A Decision-Support Framework for Airport Stormwater Mitigation Using Drone-Based LiDAR and GIS Analytics

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***Abstract*—Airport stormwater management is becoming more difficult as impervious surfaces expand, drainage infrastructure ages, and extreme precipitation events intensify. Traditional approaches, such as static sensors, periodic field inspections, and infrequent updates of terrain datasets, result in limited spatial coverage and often lag in adapting to rapidly changing airfield conditions. These limitations may impose significant operational and financial burdens on airports by increasing the likelihood of localized flooding, pavement deterioration, maintenance disruptions, and inefficient drainage performance.**

This paper proposes a UAV-based LiDAR and GIS-enabled decision-support framework for airport stormwater assessment. To identify likely runoff concentrations, localized depressions, and locations that may require further inspection or mitigation to improve drainage efficiency, the framework uses high-resolution terrain data acquisition, georeferenced point cloud processing, digital elevation model generation, and GIS-based terrain drainage analysis. Additionally, this study examines operational feasibility through stakeholder input, an FAA-based operational risk assessment, cost-benefit analysis, and EONS sustainability review. The proposed framework is expected to support more responsive and spatially informed airport stormwater planning by improving terrain update capability and informing inspection, maintenance, and infrastructure design decisions.

Keywords—LiDAR, Remote Sensing, Environmental Monitoring, UAV, Airport Survey

I. INTRODUCTION

Airport stormwater systems face increasing pressure as impervious surfaces expand, drainage infrastructure ages, and extreme rainfall events become more frequent [1], [2]. These factors result in higher runoff volumes, greater flood risk, and increased transport of pollutants into nearby environments. In practice, these impacts often extend beyond environmental concerns and begin to affect airport operations. Water accumulation near runways, taxiways, or terminal aprons can delay aircraft movements, damage pavement, and pose safety risks for both aircraft and ground crews.

Despite its significance, current stormwater monitoring practices are still limited. Most airports rely on a mix of static sensors, periodic inspections, and existing terrain datasets [1], [2]. These approaches provide useful information, but they do not capture how conditions change across the entire airfield. Sensors are fixed in place, and inspections take time, require coordination, and access to restricted areas. In many cases, issues are only found after they start impacting system performance. Recent advances in UAV platforms equipped with LiDAR sensors offer a more adaptable means of collecting high-resolution terrain data. When combined with GIS-based analysis, these data can enable repeatable screening of runoff behavior and drainage vulnerabilities. This paper introduces a decision-support framework that integrates UAV-based LiDAR data with GIS-based terrain analysis to aid stormwater mitigation planning at airports. The goal is to help airport stakeholders identify problem areas, prioritize inspections and maintenance, and support infrastructure planning decisions.

The paper is organized as follows: Section II reviews the background and limitations of existing stormwater assessment approaches in airport environments. Section III describes the proposed methodology. Section IV presents the conceptual application of the framework, and Section V discusses operational feasibility, risks, and cost-benefit considerations.

II. BACKGROUND

A. Existing Stormwater Assessment Approaches

Traditional stormwater assessment methods in airport environments depend on periodic inspections, static sensor networks, or existing terrain datasets. While these approaches provide useful information, they are often limited in spatial resolution, update frequency, and coverage within complex airside environments [2]. These constraints become more pronounced as airport surfaces evolve. Runway rehabilitation, apron expansion, and grading changes can shift drainage pathways over time, yet updated terrain data are not always available when these changes happen. Stakeholder feedback from airport planning and operations emphasizes this problem, highlighting that drainage studies can be costly, consultant-heavy, and infrequent, making it difficult to keep up with changing conditions.

B. *Operational Challenges in Airport Environment*

The limitations become more significant at airports because repeated field surveys are difficult under normal operating conditions. Access to the airside is limited, survey activities need to be coordinated with ongoing operations, and large-scale assessments often require substantial time, consultant support, and operational planning. This is not a minor issue. Airport surfaces change over time. Runway repairs, apron expansions, grading adjustments, and other infrastructure changes can modify local drainage paths. Some of these changes may seem minor individually, but their combined effect can still impact how runoff flows across the airfield.

Stakeholder input from airport planning and operational contexts reinforced this point. Drainage-related studies are described as costly, consultant-heavy, and too infrequent to keep up with changing conditions. In practice, this means airports may continue to rely on terrain assumptions that no longer match current surface conditions. Without updated terrain data, changes in runoff behavior might go unnoticed until reduced drainage performance or localized flooding occurs during operations.

C. *Research Gap*

Previous studies, including ACRP Reports 99 and 166, have highlighted the need for improved monitoring methods that offer better spatial coverage and data quality [3], [4]. Environmental guidance from the U.S. Environmental Protection Agency also emphasizes the importance of effective stormwater management to reduce contamination and ensure regulatory compliance [5]. Collectively, these studies indicate a need for more flexible and repeatable terrain-based assessment methods in airport environments.

Less attention has been given to repeatable, terrain-based screening methods that aid practical decision-making for airport stakeholders. This gap is especially critical in airport settings, where operators often require timely information about where to inspect, maintain, and make infrastructure adjustments. The framework introduced in this paper aims to address that need.

III. METHODOLOGY

The proposed framework combines UAV-based LiDAR data collection with GIS-based terrain analysis to support stormwater assessment in airport environments. Its goal is to generate terrain information that helps airport stakeholders identify drainage issues, prioritize inspections, and plan mitigation measures. The methodology includes three main stages: data acquisition, surface model generation, and drainage-related terrain analysis. As shown in Fig. 1, the framework has three key components: (A) UAV-based data acquisition, (B) Surface model generation, and (C) Terrain drainage analysis. The simplified framework path is shown in Fig. 1. Additionally, the overall workflow of the framework, including data collection, post-processing, and GIS-based output generation, is further illustrated in Fig. 2.

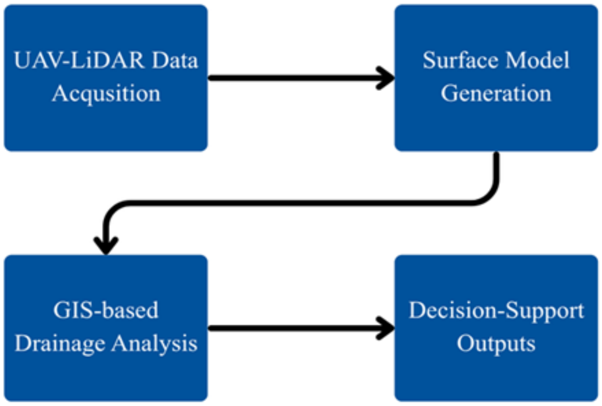


Fig. 1. Conceptual flow of the methodology for the proposed airport stormwater assessment framework.

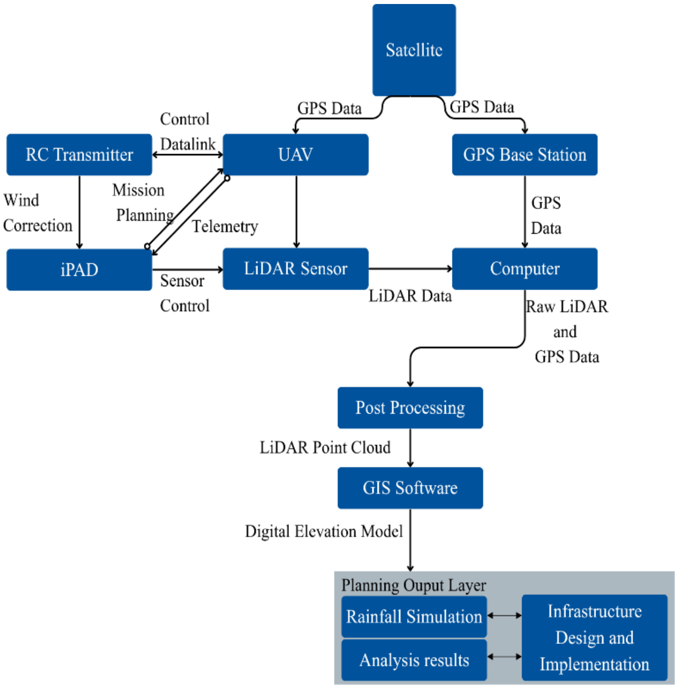


Fig. 2. Detailed UAV-LiDAR and GIS-based decision-support workflow for airport stormwater assessment.

Together, Fig. 1 and Fig. 2 illustrate the framework's conceptual structure and the detailed sequence for producing decision-support outputs.

A. *Data Acquisition*

First, high-resolution terrain data will be collected using a UAV platform equipped with a LiDAR sensor, as shown conceptually in Fig. 1 and Fig. 2. Unlike traditional field surveying, the UAV-based method offers greater flexibility in the airport environment. The UAV-LiDAR system will capture surface conditions relevant to stormwater behavior, including paved airfield areas, graded surfaces, drainage channels, and nearby stormwater features. The LiDAR USA Revolution 120 serves as the primary sensing system because its point density of over 200 points per square meter provides detailed images of terrain features important for drainage assessment. A GNSS base station is used to enhance positional accuracy during data collection and post-processing. The main advantage of this approach is that the survey can be repeated as needed, enabling more frequent updates to terrain information than traditional field methods.

B. *Surface Model Generation*

The LiDAR survey generates georeferenced point-cloud data, which is processed to create a terrain surface suitable for drainage analysis. As shown in Fig. 1 and Fig. 2, this step links data acquisition to terrain-based analysis. GNSS-supported positioning and post-processing are used to enhance spatial accuracy, and then the resulting point cloud is converted into a Digital Elevation Model (DEM). The generated DEM is utilized in GIS-based simulation analysis.

To enhance georeferencing quality, Scanlook PPK is used to refine the survey trajectory, produce georeferenced point clouds, and assist with positional correction during post-processing. When necessary, control point adjustment can also be applied to improve spatial consistency. The purpose of this step is not to evaluate LiDAR accuracy as a standalone research objective but to develop a terrain model that supports screening-level stormwater evaluation.

C. *Terrain Drainage Analysis*

The DEM is analyzed within a GIS environment to evaluate terrain-driven runoff behavior [6]. Through this process, the simulation will provide an initial indication of how water is likely to move across the surface and where runoff may concentrate [6]. Additionally, review of low-lying areas and localized depressions will help airport operators to identify locations where inefficient drainage may occur.

IV. CONCEPTUAL APPLICATION

In the airport, environmental conditions and operational constraints shape stormwater assessment. Drainage problems are not always caused by a single failure point. Instead, they usually develop gradually as surface conditions change, infrastructure is modified, and drainage assumptions become outdated. Due to these factors, a practical screening framework is valuable.

A. *Airport Operation Context*

Airports pose a challenging setting for frequent stormwater assessments. Constraints such as airside activity limitations, coordination with ongoing operations, and the need for substantial time and consultant support for large-scale surveys may lead to infrequent drainage assessments despite the evolving airport infrastructure.

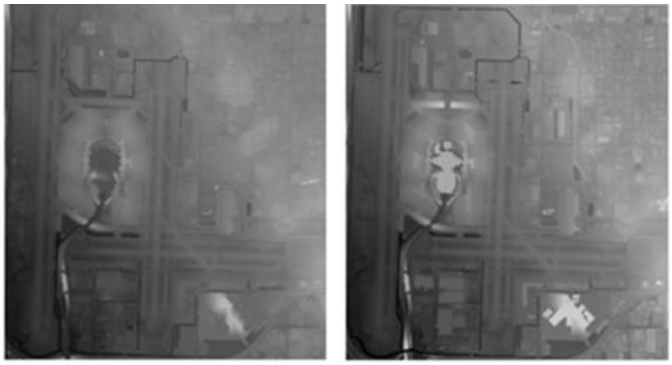
In the dynamic airport environment, infrastructure modifications can alter local drainage behavior over time. These changes often appear to have a minor impact on the stormwater system; however, their combined effect can shift runoff pathways and create localized drainage concerns. Without updated terrain information, these changes may go unnoticed until drainage system failure or flooding occurs

B. *Screening Planning Value*

This framework is intended to help airport stakeholders prioritize field inspection, maintenance, and follow-up mitigation in operationally sensitive areas

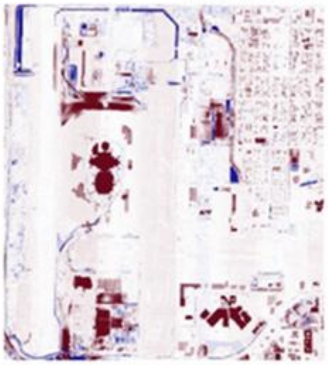
From a planning perspective, the framework also supports a more repeatable and proactive approach to stormwater management. Updated terrain data can help airport operators track how drainage conditions evolve, assess whether mitigation measures are improving performance, and identify emerging issues before they become operational disruptions. Furthermore, the outputs may support broader infrastructure planning by identifying candidate areas for regrading or drainage modification and improving coordination between airfield development and stormwater management objectives.

For conceptual illustration, NOAA-derived DEM datasets were used to compare terrain conditions across two time periods [7]. Those two time periods were selected following the conventional master drainage update cycle, which ran from 2007 to 2017. Then, the data were processed and visualized using QGIS. As shown in Fig. 3(a) and Fig. 3(b), the 2007 and 2017 DEMs provide a basis for comparing terrain alteration over 10 years at KTPA, and Fig. 3(c) highlights the elevation difference between the two different time periods. The corresponding hydrological analysis results in Fig. 4(a) and Fig. 4(b) show how these terrain differences influence runoff patterns. Together, these figures illustrate how updated terrain data and GIS-based screening can help identify evolving drainage patterns and support more proactive airport stormwater planning.



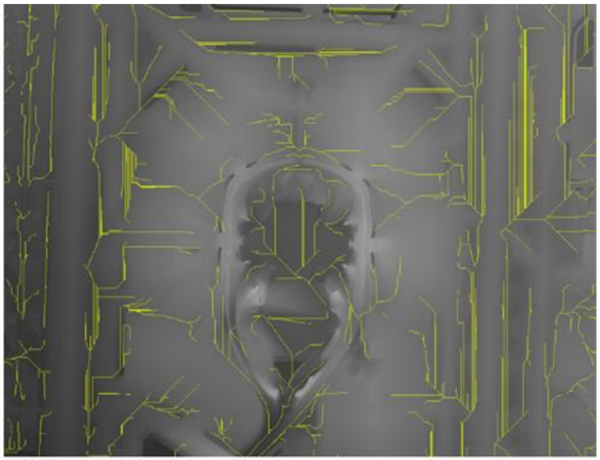
a) DEM of 2007 KTPA

b) DEM of 2017 KTPA

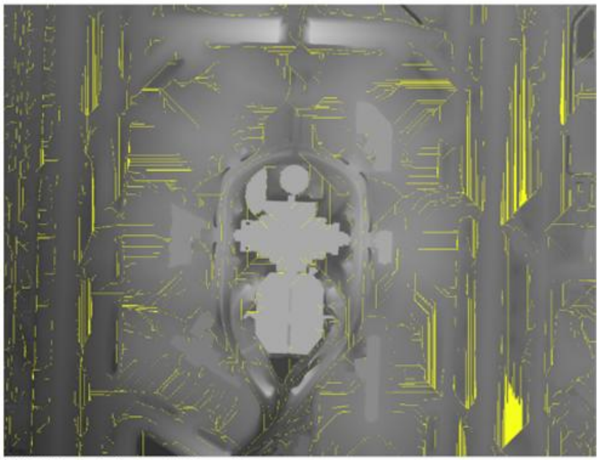


c) Elevation difference between 2007 and 2017

Fig. 3. NOAA-derived DEM comparison at KTAP: (a) 2007 DEM, (b) 2017 DEM, and (c) elevation difference between the two time periods



a) 2007 hydrological analysis results



b) 2017 hydrological analysis results

Fig. 4. Comparison of hydrological analysis results derived from NOAA-based DEM datasets at KTPA: (a) 2007, (b) 2017. Analysis and visualization were performed in QGIS.

V. OPERATIONAL RISK AND COST CONSIDERATIONS

The practical value of the proposed framework depends on more than technical capability alone. A proposed stormwater assessment method must fit within operational constraints, meet safety requirements, and provide sufficient value to airport stakeholders. These major considerations were evaluated through stakeholder input, an operational feasibility review, a risk assessment, a cost-benefit analysis, and an EONS-based sustainability evaluation.

A. *Stakeholder Insight and Operational Feasibility*

The input from the airport stakeholders emphasized that the current stormwater assessment system is constrained by time, cost, and the difficulty of repeating large-scale field surveys. At Tampa International Airport (KTPA), stakeholders noted that their stormwater systems were still based on plans developed more than a decade ago, which makes it difficult for airport operators to prepare for changing weather patterns and increasing rainfall intensity. They also emphasized the importance of protecting critical infrastructure, such as baggage tunnels, and improving preparedness for extreme weather events. In recent hurricane events, including Milton and Helene, reported impacts included storm surges of 6-7 ft and damage totaling double-digit millions of dollars from erosion and infrastructure damage. Also, the stakeholder further noted that more accessible LiDAR data could support stormwater simulation and emergency training while reducing reliance on outside consultants.

For the Daytona Beach International Airport (KDAB), they also showed a similar pattern. Stakeholders described the 2019 airport master plan update and associated drainage study as a consultant-driven effort that took more than 18 months and cost more than $1 million. In that $1 million, more than $200,000 was devoted solely to stormwater and drainage data collection.

Despite many airports facing similar constraints, they also emphasized major implementation barriers arising from the airport's high operational volume. Based on stakeholder interviews, both airports are busy; KDAB has more than 380,000 annual aircraft operations, and KTPA has more than 226,000. Because of this, they emphasized the challenge of integrating UAV operations into dense, active airspace. They also emphasized FAA Certificate of Authorization (COA) requirements and liability concerns. Both interviewees viewed the concept as financially feasible and operationally beneficial in principle. However, they also stressed that successful deployment would depend on navigating regulations, collaborating with stakeholders, and timing in a highly dense operating environment.

To address these considerations, the framework implemented several practical considerations. The UAV deployment will be treated as an airport-coordinated activity rather than a routine field survey. To successfully implement this framework in current airport systems, it will require preplanned mission boundaries, coordination with airport operations personnel, and scheduling during lower-density operating windows to mitigate interference with ongoing airside activity. Also, survey mission planning for UAVs will vary by airport context, with busier airports requiring tighter scheduling, greater coordination, and more restrictive operating conditions than smaller or less-congested airports.

B. *Operational Risk Assessment*

To address the hazards associated with the UAV-LiDAR framework, this framework included a structured risk assessment using safety matrices for aviation operations suggested by FAA AC 150/5200-37 [8]. FAA assessment is based on the combination of severity and likelihood. In simplified form, the risk rating may be expressed as

$$Risk = f(Severity, Likelihood) \quad (1)$$

where severity reflects the consequence of a hazard and likelihood reflects the probability of occurrence. In this framework, likelihood and severity are each divided into five categories. Likelihood categories were Frequent (A), Probably (B), Remote (C), Extremely Remote (D), Extremely Improbable (E). Severity categories were Minimal (5), Minor (4), Major (3), Hazardous (2), Catastrophic (1). Each hazard was then evaluated separately and assigned a final risk rating as presented in Table I.

The primary hazards identified were loss of command-and-control link, adverse weather, wildlife encounters, collision with aircraft, and GPS signal loss. Before the implementation of mitigation strategies, these hazards were categorized as loss link (1B), weather (3C), wildlife encounters (2B), collision with aircraft (3A), and GPS signal loss (2C).

As seen in Table I, before mitigation, these hazards represented meaningful operational exposure in the airport environment because UAV deployment must account for both safety consequences and likelihood. After mitigation, each hazard exhibits a lower risk level, indicating that the proposed controls can improve operational feasibility.

TABLE I. OPERATIONAL RISK RATINGS BEFORE AND AFTER MITIGATION[8]

Situation	Operational Concern	Pre-Mitigation Risk	Post-Mitigation Risk
Loss Link	Loss of aircraft control, Unintended airspace incursion, Mission interruption	1B	4E
Adverse Weather	Reduced Stability, Degraded sensor performance, Unsafe flight conditions	3C	4D
Wildlife Encounters	Bird strike risk, Loss of control, Mission termination	2B	5E
Collision With Aircraft	Catastrophic conflict with manned aircraft during active airport operations	3A	5C
GPS Signal Loss	Navigation degradation, positional error, and reduced georeferencing reliability	2C	4E

TABLE II. MITIGATION STRATEGIES FOR IDENTIFIED OPERATIONAL HAZARDS

Hazards	Possible Solution	How It Mitigates
Loss Link	Return-to-home, Controlled Landing, Secondary Comm Link	Reduces the likelihood of uncontrolled flight and limits airspace deviation during link failure
Adverse Weather	Preflight METAR/TAF, Weather Minimums, Go/No Go Criteria	Avoids flight under unsafe wind, rain, or visibility conditions
Wildlife Encounters	Lower-risk timing, Coordination with wildlife management	Reduces the probability of bird interaction and mission interruption
Collision With Aircraft	Geofencing, COA/LOA coordination, visual observers, ADS-B integration, Operations during lower-density windows	Reduces conflict with manned traffic and improves situational awareness in active airspace
GPS Signal Loss	GNSS base station support, Contingency procedures, Emergency landing plan	Improves positional reliability and provides a controlled response to degraded navigation

C. *Cost-Benefit Considerations*

The cost estimate in this study was developed using multiple sources. Conventional survey costs were informed by stakeholder interviews, KDAB master plan 2020 [9], and the Adopted Budget Fiscal Year 2020-2021 [10]. Also, the cost estimates for the UAV-LiDAR framework were developed from a combination of vendor-listed or market pricing available at the time of the study, stated software and training costs, and operational staffing assumptions.

As mentioned previously, the conventional stormwater assessment was characterized as labor-intensive, operationally disruptive, and expensive. Typical cost of approximately $3,500 - $5,000 per linear mile. For airports with about 100 linear miles of survey, the annual cost can vary from $350,000 to $500,000.

For the UAV-LiDAR framework, the first-year system cost was projected at $497,654.80. To specify the sum of the first-year system cost: a Freefly Astro Max UAV estimated at $31,794.80, a LiDAR USA Revolution 120 sensor estimated at $30,000, and an initial training cost estimated at $7,200. Also, the other startup expenses, such as graduate research member wages, faculty advisor costs, airport consultants, and legal consultants' wages, were added. Recurring annual operating cost was projected at 157,800.00. This value was driven mainly by software and labor assumptions, including approximately $500 per year for LiDAR processing software, $4,200 per year for ArcGIS Pro, and an estimated sum of the GIS analyst salary and UAS pilot salary of $124,800, with labor assumed at $30 per hour. Using this estimated cost, the total projected system cost over a 10-year planning period was approximately $2,075,654.80

Based on the cost assumptions adopted in this analysis, the UAV-LiDAR system was expected to survey approximately 1,000-1,500 linear miles per year. This yields a range of $160-$230, substantially lower than the assumed $3,500-$5,000. On this basis, long-term savings were projected to be approximately $1.7- $3.4M, depending on airport size and the frequency of drainage surveys.

Furthermore, this framework not only benefits the economic context but also reduces other costs related to infrastructure damage or flooding by enabling more realistic terrain updates after grading changes, pavement rehabilitation, and storm events

D. *EONS-Based Sustainability and Broader Value*

The EONS assessment was used to evaluate the framework's broader value [11]. It considers economic vitality, operational efficiency, natural resource conservation, and social responsibility in airport sustainability planning. In the EONS sustainability assessment, the UAV-LiDAR stormwater management framework showed positive effects across all four categories, with one notable trade-off: battery-related electronic waste.

Table III shows the specific details of the EONS assessment results and the value beyond technical monitoring, including improved responsiveness, workforce safety, environmental stewardship, and long-term planning capability.

TABLE III. EONS Sustainability Results[11]

EONS	**Sustainability Impact and Effects**	
Economic Vitality	Savings from the traditional ground-based assessment method	+
	Decreased labor demand and risk exposure for staff/ lowers liability and insurance cost	+
	Improves budget flexibility for airport upgrades and innovation	+
Operational Efficiency	Enhanced real-time monitoring and maintenance scheduling	+
	Reduce unexpected stormwater failures	+
Natural Resource Conservation	Optimized stormwater system monitoring reduces resource overuse	+
	Automated data reduces the need for fuel-based ground vehicles	+
	Battery-related electronic waste	-
Social Responsibility	Improved flood mitigation protects the nearby community	+
	Faster response during emergencies supports the continuity of services	+
	Creation of job opportunities	+

VI. Conclusion

The purpose of this paper is to present a decision-support framework that integrates UAV-based LiDAR data collection with GIS-based terrain analysis to support airport operators' stormwater management tasks. The proposed approach was developed to address a practical limitation of current stormwater monitoring system, which are infrequent, resource-intensive, and operationally constrained to follow up with changing airfield conditions. With the ability to repeat survey frequently the framework can help airport stakeholder to proactively plan inspections, maintenance, and infrastructure planning. The feasibility, risk, cost-benefit analysis, and EONS assessment results further verified the usefulness of this approach.

The successful implementation of this framework into a current airport environment does not only depend on technical feasibility, but also on whether it can be integrated into airport operations within an appropriate safety and regulatory structure.

Acknowledgment

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Appendix

TABLE IV. Table of ABBREVIATIONS

Abbreviation	**Full Term**
ACRP	Airport Cooperative Research Program
COA	Certificate of Authorization
DEM	Digital Elevation Model
EONS	Economic vitality, Operational efficiency, Natural resource conservation, and Social responsibility
FAA	Federal Aviation Administration
GIS	Geographic Information System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
KTPA	Tampa International Airport
KDAB	Daytona Beach International Airport
LiDAR	Light Detection and Ranging
NOAA	National Oceanic and Atmospheric Administration
UAV	Uncrewed Aerial Vehicle

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