal Accuracy Accuracy of the signal of the Global Navigation Satellite System (GNSS) used for determination of the UAS horizontal position, based on the circular error probability (50% CEP). Two-octet fixed length Data Item	110
UC-08	Intruder Navigation Accuracy Category for Velocity (NACv)		N/A
UC-09	Intruder Geometric Vertical Accuracy (GVA)		N/A
UC-10	Remote ID (20 Hex values)	Serial Number of the UAS	40
UC-11	classification		30
UC-12	Toa		70

3.3 Non-Cooperative Data Sources

Non-cooperative data will use the Absolute Geodetic Track (AGT) interface. Table 4 lists the non-cooperative surveillance data elements for ACAS sXu along with the required CAT062 elements to form the sXu input reports. The columns are defined as in the previous table.

Table 4 ACAS sXu Input Data Requirements for Non-Cooperative Intruders and CAT062 Items

Reqt. Number	Requirement Description	Data Item Description	CAT062 Data Item
N001	Intruder 24-bit address	Aircraft Derived Data	380
NC-002	Indication that the address of the intruder is non-ICAO	Since non-cooperative, always non-ICAO	-
NC-003	Track identifier assigned by the external surveillance system	Identification of a track Two-Octet fixed length data item	40
NC-004	Status of incoming track report (Pg 12)	Status of a track Variable length data item comprising a first part of one Octet, followed by 1-Octet extents as necessary	80
NC-005	Indication that the surveillance source of the intruder is non-cooperative	*see above*	80
NC-006	Indication that the surveillance source of the intruder is passive	*see above*	80
NC-007	Indication that the surveillance source of the intruder is externally validated	*see above*	80
NC-008	Intruder latitude	Calculated Position in WGS-84 Co-ordinates with a resolution of 180/2^25 degrees Eight-octet fixed length Data Item	105
NC-009	Intruder longitude	*see above.*	105
NC-010	Intruder velocity in east-west direction, true east is positive	Calculated track velocity expressed in Cartesian coordinates	185
NC-011	Intruder velocity in north-south direction, true north is positive	*see above*	185
NC-012	4x4 horizontal covariance matrix represented as 16-element vector [ew dew ns dns]	Missing cross-terms for velocity	500

Reqt. Number	Requirement Description	Data Item Description	CAT062 Data Item
NC-013	Intruder pressure altitude	Calculated Barometric Altitude of the track. Two-Octet fixed length data item	135
NC-014	Intruder pressure altitude rate	Calculated rate of Climb/ Descent	220
NC-015	2x2 vertical covariance matrix for pressure altitude [h dh]	Missing vertical accuracy information	N/A
NC-016	Intruder geodetic height-above-ellipsoid (HAE) altitude	Vertical distance between the target and the projection of its position on the earth's ellipsoid, as defined by WGS84. Two-Octet fixed length data item	130
NC-017	Intruder geodetic height-above-ellipsoid (HAE) altitude rate	Calculated rate of Climb/Descent of an aircraft	220
NC-018	2x2 vertical covariance matrix for HAE altitude [h dh]		500
NC-019	Time of applicability	Absolute time stamping of the information provided in the track message, in the form of elapsed time since last midnight, expressed as UTC.	70

4 Surveillance Data and Interface Standard Analysis

Based on the data elements that a lower altitude surveillance system is required to provide (see Section 3), an analysis of existing aircraft surveillance standards was performed. The goal was to leverage existing, widely used interface standards if possible. The tables below represent the recommended interfaces that are utilized as the input data to LAASS and are based on the FAA and ASTERIX data formats. ASTERIX data formats are widely used for surveillance data. For example, the current ODOT SkyVision system uses ASTERIX CAT-062, and the ODOT UTM system uses ASTERIX CAT-048 for providing surveillance services.

Based on the analysis, the CAT-033 data interface, which is designed for ADS-B data, would be leveraged for all cooperative crewed aircraft sensors. The CAT-129 message is designed for UAS Remote ID and would provide the interface standard for all cooperative UAS. For all non-cooperative traffic, whether crewed or uncrewed, the CAT-062 interface would be utilized.

All data items from the Asterix CAT033, CAT129, and CAT062 messages (respectively) are shown listed here for reference.

4.1 ASTERIX CAT 033

Table 5 lists all the data items encoded in the CAT033 message.

Table 5. Complete list of CAT033 Data Items

Field Reference Number (FRN)	CAT 033 Message Data Items	Definition
1	Service Volume Identifier	Identification of the Service Volume that is providing data to the Service Delivery Point (SDP).
2	Version Number	Version of this CAT033 format.
3	Link Technology Indicator	Used to specify the data link or link(s) to which the Target Report is applicable.
4	Time of Applicability	Time at which the target position is expected to be an accurate estimate of the true target state vector.
5	Target Address	Identifies a target through a 24-bit address associated with the target plus 3 bits of address qualifier
6	Integrity and Accuracy Parameters	This data item conveys the accuracy and integrity parameters reported by the ADS-B target.
7	Latitude and Longitude	Target latitude and longitude position.
8	Pressure Altitude	Barometric Aircraft altitude referenced to standard atmospheric pressure of 29.92 in. Hg. This is the uncorrected barometric pressure altitude.
9	Velocity (Airborne)	The Velocity reported by the aircraft indicated by the North/South and East/West Velocity (relative to true north) and the geometric vertical rate of change reported by the aircraft.
10	Velocity (Surface)	Velocity format reported when target is known to be ON GROUND.
11	Mode 3/A Code	Aircraft's Mode-3/A code reported by the aircraft.
12	Target Identification	Target Identification (in 8 characters) reported by the aircraft/vehicle. This is generally the radio call sign.
13	Emitter Category	The target's category code for the current position report.
14	Target Status	Status information currently being reported by the target.
15	Geometric Altitude	Aircraft altitude derived from GNSS, INS or ground based measurement represented as Height Above Ellipsoid (HAE).

16	Modes and Codes	This FRN contains the ADS-B Independent Validation, operational Modes and Capability Codes.
17	TCAS RA Messages	Information on a TCAS Resolution Advisory that has been initiated by the aircraft's on-board TCAS system.
18	Time of Message Reception	The time at which the ADS-B message was received by the ADS-B Service expressed as fractional seconds from the UTC second.
19	GPS Antenna Offset	This defines the offset from the aircraft's ADS-B Position Reference Point to the GPS antenna that is utilized by the GPS positioning source that measures the ADS-B position for the aircraft.
20	Target State Data	This FRN provides Target State information broadcast by ADS-B.
21	ADS-B Data Quality Parameters	The ADS-B Data Quality field contains parameters concerning the quality of the data provided in various FRNs.
22	Data Source Qualifier	Identification of the data source supplying status data.
23	Report Identifier	Arbitrary persistent number used for traceability. This FRN is for Service Provider use only.
24	Time of Origination	Time at which the radar data for a TIS-B report was received at the Service Delivery Point (SDP).

4.2 ASTERIX CAT 129

Table 6 lists all the data items encoded in the CAT129 message.

Table 6. Complete list of CAT129 Data Items

Item No.	CAT 129 Message Data Items	Notes
010	Data Source Identification	Identification of the station generating the ASTERIX record
015	Data Destination Identification	Identification of the station to which the ASTERIX record is routed
020	UAS Manufacturer Identifier	UAS Manufacturer Identifier in ASCII Characters
030	UAS Model Identifier	UAS Model Identifier in ASCII Characters
040	UAS Serial Number	Serial Number of the UAS
050	UAS Office Registration Country	UAS Office Registration Country
070	Time of Day	UTC time of transmission of this ASTERIX message
080	Position in WGS-84 Coordinates	Position in WGS-84 Co-ordinates
090	Altitude above Mean Sea Level	Altitude above Mean Sea Level (AMSL).
100	Altitude above Ground Level	Altitude above Ground Level (AGL)

110	GNSS Signal Accuracy	Accuracy of the signal of the Global Navigation Satellite System (GNSS) used for determination of the UAS horizontal position, based on the circular error probability (50% CEP).
120	Operational Risk Levels	Risk level of the UAS Operation following the "Specific Operations Risk Assessment (SORA)" methodology defined by JARUS and according to the "Introduction of a regulatory framework for the operation of uncrewed aircraft" by EASA.
185	Horizontal Velocity (Cartesian)	Horizontal velocity vector expressed in target centric Cartesian coordinates, where X axis is pointing East and Y axis is pointing to the geographic North regarding reported position, in two's complement representation.
220	Vertical Velocity	Vertical velocity as given by the rate of change of the Altitude. Positive values indicate climbing target and negative values indicates descending target.

4.3 ASTERIX CAT 062

Table 7 lists all the data items encoded in the CAT062 message.

Table 7. Complete list of CAT062 Data Items

Item No.	CAT 062 Message Data Items	NOTES
10	Data Source Identifier	Identification of the system sending the data Two-octet fixed length Data Item
15	Service Identification	Identification of the service provided to one or more users
40	Track Number	
60	Track Mode 3/A Code	
70	Time Of Track Information	
80	Track Status	
100	Calculated Track Position (Cartesian)	
105	Calculated Position In WGS-84 Co-ordinates	
110	Mode 5 Data reports & Extended Mode 1 Code	
120	Track Mode 2 Code	
130	Calculated Track Geometric Altitude	
135	Calculated Track Barometric Altitude	
136	Measured Flight Level	
185	Calculated Track Velocity (Cartesian)	
200	Mode of Movement	
210	Calculated Acceleration (Cartesian)	
220	Calculated Rate of Climb/Descent	

245	Target Identification	Target (aircraft or vehicle) identification in 8 (6 bit) characters. Seven-octet fixed length Data Item
270	Target Size & Orientation	Target size is defined as length and width of the detected target, and orientation. Variable length Data Item comprising a first part of one octet, followed by one-octet extents as necessary
290	System Track Update Ages	Ages of the last plot/local track/target report update for each sensor type. Compound Data Item, comprising a primary subfield of up to two octets, followed by the indicated subfields
295	Track Data Ages	Ages of the data provided. Compound Data Item, comprising a primary subfield of up to five octets, followed by the indicated subfields.
300	Vehicle Fleet Identification	Vehicle fleet identification number. One octet fixed length Data Item
340	Measured Information	
380	Aircraft Derived Data	
390	Flight Plan Related Data	
500	Estimated Accuracies	
510	Composed Track Number	

5 Summary and Recommendations

This sensor source study for lower altitude aircraft surveillance captures the results of a thorough analysis for the purpose of determining a sensor interface standard for accepting a wide array of airspace surveillance sources. This report documents the three primary activities undertaken as part of this effort, including: (a) a surveillance market analysis, (b) an analysis of the surveillance data item requirements, and (c) a surveillance data and interface standard analysis.

The study organized the various sensor sources into four main categories for the analysis, (1) cooperative crewed aircraft, (2) non-cooperative crewed aircraft, (3) cooperative UAS, and (4) non-cooperative UAS. Then, utilizing the goal of tactical deconfliction or collision avoidance as the most stringent from a data requirements perspective, the study derived the data requirements that would be needed for each of the four sensor types. Additionally, by treating all non-cooperative aircraft, both crewed and uncrewed, in a similar manner from a data perspective, the four sensor categories can be further reduced three main data interface types:

1. Cooperative Crewed Aircraft

2. Cooperative Uncrewed Aircraft

3. Non-Cooperative Aircraft

These three aircraft surveillance data types will form the basis for the input types for the LAASS. The study also provides a recommendation for an interface standard for each of these three types, summarized in Table 8.

Table 8: Aircraft Surveillance Interface Summary

Sensor / Aircraft Type	Interface Standard	Description
Cooperative Crewed Aircraft	ASTERIX CAT-033	Covers all cooperative crewed aircraft, but geared mostly towards ADS-B.
Cooperative Uncrewed Aircraft	ASTERIX CAT-129	Covers all cooperative uncrewed aircraft, either through direct network or broadcast.
Non-Cooperative Aircraft	ASTERIX CAT-062	Covers all surveillance types where the aircraft doesn't broadcast any information on itself.

The analysis results showed that these three ASTERIX messages can almost entirely satisfy the current data requirements for tactical deconfliction services. The biggest gap is for cooperative uncrewed aircraft and the lack of vertical accuracy information in the CAT-129 message. We have discussed this matter with the FAA ACAS program office and are in active engagement with the EUROCONTROL standard committee to make a request to add these additional vertical fields to the next release of the CAT-129 interface standard. If resolution to these gaps is unable to be reconciled with EUROCONTROL, additional means for providing this information will have to be developed. This could be achieved by adding estimation capabilities to the surveillance service and appending the ASTERIX messages with the additional required data elements.

6 References

[6] "Minimum Operational Performance Standards for Airborne Collision Avoidance System sXu (ACAS sXu)", RTCA DO-396, December 15,2022.

[7] "Algorithm Design Description of the Airborne Collision Avoidance System sXu", Traffic Alert & Collision Avoidance System (TCAS) Program Office, February 19, 2021.

[8] *Asterix*, https://www.eurocontrol.int/asterix. Accessed 24 August 2023

[9] US Department of Transportation, FAA Specification for Surveillance Data Exchange ASTERIX, Part 12 Category 33, April 6, 2021.

[10] EUROCONTROL Specification for Surveillance Data Exchange ASTERIX Part 29 Category 129 UAS Identification and Target Reports, 12/06/2019.

[11] EUROCONTROL Specification for Surveillance Data Exchange – ASTERIX Part 9 Category 062: SDPS Track Messages, 11/12/2020.

7 CAT 33 ACAS Mapping

Equivalent CAT 33 DATA ITEM (MSB/LSB)	Data Requirements			
Table 2 (ADD Table 9). STM Input Variables - State Vector Position Report				
7 (48/25)	lat	degrees	real	Intruder latitude
7 (24/1)	lon	degrees	real	Intruder longitude
8 (14/1)	alt	feet	real	Intruder altitude (nominally pressure altitude)
15 (16)	is_alt_geo_hae	N/A	bool	Intruder reporting geodetic height-above-ellipsoid (HAE) altitude
5 (24/1)	mode_s	N/A	uint32	Intruder 24-bit aircraft address
6 (23/20)	nic	N/A	uint32	Intruder Navigation Integrity Category (NIC)
8 (16/15)	q_int	feet	uint32	Intruder altitude quantization (25 or 100)
-	rebroadcast	N/A	bool	Flag to indicate message received from ADS-R
5 (25)	non_icao	N/A	bool	Flag to indicate that the address is a non-ICAO 24-bit aircraft address (anonymous address)
4 (32/9)	toa	seconds	real	Time of applicability
Table 3 (ADD Table 10). STM Input Variables - State Vector Velocity Report				
9 (23/12)	vel_ew	knots	real	Intruder velocity in east-west direction, true east is positive
9 (36/25)	vel_ns	knots	real	Intruder velocity in north-south direction, true north is positive
5 (24/1)	mode_s	N/A	uint32	Intruder 24-bit aircraft address
6 (23/20)	nic	N/A	uint32	Intruder Navigation Integrity Category (NIC)
-	rebroadcast	N/A	bool	Flag to indicate message received from ADS-R (not an allowed source for sXu)

5 (25)	non_icao	N/A	bool	Flag to indicate that the address is a non-ICAO 24-bit aircraft address (anonymous address)
4 (8/1)	toa	seconds	real	Time of applicability

Table 4 (ADD Table 12). STM Input Variables -Mode Status Report

3 (7/5)	adsb_version	N/A	uint32	Intruder ADS-B version
6 (16/12)	nacp	N/A	uint32	Intruder Navigation Accuracy Category for Position (NACp) (0-11)
6 (6/3)	nacv	N/A	uint32	Intruder Navigation Accuracy Category for Velocity (NACv) (0-4)
6 (18/17)	sil	N/A	uint32	Intruder Source Integrity Level (SIL) (0-3)
21 (10/9)	sda	N/A	uint32	Intruder System Design Assurance (SDA) (0-3)
5 (24/1)	mode_s	N/A	uint32	Intruder 24-bit aircraft address
-	rebroadcast	N/A	bool	Flag to indicate message received from ADS-R
3 (3)	is_uat	N/A	bool	Flag to indicate message received on UAT 978MHz frequency
5 (25)	non_icao	N/A	bool	Flag to indicate that the address is a non-ICAO 24-bit aircraft address (anonymous address)

Table 5 (ADD Table 11). STM Input Variables - State Vector UAT Report

7 (48/25)	lat	degrees	real	Intruder latitude
7 (24/1)	lon	degrees	real	Intruder longitude
8 (14/1)	alt	feet	real	Intruder altitude (nominally pressure altitude)
15 (16)	is_alt_geo_hae	N/A	bool	Intruder reporting geodetic height-above-ellipsoid (HAE) altitude
9 (23/12)	vel_ew	knots	real	Intruder velocity in east-west direction, true east is positive
9 (36/25)	vel_ns	knots	real	Intruder velocity in north-south direction, true north is positive
5 (24/1)	mode_s	N/A	uint32	Intruder 24-bit aircraft address
6 (23/20)	nic	N/A	uint32	Intruder Navigation Integrity Category (NIC)
8 (16/15)	q_int	feet	uint32	Intruder altitude quantization (25 or 100)
5 (25)	non_icao	N/A	bool	Flag to indicate that the address is a non-ICAO 24-bit aircraft address (anonymous address)
4 (8/1)	toa	seconds	real	Time of applicability

9 Appendix B – Functional Requirements Document

Open Framework Standards for Combined Aircraft Sensor Network

for the State of Ohio to Detect and Track Lower Altitude Aircraft

Functional Requirements Document

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1 Purpose and Scope

This document proposes open framework standards for a combined aircraft sensor network for the state of Ohio to detect and track lower altitude aircraft. The current gap in such standards is briefly described, and an overview of the envisioned solution is presented, including the intended functionality and operational goals. Functional and performance requirements of the network and its integration are then specified. These requirements are the product of a robust systems engineering approach conducted by local industry experts and have been informed by extensive stakeholder outreach and feedback. If adopted, these standards will support the open interfaces crucial to a reliable and robust LAASS in the state of Ohio.

1.1 Introduction

The increased number of Uncrewed Aircraft Systems (UAS) operating at lower altitudes is stretching the limits of those systems to safely manage and mitigate the full range of factors they may face. The state of Ohio has recognized this and invested in programs such as their Uncrewed Traffic Management (UTM) corridor and SkyVision that collect and leverage sensor data from disparate UAS to provide safety benefits and other services to all the participants in the local ecosystem. The standard proposed here will enable seamless integration of such systems (and future systems) to fully leverage all available surveillance data across the state.

1.2 Systems Overview

Figure 2 provides an overview of the envisioned system and its interfaces with inputs (sensors) and outputs (services). UAS operators can register sensors by accessing an online process and providing the required data artifacts. The LAASS provides services based on aggregated data received by registered sensors.

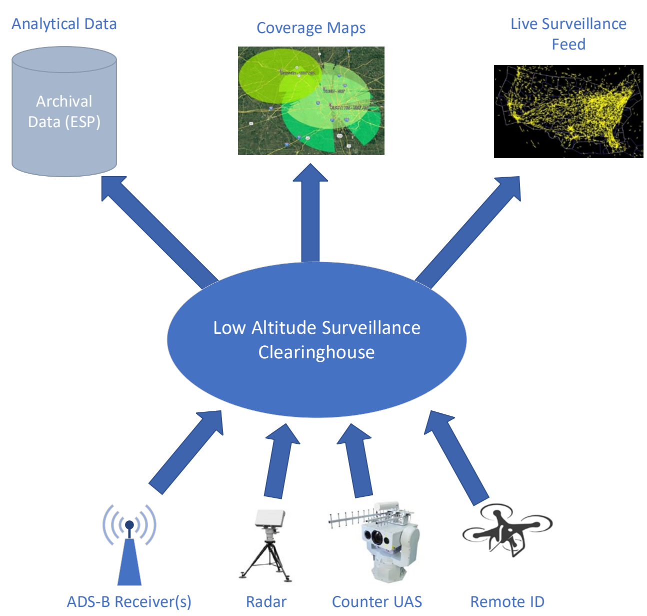

Figure 2 Lower Altitude Aircraft Surveillance Service

1.3 Intended Functions

The system is primarily intended to ingest data from various airspace surveillance sensor sources and provide users an encompassing airspace data feed for UAS flight operations. The system will have well defined interface specifications for sensor integration and for user ingestion. The system will include offline data archiving capabilities for analysis and potential post incident investigations. The system will provide users and administrators with health and integrity information. The system should include real-time coverage maps and easy access to archival data.

1.4 Assumptions

Radio Navigation Quality service requirements are derived from the Airborne Collision Avoidance System for small uncrewed aircraft systems (ACAS-sXu) Minimum Operational Performance Standards (MOPS) [12].

2 Functional Requirements

This section defines the functional and performance requirements for detection and tracking of lower altitude air traffic by the combined aircraft sensor network.

2.1 Sensor Registration

Sensor registration may involve issuance and management of login credentials for sensor owners to begin the process of interfacing the sensor database.

The system **shall** provide a network interface for attaching external surveillance sources that have submitted the requisite data artifacts and received certification of acceptable coverage and performance characteristics. These sources may consist of raw sensor-data feeds, correlated aircraft tracks, or a combination of both (see 2.6 for correlation requirements).

All sensors **shall** be qualified, prior to integration, for appropriate levels of service as described in Table 9.

Table 9 Levels of Surveillance Services

Service Level	Description	Notes
Informational Only	Supports display and situational awareness only.	Not adequate for actual operations support.
Location Quality	Supports tactical deconfliction alerting. No guidance information is permitted.	Would need FAA certification for Location purposes (conflict detection and alerting)
Radio Navigation Quality	Supports tactical deconfliction with guidance services.	Would need FAA certification for Navigation purposes (conflict resolution)

The system **shall** enable attributes to be assigned to each sensor onboarded for indicating whether the sensor is for public or restricted utilization. The restricted provisioning is to allow firewalling sensor data for public safety and counter-UAS use cases. Corrections facility or counter-UAS systems that don't want to make data available to the public for security reasons can assign certain sensors as restricted to ensure access to this sensor data is only available to approved users (e.g., law enforcement, airport managers).

For each sensor that is tagged as restricted, the system **shall** enable assignment of specific users for access rights to that sensor data and any associated system services using that data.

2.2 User Registration

While the system is intended to provide open access to airspace surveillance data, there are some use-cases that require limited access rights. Therefore, the system **shall** enable user access rights attributes that give users access to specific sensor feeds. An example of this is a counter-UAS sensor suite around a corrections facility, where only law enforcement personnel from that facility have access to the system services from those sensor sources.

The feeds **shall** include (at minimum) the data source type and the age of the current data.

The system **shall** implement an online account request, registration, and payment process consistent with the user levels described in Table 9.

The system **shall** be capable of providing registration credentials for up to 1000 concurrent users. This limit should be scalable to increase capacity as demand rises. It is not required that this scaling be in real-time.

2.3 Service Querying

The system **shall** enable online queries of system coverage and performance capabilities.

The system may be capable of publishing coverage maps online in response to specific queries.

The system **shall** provide sensor coverage data through a subscription service, for example an API.

The system **shall** provide query and coverage information based on sensor source access attributes. This means that if a sensor source is considered restricted, it will only show up in query results for users with access rights to those sensors.

2.4 Surveillance Data Format

The system **shall** ingest surveillance sensor data from a range of source types, including crewed and uncrewed aircraft (both cooperative and uncooperative). The sensor types include, for example, ADS-B, radar, direct telemetry, and remote ID.

Data **shall** be in ASTERIX message-format as described in this subsection for each of the three source types:

1. Cooperative Crewed Aircraft: piloted aircraft equipped with ADS-B out.
2. Cooperative Uncrewed Aircraft: autonomous or remotely piloted vehicles equipped with Remote ID either broadcast, network or equivalent.
3. Non-cooperative Aircraft: any aircraft (crewed or uncrewed) that is not broadcasting location or providing location through interrogation.

2.4.1 Cooperative Crewed Aircraft

The ASTERIX CAT033 message **shall** be used for all cooperative, crewed aircraft.

2.4.2 Cooperative Uncrewed Aircraft

The ASTERIX CAT129 message **shall** be used for all cooperative uncrewed aircraft that provide direct telemetry data or Remote ID information.

2.4.3 Non-Cooperative Aircraft

The ASTERIX CAT062 message **shall** be used for all non-cooperative aircraft.

2.5 Live Streaming

The system **shall** be capable of receiving and providing a streaming service of real-time airspace surveillance data.

The system **shall** provide a data feed to the ODOT Event Streaming Platform (ESP) via an API or Kafka connector for data archival and dissemination as described in [12]. See Appendix A for input types.

The system may have the provision to tag tracks with data such as track ID, cooperative status, operator information, or other pertinent information.

The system's live streaming service **shall** only include sensor sources provisioned for access to that user. For example, public users will not have access to data from restricted sensors sources. Additionally, a user with access to a restricted data source, should only have access to their restricted sensors, and not to other restricted sensors feeds.

2.5.1 Aircraft Surveillance Sources

If a produced track is the result of fusing data from multiple sensor types (e.g., ADS-B and a pair of overlapping ground radars), the system output **shall** include the individual source tracks (possibly blended per sensor type) together with the fused track.

2.5.2 Sensor data pre-processing

Some pre-processing may need to be performed by the SDSP. For example, duplicate ADS-B tracks must each be provided and must be identified and marked as duplicates.

2.5.2.1 Validation for Alerting Guidance

Surveillance shall provide an indication of external validation for passive surveillance inputs.

2.5.2.2 ADS-B Duplicate Address Processing

This section summarizes processing assumptions and requirements to handle duplicate address conditions. Detailed duplicate processing text is given in §2.2.3.1.6.1 in reference [12] and is leveraged from reference [13].

2.5.2.2.1 1090 Extended Squitter (ES)

Surveillance **shall** detect airborne 1090 ES ADS-B traffic with duplicate addresses.

Surveillance **shall** provide 1090 ES ADS-B reports that are NOT identified as duplicate address tracks according to the following requirements.

- reports may be marked with a duplicate address flag per DO-260C receiver, or
- may fail report-validity checks in DO-317B.

In either of the case, further processing to support tracking duplicate addresses is required as specified in §2.2.3.1.6 of [12].

2.5.2.3 Universal Access Transceiver (UAT)

Surveillance **shall** detect and track airborne UAT ADS-B traffic with duplicate addresses.

UAT ADS-B reports that fail report validity checks in DO-317B are subject to further processing to determine if they are the result of a duplicate address as specified in §2.2.3.1.6.2 of [12].

Surveillance **shall** assign the duplicate track a unique participant address for the life of the track.

Surveillance **shall** provide both tracks.

2.6 Tracking Performance Requirements

This section summarizes the SDSP performance requirements as specified in references [13] and [14].

2.6.1 Sensor track correlation

The system will routinely receive multiple sensor-tracks for a single target and must perform correlation to produce an accurate depiction of the airspace. For example, an intruder that is reporting position using ADS-B may also be tracked by a ground radar. In addition, non-cooperative surveillance sources may detect and track "ownship" UAS vehicles. To avoid undesired duplication and alerting, the system must be capable of performing both identifier and spatial correlation of the sensor feeds.

Sensor track correlation is performed using either track identifiers or spatial proximity. The choice of which correlation mechanism to use is driven by the signal source types, as well as the characteristics of the associated track IDs (e.g., ICAO vs. NON-ICAO mode S address) as specified in Table 2-19 in [12].

The system **shall** deploy correlation mechanisms in a manner consistent with Table 2-19 in [12].

The system **shall** meet the correlation performance requirements listed in Table 10 for each correlation mechanism.

Table 10 Sensor Track Correlation Requirements

Correlation Mechanism	Correlation Rate[1]	Max Permitted Decorrelation	Max Miscorrelation Rate
Identifier based	99%	0.2%	0.2%

Spatially based without Ownship	95%	1%	1%
Spatially based with Ownship (non-cooperative AGT)	99%	0.2%	1%

2.6.2 Sensor signal latency

The system's operational and installation instructions **shall** specify system component delay assumptions and installation and/or use requirements so that the total system latency bounds specified in Table 11 are satisfied.

Table 11 Surveillance and Alert Generation and Execution latency bounds

Source	Maximum Total Latency (sec)	Uncompensated Latency (sec)
Surveillance: Includes sensor latency and processing latency	3.5	0.3 to 0.7

2.6.3 Track Propagation

The system **shall** be capable of propagating tracks to compensate for intermittent dropped data from the sensor sources.

The system **shall** indicate when tracks are propagated in the output data.

The system **shall** compensate for the accuracy information of the track to reflect any propagation.

2.6.4 Integrated Track Output

The system **shall** output a best-sourced select or fused track data feed to provide a single integrated airspace surveillance picture.

The system **shall** include any cooperative identifier for the integrated track output for cooperative tracks (e.g., ICAO address, etc.).

The integrated output track priority or fusion scheme should be configurable.

2.6.5 Sensor health monitoring

The system **shall** monitor the health of reporting sensors and other critical supporting systems.

The system **shall** provide a heartbeat message that contains Boolean confirmation that the system is meeting coverage and performance requirements.

The system **shall** provide current system status and a description of any anomalies with each heartbeat message.

The system **shall** include error identifiers when coverage and performance levels are reduced.

The system **shall** provide information on scheduled degradations with a description of the event.

2.7 Data Archival

The system **shall** provide a means acceptable to ODOT IT for archiving data (e.g., Microsoft SQL, Oracle, Azure, AWS, ESP). This may be achieved by leveraging the ODOT Event Streaming Platform (ESP) via an API or Kafka connector for data archival and dissemination. See Appendix A for input types.

The system **shall** provide a front-end map-based visualization tool that will allow users to query archived data through polygon location or UAS ID (RID).

2.8 Robustness

From [14] "Because the surveillance SDSP is an important component in helping the operator or USS ensure that the UA does not collide with crewed air traffic, it is expected to meet high availability metrics as defined in this section."

Additionally, from [14], "…the system should meet the requirements in **Table 12**for MTTR (mean-time to recovery), automatic recovery time, and MTBF (mean time between failures). The SDSP is expected to employ automatic recovery, but there may be instances of unsatisfactory operation of the automatic recovery mechanism, or human intervention may be required. To allow for that, two MTBF intervals are specified."

Minimum Robustness Capabilities are given in **Table 12**, and pertain to certification for all levels of service.

Table 12 Minimum Robustness Capability

Parameter	Requirement	Notes
Mean Time to Recovery	30 minutes	The SDSP is expected to employ automatic recovery, but there may be instances of unsatisfactory operation of the automatic recovery mechanism, or human intervention may be required. To allow for that, two MTBF intervals are specified.
Automatic Recovery Time	5 minutes	
MTBF with automatic recovery	300 hours	
MTBF without automatic recovery	5,000 hours	

3 Integration Requirements Section

3.1 Services and APIs

The system **shall** provide live surveillance feeds of aircraft positions to consuming systems via documented APIs using open standard formats (e.g., GeoJSON [15], GML, OGC) and protocols (e.g., HTTPS, REST, web sockets).

The system **shall** accept live surveillance feeds of UAS positions from operator systems via documented APIs using open standard formats (e.g., GeoJSON [15], GML, OGC) and protocols (e.g., HTTPS, REST, web sockets).

The system **shall** provide authenticated REST APIs to address specific use cases, such as querying current and historical UAS positions by UAS ID (RID), by polygon location extent including an optional altitude component.

The system **shall** provide the ability to query the database by specifying temporal and geographic criteria.

3.2 Authentication and Authorization

Users and systems consuming data must be registered with the system, must be authenticated with the system, and must be authorized to use the surveillance feed or API they are trying to access. The system **shall** not allow open unrestricted access to surveillance feeds or APIs.

All user access **shall** be managed in a Single Sign-On (SSO) environment.

3.3 ODOT and State of Ohio IT Standards

The system **shall** be configured in such a way that it conforms with ODOT and the state of Ohio Office of Information Technology (OIT) standards, as it will be required to integrate with ODOT's IT network and systems.

This section defines the standards set forth by OIT that will apply to the SDSP. General IT standards are not included in this document. For the purposes of convenience, an overview of IT policy and standard links is provided below.

Table 13 OIT Policies and Standards Items

OIT Policies & Standards Item	Link
IT Policies and Standards	https://das.ohio.gov/Divisions/Information-Technology/State-of-Ohio-IT-Policies
Statewide IT Standards	http://das.ohio.gov/Divisions/InformationTechnology/StateofOhioITStandards.aspx
Statewide IT Bulletins	http://das.ohio.gov/Divisions/InformationTechnology/StateofOhioITBulletins.aspx
Other Department of Administrative Services (DAS) Policies	100-11 Protecting Privacy 700-00– Technology / Computer Usage Series 2000-00 – IT Operations and Management Series http://das.ohio.gov/Divisions/DirectorsOffice/EmployeesServices/DASPolicies/tabid/463/Default.aspx

The subsections to follow focus on ODOT specific IT requirements and needs for this project specifically.

3.3.1 Compute Requirements

3.3.1.1 Server/OS

If the system is deployed on premises at ODOT, it **shall** comply with State requirements including using the State's Virtualized Compute Platform and complying with the State's supported Server/OS versions.

Table 14 Supported Server/OS versions

Operating System	Version	Edition
Microsoft Windows	2012, 2012 R2 or higher	Standard, Enterprise, Datacenter
RedHat Linux	7 or higher	Enterprise
IBM AIX	7.1 or higher	
Oracle Enterprise Linux		Enterprise
SQL Server	2016 or higher	Enterprise
Oracle	11G or 12C or higher	

3.3.1.2 Hypervisor Environment

If the system is deployed on premises at ODOT, it **shall** comply with the State's supported VMware vSphere, and IBM Power Hypervisor environment.

3.3.2 Storage and Backup Requirements

3.3.2.1 Storage Pools

The State provides three pools (tiers) of storage with the ability to use and allocate the appropriate storage type based on predetermined business criticality and requirements. Storage pools are designed to support different I/O workloads.

If the system is deployed on premises at ODOT, it **shall** take advantage of the State's Storage Service Offerings.

Table 15 Supported Storage Pools

Storage Pool	Availability	Performance	Typical Applications
Performance	Highest	Fast	Performance pool suited for high availability applications, with high I/O (databases).
General	High	Fast	General pool suitable for file servers, etc.
Capacity	High	Average	Capacity pool suitable for file servers, images and backup / archive). Not suited for high random I/O.

3.3.2.2 Backup

If the system is deployed on premises at ODOT, it **shall** take advantage of the State's Backup Service Offering.

The backup service uses IBM Tivoli Storage Manager Software and provides nightly backups of customer data. It also provides for necessary restores due to data loss or corruption. The option of performing additional backups, archiving, restoring, or retrieving functions is available for customer data. OIT backup facilities provide a high degree of stability and recoverability as backups are duplicated to alternate sites.

3.3.3 Networking Requirements: Local Area Network (LAN) / Wide Area Network (WAN)

If the system is deployed on premises at ODOT, it **shall** work within the State's LAN / WAN infrastructure. For cloud-hosted solutions, network connectivity and access for data and services will be reviewed and approved by the IT unit.

The State provides a high bandwidth internal network for internal applications to communicate across the State's LAN / WAN infrastructure. Normal traffic patterns at major sites should be supported. Today, the State's WAN (OARnet) consists of more than 1,850 miles of fiber-optic backbone, with more than 1,500 miles of it operating at ultrafast 100 Gbps speeds. The network blankets the state, providing connectivity to all State Government Agencies.

The state of Ohio Network infrastructure utilizes private addressing, reverse proxy technology and Network Address Translation (NAT). All applications that are to be deployed within the infrastructure **shall** be tolerant of these technologies for both internal product interaction as well as external user access to the proposed system, infrastructure, or application.

The State network team will review applications requirements involving excessive bandwidth (i.e., voice, video, telemetry, or applications) deployed at remote sites.

3.3.4 Application Requirements

3.3.4.1 Application Platforms

The system **shall** be developed in open or industry standard languages (e.g., Java, .NET, PHP, etc.).

3.3.4.2 Open API's

The system **shall** be developed with standards-based Open API's. An open API is an application program interface that provides programmatic access to software applications. The system **shall** describe in detail all available features and functionality accessible via APIs.

3.3.4.3 SOA (Service Oriented Architecture)

The system **shall** be developed using a standards-based Service Oriented Architecture (SOA) model.

3.3.5 Database Platforms

The system **shall** run on databases that comply with the State's supported Database Platforms.

- Microsoft SQL Server 2016 or higher
- ORACLE 11G or 12C or higher
- DB2 version 10 f or higher
- MySQL version 8 or higher

3.3.6 Application Service Requirements

The system is required to take advantage of published IT Application Services where possible (e.g., Event Streaming Platform, Enterprise Service Bus, Content Management, Enterprise Document Management, Data Warehousing, Data Analytics and Reporting, and Business Intelligence). The State's IT Services are listed in the State's IT Services Catalog at:

http://das.ohio.gov/Divisions/InformationTechnology/StateofOhioITServiceCatalog.aspx

3.3.7 Data Encryption and Cryptography

All data transmitted to or from the system or retained by the system shall be encrypted in motion and encrypted at rest using cryptographic algorithms that comply with the minimum requirements established in state of Ohio IT Standard ITS-SEC-01 – see

https://das.ohio.gov/Portals/0/DASDivisions/InformationTechnology/IG/pdf/ITS-SEC-01.pdf

3.3.8 Accessibility

Public-facing Web pages shall be compliant with the accessibility standards established by the Web Content Accessibility Guidelines (WCAG) 2.0, Level A and Level AA.

4 Event Steaming Platform Considerations

ODOT's Event Streaming Platform (ESP) is a scalable platform for ingestion, processing, and dissemination of transportation real time data. ESP will provide mechanisms that allow Public and Private entities to share, publish and consume real-time transportation data.

The diagram represents the current ESP technology stack:

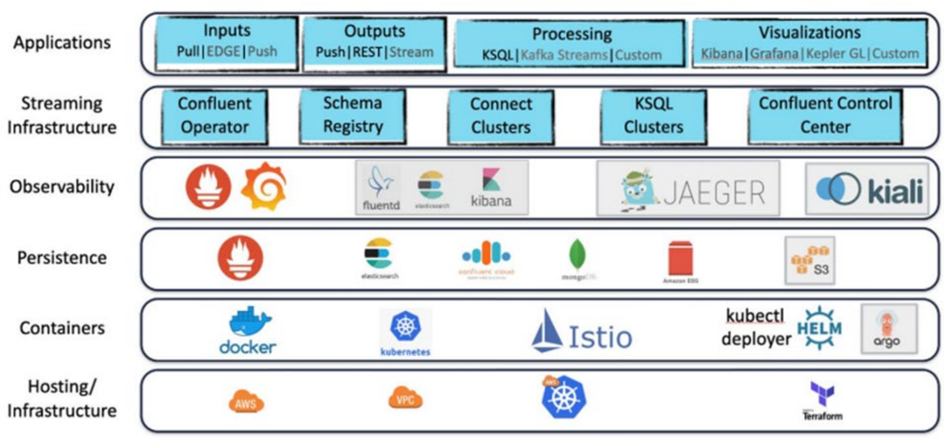

Figure 3: ESP Technology Stack

Greyed out items represent future or work in progress functionality. When describing ESP, it is useful to split it into two major building components. The first is the Platform that provides an environment to effectively build, run and operate applications, and the second is the set of Applications that address specific business needs. Up to this point a lot of the ESP team's effort went into building the Platform, but the team also built a few applications to validate the approach. The Platform was designed with two principles in mind, to be modular so independent components can be used easily, and to be generic so these components can be used across a large number of use cases.

4.1 Applications

Applications are built with the following components:

- Inputs for publishing data

- Outputs for sending data to other systems or for making it available to other systems
- Processing for writing specific business logic
- Visualizations for exploring the data

For each of the components the team strived to use a no-coding or low-coding approach while also building in flexibility to allow for custom coding when needed.

4.2 Inputs

ESP currently offers 3 input types. Each of these types can be used to ingest data from a wide variety of systems.

The first type of input, Producer Pull, is for ingesting data from systems like databases or ingesting data from REST endpoints. Technically, Producer Pull uses Kafka Source Connectors. There are hundreds of connectors available in repositories like Confluent Connect Hub. These connectors are entirely configurable and support multiple protocols. The connectors are deployed inside the ESP connect cluster and are managed by the ESP team.

The second type of input, Producer Push EDGE, is for ingesting data from endpoint devices, and this requires a different architecture. A good analogy is the bees and hive analogy. The bees are responsible for doing their work and for knowing how to come back to the hive. Similarly, the ESP is built the same way to address these use cases. The devices are expected to be responsible for doing their work and sending the data to ESP. This allows the ESP to be flexible and scalable. Two different implementations for Producer Push EDGE are under consideration. One is based on FluentD, and the other is based on a client server publish/subscribe messaging transport protocol called MQTT.

The third input type uses REST, a widely adopted standard that can be used easily by any internal or external system.

4.3 Outputs

Similarly to how the inputs were built, different output types were built with the same principles in mind. The team strived to promote a low-coding approach whenever possible. The first type of output Consumer Push uses Kafka Sink Connectors and technically they are very similar to Kafka Source Connectors, but they are configured differently.

The second type of output makes data accessible through REST API's that were written to address specific use cases, so they are less generic at this point. They offer an experience similar to traditional REST API's that allow users to query data using different parameters.

The third type exposes data through a REST API as a stream. Third parties can subscribe to various data sets and automatically get new data as is being ingested into ESP.

4.4 Processing

KSQL allows the team to write business logic with very little coding. KSQL can be extended via User Defined Functions. KSQL is not a programming language, but the goal is to implement a reasonable number of use cases quickly using this approach. A few use cases were implemented using KSQL, but it is also fair to say that some limitations were encountered. Some of these limitations were addressed by the vendor, while others were addressed by the ESP team by building tools that simplified the development experience and maintained full automation required in a DevOps environment.

KSQL is built on top of Kafka Streams which in turn is a Java Library for building streaming applications with Kafka. If the business problem requires custom coding, Kafka Streams can be used. The team also has the option of using other programming languages for Kafka-based applications. The last two options are deployed as microservices in the ESP.

4.5 Visualizations

For visualizations the same principles as described above are used, utilizing a no-code approach whenever possible while having enough flexibility for meeting very specific needs.

For generic data visualizations and simple geo-spatial visualizations needs, ESP is going to support Kibana and Grafana. These tools are being used internally and for some POC's and the intention is to add tooling support to simplify the developer experience. For advanced geo spatial analytics, the intention is to support KeplerGL, an open-source tool from Uber. Applications that require custom UI can do so using JavaScript Libraries like Angular. These applications will be deployed as microservices in the ESP.

4.6 Persistence

It is expected that a reasonable number of use cases will involve processing real-time data. These applications will use components from the Streaming Infrastructure layer like Schema Registry, KSQL Clusters or Connect Clusters. It is also understood that all applications need streaming, or even if they do real-time processing, that they have persistence needs that cannot be addressed by Kafka. This is the reason for introducing a few persistence technologies that are very versatile and help build general purpose applications faster. Elastic Search has very powerful support for searching any type of data including geospatial data. This is especially relevant to ODOT. Elastic Search is being used for the current use cases, but the team is also working on POC’s like log collection from ODOT applications that are running outside ESP.

MongoDB is a type of database that makes coding faster compared to using a relational database. It is encouraging to see that vendors that were awarded initial Statements of Work (SoW) for ESP work expressed interest in using Mongo and included Mongo as part of their solution.

Other Persistence options will be introduced over time keeping in mind the following: 1. They need to be versatile so they can be used for multiple use cases. 2.They need to be proven e to avoid unnecessary risks. 3.They need to be built on modern technologies, so they are easier to operate and maintain.

4.7 Operations Support

ESP is built with a complex set of technologies, and it is important that the team is able to maintain and evolve the platform. In order to do that, the ability to align operations support is very important. This is the reason why the Observability layer was built in our stack. This allows insight to be gained into how applications are performing and use a data-driven approach for deciding how to operate the platform efficiently.

5 Data Quality Considerations

The following table is an excerpt from the draft ASTM Surveillance Supplemental Data Service Provider (SDSP) specification. These additional performance parameters should be considered when developing the end state requirements and when the standard is in an approved state.

Table 16 Requirements for Information Quality Surveillance Sources

Parameter	Requirement	Notes
Update Rate	≤ 4 Seconds	This interval is considered one update cycle. If the sensor measurement rate is less frequent than the specified update rate, extrapolation may be used to achieve the specified update rate. A track is considered coasted (and **shall** be tagged as such) if none of the sensors detected the track in their respective last update cycles
Coverage Region Batching	< 200 ms	
Heartbeat Rate	≤ 2x Update Rate	(e.g., for an Update rate of 4 seconds, the Heartbeat rate **shall** not be less frequent than 8 seconds).
Probability of Update[2]	> 97% for each 24-hour operational period	This is to ensure that tracks are updated in a statistically consistent way and that misses (no update) are not concentrated in time and on any particular track.
Long Gaps	< 0.5% for each 24-hour period	Long gaps are larger than (3 x measurement) interval + 10%
Measurement Interval	5 Seconds	
Horizontal Position Accuracy	≤ 300m global, ≤ 330m per track	
Concentrated Position Error	≤ 0.03%	on a single flight

Vertical Accuracy (PA)	≤ 200 ft for 99.9% stable, 300 ft for 98.5% ascend/descend	if reporting altitude
Coasted Track Termination	≤ 10 Seconds The termination of a track **shall** be explicitly stated.	A coasted track **shall** be terminated after no more than 16 seconds. The number of track updates for which a coasted track exists **shall** be specified in the SLA and may vary depending on aircraft Classification. The SDSP **shall** identify coasted tracks in the track message
Track Extrapolation	Extrapolate to Current Time (if required)	If the SDSP provides extrapolation as a service, they **shall** offer all track data within a given coverage region at the current time, or with a difference between timestamps of no more than 200ms. The end user **shall** have access to the non-extrapolated track feed should their use case require it. The age of the last measured information, compared to the timestamp of the message **shall** be provided.
Latency	The SDSP **shall** define its nominal and maximum latencies in milliseconds from the time of applicability to the SDSP's dissemination endpoint. The SDSP **shall** indicate nominal latency in its heartbeat messages, including alerts if latencies exceed those guaranteed by SLA.	Expressed in the time delay from the time of applicability to the sensor; from the sensor to the surveillance SDSP; in the internal processing time of the SDSP itself; and from the SDSP to the user (including network latencies).
Track Capacity	For Surveillance SDSP's where track capacity is a limiting operational factor, the SDSP **shall** report the max number of tracks the system is capable of handling.	When information about the type of object being tracked is provided by the sensor, that information **shall** be provided by the SDSP to its users. The SDSP may report false tracks delineated by classification in addition to the requirements outlined in 8.20.
False Tracks	If the SDSP is capable of identifying false tracks for a specific coverage region, they **shall** report the false track at the time of discovery. The SDSP **shall** report false track statistics for a given coverage	(e.g., percentage of total encounters or as the number of alerts per hour) alongside the date on which the statistic was gathered.

	region that persist for more than three update cycles	False tracks are non-real tracks within a declaration volume. False tracks do not correspond to an aircraft.
Declaration Volume	For the purposes of setting limits on instances of dropped tracks and false tracks, the SDSP **shall** indicate geographic areas that constitute a single declaration volume, regardless of the number and types of sensors that lie within that region. A single declaration volume should not be smaller than the declaration volume of a single sensor. For a network of sensors, the declaration volume **shall** not be smaller than the contiguous declaration volume of the network	The SDSP may change, add, remove, enlarge or shrink its coverage regions, but **shall** provide notification of those changes to all affected parties. Adherence to chart revision cycles or similar intervals is encouraged, but ultimately is at the discretion of the competent authority.

6 References

[12] "Minimum Operational Performance Standards for Airborne Collision Avoidance System sXu (ACAS sXu)", RTCA DO-396, December 15,2022.

[13] "Minimum Operational Performance Standards (MOPS) for Aircraft Surveillance Applications (ASA) Systems", RTCA DO-317B, June 14, 2014.

[14] "Surveillance SDSP Standard", under ASTM consideration, Working group WK69690.

[15] "GeoJSON Format", see https://datatracker.ietf.org/doc/html/rfc7946.

An electric air taxi under development by U.S. startup Joby Aviation | TOYOTA MOTOR CORP. / VIA KYODO

Open Framework Standards for Combined Aircraft Sensor Network for the State of Ohio to Detect and Track Lower Altitude Aircraft: Legal Framework Analysis

Bob Tanner and Jason Lorenzon

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The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Ohio Department of Transportation or the Federal Aviation Administration. This report does not constitute legal advice. We acknowledge and express our gratitude for the input of the many people directly involved and consulted during the performance of this effort. We would also like to thank the members of the Aviation Law Committee of the Ohio State Bar Association and the Aviation Law Committee of the Florida Bar Association for their input and feedback during this project.

Section I: Project Description/Objective UAS LAASS Considerations

1 The Purpose of this Project

This project proposes open framework standards for a combined aircraft sensor network for the state of Ohio to detect and track lower altitude aircraft. The goal of this project is to develop a performance requirement of a network and its potential integration into the local and National Airspace Systems (NAS). These requirements are the product of a robust systems engineering approach conducted by industry experts and have been informed by extensive stakeholder outreach and feedback. If adopted, these standards will support the open interfaces crucial to a reliable and robust LAASS in Ohio. The number of UAS that will operate at lower altitudes will be in uncontrolled airspace where traditionally the Federal Aviation Administration (FAA) does not provide air traffic services. The Low-Altitude Airspace Surveillance Service (LAASS) will assist in mitigating a range of factors UAS may face, such as conflict between cooperative aircraft and uncooperative aircraft, uncrewed and crewed aircraft, and traffic conflicts within these lower altitudes. Ohio has recognized the issue of the increased number of UAS operations and invested in programs such as their Unmanned Traffic Management (UTM) project and SkyVision that collect and leverage sensor data from disparate UAS to provide safety benefits and other services to all the participants in the local UAS ecosystem. The LAASS will enable seamless integration of such systems (and future systems) to fully leverage all available surveillance data across the state.

What follows is a summary of the policy considerations to enable development and implementation of a UAS LAASS System in Ohio. While more exhaustive legal research should be conducted by ODOT, there are guiding principles here to help facilitate further analysis and research to guide these efforts. First, it is believed that ODOT may build and operate the LAASS under existing laws, although careful consideration must be given to the ongoing industry dialogue regarding airspace jurisdiction, as between the State and the FAA. ODOT may also fund the LAASS through its normal budgetary activity without any further enabling legislation, given the nature of this system and its parallels to traditional surface transportation infrastructure. In addition, once the LAASS system is implemented and is being more widely used, ODOT may wish to evaluate a Public Private Partnership (PPP), to help sustain longer term investment and oversight. However, to receive revenue from the public for the use, maintenance, and improvement of the LAASS the fundamental policy consideration is whether this system constitutes transportation infrastructure. The position taken in this paper is that the system that facilitates the movement of goods and people should be considered aerial or digital infrastructure. As such, it should be eligible for funding and oversight like existing surface transportation infrastructure. Please note that this is a general policy paper concerning the limited focus on the implementation of the LAASS.

1.1 Developing New Infrastructure: Building the LAASS under Existing Laws

ODOT can implement the LAASS under existing Ohio laws with careful consideration of federal laws. In developing policy for the LAASS, narrow concepts should be considered such as the *LAASS, as transportation infrastructure, will be limited to: monitoring, the surveillance of, providing of, collecting of, sharing of, disseminating of information and data as it relates to operators using the LAASS in UAS operations within the state of Ohio.*

The LAASS should be considered as part of the transportation infrastructure and consists of sensors, data collection and traffic avoidance and mitigation and a virtual domain marking the way for the ultimate vision of highways in the sky. The LAASS will facilitate the transport of persons and property. O.R.C.

§5531.09 (A)(1) is one statutory example that demonstrates that ODOT has the ability to appropriate funds for the LAASS. O.R.C. §5531.09 (A)(1) states:

> "Qualified project" means ***any public or private transportation project*** as determined by the director of transportation, including, without limitation, planning, environmental impact studies, engineering, construction, reconstruction, resurfacing, restoring, rehabilitation, or replacement of public or private transportation facilities within the state, studying the feasibility thereof, and the acquisition of real or personal property or interests therein; any highway, public transit, aviation, rail, or other transportation project eligible for financing or aid under any federal or state program; and any project involving the maintaining, repairing, improving, or construction of any public or private highway, road, street, parkway, public transit, ***aviation***, or rail project, and any related rights-of-way, bridges, tunnels, railroad-highway crossings, drainage structures, signs, guardrails, or protective structures.

The broad language of this statute enables ODOT the ability to deem the LAASS a "qualified project" by the director of transportation for a public or private transportation facility within the state on any aviation project eligible for financing or aid under any federal or state program. As a qualified project, the LAASS will be able to be funded through O.R.C.§5531.09 since the LAASS is a transportation project involving aviation. Furthermore, since the LAASS will be part of an Advance Air Mobility (AAM)[3] System that will bring economic growth to underserved areas in both rural and urban areas of Ohio, additional funding can be sought from the general assembly for the contribution of the economic revitalization and improving the economic welfare of all the people of the state. O.R.C. § 5531.09.

O.R.C. §5531.10 permits the state to issue an obligation for state infrastructure projects. O.R.C. §5531.10 (A)(8) states:

> "State infrastructure project" means any public transportation project undertaken by the state, including, but not limited to, all components of any such project, as described in division (A)(1) of section 5531.09 of the Revised Code.

Since the LAASS is a "State Infrastructure Project" and so long as the LAASS is determined to be a "qualified project", the LAASS should be able to be funded through the Ohio General Fund.

Despite the statutory authority to fund the LAASS, ODOT and the legislature must also consider the role of the Federal Government, especially the FAA and its role with Air Traffic Control and UTM. Any legislation developed at the state level must work to enhance, support, harmonize and supplement the areas of aviation the Federal Government already regulates. Largely, due to the National Airspace System (NAS), aviation issues are generally controlled by the Federal Aviation Administration (FAA). For that reason, the adoption of the LAASS, which is focused on the uncontrolled airspace that the FAA is not providing services, the legislation and operation of the LAASS must not interfere but complement, enhance, and be harmonized with the FAA's control in, and services provided within, the National Airspace System (NAS). Currently, the FAA does not provide airspace surveillance or air traffic services

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at these low-level altitudes, and yet this will likely be a requirement of the FAA for the LAASS to monitor the operations of Uncrewed Aircraft Vehicles (UAV) operating at low levels.

The LAASS will involve issues of the cyber domain that will observe and monitor uncrewed and crewed aircraft that are flying over the physical airspace of Ohio. The LAASS will collect data of UAV and crewed aircraft physically operating above the state of Ohio and provide real time and store data of cooperative and uncooperative aircraft operations. To potentially avoid a perceived violation of privacy, protection and safeguards will need to be created to protect the transfer, use, and storage of data gained from this system. The implementation of the LAASS should require a secure network or system that is adequately protected from cyberattacks, hacking and other security issues.

Sensor data is the data that is collected by the LAASS. Sensor data, potentially collected by proprietary entities, must also be given further consideration. It should be addressed under a contractual agreement between ODOT and the private entity, and the impact of the applicable federal laws and regulations. As such, any data collected by the government or entity acting on the government's behalf is in the public domain. In other words, ODOT policy on the LAASS and PPP should contain a section that defines sensor data as information that is collected by the LAASS and as such is in the public domain. This is to potentially avoid proprietary issues that might arise from a PPP with a private entity acting on behalf of the State of Ohio or collecting or using sensor data that is in the public domain.

These protections, if adequately addressed, will increase the general public's confidence in the LAASS and UAS operations. It should be recognized that any data obtained in a LAASS could potentially be used in a criminal manner, or invade a person' privacy, so this information must be properly obtained, used only for legal purposes and be protected from unauthorized users. Any implementation of the LAASS must consider the protections of Privacy under the U.S. Constitution specifically, the Fourth Amendment.

Once ODOT has preliminarily considered cyber issues, and data collection through sensor collection, ODOT must consider funding of the LAASS. ODOT could propose to fund the development and implementation of the LAASS using its normal budgetary activity through the Appropriations process. Specific process details regarding the use of motor vehicle fuel taxes and/or registration fees are details that are generally developed through Department and legislative budgetary processes. While registration of users of the LAASS is a specific funding mechanism that ODOT may consider for revenue generation, determining the appropriate fee structure along with the administrative details for the assessment and collection of such fees is a separate matter. Once ODOT determines the requirements of registration for users of the LAASS, ODOT must consider federal law and explicitly state that the registration is for the use of the LAASS and not for federal licensure, federal certification, or federal registration. Enabling the use of UAS registration fees for this purpose is a matter the legislature would address legislatively under Chapter 4503 of the Ohio Revised Code. These statutory laws that reflect Ohio's requirement of registration and licensure of motor vehicles, Aeronautics and Watercraft could be amended to add the specific licensing and use of the LAASS.

To avoid a conflict with federal law and to determine the distinction between registration as a user for the LAASS and registration for a vehicle under the FAA, consideration must be given to the specific federal regulations. Pursuant to 14 C.F.R. §§ 45, 47, 48, 49, most UAS and aircraft must be registered with the FAA. To avoid a conflict between federal and state law, a careful clarification must be addressed in any Ohio statute that is developed by the Ohio legislature. Incorporated into several ordinances as a noteworthy example, there exists explicit language affirming that the purpose of these laws is not to supersede FAA Rules and regulations, but rather to harmonize and coexist with the established Federal rules and regulations. For a concrete illustration, please refer to Cleveland, Ohio Ordinance §490.02. This Cleveland ordinance states …this law is not intended to preempt FAA Rules and regulations, but to operate in conjunction with those Federal rules and regulations….

A requirement for a UAS to be registered for use in the LAASS is to require a user to provide the certificate of registration with the FAA. If an approach is used in distinguishing and requiring the Federal UAS Registration, the LAASS user fee is separate and not intended to preempt the FAA Registration requirements. See 14 C.F.R. §§ 45, 47,48, 49. In many instances of the Ohio Revised Code (O.R.C.), registration under state law and federal law do successfully co-exist. See O.R.C. §§ 4561.17, 4561.18. Likewise, in developing policy these issues of federal and state law should be considered for LAASS registration of users.

1.2 **Funding the LAASS**

Currently the LAASS could be funded by ODOT as mentioned above through the normal budgetary activity. And while the money can be requested to be added to ODOT's budget from the General Revenue Fund, there is no guarantee that this request will be added, and LAASS will be funded. However, ODOT should consider generating revenue from the users of the LAASS. ODOT may consider developing a subscription service for the users of the LAASS. Since the LAASS is a component of transportation infrastructure, fees can be potentially collected by ODOT since ODOT will be responsible for implementing the system. After the LAASS is established and produces revenue, the benefit of entering into a private public partnership could be considered. The state could facilitate the development of a public private partnership as a future funding option.

The establishment of a transportation infrastructure is fundamentally a government function. Throughout the history of the United States, Federal and state governments have been instrumental in providing the necessary funding for transportation infrastructure. Given the history of the development of the American transportation system, the railway, the public highway system, the National Airspace System (NAS) and the airports have all served as examples that have their economic foundations rooted in government funding. Airports also serve as examples of publicly financed infrastructure, as such the LAASS through careful legislative drafting, the LAASS can be publicly funded since it is part of the infrastructure. Since in Ohio, publicly owned airports cannot be funded with the same funds used for highways and bridges, this must be addressed in any new LAASS legislation.

As publicly built and maintained infrastructure, airports were originally conceived as public enterprises that worked with cities, states, and even the Federal Government to provide a place for private airlines to do business, i.e., transport people. Likewise, the LAASS is an integral part of the transportation infrastructure and Ohio has an opportunity to be one of the first states to officially consider AAM related infrastructure analogous to traditional surface transportation infrastructure.

The role of the government in developing transportation infrastructure and the LAASS is crucial for fostering economic growth, ensuring public safety, and facilitating the movement of people and goods efficiently. Ohio must work at various levels, including nationally, regionally, and locally to address the planning, funding, and oversight and the maintenance of the LAASS infrastructure. The following are some key aspects of the process necessary to incorporate this new aerial technology within the definition of transportation infrastructure:

1. Planning and Policy: Governments are responsible for formulating transportation policies and plans that align with the broader economic, social, and environmental goals of the country or region. They assess current and future transportation needs, conduct feasibility studies, and develop long-term strategies for infrastructure development. The existing work that ODOT has done via the Crown/NEXA Capital Partners study: Infrastructure to Support Advanced Autonomous Aircraft Technologies in Ohio (2021), a study done on the economic viability of AAM for ODOT, provides an excellent foundation for the development of State level policy.
2. Funding: Developing transportation infrastructure often requires substantial financial resources, which are typically provided by the government. Governments allocate funds from public budgets, secure funding from bonds, or engage in public-private partnerships to finance infrastructure projects. They also explore alternative funding mechanisms such as tolls, fuel taxes, and other user fees and can also pursue various federal funding options, which currently exists as part of the Federal Infrastructure Bill. The creation of a subscription service for the users of the LAASS is one of the more feasible and sustainable ways of recouping Ohio's cost for developing this new infrastructure system; however, the system will need to be developed and operated for some period of time before the user community sees value and is willing to pay for the service.
3. Infrastructure Investment: Governments invest in the creation, development, construction, expansion, and maintenance of transportation infrastructure. This includes building and maintaining roads, highways, railways, airports, seaports, bridges, tunnels, and public transportation systems like buses, trains, and subways. They work closely with engineers, urban planners, and other experts to ensure infrastructure projects meet safety and quality standards. The LAASS should be considered a new component of the transportation infrastructure. While many within the AAM industry understand how digital services and communications critical airspace infrastructure is, it may benefit ODOT to have the legislature evaluate how or whether there is benefit in providing more definition within the existing O.R.C., to better explain how this new infrastructure can qualify for state funding, the same way current surface transportation infrastructure is funded.
4. Public-Private Partnerships (PPPs): Governments often collaborate with private sector entities through PPPs to develop transportation infrastructure. These partnerships allow governments to leverage private sector expertise, innovation, and resources while sharing risks and responsibilities. PPPs can bring efficiency to infrastructure development, promote innovation, and attract private investments.

In summary, Ohio's role in developing the LAASS infrastructure encompasses planning, funding, regulation, investment, maintenance, and ensuring the safety and accessibility of transportation systems. By undertaking these responsibilities, governments aim to foster economic development, enhance mobility, and improve the overall quality of life for citizens. The development of a subscription service for users of the LAASS is one way that the State could potentially recoup some of the initial costs of the development of the LAASS but there would certainly be lag in terms of revenue, based on how long it takes the User community to adopt and utilize the LAASS services.

1.3 Developing a Private-Public Partnership Option

Once the LAASS is established, Ohio may want to consider other funding opportunities to expand, support or maintain the LAASS. One of the tools to consider expanding funding opportunities through the use of Private-Public Partnerships (PPP). Another benefit of ensuring public support and benefit of the LAASS is to encourage the use of PPP. Conceptually, PPP is employed to encourage entrepreneurial growth and investment with private sector industry in the development, creation, and implementation of the LAASS.

The O.R.C. grants the Ohio Department of Transportation authority to enter into private public partnerships (PPP). O.R.C. §§ 5507.71, 5501.72. The Ohio public private partnership statute gives authority to the Ohio Department of Transportation (ODOT) to undertake a public private initiative with a private entity to develop, finance, maintain or operate transportation facilities O.R.C. §§ 5501.71 and 5501.72).

Beyond traditional infrastructure funding, from federal and state revenues, PPP is a model that can be followed for a method of delivery of services, investment of capital and assumption of risk, especially if significant capital is needed. Since the LAASS is a project that develops a virtual infrastructure, several factors to attract private investment will need to be considered. For example, a great deal of investment with little financial return may be the result at the beginning of the implementation of the LAASS. One possibility is that consideration could be given to the development rights in exchange for infrastructure investment in potential future projects that are the direct result of the economic impact of the LAASS. The scope of this section is limited to those private entities working in partnership to provide the subscription service. The considerations from the government position are that Ohio is governed by laws which require transparency and fundamental fairness with private actors, normally meaning a fair competitive request for proposals or a competitive bidding process. One of the policy goals would be to have private entities that deploy the sensors receive a share of the revenue of the fees collected from users.

PPPs allow large-scale government projects, such as roads, bridges, or hospitals, to be completed with private funding. These partnerships work well when private sector technology and innovation combine with public sector incentives to complete work on time and within budget. Risks for private enterprises include cost overruns, technical defects, and an inability to meet quality standards, while for public partners, agreed-upon usage fees may not be supported by demand—for example, for a toll road or a bridge. Despite their advantages, PPPs are often criticized for blurring the lines between legitimate public purposes and private for-profit activity, and for perceived exploitation of the public due to self-dealing and profit seeking that may occur.

By examining the provisions in the O.R.C., a state transportation project could be developed in Ohio to enable PPP investment in LAASS infrastructure. Specifically, under this statute authority is provided to ODOT to undertake a PPP initiative to develop, finance, maintain or operate transportation facilities. The LAASS system should be considered as meeting the definition of PPP investment.

PPPs can take several forms. The PPP can be privately funded, and government run; privately and government funded and privately run, or privately and government funded and privately and government run or any combination thereof. In this project, the private entities could deploy sensors and may receive a share of the revenue from the user fee the state collects.

This funding mechanism would require additional study and legal analysis but one or more of these categories should present Ohio with a unique model for joint investment into the necessary UAS infrastructure that all states and localities are going to need to enable this new mode of transportation.

In general, the statutory authority does permit PPPs so long as the statutory requirements are followed, a bidding processes that is open to stakeholders is competitive, and the private actor assumes both the risk and reward of the specific private investment. In any PPP agreement, a contract should be carefully drafted to meet the goals of the public and private partnership as well as further sources of funding such as insurance if a risk of loss results in loss or damage to persons or property.

2 Conclusions

ODOT has the authority under existing laws to develop and implement the LAASS with potential funding through the Ohio General Fund so long as the specific statutory requirements are met, as discussed above. O.R.C. §5531.09 & 5531.10. To secure additional funding beyond its normal budgetary process, ODOT can consider a registration/subscription fee arrangement. However, if ODOT intends to generate revenue from LAASS users through registration and subscription fees, it would require a specific enabling statute and regulatory framework for collecting subscription fees for the LAASS. Additionally, careful attention must be given to potential conflicts with federal regulations regarding the registration of LAASS users compared to the registration of Unmanned Aircraft Systems (UAS) with the Federal Aviation Administration (FAA).

To address this, any LAASS-related legislation should include provisions stipulating that prospective LAASS users must first comply with federal regulations. Specifically, FAA regulations mandate the registration of all UAS weighing between 0.55 pounds and 55 pounds. Furthermore, operating a UAS requires obtaining an FAA sUAS Part 107 Certificate, unless it is solely used for recreational and hobby purposes. Consequently, LAASS legislation should require full compliance with federal requirements as a prerequisite for LAASS registration. It is essential that any state LAASS legislation includes references to these federal requirements to ensure alignment and adherence to both state and federal laws.

Lastly, to develop further PPP relationships after the Government is satisfied with the development and implementation of the LAASS, statutory provisions for Public Private Partnerships are in existence in the O.R.C.These provisions can be used effectively to include further investment, development, maintenance, and expansion of the LAASS.

Ohio could become a leading authority on how to enable policy influenced legislation that invites commercial market growth, but also protects rights and duties of its citizenry. Through the course of aviation history, disruptive technology has been the forerunner to the advent of regulations. In addition, Ohio has been the global leader for aviation innovation. The goal of this section is to provide the legislature with information to help formulate the policy foundation of our highways in the sky. Ohio can be the first entity to place an LAASS that is safe, active, and successful into the stream of commerce, and as usual other states will follow. The FAA will listen and craft Federal Regulations to embrace Ohio's innovation.

3 Summary of Next Steps

Assist ODOT with a Policy roadmap	**1) ODOT can use existing laws to build and operate the LAASS. ODOT can fund the LAASS by using the normal budgetary administrative procedure to seek funding to support LAASS development, and implementation;** **2) If ODOT wishes to receive revenue from the users of the LAASS, ODOT can develop a policy to institute a subscription fee to recoup some of the cost of government investment; and** **3) If ODOT wishes to expand the LAASS it can utilize the tools of the different forms of PPP to foster further capital investment.**
Set up a network of community engagement workshops to help educate the general public and stakeholders	**Based upon the information contained in this document, a further next step is for ODOT to develop a continuous set of community engagement workshops and a public campaign about the future technological advancements that will help improve the transportation systems and lives of all Ohioans. The goal should be to gain public support for UAS Operations in Ohio.**
Engage in helping FAA and Federal Government see that Ohio has policy leaders.	**Based upon industry, academia, and state and local governments, Ohio is uniquely positioned to develop a LAASS that can be the model for the rest of the nation. Ohio has a strong balance of technological development, legal and regulatory expertise, and an existing base structure for continued development of the transportation infrastructure. A close communication infrastructure should be established with the local FAA Flight Standards district office and the UAS Integration Office under the FAA's Office of Safety in Washington.**

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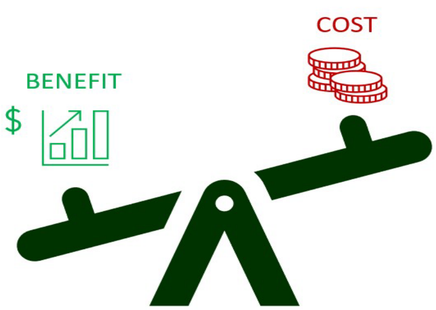
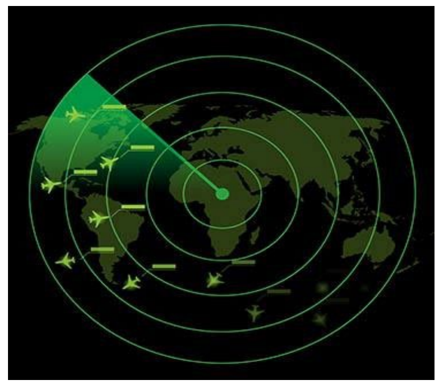
11 Appendix D - Cost-Benefit Analysis Report

Open Framework Standards for Combined Aircraft Sensor Network for the State of Ohio to Detect and Track Lower Altitude

Aircraft: Cost-Benefit Analysis





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The contents do not necessarily reflect the official views or policies of the Ohio Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

We acknowledge and express our gratitude for the input of the many people directly involved and consulted during the performance of this effort. Special gratitude for guidance on this project goes to the Technical Advisory Committee members, Fred Judson and Richard Fox, and Sean Calhoun from CAL Analytics, and Rubén Del Rosario from Crown Consulting. We also acknowledge the use of the findings from the AAM aircraft surveillance source study, system requirements study and legal and policy analysis study conducted as part of the project.

1 Introduction

Advanced Air Mobility (AAM) will enable emerging aircraft, such as small uncrewed aircraft system (sUAS) and electric vertical takeoff and landing aircraft (eVTOL), to operate in lower altitude airspace for passenger and cargo transportation and other use cases in the near future. To ensure safe and efficient AAM operations, surveillance sensors are needed to detect and track AAM traffic. Additionally, a LAASS is needed to function as a cloud-based surveillance data collection, monitoring, and distribution center, where AAM operators, AAM service suppliers, law enforcement agencies, correctional facilities, and municipalities can subscribe to receive relevant AAM traffic data to plan their operations.

An overview of the cost optimized AAM surveillance network and LAASS framework and its associated cost and benefit factors are illustrated in Figure 1. Based on a survey of the present AAM sensor market, we selected six different sensor types: radar, radio frequency sensor, ADS-B, remote ID, optical camera, and acoustic sensor. The surveillance and telemetry data associated with sUAS, eVTOL, and general aviation traffic — such as position, velocity, flight intent, remote identification (RID) — can be captured and generated by the optimized surveillance network, allowing the aircraft movement in the airspace to be tracked. This surveillance data can then be ingested into LAASS, which will provide the subscribers of LAASS with information about scheduled and real time AAM operations and relevant airspace activities so that they may plan for their flight operations accordingly. The subscribers of LAASS will potentially include AAM operators engaged in different AAM use cases such as passenger and cargo transportation, bridge inspections, medical and other delivery, airspace service providers, law enforcement agencies, correctional facilities, and municipalities.

As for any other major infrastructure project, to justify the investment in AAM surveillance network and LAASS, a rigorous cost-benefit analysis is needed. To address this need for the state of Ohio, a cost-benefit analysis is performed in this report for the state of Ohio by analyzing the associated cost and benefit factors of AAM surveillance network and LAASS for the next 10 years (2024-2033). The three major cost factors of AAM surveillance network and LAASS considered are: 1) surveillance sensor cost, the cost to purchase the sensors needed in the AAM operating regions in Ohio; 2) cloud computing cost to process and store the surveillance data for the subscribers; and 3) cost due to sharing of revenue in public-private partnership (PPP). To evaluate the surveillance sensor cost, a Surveillance for AAM Network Design (SAND) optimization model was developed, which can determine the optimal number and location of the sensors needed to build the AAM surveillance network in Ohio such that full coverage is provided in the desired region of operation and the total sensor cost is minimized. In determining the optimal sensor placement solution, the model considers the range of various sensor types within the operating region. The revenue generated from the monthly subscription fees charged to subscribers for access to LAASS data and functionalities was considered as the main benefit factor in this analysis. The cost-benefit analysis can be used to estimate the *break-even point (BEP)* for the different sensor types, the time to reach break-even in terms of the net present value of the return generated in the AAM operating regions.

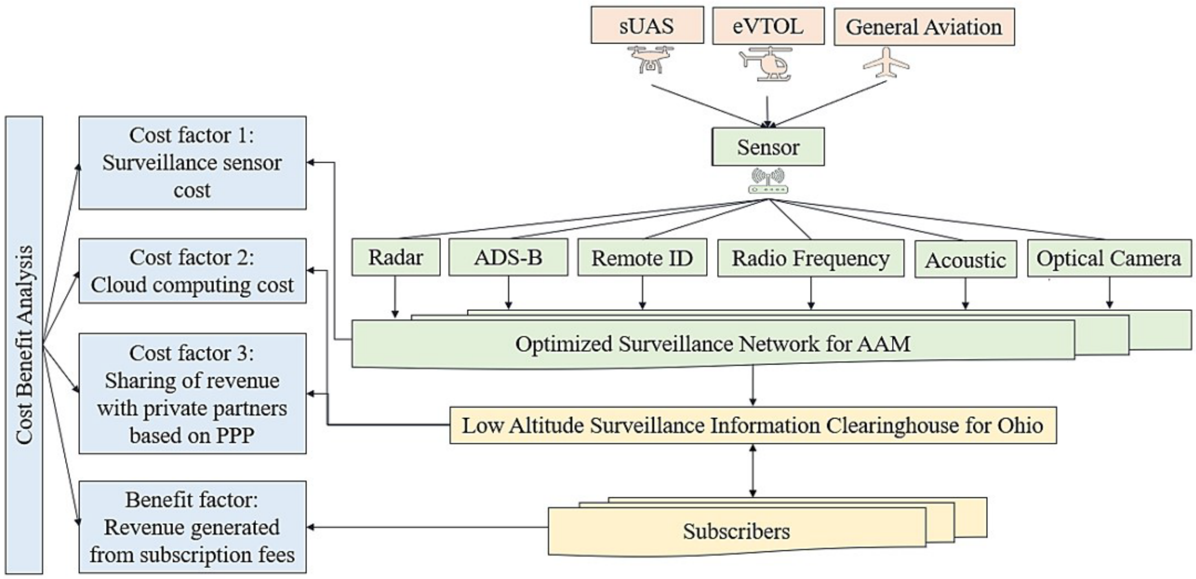


Fig. 1 Overview of the AAM surveillance network and LAASS and associated cost and benefit factors

The insights generated from this analysis can potentially aid government and private investors in making decisions to invest in AAM surveillance infrastructure, and policymakers in formulating relevant policies and regulations.

The remainder of this report is structured as follows. In Section II, the methodology used to carry out the cost benefit analysis is discussed. The potential cost and benefit factors are presented in Section III. After that, Section IV presents the results of cost-benefit analysis. Lastly, Section V concludes the report with the summary of the findings obtained from the analysis and recommendations for implementation of this surveillance project.

2 Methodology

The cost-benefit analysis was driven by data on AAM traffic projections and cloud computing pricing, as well as findings of other studies related to AAM surveillance network and LAASS conducted as part of this project. An outline of our methodology for the cost-benefit analysis of AAM surveillance network and LAASS is presented in Figure 2. The analysis period was considered to be the next 10 years, from 2024-2033. To undertake the cost-benefit analysis of LAASS for the state of Ohio, we computed the net present value (NPV) of AAM surveillance network and LAASS for the six major cities of Ohio (SMCO): Columbus, Cleveland, Cincinnati, Akron, Toledo, and Dayton. The NPV is a measure of the future return on investment expected from an investment in a project in terms of today's dollars. The NPV metric takes into account the time value of money and future cash flows, which is further discussed in Section III.D. The formation of SMCO was predicated on the finding of significant demand potential for AAM use cases in those cities considering socioeconomic factors, such as population, population density, gross domestic product, median per capita income, cost of living, city total area, cities in motion index, human capital, etc. [25].

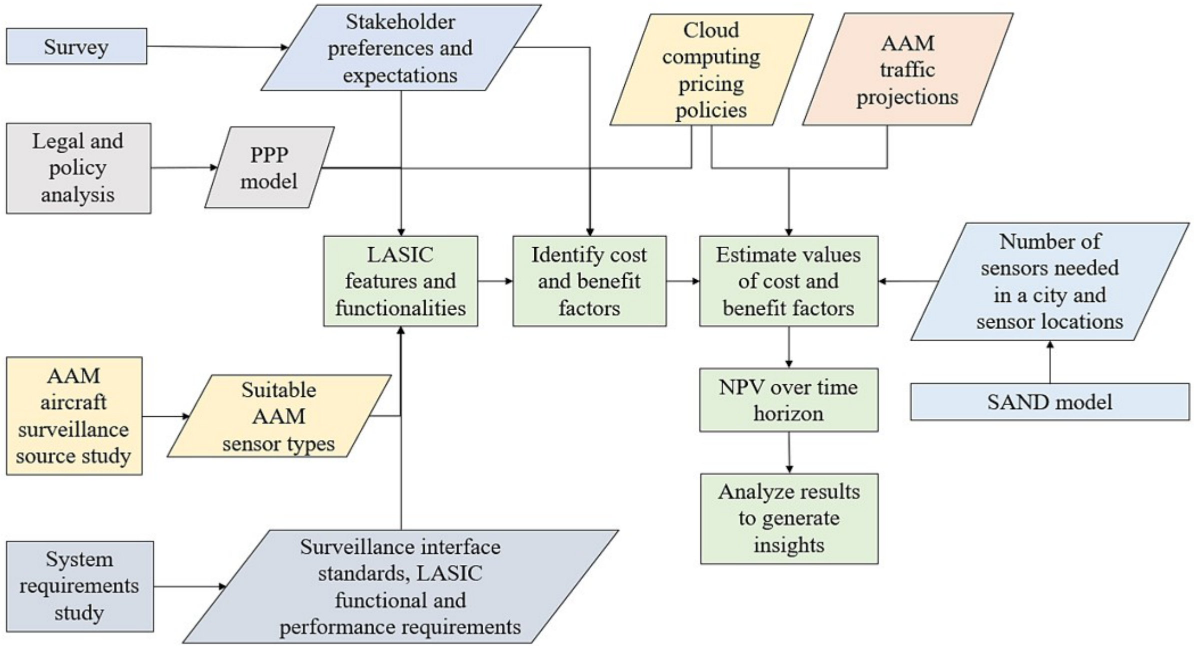


Fig. 2 A flow chart illustrating the steps associated with cost-benefit analysis of LAASS

A survey of AAM stakeholders was first carried out to determine the stakeholder preferences and expectations concerning LAASS services, features, and pricing. The survey responses indicate a strong preference and demand for LAASS functionalities and services, including access to live surveillance feeds, real-time coverage map, and archival data; data analytics and visualization; tactical deconfliction; and querying current and historical UAS positions by UAS ID and location. Also, the survey responses revealed the willingness to pay of potential subscribers of LAASS for the services offered by it. The range of suitable subscription fee of LAASS was set based on these responses. This was used in the computation of benefit factor, the revenue generated from LAASS. It is also evident from the survey responses that private entities are open to considering investing in surveillance equipment for integration with Ohio's LAASS through PPP with an expectation of 10%-20% annual return on investment (ROI). Therefore, a PPP model was considered in the analysis based on the findings of the survey and the LAASS legal and policy analysis study to allow sharing of the AAM surveillance sensor cost and revenue between Ohio and private entities. Although private entities have expressed an initial interest in hopping on the AAM surveillance network and LAASS bandwagon, it is unlikely that they will commit to major investments immediately because of several existing challenges, such as lack of availability of AAM infrastructure, regulatory hurdles, and uncertain demand, which are further discussed in Section III.C.

The findings from several other studies related to AAM surveillance network and LAASS informed the cost-benefit analysis. The surveillance data interface standards, surveillance data types, and LAASS functional and performance requirements obtained from the LAASS system requirements study were used to determine the key features and functionalities of LAASS. These features and functionalities were used to identify and determine the cloud computing cost associated with surveillance data storage and processing, as detailed in Section III.B. The surveillance network design and the sensor cost depends on the sensor types and models considered. The sensor types and models identified to be suitable for AAM traffic surveillance in the AAM aircraft surveillance source study was considered in the analysis. The sensor types are: radar, radio frequency sensor, ADS-B, remote ID, optical camera, and acoustic sensor. The performance characteristics and costs of these sensors were collected from the corresponding sensor vendors.

Surveillance data generated by sensors need to be safely processed and preserved either in cloud or locally owned servers. Among the two choices, cloud computing servers are better because local servers suffer from several drawbacks. The most significant disadvantages of local servers are the time and effort required to set up and maintain them. They also require a lot of space and expensive hardware. On the other hand, cloud computing servers can be a cost-effective solution for businesses, as they eliminate the need to invest in expensive hardware and infrastructure. Instead, businesses pay only for the resources they use in the cloud. Cloud computing servers provide a higher level of security compared to local servers, since cloud computing servers invest heavily in security measures such as firewalls, encryption, and intrusion detection systems to protect their infrastructure and customers' data from cyber threats. Additionally, cloud computing servers have dedicated security teams that constantly monitor and update their systems to stay ahead of potential vulnerabilities. In contrast, local servers are often managed by the small information technology teams or individual users who may not have the expertise or resources to implement and maintain robust security measures. Cloud computing servers can also be scaled up or down depending on the needs of the business, allowing for easy adjustment of computing resources such as storage and processing power. Conversely, local servers have a fixed number of resources and require additional hardware investments to accommodate additional demands. Cloud computing servers can be accessed from anywhere with an internet connection, making it possible for employees to work remotely and collaborate with colleagues in different locations. This is particularly important in today's business environment, where remote work is becoming increasingly common. In contrast, local servers are typically only accessible from the office where they are located. Cloud computing server can play a significant role in enabling intelligent transportation networks by managing traffic flow data [26]. To reduce costs and improve performance and efficiency, a technique for moving air traffic management operations to the cloud computing was developed in [27]. Thus, a cloud-based server is considered to be more suitable to host the surveillance data of LAASS.

To evaluate the cloud computing cost associated with LAASS, it is necessary to determine the amount of surveillance data that would be generated from the surveillance network and its corresponding data storage and computing requirements. This will depend on the projected AAM traffic volumes for the various use cases. The estimated yearly AAM passenger and cargo traffic was obtained from [25]. For other AAM use cases [28], the potential future AAM traffic was estimated through forecasting. Using the AAM traffic projections data and Microsoft Azure cloud computing pricing policies, the cloud computing cost was then estimated.

For evaluating the sensor cost, a location selection problem needs to be solved to find the optimal location and number of sensors needed to be placed in SMCO for AAM traffic surveillance. The SAND optimization model was developed to solve this problem with the goal of minimizing the sensor cost while ensuring complete surveillance coverage is provided in SMCO. After estimating the cost and benefit factors, the NPV of different sensor types were calculated over the analysis period to determine whether an investment in AAM surveillance network and LAASS is financially viable. Then, a sensitivity analysis was performed to evaluate the effect of key parameters — such as subscription fee, number of subscribers, and PPP cost-sharing percentage — on the NPV generated. Lastly, the results were analyzed to generate relevant insights for government and private investors and policymakers.

3 Cost and Benefit Factors

The expected significant cost and benefit factors related to AAM surveillance network and LAASS are presented in this section. The cost factors considered to be significant in this analysis are: 1) surveillance sensor cost, 2) cloud computing cost, and 3) cost due to revenue sharing through PPP. For every sensor type, the capital required for purchasing and installing sensors to build the surveillance network across SMCO is considered to be invested once in the initial year of operation. The cloud computing cost will be incurred every month throughout the period of operation of the network. The revenue generated from subscription fees charged to the potential subscribers of LAASS is considered to be the main benefit factor.

3.1 Surveillance Sensor Cost

Based on the aircraft surveillance source study, six types of sensors were deemed to be suitable for AAM traffic surveillance: radar, radio frequency sensor, ADS-B, remote ID, optical camera, and acoustic sensor. An overview of these aircraft surveillance sensors is provided in this section.

3.1.1 Ground Based Radar

Both cooperative and non-cooperative aircraft can be detected and tracked using ground-based radars. The radar transmits electromagnetic waves signal towards aircraft which bounce off the aircraft and create a detailed image of its size, shape, and location. The radar cross-section (RCS) signature of each aircraft type is distinctive, which leads to varying reflection patterns of radio waves. The radar utilizes these patterns to identify the aircraft type and determine its position, velocity, and travel direction. In this study, the EchoGuard radar is considered. It is a top-tier 4D radar with an easy user interface that is easily adaptable to site and mission requirements for high performance ground-based detect and avoid (see Figure 3a). It tracks crewed and uncrewed aircraft to allow continuous eyes-on-object monitoring, even at high zoom levels. The features of this radar are presented in Table 1.

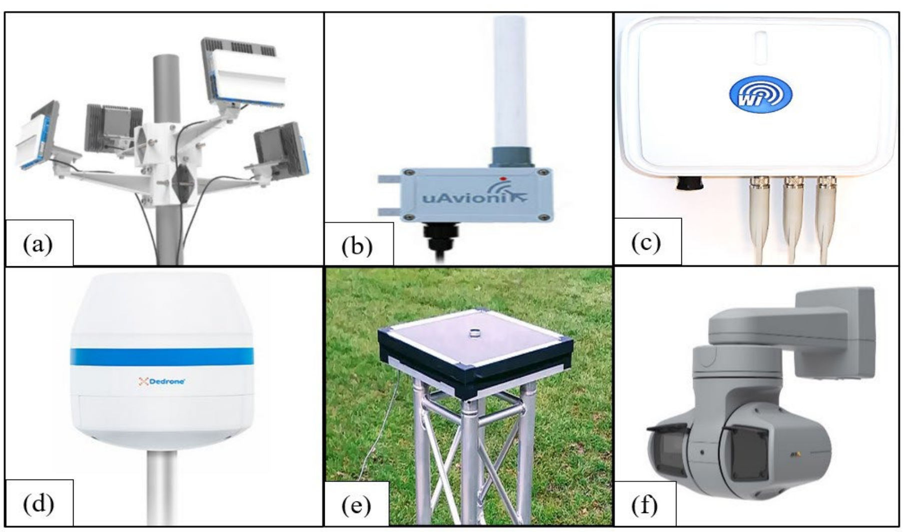


Fig. 3 Surveillance sensors of different types: (a) EchoGuard Radar [16], (b) PingStation ADS-B receiver [17], (c) Drone Scout remote ID receiver [18], (d) Dedrone sensor RF-360 [19], (e) Drone Hound acoustic sensor [20], and (f) Q6225-LE PTZ Network camera [21]

Table 1 Features of EchoGuard Airspace Management Radar [16]

Feature	Description
Range	2.41 km (approx.)
Field of view	120° azimuth x 80° elevation
Angular resolution	2° azimuth x 6° elevation
Frequency	24.45 - 24.65 GHz (multi-channel)
Control I/O	Gigabit ethernet
R/ Vmaps data output	40 MB/s
Power I/O	Snap lock 12 pin connector
Price (per unit)	$35,000 (approx.)

3.1.2 Automatic Dependent Surveillance-Broadcast

Automatic Dependent Surveillance-Broadcast (ADS-B) is a surveillance system that allows an aircraft to periodically broadcast and track its location via satellite navigation. Currently, FAA acknowledges ADS-B as a key enabler for trajectory-based air traffic management in the future. We considered 'pingStation 3' from AVIONIX Software S.L. as an ADS-B frequency ground receiver for our analysis (see Figure 3b). It is a networkable weatherproof 978/1090 MHz ADS-B receiver including GPS and antenna in an IP67 weatherproof enclosure, with power and data provided by a single Power-Over-Ethernet (POE) network cable connected right to LAN [17]. It has applications in airspace surveillance, aircraft detect and avoid (DAA), and airport surface monitoring. Its features are given in Table 2.

Table 2 Features of 'pingStation 3 [17]

Feature	Description
Range	321.87 km (approx.)
Input voltage / power	44-57V / 350mA Power over Ethernet
Size	673.70 x 178.45 x 36 mm
Weight	545 grams
Interface	Asterix CAT033
IP rating	IP67
Price (per unit)	$2250 (approx.)

3.1.3 Remote ID

The ability of sUAS and eVTOL to broadcast identification and location data during its flight is known as *remote identification (remote ID)*. For our study, we considered DroneScout, a (direct/broadcast) remote ID receiver, which receives remote ID signals sent from aircraft (see Figure 3c) [18]. The specifications of DroneScout are given in Table 3.

Table 3 Features of DroneScout [18]

Feature	Description
Range	5.02 km (approx.)
Short-range radio	Bluetooth & WiFi 2.4 GHz, 5.2 GHz, 5.8 GHz
Antennas	5 dBi (N connector, 1x Bluetooth, 2x WiFi tri-band antenna)
Power	PoE (Power over Ethernet) - 802.3af/at
Average current consumption	Less than 5 W
Connectivity	10/100M/1000M Ethernet interface
IP rating	IP67
Operating temperature	-10°C to +40°C
Price (per receiver)	$1100 (approx.)

3.1.4 Radio Frequency Sensor

Like the radar, radio frequency (RF) sensor is also able to accurately detect and categorize aircraft. However, RF sensors can detect and track small drones that may not be detectable by radar, particularly at low altitudes where the radar signal may not reflect off the drone as effectively as it would off a larger aircraft. Also, RF sensors can be more effective than radar in urban or cluttered environments where there may be many buildings, trees, and other obstacles that can reflect or absorb radar signals. RF sensors are less affected by these obstacles because their signals can penetrate walls and other structures, making them useful for monitoring drones in indoor or urban environments. The key advantages of the RF sensor system include its low cost, ease of installation, and simplicity of integration with several other sensors, including cameras and radars. The DedroneSensor RF-360 is considered in this study. It is a passive, network-attached radio sensor for the detection, classification, and localization (geolocation) of aircraft and their remote controls (see Figure 3d) [19]. The DedroneSensor RF-360 specifications are listed in Table 4.

Table 4 Features of Dedrone Sensor RF-360 [19]

Feature	Description
Range	4.99 km (approx.)
Radio Frequency	Omnidirectional, passive detection, and direction finding
L x W x H	12" x 12" x 15.96" (300 mm x 300 mm x 405 mm)
Weight	15.5 lb (7.0 kg)
Ingress protection rating	IP65

Operating temperature	-4 °F to +131 °F (-20 °C to +55 °C)
Power supply cellular operation	AC 100-240V 50/60 Hz max. 1 A
Communication technologies	Cellular communication or Ethernet
Price (per unit)	$35,000 (approx.)

3.1.5 Acoustic

An audio pattern that is transmitted by an aircraft's propeller can be detected by acoustic sensors and used for aircraft positioning and classification. The OptiNav Drone Hound system is an acoustic sensor that can detect, identify, and track sUAS. Unlike other sensors, it does not rely on electromagnetic emissions from the sUAS (see Figure 3e). It uses passive acoustic sensor technology with no RF emissions, where the solid state-sensor is an array module including digital microphones and digital processors [20]. The specifications of OptiNav Drone Hound sensor are given in Table 5.

Table 5 Features of Drone Hound [20]

Feature	Description
Range	0.5 km (approx.)
Coverage	360 degrees in azimuth, 90 degree in in altitude
Software	Windows 8 / Windows 10 compatible
Image resolution	Up to 1080p
Price (per unit)	$9,000 (approx.)

3.1.6 Electro-Optical/Infrared Camera

An Electro-Optical/Infrared (EO/IR) system is a type of electronic equipment that combines electro-optical and infrared sensors to produce accurate optical information of air traffic in the airspace within its coverage range at any time. EO/IR systems can be used to carry out object tracking, assess threats from a certain distance, or monitor other aircraft or ground obstructions that must be avoided. We considered the Q6215-LE PTZ Network Camera from Axis Communications in our analysis (see Figure 3f). The features of this optical camera are provided in Table 6.

3.2 Cloud Computing Cost

Cloud computing is needed to store and process the surveillance data generated by the sensors. The cloud computing cost depends on several factors, including the total yearly surveillance data generated in SMCO, surveillance data types and associated interface standards and data sizes, and the required cloud computing tools.

Table 6 Features of Q6215-LE PTZ Network Camera [21]

Feature	Description
Range	0.4 km (approx.)
Field of view	58.6 to 2.2°
Optical zoom	HDTV 1080p and 30x
Others	MIL-STD-810G and NEMA TS-2 compliant
Price (per unit)	$3500 (approx.)

3.2.1 Surveillance Data Types and Sizes

Informational only, radio location quality, and radio navigation quality are the three possible service levels that can be provided to subscribers of LAASS, according to the aircraft surveillance source study. These service levels have different data requirements. The radio navigation level service that provides tactical deconfliction services is used to determine the data requirements that are the most stringent. The all-purpose structured EUROCONTROL surveillance information exchange (ASTERIX) was used as the interface standard. ASTERIX is a collection of interface definitions and documentation outlining the data format used for transmitting a range of surveillance data.

The yearly total surveillance data that would be generated in SMCO was determined based on the projected yearly flight hours of AAM traffic estimated for potential AAM use cases — including passenger and cargo transportation, bridge inspections and medical items delivery by sUAS — and projected yearly flight hours of general aviation traffic [29] and size of surveillance messages generated by the sensors. The surveillance message sizes were calculated based on three main types of aircraft and their corresponding interface standards, which are listed in Table 7.

Table 7 Types and sizes of surveillance data [22–24]

Aircraft Type	Interface Standard	Number of Data Items	Message Size
Cooperative Crewed Aircraft	ASTERIX CAT-033	42	1136
Cooperative Uncrewed Aircraft	ASTERIX CAT-129	14	432
Non-Cooperative Aircraft	ASTERIX CAT-062	27	2648

3.2.2 Cloud Components of LAASS

Several different cloud computing tools or components are needed to enable the desired real-time and offline LAASS features and functionalities. The Microsoft Azure Web cloud computing services was considered in this study to estimate the cloud computing costs. Microsoft Azure provides a range of cloud-based services that can be utilized to create a platform for real-time analysis of live surveillance data. It can be used to continuously ingest and process LAASS data in near-real time. The ODOT event streaming platform (ESP) is considered to be used for data archival and dissemination.

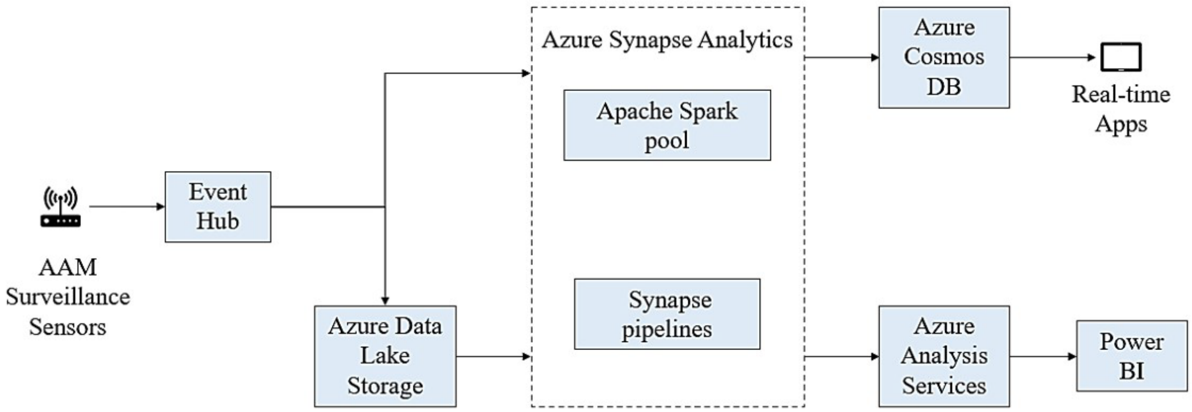


Fig. 4 A flowchart showing the connections of the cloud components of LAASS

The Microsoft Azure pricing policies were used to estimate the required cloud computing cost based on the number of units of surveillance data published and received by LAASS. As the pricing policies of ESP are not available yet, we considered Microsoft Azure Data Lake Storage's pricing policy to evaluate the data storage cost in our analysis.

A cloud computing architecture capable of real time analytics on big data would need to be created to enable the data flow through LAASS. The cloud computing architecture would consist of six components: 1) Azure Event Hub, 2) Azure Synapse Analytics, 3) Azure Data Lake Storage, 4) Azure Cosmos Database (DB), 5) Azure Analysis Services, and 6) Power BI [30]. An overview of the cloud components of LAASS is shown in Figure 4. The Azure Event Hub is a big data streaming platform and event ingestion service, where millions of data units can be received and processed in a single second [31]. It can be used to easily ingest live streaming data from the AAM surveillance sensors. Then, a real-time analytics provider or storage adapter can be used to transform and store data that has been provided to the Azure Event Hub, respectively. The Azure Synapse Analytics is an analytics service that combines data integration, enterprise data warehousing, and big data analytics [32]. For large-scale access and movement of surveillance data, Azure Synapse Analytics would require the use of Apache Spark pool and Synapse pipelines. These components can be used for data cleaning, transforming, and analyzing; and can enable the use of Python, Scala, or .NET, and scalable machine learning/deep learning techniques to derive deeper insights from LAASS data. Azure Data Lake Storage allows massively scalable and secure data lake functionality built on Azure Blob Storage [33]. The Azure Blob Storage helps to create data lakes for analytics needs and provides data storage [34]. To access the intended data through real-time apps, data would need to be transferred from Apache Spark pools to Azure Cosmos DB [35]. Analytics dashboards and embedded reports can be created using Azure Analysis Services and Power BI to share insights across LAASS operator and subscribers [36, 37]. The Microsoft Azure pricing calculators for each cloud component were used to determine their respective costs.

3.3 Public-Private Partnership: Cost and Revenue Sharing

PPP allows collaboration between government agencies and private sector companies to complete large-scale government projects with both public and private funding. It works successfully when private sector technology and expertise are combined with public sector incentives to finish work on time and under budget.

Attracted by the potential high market value of AAM use cases, the interest of private investors in AAM is slowly gaining momentum. To advance AAM and realize its market value, private investors such as Amazon and Uber Technologies have been exploring the costs and requirements of the AAM infrastructure, lending significant weight to the AAM, and attracting further attention and investment from other AAM stakeholders [38].

Despite the growing interest in AAM, significant investment in AAM from the private investors has not yet happened due to several unresolved obstacles and concerns. These include the need for new widespread infrastructure to support AAM operations, such as vertiports, takeoff and landing sites, charging stations, air traffic control systems, airspace routes and surveillance network. Additionally, the current regulatory framework for air transportation is not designed for AAM, which requires new regulations and standards. Another concern for private investors is the uncertainty associated with the demand for AAM. Factors such as changes in consumer preferences, regulatory requirements, and technological advancements could all affect the adoption and growth of AAM services.

These obstacles and concerns are gradually being addressed through research and development by government, industry, and academia, making potential private investors cautiously optimistic about AAM. As investment in AAM infrastructure continues to pour in from the state of Ohio, private entities are likely to become more eager to invest as well. Under these circumstances, it is reasonable to expect that private investment in AAM surveillance infrastructure will be small initially. However, the PPP model for AAM surveillance network and LAASS is likely to gain traction after a few years as many of the AAM challenges get resolved over time. Initial investment from the state of Ohio in the AAM surveillance network and LAASS will start addressing some of the AAM infrastructure concerns and promote regulatory development, which will build confidence in AAM of private investors as well as public acceptance. Hence, based on the survey responses and the findings of the LAASS legal and policy analysis study, we considered a PPP model to allow the sharing of the surveillance sensor cost and revenue generated from AAM surveillance network and LAASS between Ohio and private investors. The PPP cost and revenue sharing percentages were varied in our analysis based on the survey responses.

The state government should invest to promote regulatory development and should start planning as soon as possible, given the extensive lead times involved in designing, building, and acquiring the necessary infrastructure, including vertiports [39].

3.4 Benefit Factor

The benefit factor considered in the cost-benefit analysis of AAM surveillance network and LAASS is the revenue generated from subscription fees charged to the potential subscribers of LAASS. According to the survey responses, the range of subscription fees that potential subscribers were willing to pay was found to be $100-$400. The potential subscribers of LAASS include parcel and cargo delivery operators, medical item delivery companies, air taxi operators, infrastructure inspection companies, airspace service providers, state penitentiaries, law enforcement agencies, correctional facilities, and municipalities. The number of potential subscribers in the various years of the analysis period were estimated based on global and US AAM market growth rates reported in AAM market studies such as [40], [41], and [42].

To evaluate the financial viability of LAASS, its NPV and return on investment (ROI) over the analysis period were computed and analyzed. The NPV represents the estimated total value of all future cash flows generated by an investment over the lifetime of the project, taking into account both positive and negative future cash flows. A positive NPV implies that the expected revenue from the investment exceeds the projected costs, and thus, the investment is considered profitable. Conversely, a negative NPV suggests that the investment would result in a net loss. In this analysis, the yearly NPV calculation of AAM surveillance network and LAASS was carried out based on the difference between the revenue generated and the operating costs incurred by LAASS. A discount factor was considered to account for the time value of money, which reflects the idea that a dollar received in the future is worth less than a dollar received today. *Return on investment* is another financial performance indicator used to measure an investment's profitability and efficiency. It reflects the return earned on an investment relative to its initial cost. ROI holds great significance in the undertaking of new projects as it helps investors to evaluate the financial feasibility of an investment. Through comparing the investment return to its initial cost, investors can determine whether the investment is profitable or not.

4 Results

Following the methodology described in Section II, the costs, revenue and NPV of AAM surveillance network and LAASS were computed. Two different types of surveillance network were considered in the analysis: homogeneous and heterogeneous network. Homogeneous networks comprise only one type of sensor whereas heterogeneous networks are composed of different types of sensors. PPP models with different ROI expected by private investors, cost-sharing percentage, and implementation year were also investigated to evaluate the impact of PPP on NPV.

The NPV of the different sensor types were compared with each other in terms of two criteria: 1) the number of years required to reach the break-even point, and 2) the estimated NPV in the final year of the analysis period. Given the uncertainty of AAM market, a sensitivity analysis was conducted to examines how the NPV responds to changes in key market parameters — namely, the yearly number of subscribers and subscription fees. The results are presented in the following subsections.

4.1 Revenue Analysis

The total yearly revenues generated by AAM surveillance network and LAASS is determined by two factors: the yearly number of subscribers and the monthly subscription fee of LAASS. It does not depend on the sensor type used in the surveillance network provided that complete coverage is present across SMCO. Hence, for all sensor types, the revenue generated is the same. The yearly revenues generated by AAM surveillance network and LAASS in SMCO with a fixed subscription fee of $400 are depicted in Figure 5. As the number of subscribers increases over the years, the revenue grows proportionally. The revenue starts at $0.6 million in the first year and is projected to reach approximately $15 million by 2033.

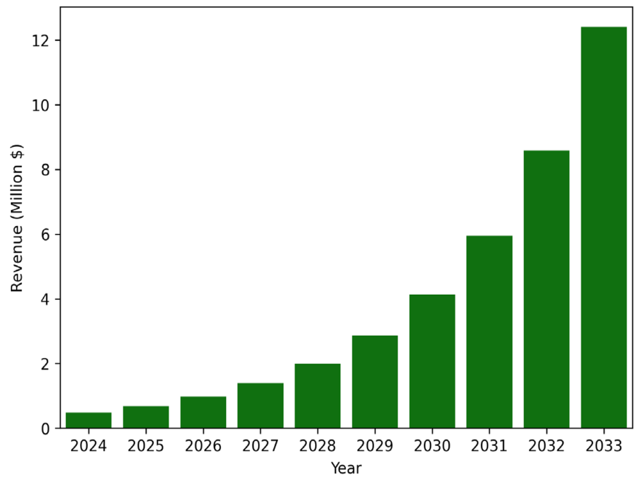


Fig. 5 Yearly revenues generated by AAM surveillance network and LAASS

4.2 Homogeneous Sensor Placement Analysis

In the homogeneous sensor placement analysis, the surveillance network across SMCO is considered to be built using one sensor type instead of a mix of sensor types. This allows for a more in-depth analysis of each individual sensor type's suitability for AAM surveillance and capability to produce NPV over the analysis period.

For each sensor type, the optimal location and number of sensors needed to build the homogeneous surveillance network at minimum sensor cost in SMCO were determined using the SAND model. The optimal sensor locations of RF sensors in the surveillance network across SMCO are shown in Figure 6. For any given sensor type, the number of sensors required to cover a given city increases with the area of the city. Among SMCO, Columbus requires the largest number of sensors as it has the largest area and Dayton the smallest as it has the smallest area.

Based on the unit price of each sensor type and number of sensors required of a sensor type for each city, the city-wise sensor cost of all sensor types were calculated, as depicted in Figure 7. The different sensor types listed in ascending order of sensor cost are: ADS-B, remote ID, RF, radar, optical camera, and acoustic. The sensor costs of ADS-B and remote ID sensor types are observed to be much less compared to others as they have longer ranges and lower unit prices.

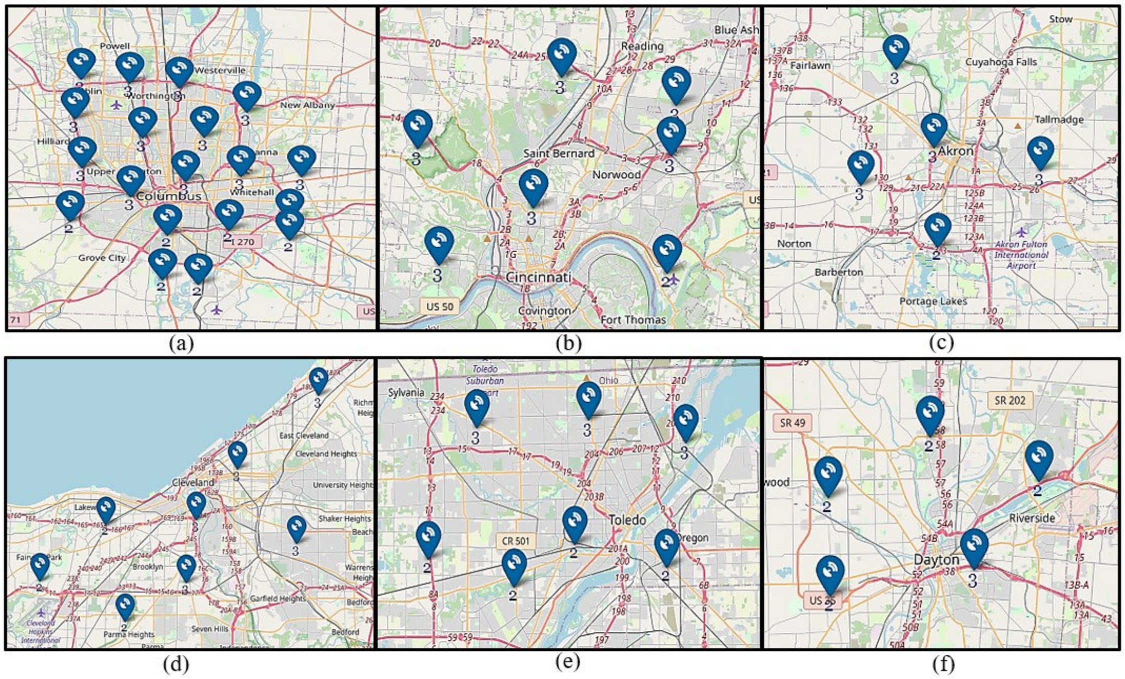
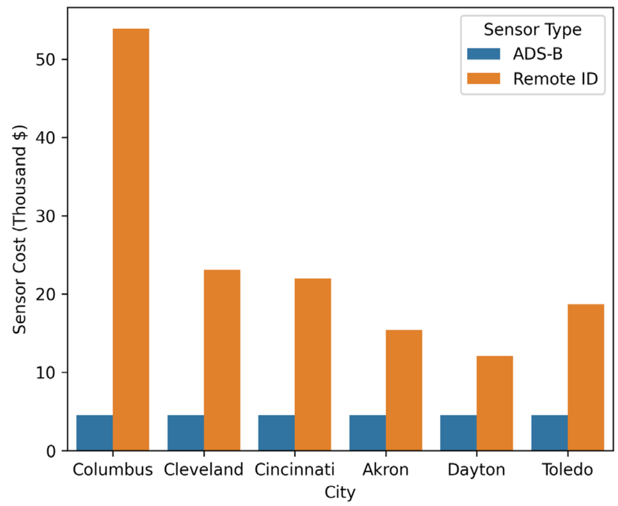


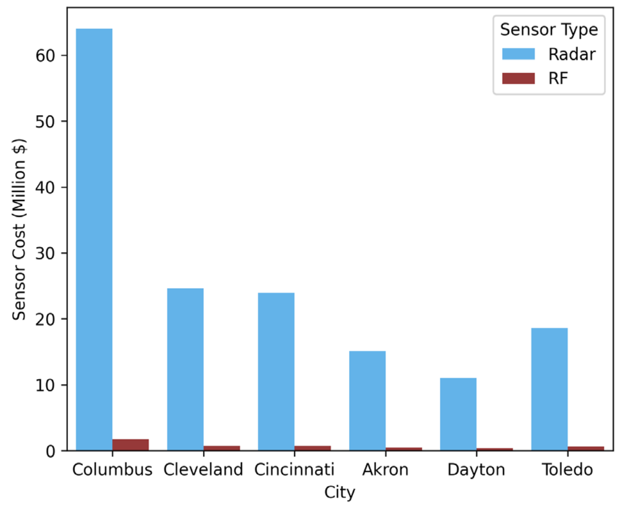
Fig. 6 Optimal locations of RF sensors in six cities (a) Columbus, (b) Cincinnati, (c) Akron, (d) Cleveland, (e) Toledo, and (f) Dayton

At the other end of the sensor cost spectrum are optical cameras and acoustic sensor types. Though the unit price of acoustic sensor is cheap, the acoustic sensor type requires a large number of sensors to cover SMCO because of its small range. Hence, its total sensor cost becomes very high. Like the acoustic sensor type, the unit price of optical cameras are low, but it too requires a large number of sensors to cover SMCO because of its small range and limited field of view. Among the six cities, Columbus requires the highest sensor cost and Dayton the lowest.

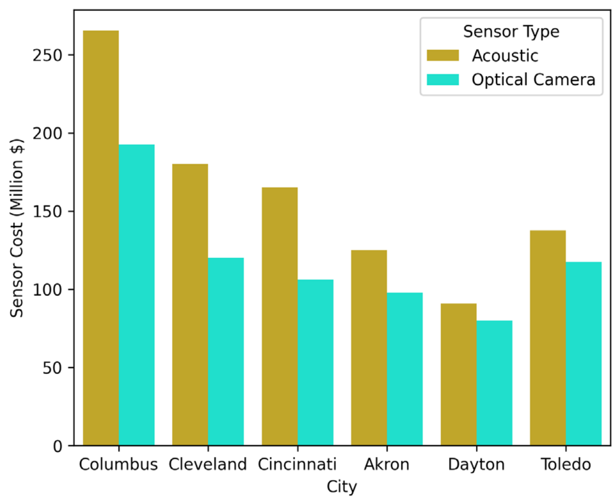
The ten-year cloud computing cost breakdown for each cloud component and each city within SMCO is illustrated in Figure 8. According to the Microsoft Azure pricing policies, the cost of cloud computing components depend on the projected amount of surveillance data generated in each city, which in turn depends on the projected AAM traffic in each city. The Azure Event Hub and Azure Data Lake Storage have the two lowest costs among all the components. The Azure Event Hub operates on a tiered pricing model, where the cost of the service varies based on the level of usage of surveillance data by a subscriber. The cost begins at a relatively low level as the surveillance data and number of subscribers is initially low, and the cost increases in steps as the surveillance data and number of subscribers increases. When the Azure Event Hub usage reaches a defined threshold, the cost climbs to a higher level, and this pattern repeats for each subsequent tier, creating a step function of the cost with respect to usage. The costs for Azure Event Hub and Azure Data Lake Storage increases with the amount of incoming data ingested into the hub and stored in the Data Lake, respectively. Additionally, the frequency of data access also influenced the rise in cost, with higher amounts of access due to increasing number of subscribers leading to an increase in cost in successive years.



(a) Sensor cost of ADS-B and remote ID

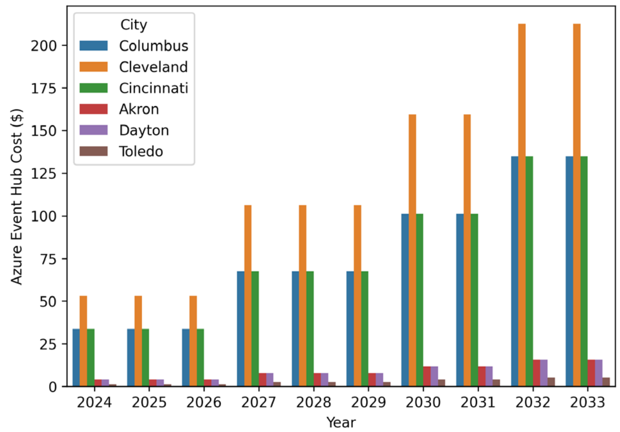


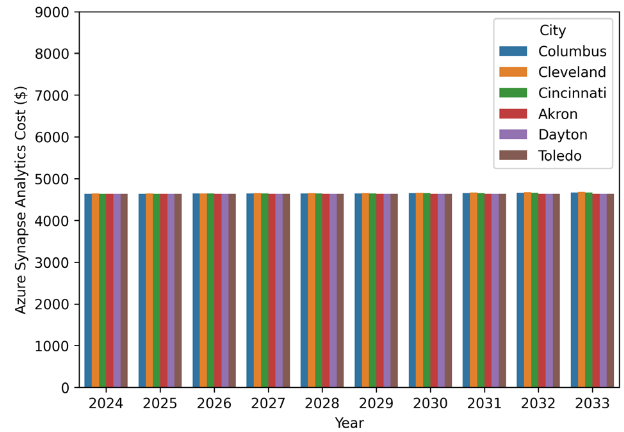
(b) Sensor cost of radar and RF



(c) Sensor cost of acoustic and optical camera

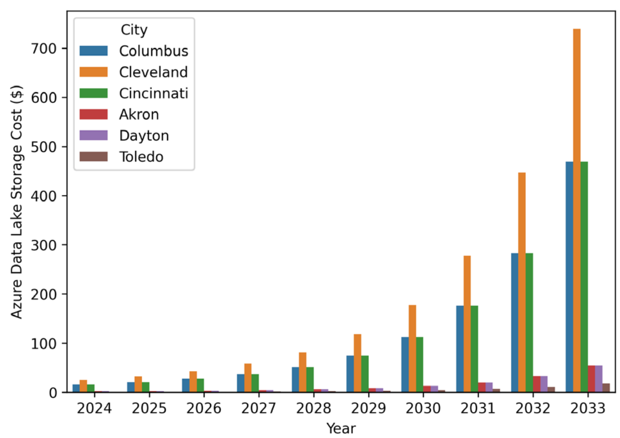
Fig. 7 City-wise sensor cost for different sensor types

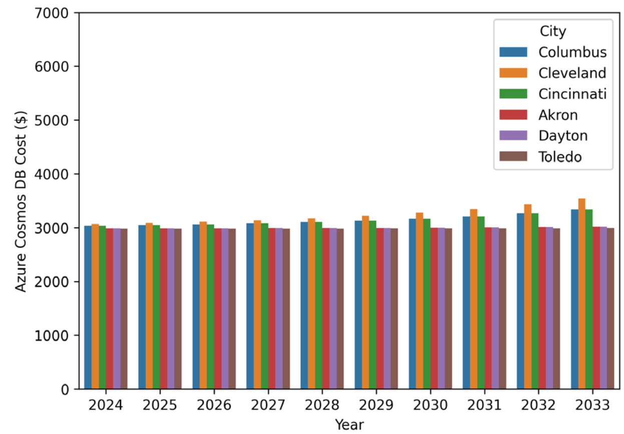




(a) Azure Event Hub cost

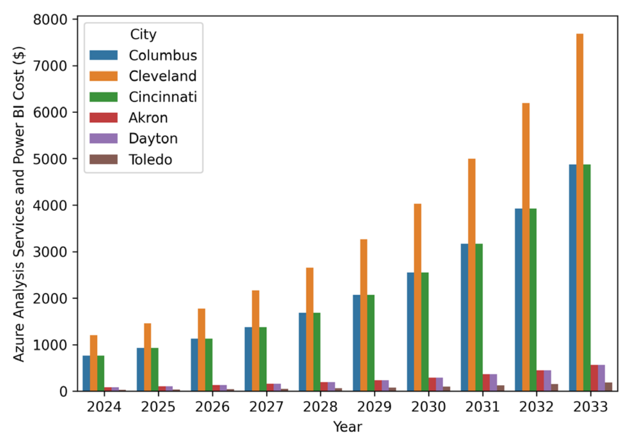
(b) Azure Synapse Analytics cost





(c) Azure Data Lake Storage cost

(d) Azure Cosmos DB cost



(e) Azure Analysis Services and Azure Power BI cost

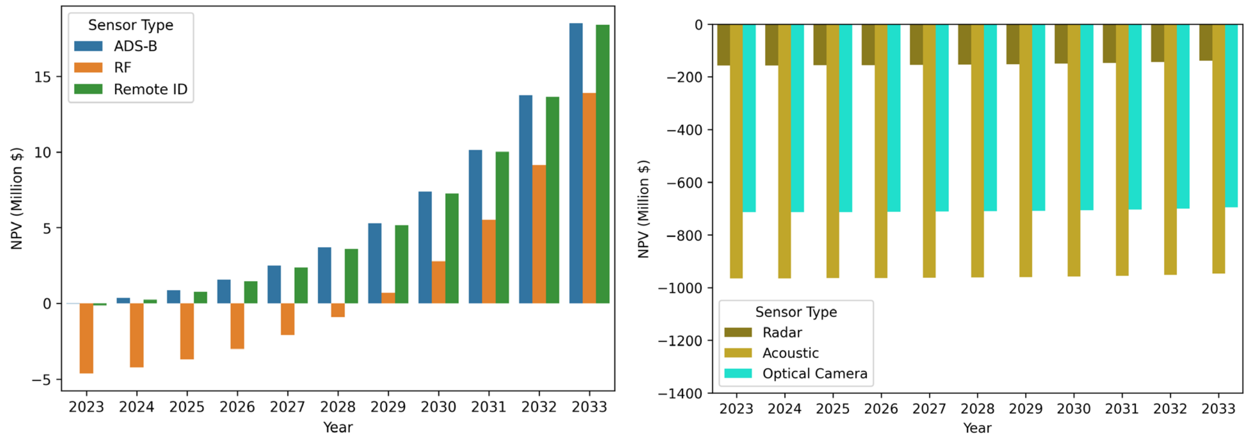
Fig. 8 Cost of different cloud components

The Azure Analysis Services and Azure Power BI costs increase with time commensurate with the projected increase in the amount of data stored, number of queries run, and number of users accessing the services. Lastly, the pricing of Azure Synapse Analytics and Azure Cosmos DB includes both a yearly fixed cost and a yearly variable cost. The yearly fixed cost is associated with the provisioning of virtual machines, storage, and other necessary resources to operate the services. The yearly variable cost depends on the amount of data processed in LAASS. As the yearly fixed cost is much higher than the yearly variable cost, Azure Synapse Analytics and Azure Cosmos DB costs are nearly constant, increasing slightly over the years. Across all cities, the cloud computing component cost associated with ingesting, storing, and analyzing the surveillance data generated in Cleveland is the highest as it has the highest air traffic demand forecast across SMCO, and hence produces the largest amount of surveillance data; whereas for Toledo, the cost is the lowest as it generates the lowest air traffic demand forecast, and hence the lowest amount of data.

The yearly NPV associated with all sensor types are presented in Figure 9. For all sensor types, the steady increase in NPV over time is fueled by the yearly revenues generated from the subscription fees. This NPV growth is less noticeable for radar, optical camera, and acoustic sensor types as they have high initial sensor costs. ADS-B, remote ID, and RF sensor types generate positive NPVs within the analysis period. ADS-B generates the largest NPV, followed closely by remote ID, while RF brings the third largest NPV. These sensor types lead the NPV race because they have lower unit prices and higher ranges, thus requiring fewer sensors to cover a city, and hence have lower sensor costs. Both the ADS-B and remote ID sensor types quickly reach BEP in 2024. Their projected NPVs reach around $18.50 million and $18.38 million in the final year of the analysis period, as illustrated in Figure 9a. The RF sensor type takes longer to reach BEP, gaining positive NPV from 2029, and rises to approximately $13.91 million in 2033. On the other hand, as shown in Figure 9b, the projected yearly NPVs for the radar, acoustic, and optical camera sensor types feature negative NPVs over the 10-year analysis period due to their high initial sensor costs.

The ROI values for ADS-B, remote ID, RF, radar, optical camera, and acoustic sensor types are 1440.38×10^2%, 267.02×10^2%, 742%, -75%, -96%, and -95%, respectively. Based on these ROI values, the sensor types that have positive ROI values are ADS-B, remote ID, and RF because their net returns or profits over the 10-year analysis period are significantly higher than the cost of investment. This means that investing in these sensor types are expected to be financially viable and result in a net profit over the analysis period. A 742% ROI for RF means that for every dollar invested, the investment generated a return of 7.42 dollars over the 10 years. On the other hand, the sensor types with negative ROI values — radar, optical camera, and acoustic sensor — may not be financially viable investments and could result in a net loss. Therefore, the state of Ohio should consider investing in the sensor types with positive ROI values for the AAM surveillance network and LAASS.

As discussed previously in Section III.A, each sensor type can detect and track cooperative and/or non-cooperative aircraft flying in low-altitude airspace. Radar, RF, acoustic, and optical camera are capable of tracking both types of aircraft, while ADS-B and remote ID can only track cooperative aircraft. Based on the NPV and ROI results, if tracking only cooperative aircraft is sufficient, then ADS-B and remote ID are the most financially viable sensor types for AAM surveillance network and LAASS. If tracking both cooperative and non-cooperative aircraft, especially those flying over penitentiary areas, is a requirement, then RF is the most profitable sensor type.



(a) Yearly NPV of ADS-B, RF, and remote ID **(b) Yearly NPV of radar, acoustic, and optical Camera**

Fig. 9 Yearly NPV of six sensor types

4.3 Heterogeneous Sensor Placement Analysis

The heterogeneous sensor analysis aimed to investigate the network composition and costs associated with using a combination of sensors of different types rather than selecting sensors of just one type. The SAND model identified the optimal sensor locations of the assorted sensor types to build the AAM surveillance sensor network across SMCO. This analysis is particularly useful when it comes to providing coverage to the sensitive locations within SMCO, such as penitentiaries, police stations, and airports, where detecting both cooperative and non-cooperative aircraft are equally important. For this analysis, radar, acoustic, and optical camera sensor types were considered as they can detect both types of aircraft. Also, the analysis focused on only the city of Akron.

The optimal sensor locations in the heterogeneous surveillance network for the city of Akron is shown in Figure 10, where the red markers represent the location of radars, and the green markers the location of acoustic sensors. The total sensor cost for setting up this network was found to be $5.06 million. This cost is much lower than the separate sensor costs for radar, optical camera, and acoustic sensor types for the city of Akron found previously in the homogeneous network analysis, which were $15 million, $97 million, and $125 million, respectively (see Figure 7). The heterogeneous network cost is lower because an optimal combination of sensors with the most appropriate ranges can be chosen to cover the given area. In other words, the ranges of the different sensor types are utilized effectively in the heterogeneous network to reduce the sensor cost. For example, near the outer edges of the city and in small pockets within the city, sensors with a smaller range are placed, such as optical cameras, instead of sensors with a higher range, like radar, to minimize the sensor cost.

By using heterogeneous sensor placement, it is possible to design a surveillance network with minimum cost which installs sensor types that can track non-cooperative aircraft (e.g., RF) in security sensitive areas (e.g., penitentiaries, law enforcement facilities, and correctional facilities) and sensor types that can track either cooperative or non-cooperative aircraft (e.g., ADS-B and remote ID) in non-security sensitive or general public areas. Other sensor placement constraints can also be enforced while designing heterogeneous surveillance networks based on the requirements, preferences, and regulations of Ohio.

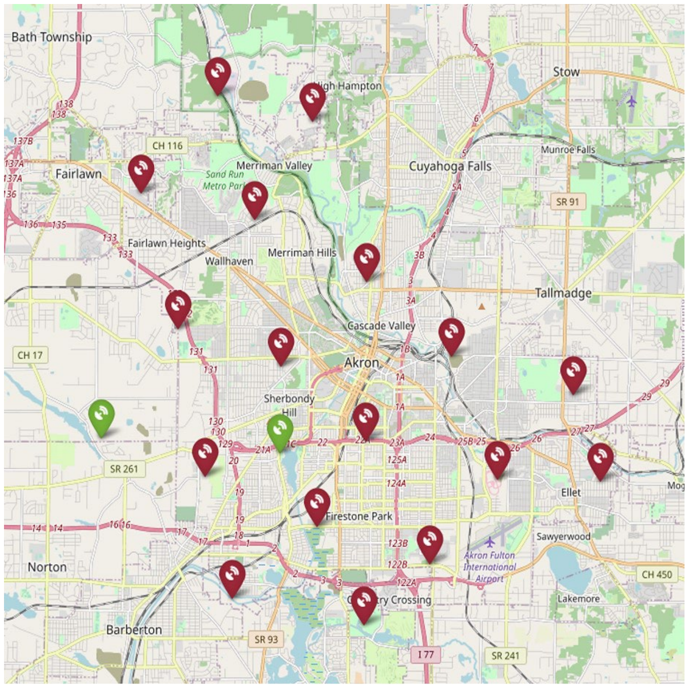
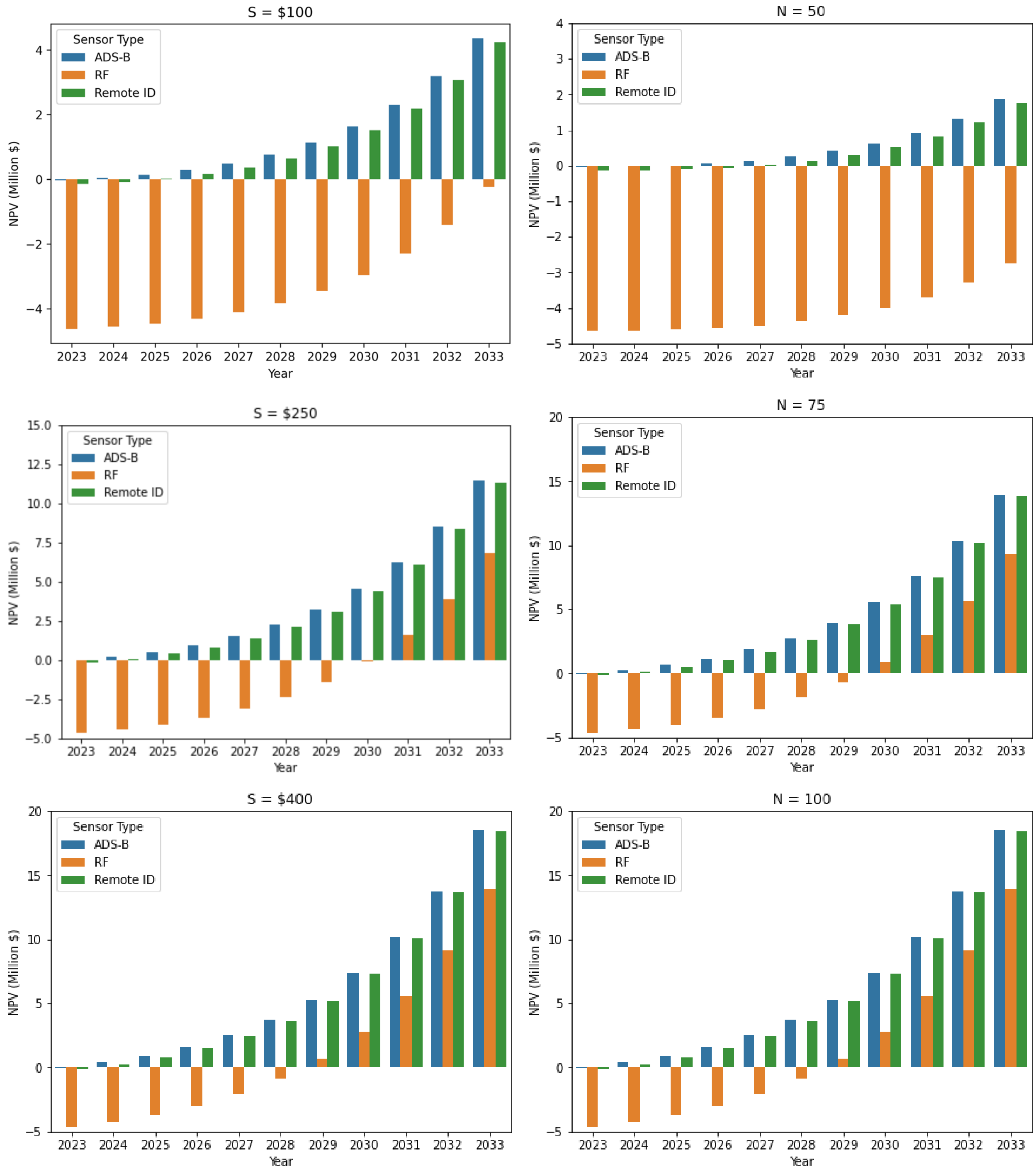


Fig. 10 Optimal locations of mixed sensors in Akron (red markers represent the location of radars, and the green markers the location of acoustic sensors)

4.4 Sensitivity Analysis

A sensitivity analysis was conducted to examine the impact of changes in subscription fees and the yearly number of subscribers on the NPV over the analysis period. For this analysis, the sensor types with the three highest producing NPVs — ADS-B, RF and remote ID — were considered. To vary the yearly number of subscribers for LAASS, the number of subscribers in the initial year (2024) was varied, which affects the number of subscribers in the subsequent years. Based on survey responses, three values for the monthly subscription fee per subscriber (S) — \$100, \$250, and \$400 — and three values for the number of potential subscribers in 2024 (N) — 50, 75, and 100 — were considered.

The trends observed in Figure 11 show that higher values of S and N lead to increases in the NPV and causes the BEP to occur earlier. These effects can be attributed to the increase in revenue generation prompted by increases in S and N. As demonstrated by the example of RF sensor type, when S is \$100, the NPV in 2033 is \$-0.5 million and cannot reach BEP within the analysis period. On the other hand, when S increases to \$400, for the same sensor type, NPV in 2033 rises to \$13 million and crosses BEP in 2029. Similarly, if N is 50, the NPV shows a net loss of \$2.8 million in 2033, and it is not possible to reach BEP during the analysis period. However, for the same sensor type, when N increases to 100, the NPV in 2033 jumps to \$9 million, and it is expected to reach BEP in 2029.



(a) Yearly NPV for six sensor types varying $\mathcal{S}$ **(b) Yearly NPV for six sensor types varying $\mathcal{N}$**

Fig. 11 Yearly NPV for six sensor types varying $\mathcal{S}$ and $\mathcal{N}$

The analysis highlights that Ohio can achieve a net profit for several sensor types within the analysis period as long as S and N are not too low. The values of S and N at which positive NPV is ensured are contingent on the chosen sensor type. If the objective is to detect and track solely cooperative aircraft, then ADS-B and remote ID are profitable options as the sensor type for the AAM surveillance network and LAASS, as discussed in Section IV.B. For this case, even if S and N assume values of $100 and 50, respectively, Ohio can still attain a net profit within the analysis period. On the other hand, if both cooperative and non-cooperative aircraft are required to be tracked, then RF represents the most suitable sensor type for the AAM surveillance network and LAASS, as discussed in Section IV.B. In this scenario, the state of Ohio should ensure S and N to be no less than $250 and 100, or $400 and 75, respectively, to achieve a net profit within the analysis period.

4.5 Public-Private Partnership Analysis

As evident from the previous analyses, the initial investment required to cover the sensor costs for establishing the

AAM surveillance network and LAASS across SMCO is high. PPP provides a mechanism for Ohio to source a percentage of the required investment from private investors. This alleviates the burden of entirely self-financing the initial investment for the state of Ohio. In this analysis, a PPP model is considered based on the findings of the legal and policy analysis study to allow the sharing of costs and revenues related to AAM surveillance network and LAASS between the state of Ohio and private investors.

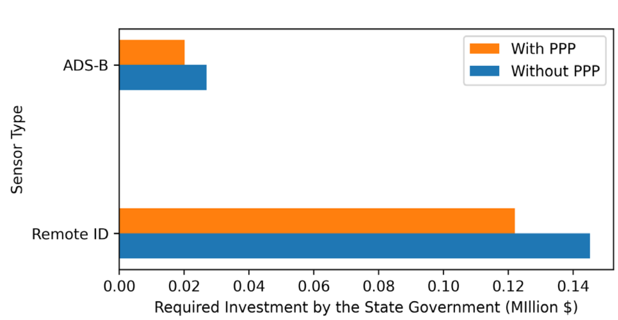
Survey responses indicate a strong interest of private entities to invest in AAM surveillance infrastructure. However, the amount of private investment is expected to be small initially due to several AAM obstacles, as discussed in Section III.C. The PPP model for AAM surveillance network and LAASS is likely to gain traction after a few years as many of the AAM concerns of private investors get resolved over time.

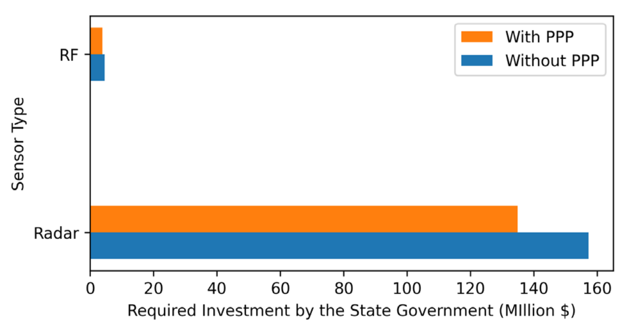
Taking these factors into account, the PPP entry year (EY), the year when the PPP model will be implemented, is considered to be 2028, which is the fifth year of our analysis period. Ohio is considered to make the initial investment without PPP in 2023, at the start of the analysis period, to implement AAM surveillance infrastructure in Columbus, Cleveland, and Cincinnati, the cities with the three largest AAM market potential in SMCO. Afterwards, at the PPP EY, the infrastructure is considered to be expanded to the other three cities of SMCO — Dayton, Toledo, and Akron — through investment based on a PPP model. According to the survey responses, the private investors' cost-sharing percentages are varied from 10%-90% and their expected yearly ROI from 5%-20%. Depending on the PPP cost-sharing percentages, private investors are expected to contribute a certain percentage of the second round investment, with the rest coming from the state of Ohio. The PPP revenue sharing percentage is determined by the private investors' expected yearly ROI.

4.5.1 Public-Private Partnership vs Public Investment Only

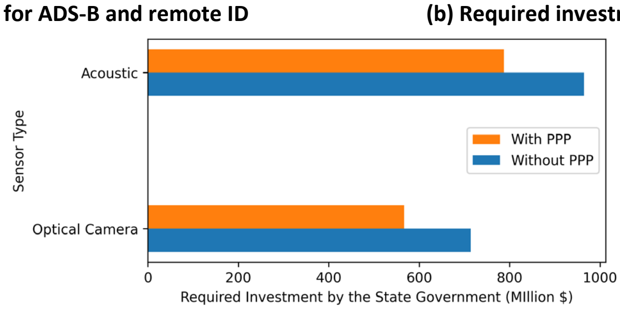
Ohio's required investment for the sensor cost, NPVs and BEPs associated with the project implementation with PPP was benchmarked against those for the case without PPP to assess the value added by PPP for this project. For the NPV and BEP comparison, only the three sensor types which yielded positive NPV within the analysis period — ADS-B, remote ID, and RF — were considered.

By comparing the required investment levels from the state of Ohio for the sensor types for project implementation with PPP and that without PPP, as shown in Figures 12, it can be observed that the required investments are lower for all sensor types when Ohio is pursuing PPP. The differences in required investment can be attributed to the additional financial resources that private entities bring to the table. By sharing the investment costs with private entities, the government can allocate more resources to other critical AAM infrastructure projects. Additionally, this partnership can lead to risk sharing, as private entities can absorb a portion of the financial risk. Therefore, the partnership with private entities present a promising option for Ohio when seeking to mitigate the financial burden of initial investment and risk associated with implementing AAM surveillance network and LAASS. PPP allows to generate a greater net profit, and hence higher NPV and ROI, and obtain an earlier attainment of BEP. It means the investors can recoup their initial investment sooner and start earning a profit, which can be reinvested to expand the project or fund other initiatives. For the RF sensor type, the projected NPV with PPP is expected to cross BEP in 2028 and reach approximately $14.59 million in 2033, as shown in Figure 13. On the other hand, without PPP, the projected NPV of the RF sensor type made it to the BEP one year later in 2029, and achieved a lower NPV of $13.91 million in 2033, as shown in Figure 9a. Similar trends were observed for the other sensor types. Compared to the case without PPP, the ROI values for all sensor types for the case with PPP are higher. Note that a reduction in the NPV growth can be observed at the EY as expected due to the PPP investment cost at the start of EY. As was found for the case without PPP, the same sensor types generated positive NPVs and ROI in the case of PPP. ADS-B, remote ID, RF sensor types generated positive NPVs and ROIs, whereas radar, optical cameras, and acoustic sensor types could not reach BEP within the analysis period.





(a) Required investment for ADS-B and remote ID **(b) Required investment for RF and radar**



(c) Required investment for acoustic and optical camera

Fig. 12 Required investment by Ohio with PPP and without PPP for different sensor types

For the following analyses, the ADS-B sensor type was selected, which generated the highest NPV among the group of AAM sensors that can detect and track only cooperative aircraft. Similarly, the RF sensor type was selected, which generated the highest NPV among the group of AAM sensors that can detect and track both cooperative and non-cooperative aircraft. A comprehensive understanding of the overall trend for all sensor types can be obtained through the observation of these two sensor types.

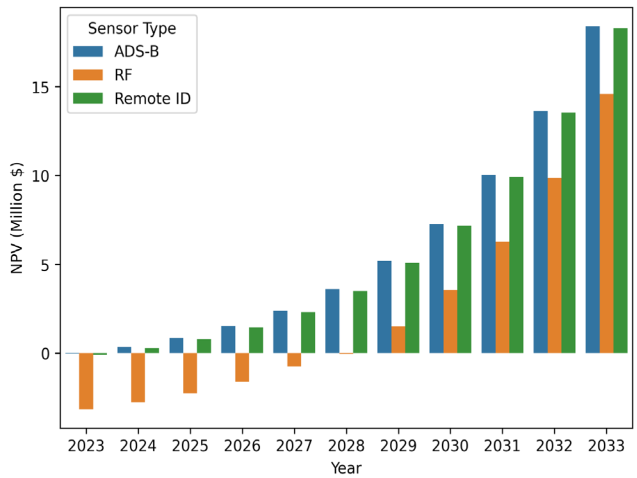


Fig. 13 Yearly NPV of ADS-B, RF, and remote ID considering PPP model

4.5.2 Impact of Varying Private Investors' Expected Annual Return on Investment

To analyze the impact of different expected annual ROI rates by private entities on Ohio's NPV during the analysis period, we varied the expected ROI rates from 5%-20% while setting the EY as 2028, the cost-sharing percentage as 50%-50%, S as \$400, and N as 100. The analysis focused on ADS-B and RF sensor types. Their respective yearly NPVs for different ROI rates are given in Tables 8 and 9. As the EY of PPP is considered to be 2028, the NPVs for the various ROI settings are same before 2028 and different starting from the year 2028. The ADS-B sensor type yields positive NPV at all ROI rates and reach BEP in 2024. The NPV for ADS-B generated decreases with increase in ROI by private investors. This decrease is less noticeable due to significantly high NPV associated with ADS-B sensor type. On the other hand, the NPV of RF sensor type is negative for the first few years at all ROI values; however, it crosses the BEP in 2029 and gradually increases over the years. Ohio's NPV for the sensor types decreases with an increase in private investors' expected ROI as Ohio's needs to share a larger portion of the revenue with the private investors for any given PPP cost-sharing percentage. These results highlight the importance of considering annual ROI rates by private investors when formulating PPP agreements on AAM surveillance network and LAASS. Based on the findings, Ohio should strive to negotiate as low a

ROI for the private investor as possible, but high enough to keep the private entities interested in participating in the PPP.

Table 8 NPV of ADS-B sensor type for different ROI

	NPV ($)			
Year	ROI = 5%	ROI = 10%	ROI = 15%	ROI = 20%
2024	0.3687	0.3687	0.3687	0.3687
2025	0.8706	0.8706	0.8706	0.8706
2026	1.5309	1.5309	1.5309	1.5309
2027	2.3956	2.3956	2.3956	2.3956
2028	3.5981	3.5979	3.5976	3.5974
2029	5.1845	5.1841	5.1837	5.1833
2030	7.2733	7.2728	7.2722	7.2716
2031	10.0219	10.0212	10.0204	10.0197
2032	13.6386	13.6378	13.6369	13.636
2033	18.3979	18.3969	18.3959	18.3949

Table 9 NPV of RF sensor type for different ROI

	NPV (million $)			
Year	ROI = 5%	ROI = 10%	ROI = 15%	ROI = 20%
2024	-2.77	-2.77	-2.77	-2.77
2025	-2.27	-2.27	-2.27	-2.27
2026	-1.61	-1.61	-1.61	-1.61
2027	-0.74	-0.74	-0.74	-0.74
2028	-0.01	-0.04	-0.06	-0.08
2029	1.55	1.51	1.47	1.42
2030	3.62	3.56	3.50	3.44
2031	6.35	6.27	6.20	6.12
2032	9.96	9.86	9.77	9.67
2033	14.70	14.59	14.48	14.37

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4.5.3 Impact of Varying Public-Private Partnership Cost-Sharing Percentage

In this analysis, the impact of the PPP cost-sharing percentage on the NPVs of the various sensor types were assessed by varying the cost-sharing percentages to different settings while keeping the PPP EY as 2028, the ROI rate as 10%, S as \$400, and N as 100. The public-private partnership cost-sharing percentage represents how the total surveillance sensor cost or required project investment will be shared between Ohio and the private investors. For example, if the ratio is 50%-50%, it means that the cost will be shared equally between Ohio and private investors. Similarly, if the ratio is 75%-25%, it means that Ohio will bear 75% of the cost while the private investors will bear 25% of the cost. The analysis focused on ADS-B and RF sensor types. Ohio's NPV for ADS-B sensor type, as presented in Table 10, are all positive, and the NPV trend crosses the BEP in 2024 for all PPP cost-sharing percentages. In contrast, the values presented in Table 11 depict Ohio's negative NPV for RF sensor type for the first four years across all cost-sharing percentages. The values become positive in 2029, the BEP year, and increase over time. The highest NPV is associated with 10%-90% ratio, and the lowest NPV with 90%-10% ratio. The results show that Ohio's NPV decreases if the cost-sharing percentage increases from Ohio's side, which means that Ohio will have to contribute a higher percentage towards the required investment compared to the private investors, assuming that the ROI and EY are the same. Therefore, Ohio should strive to negotiate a PPP cost-sharing percentage which specifies lower investment from their side and higher from the private entities' side.

Table 10 NPV of ADS-B sensor type for different PPP cost-sharing percentage

	NPV (million $)				
Year	**10%-90%**	**25%-75%**	**50%-50%**	**75%-25%**	**90%-10%**
2024	0.3687	0.3687	0.3687	0.3687	0.3687
2025	0.8706	0.8706	0.8706	0.8706	0.8706
2026	1.5309	1.5309	1.5309	1.5309	1.5309
2027	2.3956	2.3956	2.3956	2.3956	2.3956
2028	3.6009	3.5997	3.5979	3.5960	3.5948
2029	5.1868	5.1858	5.1841	5.1824	5.1814
2030	7.2752	7.2743	7.2728	7.2713	7.2703
2031	10.0234	10.0225	10.0212	10.0198	10.0190
2032	13.6397	13.6390	13.6378	13.6365	13.6358
2033	18.3986	18.3980	18.3969	18.3958	18.3951

Table 17: NPV of RF sensor type for different PPP cost-sharing percentage

	NPV (million $)				
Year	10%-90%	25%-75%	50%-50%	75%-25%	90%-10%
2024	-2.77	-2.77	-2.77	-2.77	-2.77
2025	-2.27	-2.27	-2.27	-2.27	-2.27
2026	-1.61	-1.61	-1.61	-1.61	-1.61
2027	-0.74	-0.74	-0.74	-0.74	-0.74
2028	0.29	0.17	-0.04	-0.24	-0.36
2029	1.80	1.69	1.51	1.32	1.21
2030	3.83	3.73	3.56	3.39	3.30
2031	6.51	6.42	6.27	6.13	6.04
2032	10.07	9.99	9.86	9.73	9.65
2033	14.78	14.71	14.59	14.47	14.40

5 Summary of Findings and Recommendations

A number of significant findings were drawn from the cost-benefit analysis that can help Ohio and private sector make informed investments toward the implementation of AAM surveillance network and LAASS for the state of Ohio. For the analysis, we followed a rigorous data-driven methodology and leveraged external AAM market data and surveyed the relevant inputs and expectations of AAM stakeholders. Throughout the 10-year analysis period from 2024-2033, an AAM surveillance network with LAASS in Ohio has demonstrated the potential to enable safe AAM operations and generate positive NPV and ROI from LAASS, providing strong justifications for investment in the surveillance infrastructure. The key findings and recommendations are listed below.

- Based on the AAM surveillance sensor study, six types of sensors have been considered that can be potentially used for AAM surveillance. Cost-minimized homogeneous and heterogeneous AAM surveillance sensor networks connected to LAASS were designed to determine the optimal number and locations of sensors, the required sensor cost, cloud-based data storage and processing costs, revenues, NPVs and ROIs for the sensor types for the SMCO.
- Homogeneous sensor placement: Within the analysis period and among the six sensor types considered, ADS-B, remote ID, and RF sensor types produce positive NPVs. ADS-B generates the largest NPV, followed closely by remote ID, while RF brings the third largest NPV. Based on the

NPV and ROI results, if tracking only cooperative aircraft is sufficient, then ADS-B and remote ID are the most financially viable sensor types for AAM surveillance network and LAASS. If tracking both cooperative and non-cooperative aircraft is required, then RF is the most profitable sensor type.

- Heterogeneous sensor placement: The study found that larger range sensors were mostly used to cover a given city, but smaller and less expensive sensors were used to cover the blocks near the outer edges of a city and smaller pockets of areas within a city. This approach of using a combination of different sensor types helps to minimize the total number of sensors needed, and hence the overall sensor cost, by choosing an optimal combination of sensors within the area.
- The cost-benefit analysis show that investment in Ohio's surveillance network and LAASS is expected to be profitable as a positive final-year NPV and ROI were generated for various sensor types within the analysis period. ADS-B, remote ID, and RF sensor types were found to achieve BEPs within the next 10 years, with both ADS-B and remote ID sensor types reaching BEPs in 2024 and RF in 2029. Among the various cities within SMCO, Columbus has the potential to generate the largest NPV from AAM surveillance network and LAASS for the state of Ohio.
- The revenue generated depends on the subscription fee and number of potential subscribers. For all sensor types, higher values of these two metrics lead to increases in the NPV and causes the BEP to occur earlier. For tracking solely cooperative aircraft with ADS-B and remote ID, the subscription fee should be set to no less than $100, provided that the initial number of subscribers is at least 50, to ensure profitability within the next 10 years. For tracking both cooperative and non-cooperative aircraft with RF sensor type, the subscription fee should be set to no less than $250, provided that the initial number of subscribers is at least 100, to achieve profitability over the same period.
- The different sensor types listed in ascending order of total sensor cost to set up a surveillance network across SMCO are: ADS-B, remote ID, RF, radar, optical camera, and acoustic. The sensor costs of ADS-B and remote

  ID sensor types are observed to be much less compared to others as they have longer ranges and lower unit prices. Among SMCO, Columbus requires the largest number of sensors, and hence the highest sensor cost, as it has the largest area and Dayton the lowest sensor cost as it has the smallest area.
- Due to larger areas and higher air traffic demand forecasts in Cleveland, Columbus, and Cincinnati compared to

Akron, Toledo, and Dayton, the cloud computing costs are higher in the former set of cities.

- A PPP model can enable the sharing of AAM surveillance sensor cost and revenue between Ohio and a private investor. Ohio's required investments are lower for all sensor types when Ohio is pursuing the project implementation through PPP. Pursuing PPP allows to generate a greater net profit and NPV and obtain an earlier attainment of BEP compared to the case of project implementation without

PPP. Ohio's NPV decreases if their cost-sharing percentage increases. Therefore, Ohio should strive to negotiate a PPP cost-sharing percentage which specifies lower investment from their side and higher from private entities' side. An increase in the private investors' expected

ROI leads to a decrease in Ohio's NPV. Hence, Ohio should negotiate for a lower ROI value (revenue sharing percentage) for the private entities while offering a sufficiently high ROI to keep them interested in the PPP.

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