An In-time Aviation Safety Management System (IASMS) Concept of Operations for Part 139 Airports

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Today's airports are complex multi-faceted ecosystems. Currently, of the 517 certificated airports, 270 are required to use safety management systems (SMSs) to identify and mitigate known hazards and emergent risks and to voluntarily share safety data with commercial operators and tenants. Airports manage a wide variety of hazards. These traffic hubs have direct responsibilities, such as removing foreign object debris from runways and taxiways and configuring runways to help prevent against incursions and tail strikes during takeoff. To ensure safety in the future NAS, the National Academies recommended an In-time Aviation Safety Management System (IASMS). An IASMS will employ services, functions, and capabilities (SFCs) to identify and mitigate hazards that are proactively and predictively managed based on data analytics of detected anomalies, precursors, and trends. SFCs would scale with airport complexity and environmental conditions using increasingly automated systems to respond proactively to hazards and, by using integrated data sources and predictive safety analytical methods, discover new, never before seen risks.

I. Introduction

The Federal Aviation Administration (FAA) foresees significant growth in air transportation in the years ahead. Growing traffic density and vehicle and mission diversity will necessitate increased innovation and the adoption of new processes to maintain and enhance aviation safety. SMSs of the future will contribute to aviation safety by detecting and mitigating safety problems before these result in accidents and incidents throughout the National Airspace System (NAS), including those airports classified under Title 14 of the Code of Federal Regulations (CFR) Part 139. A Part 139 airport is so classified when it has scheduled passenger service of aircraft carrying nine passengers or greater or unscheduled passenger service of aircraft carrying 31 passengers or greater [1].

The FAA reports there are some 5,000 public-use and 14,400 private-use airports, heliports, and seaplane bases in the United States (U.S.) [2], 517 of which are classified as Part 139 airports [3]. The FAA indicated that in 2022 domestic passenger volume reached 99% of the pre-COVID-19 level and international passenger volume reached 86% [4]. In fiscal year 2022, certain Core 30 airport operations returned to pre-pandemic levels (e.g., Denver, Las Vegas, Miami, Orlando, and Tampa airports [5]). Commercial operations (air carrier and commuter/air taxi) are forecast to increase 2.0 percent a year through 2043, while airline passenger growth will increase 2.6 percent as airlines use larger aircraft (seats per aircraft mile) and higher load factors [4].today's safety technology must evolve alongside the NAS.

Current airport operations contend with various hazards. The International Air Transport Association (IATA) analyzed the occurrence of non-fatal year 2023 accidents involving commercial air carriers and found for airports the most frequent were landing gear (9 events), ground damage (5 events), tail strike (5 events), hard landing (4 events), runway excursion (2 events), and off airport landing/ditching (2 events) [6]. IATA audits of ground operations at 209 international airports found the top safety issue was difficulty integrating and implementing an SMS throughout the organization to manage ground operations safety risks.

For decades now, many safety-critical industries have utilized an SMS. An SMS is the formal, top-down, organizational-wide approach to managing safety, assuring the effectiveness of safety risk controls, and promoting safety culture. The modern digital world facilitates data-driven safety decision making that is facilitated through the rapid collection and analysis of data to help quickly identify hazards, analyze the associated risk, design their mitigating controls, and continuously monitor operations to assure their effectiveness. In aviation, the International Civil Aviation Organization (ICAO) reports that the implementation of SMS has contributed to the lowered accident rate over the last ten years [7].

Today, airports and airport industry groups (e.g., American Association of Airport Executives (AAAE), Airports Council International–North America (ACI–NA), and so forth) are strong advocates for both airport safety and SMSs. In alignment with ICAO Annex 19 guidance, the FAA has made an SMS mandatory for certain airports and the FAA Office of Airport Safety and Standards is responsible for airport SMS certification. Airport safety is also focal for airlines, general aviation, other operators, and aviation safety organizations (e.g., Commercial Aviation Safety Team). The Transportation Research Board, as part of the National Academies, published guidance for airport SMSs as well as guidance for airport safety risk management panel activities [8, 9, 10]. Within the airport there are different groups of stakeholders involved in airport safety [11]. These include airport departments and staff; police; fire including aircraft rescue and firefighting (ARFF); tenants, airlines, and ground service providers (GSPs); fixed base operators (FBOs); FAA departments and staff; passengers, the flying public, and communities; pilots, third parties such as construction workers; Transportation Security Administration departments and staff; and others. Off-nominal actions by stakeholders can pose a hazard to safe airport operations. Stakeholder response to off-nominal conditions can introduce a hazard.

Airports are a critical node in the NAS for the safe and expeditious transportation of passengers and cargo. Airports rely daily on interactions with varied numerous tenants including commercial operators (14 CFR Part 121), commuter and on-demand operators (14 CFR Part 135), and general aviation (14 CFR Part 91). For example, Hartsfield-Jackson Atlanta Airport (the world's busiest in terms of passenger traffic) has eight mainline domestic airlines, seven regional airlines, 11 foreign flag airlines, and 20 cargo airlines [12]. Other tenants include third-party service providers such as aircraft maintenance, catering, fueling, baggage and cargo handling, flight schools, and military. Airports coordinate construction activities in terminals, concourses, gates, fueling stations, taxiways, and runways.

520 air traffic control towers (ATCTs) [5] manage the safe flow of arrival, surface (e.g., pushback from gate and taxiing), and departure traffic; clear airport vehicles operating on runways and taxiways; and handle non-normal operations. Uncontrolled non-towered airports conduct these activities at the pilot's discretion for separation and accident avoidance. This methodology relies heavily on individual decision making and accountability and can pose other challenges to SMSs. These airports may not be certificated under Part 139 but do pose many of the same safety issues at a lower frequency.

In a 2018 paper, the National Academies called for SMS augmentation and evolution into an In-Time Aviation Safety Management (IASMS) [13]. The National Aeronautics and Space Administration (NASA) described an IASMS as services, functions, and capabilities (SFCs) necessary for monitoring known hazards and emergent risks, assessing safety data for anomalies, precursors, and trends, mitigating hazards that reach safety thresholds, and assuring efficacy of controls in mitigating hazards [14]. An IASMS will continually monitor the NAS to collect data on the status of aircraft, air traffic management (ATM) systems, weather, and airports. Airports have unique hazards, risks, and mitigations which this paper will attempt to categorize and highlight research needed to integrate airport an IASMS into the NAS. Prior NASA research has aligned IASMS including for Part 121 commercial air carriers [15] and Part 135 operators that are limited in the number of passenger seats and amount of cargo that can be carried [16].

This paper examines in-time safety management for Part 139 airports and identifies in-time safety needs for airports. First, ICAO and FAA regulatory requirements are reviewed, followed by discussions of today's Part 139 Airport SMSs and safety challenges. Lastly, the paper presents an IASMS system interfaces for Part 139 airports followed by conclusions.

II. Regulatory Requirements

Regulations, standards, and guidance regarding airports and SMSs, established by ICAO, flow down to the FAA. The FAA then develops additional rules and guidance for airports and airport SMSs.

A. ICAO Standards and Guidance

The ICAO "Safety Management Manual" (Document 9859) defines an SMS as "a systematic approach to managing safety, including the necessary organizational structures, accountability, responsibilities, policies, and procedures" [17]. An SMS is comprised of four components: Safety Policy and Objectives, Risk Management, Safety Assurance, and Safety Promotion [17]. ICAO provides Standards and Recommended Practices (SARPs) on safety management principles, concepts, and implementation for the continued evolution of safety management in accordance with provisions of Annex 19 [18]. ICAO first required member states to certify their international airports have an SMS in 2005 [19].

In addition to SMS SARPs, ICAO published SARPs for Aerodromes in Annex 14 with Volume I, Aerodrome Design and Operations, that covers technical specifications and requirements for aerodrome certification, design, services, and safety [20, 21]. Volume I provides guidance on:

- Aerodrome data (e.g., pavement strength),
- Physical characteristics,
- Obstacle restrictions,
- Visual aids for navigation (e.g., runway markings and signs),
- Aerodrome services (e.g., emergency planning, firefighting and rescue), and
- Aerodrome maintenance.

Annex 14 Volume II contains SARPs for heliports that may be co-located with airports [22]. Additional ICAO publications related to aerodrome include:

- Airport Planning Manual, Document 9184 which covers master planning, land use and environmental control, and guidelines for consultant/construction services [23].
- Part 1 of the Aerodrome Design Manual, Document 9157 provides guidance on runways [24], while Part 2 covers taxiways, aprons, and holding bays [25]. Other Parts address pavements, visual aids, electrical systems, and frangibility.
- Airport Services Manual, Document 9137 covers rescue and firefighting [26] and other topics, such as pavement surface conditions, wildlife control and mitigation, and removing disabled aircraft. ICAO materials on the bird strike information system and surface movement guidance and control system are addressed later in this paper.

B. FAA Regulations

The FAA follows the State Safety Program (SSP) framework of an SMS as outlined in ICAO Annex 19 [18]. The FAA Part 139 Airport SMS rule was specified in Title 14 CFR, effective April 24, 2023 [27]. The rule requires certain airport certificate holders to develop, implement, maintain, and adhere to an SMS [27]. This change helps the FAA to align with ICAO standards more closely.

Regulations for Part 139 Airports

Part 139 specifies certification requirements for certain standards for airport design, construction, maintenance, and operations as well as firefighting and rescue equipment, runway and taxiway guidance signs, control of vehicles, management of wildlife hazards, and record keeping. Part 139 requires airports to hold Airport Operating Certificates (AOC) to serve scheduled air carrier aircraft with more than 9 seats or unscheduled air carrier aircraft with more than 30 seats [28].

Under Part 139, a certificate holder must develop and maintain an Airport Certification Manual (ACM) that contains the processes and procedures the airport uses to comply with Part 139 requirements [29]. According to FAA Advisory Circular (AC) 150/5210-22 [29], the ACM must address key elements. Some of the more salient elements are:

- A map identifying terrain features on or around the airports that are significant to emergency operations; the location of each obstruction must be lighted or marked.
- A description of each movement area available for air carriers that is prepared or suitable for reducing the risk of damage to aircraft in the event of an undershoot, overshoot, or excursion from a runway or the unintentional departure from a taxiway. A movement area is defined as runways, taxiways, and other areas

of an airport that are used for taxiing, takeoff, and landing of aircraft, exclusive of loading ramps and aircraft parking areas [30].

- Procedures for avoidance of interruption or failure during construction work of utilities serving facilities or NAVAIDs that support air carrier operations.
- A plan showing the runway and taxiway identification system, which can be used as a runway incursion prevention initiative, including the location and inscription of signs, runway markings, and holding position markings.
- A snow and ice control plan.
- A description of the facilities, equipment, personnel, and procedures for meeting the aircraft rescue and firefighting requirements.
- Procedures for protecting persons and property during the storing, dispensing, and handling of fuel and other hazardous substances and materials.
- An emergency plan to address hazards such as aircraft accidents, natural disasters, terrorism, fires, hazardous materials, water rescue, and power failure [31].
- Procedures for conducting the self-inspection program required under 14 CFR 139.327 [32]. These include, but are not limited to, daily inspections (typically a minimum of one during daylight hours and one at night, but it can be more frequent), regular inspections of safety areas, periodic inspections of fuel trucks or farms, and emergency inspections following emergency landings or unusual meteorological conditions that affect movement areas.
- Procedures to protect NAVAIDs and prevent interference during meteorological events like snow accumulation.
- Procedures for wildlife hazard management.
- Procedures for airport condition reporting, such as the issuing of Notices to Air Missions (NOTAMS).

The FAA categorizes airports by Classes I–IV relative to scheduled/unscheduled service and large/small air carrier aircraft as follows [33]:

- Class I – scheduled and unscheduled operations of large air carrier aircraft having 30 or more seats and scheduled small air carrier aircraft having 10–30 seats.
- Class II – scheduled operations of small air carrier aircraft having 10–30 seats, and unscheduled large air carrier aircraft having 30 or more seats.
- Class III – scheduled operations of small air carrier aircraft having 10–30 seats.
- Class IV – unscheduled large air carrier aircraft having 30 or more seats.

Table 1 shows the number of airports falling into each of these Classes, including how many have an air ATCT and are under the FAA SMS requirement [3].

Table 1. Part 139 airports by classification [3].

Airport Class	Number	ATCT	SMS
Class I	415	326	237
Class II	10	3	2
Class III	13	3	0
Class IV	79	55	31
TOTAL Part 139 Airports	**517**	**387**	**270**

The FAA also uses a categorization scheme for Part 139 airports based on types of activities:

- The Commercial Service category involves 31 large hub airports having 1 percent or more of the annual U.S. commercial enplanements, 33 medium hub airports having 0.25 to 1 percent of enplanements, 73 small hub airports having 0.05 to 0.25 percent enplanements, 241 non-hub airports having less than 0.05 percent but more than 10,000 enplanements. All of these are referred to as primary airports. Non-hub non-primary airports have between 2,500 and 10,000 enplanements [2, 3].

- The Reliever category involves airports designated to relieve congestion at a commercial service airport and to provide more general aviation access to the community.
- The general aviation category involves public-use airports with no scheduled service or scheduled service with less than 2,500 passenger boardings per year. Both are non-primary airports.

SMS AC for Part 139 Airports

The FAA in its SMS AC for Part 139 airports states, "SMS enhances safety, ensures compliance with applicable regulatory standards, and can be integrated into all aspects of airport operations, including business and management practices. This AC provides guidance about developing and implementing SMS and explains how SMS will help airports develop an explicit, pro-active, and engaged process for identifying and quantifying potential hazards and risks and for managing them in a systematically coherent, logical, and reasonable way" [19]. The AC identifies means of compliance with applicable regulatory standards associated with the four ICAO components of SMS and describes how SMS supports airports in developing an explicit, proactive, and engaged process for identifying, quantifying, and managing hazards and risks. Key subparts of Part 139 are 139.401 on General Requirements, 139.402 on Components of the airport SMS, and 139.403 on airport SMS implementation [34]. The FAA estimates that the current SMS rule covers over 90 percent of all U.S. passenger enplanements and includes airports with the largest number of commercial air transportation operations.

The Part 139 SMS AC explains that safety risk management (SRM) and safety assurance (SA) components are closely linked, as shown in Fig. 1. SRM ensures hazards and their associated risks are identified, analyzed, and assessed so that necessary mitigations can be established. SA processes then take over, analyzing operational data to evaluate whether the mitigations are having the desired effect. Airlines and other stakeholders may participate in airport safety risk assessments and share portions of de-identified datasets. Airports may use these confidential safety risk reports to coordinate investigation of ground incidents and accidents and promote safety culture. The AC for airport SMS states that reporters can submit a safety concern anonymously or include their name and contact information [19]. There is a concern that the name of the individual submitting an airport safety concern could be revealed through a Freedom of Information Act (FOIA) request made under state law.

The FAA Airports SMS AC states that safety issues can be identified through the airport's hazard reporting system, airport self-inspections, maintenance activities, and manager or tenant meetings. In addition, the evaluation of certain activities or events may identify safety issues including airport accidents or incidents, airfield changes (including geometry, construction, conversion from movement to non-movement areas, airfield procedures, and pavement marking modifications), irregular operations or events, winter weather operations, tenant operational changes (including new servicing equipment and aircraft using airport), and ramp operations (including use of ramp for activities not originally intended). Addressing hazards is key to SRM. Not all hazards could technically result in a catastrophic accident, but the airport should consider the worst credible outcome (harm), i.e., the most unfavorable condition that is believable and possible. The airport should strive for quantitative or real-life examples of hazard-based outcomes. Using examples from airports of similar size and operations may help add credibility. Based on the worst credible outcome of each hazard, the airport then determines the severity and likelihood of that outcome using qualitative and/or quantitative methods. To do this, the airport should have pre-defined severity and likelihood levels. These levels are typically unique to each organization, since they are management's means of defining what constitutes acceptable and unacceptable levels of risk. The airport should develop levels commensurate with its operational needs and complexity.

The airport's SA processes should include procedures to trigger re-evaluations of the hazard if data or hazard reports indicate a mitigation is not effectively reducing the risk of the hazard's outcome. For example, if an airport put in place a mitigation to decrease the likelihood of a runway incursion but safety performance data then showed an increase in runway incursions after the mitigation was put in place, then the mitigation may need to be reassessed for effectiveness. If an airport experiences a damaging bird strike to an air carrier aircraft, or other triggering events, then the Wildlife Hazard Mitigation Plan must be re-evaluated.

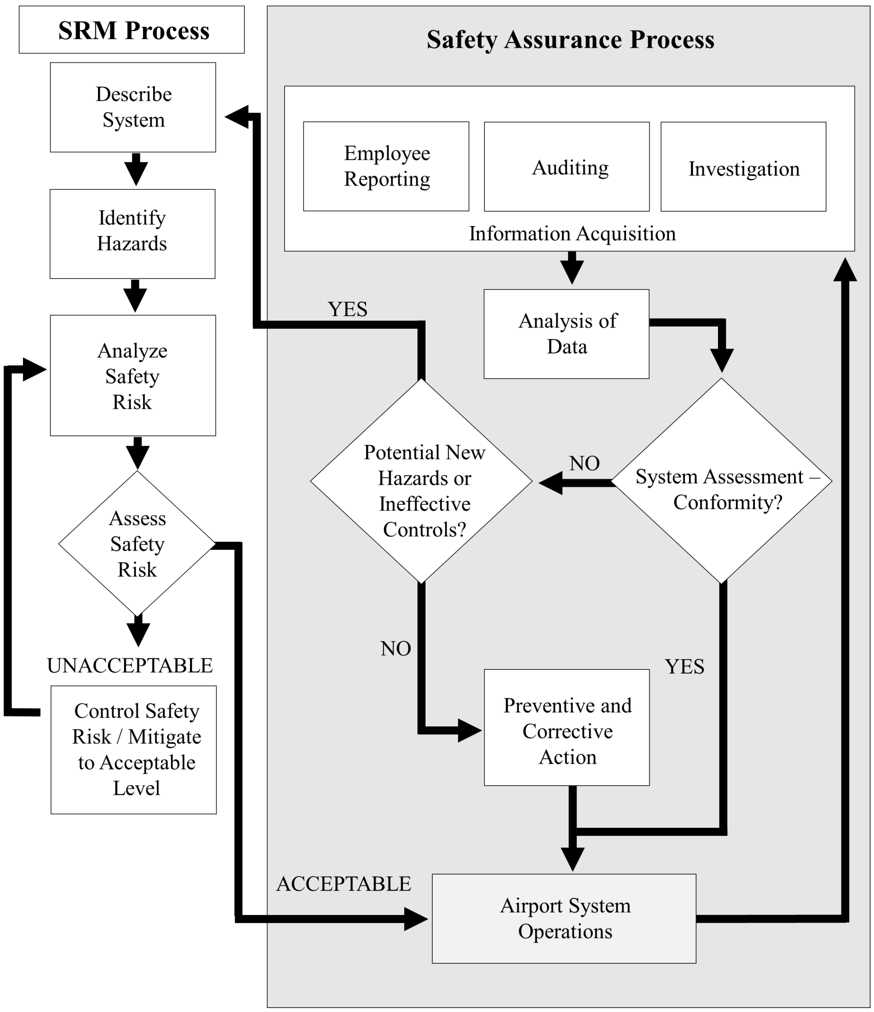

Figure 1. FAA SMS for Part 139 Airports Showing SRM/SA Relationship (Adapted from [19] Figure 5.2).

The FAA AC for Airports SMS [19] addresses scaling of SMS with small airport operators using simple methods for conducting the processes within the SMS. Medium and large airports may require more detailed processes within the SMS. To encourage hazard reporting and data sharing the FAA developed AC No. 120-92D, "Safety Management Systems for Aviation Service Providers," that provides guidance for a voluntary non-punitive program for commercial air carriers including pilots so that protected safety reporting data are anonymous and confidential [35]. Under federal law these reports cannot be disclosed under FOIA. In contrast, similar programs do not exist for airports and their employees, and information which is deemed protected under federal law may not be protected under various state and local laws. This may discourage the reporting of hazards and sharing of data both within the airport organization and between the airport and outside entities such as air carriers. Furthermore, while airports are not a current source of data for the Aviation Safety Information Analysis and Sharing (ASIAS) program, it is envisioned that Part 139 airports will collaborate in knowledge sharing of safety insights as part of the ASIAS 3.0 program [36].

Another facet of SA involves runway condition reports, which are not always accurate to actual conditions. Runway use decisions rely on collected airport data that can quickly change, such as runway visual range, winds, and friction reports/braking temperature. These conditions and decisions have implications for runway excursions, un-stabilized approaches, and go-around decision-making. Further, these ripple effects can be more pronounced at airports that contend with significant rapid weather changes, leading to larger varying degrees of uncertainty [19].

There are inherent drawbacks to current SMS, most notably the time required to address a new hazard or ineffective control. The collecting and analyzing of safety data and determining and validating controls for hazard mitigation can take extended periods of time. On the one hand, some hazards require immediate mitigation, such as detected foreign object debris (FOD) that closes a runway. On the other hand, this process can take days, weeks, or even months from the first notification of a new hazard or ineffective control, such as faded paint that hides the edge of a runway, to the development of an effective mitigation. As the NAS evolves to accommodate increased commercial traffic and new entrants, aviation safety programs must evolve to ensure that changes to the NAS do not inadvertently introduce new risks. This will necessitate the automaton of safety assurance for air transportation system components, integrating component-level systems, and reducing the safety assurance cycle time until in-time safety assurance is achieved at the system-of-systems level. The future NAS is expected to maintain or exceed the current level of aviation safety while accommodating global increases in air travel and rapid introduction of new technologies.

FAA Air Traffic Organization (ATO) SMS Policy

The FAA ATO core business function is providing safe and efficient ATM services in the NAS. Specifically with regards to airports, the ATO is responsible for collaborating with the FAA Office of Airports (ARP) to review and approve SRM documentation for relevant systems, services, operations, and products [37].

C. FAA Business Plans

The FAA lines of business, e.g., ARP, ATO, the Office of Aviation Safety (AVS), and staff offices, each develop a business plan every fiscal year (FY). A business plan provides understanding of some of the key goals, initiatives, and targeted accomplishments to be attained by the end of the FY.

FAA Airports Business Plan

The ARP business plan for FY 2024 provides understanding and insight into safety matters of highest priority, although these do not necessarily represent all safety-related activities developed and undertaken during the year; other activities may not have the same high-level importance and as such are not included in the business plan [38]. ARP's FY 2024 business plan includes the following targeted safety actions:

- Assist Part 139 airports with 100,000 operations and international operations in meeting their required deadline for submission of their SMS implementation plan due October 31, 2024.
- Work with industry on best practices, issues, and concerns during the SMS rule implementation period.
- Identify and analyze the 131 non-towered Part 139 airports for problematic taxiway geometry (PTG) locations using the principles established in the runway "Hot-Spot Improvement Program" (HIP).

Additional safety targets involve providing additional guidance and oversight of Part 139 inspections for regulatory application, compliance, and assessment of safety data. ARP leads and support safe integration of unmanned aircraft systems (UAS) operations, including UAS detection, mitigation technologies, and UAS wildlife dispersal.

FAA ATO Business Plan

The FAA ATO operational line of business also publishes its annual business plan [39]. The ATO business plan for FY 2024 mirrors the ARP business plan for understanding and insight into safety matters of highest priority. The ATO's FY 2024 business plan includes the following targeted safety accomplishments:

- Advance surface safety tools that enable real-time situational awareness through technology sprints.
  - Approach runway verification (ARV) provides tower and TRACON ATC alerts of aircraft wrong runway, closed runway, and wrong airport alignments.
  - The Runway incursion device (RID) is an ATC memory aid device used to augment situational awareness of occupied and closed runways.
  - The Surface Awareness Initiative (SAI) is deploying a display of airport surface traffic to ATC in towers at airports that do not currently have a surface surveillance system.
- Utilize the surface safety metric to establish consensus among Runway Safety Action Team (RSAT) stakeholders on a policy to assess and quantify the risk in runway safety events. Address precursors, as well as latent risks by proactively providing event trend summaries and best practices to the field.
- Develop advanced analytics for a surface safety metric to support surface SRM.
- Sustaining the Juneau Airport Wind System (JAWS) that measures and transmits terrain-induced wind and turbulence to a commercial airline, the Juneau Automated Flight Service Station, and National Weather Service for weather forecasting.

Part of the ATO mission efficiency goal are activities supporting airport safety. For example, as part of the Bipartisan Infrastructure Law, the FAA is constructing 30 low-activity staffed ATCTs by 2030 based on a standard design.

III. Today's Part 139 Airport SMS

In the U.S., there are currently 517 14 CFR Part 139 certified airports, which are separated into classes based on operations [3]. Eighty percent are Class I airports (the highest) meaning "an airport certificated to serve scheduled operations of large air carrier aircraft that can also serve unscheduled passenger operations of large air carrier aircraft and/or scheduled operations of small air carrier aircraft."

A. Part 139 Stakeholder Interfaces

Airport SMS involves numerous stakeholders ranging from federal and local governments to first responders (police, fire), and different operators (airlines, ground handlers, security, and airline customers) [40, 41, 42]. Airports have an SMS interface with airlines involving limited data sharing, safety risk assessments, confidential reporting, and ground incident and accident investigation coordination. Airports may share safety information and data with airlines and others through interfaces established through their respective complementary SMS approaches. These interfaces include regular planned periodic meetings and ad hoc meetings, when necessitated by safety-critical matters. SMS data reporting is intended to be proactive using de-identified data. The safety data is entered into the SRM/SA process has shown in Figure 1 which uses formal process for analyzing risk, implementing mitigations, and continuously monitoring hazards and controls.

B. Airport Emergency Plans

The airport emergency plan (AEP), which is required for inclusion in the AOC as previously discussed, covers several areas identified in FAA AC 150/5200-31C associated with systematic approaches of determining all hazards that warrant emergency preparedness [29, 31]. The AEP is developed in coordination with local communities, state organizations, and federal agencies in emergency management and preparedness so that expertise and resources are incorporated to the mutual benefit of all parties. For example, the Hartsfield-Jackson Atlanta International Airport (ATL) AEP includes planning for the deplanement of passengers following excessive apron delays, sharing of facilities to make gates available in an emergency, and providing a sterile area for passengers who have not cleared U.S. Customs and Border Protection [43]. The AEP identifies ATL use of the Aerobahn Surface Management System for real-time display of taxiing aircraft providing situational awareness in all weather conditions; this system provides the ability to set event alerts, such as time elapsed during taxi, for proactive management of critical situations. Some airports go beyond FAA AEP requirements and develop annexes for active shooter plans, administration facility evacuation plans, business continuity plans, mass casualty, and water rescue [44].

Airports certified under part 139 are required to conduct a triennial full-scale drill for training of emergency response personnel [31]. Other types of exercises are orientation seminars, drills of single emergency response procedures, tabletop exercises, functional exercises, and full-scale exercises.

C. Airport Aviation Services / NOTAMs

Part 139 airports participate in various certified aviation services. The FAA publishes Notices to Air Missions (NOTAMS) to inform flight operation personnel of abnormal statuses of any facility, service, procedure, or hazard in the NAS that is not known far enough in advance to be publicized by other means [45, 46]. NOTAMs are issued for unserviceable taxiway lights, tower obstruction lighting not operating in accordance with current regulations, runway closures, aerobatic aircraft in the airspace, and a change to communication frequency. NOTAMs affect every NAS user, including pilots, airport operator, air traffic control, flight dispatch, and flight service stations (FSS). NOTAMs have different categories like aerodrome, obstruction, airspace, procedure, NAVAID, and Letter to Airmen [47]. For example, on November 18, 2023, Hartsfield-Jackson Atlanta International Airport (ATL) had a total of 40 NOTAMs: 10 aerodrome, 21 procedures, four NAVAID, two obstruction, one airspace, and two service NOTAMS. Los Angeles International Airport (LAX) had 153 NOTAMS: 38 aerodrome, 17 procedures, five NAVAID, 85 obstruction, two airspace, and six letters of agreement (LTA) NOTAMS. According to the Aeronautical Information Manual (AIM), pilots are responsible for being aware of NOTAMs for their flight gathering all information vital to the nature of the flight including at departure and arrival airports [48]. Airline transport pilots are certified on NOTAM collection, dissemination, interpretation, and use [49]. Airports can accomplish safety promotion by use of safety bulletins, which may be higher level in nature and remind employees about safety, or specifics such as a requirement of personal protective equipment in certain areas (e.g., reflective vests).

D. Audits and Inspections

Another technique is the use of airport conducted audits and inspections, such as for ramp and fire safety, augmented with safety observations. FAA Certification Inspectors perform annual audits including checks of the airport's inspection documents. These checks assess how often audits were conducted, what hazards were found, and what mitigations were used over the past two years. Airports must retain records of safety reports, such as PIREPs concerning birds, anonymous safety reports, and voluntary reports from the public about observed hazards. Penalties for company violations and individual citations help ensure responsiveness to correct deficiencies.

E. Airport Safety Data/Databases

The FAA provides airport safety databases involving over 3,957 airports [50]. Database searches can involve 20 categorizations of data, including searches according to airports (e.g., runway/taxiway location, weather phenomena, phase of flight), incidents (e.g., occurrence type, such as accident or runway incursion, surface condition, runway incursion severity category A, B, C, or D defined later in this paper, data sources (e.g., meteorological condition, Part 91, 121, or other type of operation, injuries/fatalities), and key word search, such as "hot spot occurrence." The airport safety database contains FAA-internal sources of data, which are part of the FAA ASIAS program, plus external sources of data:

- FAA Accident and Incident Data System (AIDS) contains 109,186 events from 1978 to February 5, 2024 [51].
- FAA Runway Safety Office Runway Incursion Database contains 31,934 incursions from 2001 to January 31, 2024 [52].
- FAA Vehicle/Pedestrian Deviation System (VPDS) [53], related to FAA guidance on ground vehicle operations including taxiing or towing an aircraft on airport grounds [54].
- The National Transportation Safety Board (NTSB) Accident and Incident Data System contains 420 ground collision accidents/incidents going back some 15 years. These accidents/incidents caused 13 fatalities, 18 serious injuries, and 60 minor injuries [55]. From these data, one investigation contained a safety recommendation, although it was not directed to the airport.
- NASA Aviation Safety Reporting System (ASRS), a confidential voluntary reporting system, collects and de-identifies information from pilots, maintenance technicians, air traffic controllers, and others [56]. ASRS archives the data for routine and special studies on potential air safety hazards [57]. The FAA established the Aviation Safety Action Program (ASAP) to provide guidance on voluntary safety reporting, with the objective to identify hazards and unsafe conditions so that corrective action could be taken to eliminate or reduce the risk [58].

SMS data reporting supports proactive safety in understanding the "big picture" of interdependencies across different parts of airport operations. This safety perspective provides a more thorough assessment of risk exposure and encourages further collaborations among stakeholders, airport safety managers, and others responsible for Part 139 safety management.

Methods used for Part 121 commercial air carriers have been adapted for use in the Part 139 Airports domain. For example, flight deck Line Operations Safety Audit (LOSA) was extended for use in aircraft maintenance and ramp operations in part to encourage air carrier and repair station employees to proactively support aviation safety. Maintenance and ramp LOSA techniques were developed in coordination with airlines, original equipment manufacturers (OEM), and others to leverage already existing similar programs. [59, 60, 61]. Maintenance LOSA was included as part of FAA human factors guidance for aviation maintenance [62]. With recognition of safety culture as an important part of SMS [40, 41, 42], the FAA addressed safety culture with the maintenance workforce through the development of a Job Demands-Resource Model and an employee questionnaire called the maintenance safety culture assessment and improvement tool (M-SCAIT) [63].

Today's Part 139 SMS provides a framework for examining the safety challenges that airport operators, air carriers, and other tenants address through their own respective SMSs and safety collaborations with one another. The FAA AC for SMS at Part 139 airports provides examples of safety data dashboards as visualizations of data analytics and safety trends (see Appendix E, FAA AC 150/5200-37A) [19]. The AC provides multiple sample dashboards that illustrate the different ways that Part 139 airports depict information through tabular data and various chart visualizations. For example, Appendix E-3 presents sample dashboards for ATL that categories data into metric for (a) Action Plan (number of findings + % of change, closure rate % + % change) and Risk Profile (High Risk (HR) % + % HR Change YTD, % to Goal + % Change YTD) into an "At a Glance Dashboard." Additionally, the ATL dashboard further breaks down SMS data into various categories and indicators, providing both tabular data and bar and/or pie chart visualization for: (a) location of safety incident, (b) contributing factors, (c) hazard category, (d) Part 139 indicators, I Responsible Party and/or Department, and (f) risk (not operationally defined in AC). Table 2 presents the tabular data portion of the provide sample AC 150/5200-37A provided ATL January 2023 SMS airport data (Note: Appendix E-3 also provides chart visualizations of these data not shown here).

Table 2. Sample ATL Airport Dashboard Tabular Data [Adapted from [19] Appendix E-3].

LOCATION

	Gates	Other	Ramp	Runway	Taxiway	Throat Area
FREQUENCY	5	7	4	9	0	0
PERCENTAGE	20%	28%	16%	36%	0%	0%
% CHANGE	-51%	not enough data	-46%	872%	-100%	-100%

HAZARD CATEGORY

	FOD	Fuel/Oil/Toxin	Mechanical	Personal	Structural	Wildlife
FREQUENCY	9	4	8	0	0	4
PERCENTAGE	36%	16%	32%	0%	0%	16%
% CHANGE	-23.2%	28%	924%	-100%	-100%	2%

CONTRIBUTING FACTORS

	Equipment Failure	Human Factor	Rules/Standards/Policies	Work Environment
FREQUENCY	9	3	5	8
PERCENTAGE	36%	12%	20%	32%
% CHANGE	1052%	-57%	28%	-32%

RESPONSIBLE PARTY/DEPARTMENT

	Airlines	Airport Maintenance	Airport Operations	Other 3rd Party
FREQUENCY	5	13	4	3
PERCENTAGE	20%	52%	16%	12%
% CHANGE	540%	10.93%	-43%	28%

RISK

	HIGH	MEDIUM	LOW
FREQUENCY	2	15	8
PERCENTAGE	8%	60%	32%
% CHANGE	28%	13%	-21.23%

PART 139 INDICATOR

	Handling/Storage Hazardous material	Noncomplying Condition	Pedestrians & Ground Vehicles	Self-Inspection Program	Wildlife Hazard Management	Aircraft Rescue & Firefighting
FREQUENCY	4	0	4	9	4	4
PERCENTAGE	16%	0%	16%	36%	16%	16%
% CHANGE	24%	0%	148%	-7%	-0.8%	not enough data

F. Airport, Pilot, and ATC Safety Systems

Over the years, airports, the FAA, and operators have fielded different surface surveillance and other systems that support safety monitoring and situational awareness and provide safety alerting for pilot and air traffic controller attention and response [48]. Surface surveillance systems are installed in some of the approximately 500 commercial airports that could benefit from these systems [64]. Examples of these systems may arguably include:

- Runway Visual Range (RVR) allows airports to conduct takeoff and landing operations in low visibility conditions. RVR provides air traffic controllers with a measurement of the visibility at key points along a runway that they can then communicate to pilots and decide whether it is safe to take off or land during limited visibility conditions [65]. RVR system measurements establish airport operating categories so properly equipped aircraft with a trained crew can operate under reduced visibility Category I, Category II, and Category III conditions. An accurate measure of runway visibility decreases diversions and delay. The RVR information affects decisions by airline dispatch and air traffic management (ATM) for whether flight plans should be approved to fly to or take off from an airport with low visibility.
- Low Visibility Operations/Surface Movement Guidance and Control Systems (LVO/SMGCS) [66] is a voluntary FAA program that airports can adopt to enhance safe taxi operations during low visibility conditions. LVO/SMGCS supports surface movement operations of aircraft and ground vehicles in three low visibility levels, i.e., less than RVR of 1200 ft, less than 500 ft, and less than 300 ft and is at the discretion of the airport operator. LVO/SMGCS can be costly, involving changes to taxiways, runways, clearance bars/holding position markings, taxi guidance signing and marking, ramps, apron traffic management, and use of charts, plus other technology enhancements such as airport surface detection equipment (ASDE). To justify the expense, Part 139 airports that employ LVO/SMGCS are either large and/or have historically low visibility [67].
- Airport Surface Detection Equipment – Model X (ASDE-X) systems are installed at 35 airports that use radar and Automatic Dependent Surveillance-Broadcast (ADS-B) to track aircraft and vehicles and provide situational awareness to air traffic controllers to help prevent collisions and reduce runway incursions [64]. Another eight airports have ADS-B Airport Surface Surveillance Capability (ASSC), like ASDE-X, that uses Traffic Information Services – Broadcast (TIS-B) to transmit traffic information to aircraft for display to pilots [68, 69].
- Runway Status Lights (RWSL) systems provide tower air traffic controllers, pilots, and vehicle operators with situational awareness of runway occupancy. The system integrates runway lighting equipment with ASDE-X to provide a visual signal to pilots and vehicle operators indicating when it is unsafe to enter, cross, or takeoff from a runway. Flight vision systems consist of enhanced vision systems (EVS), synthetic vision systems (SVS), combined vision systems (CVS), or enhanced flight vision systems (EFVS) [70].
  - An EVS provides a display of the forward external scene topography through imaging sensors, such as forward looking infrared (FLIR), millimeter wave (MMW) radar, and/or an intensified low-light-level image.
  - An SVS displays a computer-generated image of the external scene topography relative to the aircraft based on aircraft attitude, high-precision navigation solution, and a database of terrain, obstacles, and other features.
  - A CVS would initially use the SVS picture and as the aircraft nears the runway the picture would gradually and smoothly transition to EVS to display the runway environment.
  - An EFVS presents sensor imagery, aircraft flight information, and flight symbology, for example on a head up display, in a manner that is clearly visible to the pilot flying in his or her normal position with the line of vision looking forward along the flight path. EFVS can be certified for approach only (i.e., below 100 ft the pilot uses natural vision to identify the runway threshold or touchdown zone) or for approach and landing [71].
- In response to an ICAO recommendation that standardizes the equipment used to allow pilots to determine visually that they are on the proper glideslope for landing, the FAA ATO is replacing approximately 1,387 older (pre-1970s) visual approach slope indicator (VASI) lights with precision approach path indicator (PAPI) lights. VASI uses either two, four, six, 12, or 16 light units arranged in two or more bars. PAPI uses similar light units but are installed in a single row of either two or four lights [48].
- Distance measuring equipment (DME) is a radio navigation aid used by pilots to determine the aircraft slant distance from the DME base location. DME provides better specification and control over the vertical descent profile, reduces controlled-flight-into-terrain (CFIT) risk, and reduces the need for less desirable step-down, non-precision approach procedures. When critical DMEs are not available, navigation service may not be available because minima criteria is not met for certain terminal area navigation (RNAV) departure

procedures (DP) or Standard Terminal Arrival Routes (STARs) [72]. The FAA lists over 400 critical DMEs relative to specific DPs and STARS at over 70 airports in the NAS [73].

- Pilot electronic flight bags (EFBs) and portable electronic devices (PEDs) (e.g., tablets or personal computers) with applications that replace conventional paper products and tools carried in the pilot's flight bag [74]. An EFB provides a moving map-centering feature showing own-ship position on current airport diagrams with aircraft location accuracy of 5 meters or less.
- The low-level wind shear alert system (LLWAS) is a ground-based sensor system located close to runway approach corridors that detects and warns tower controllers and pilots about intense windshear from microbursts [75, 76].

G. FAA Air Traffic Arrival and Departure Procedures

FAA procedures for arrivals and departures correspond with visual flight rules (VFR) and instrument flight rules (IFR). VFR flight plans require pilots to see-and-avoid other traffic using 500 feet vertical separation; pilots must also comply with basic VFR weather minimums, which are based on airspace class and corresponding altitude [48]. Pilots of IFR flight plans follow an ATC-coded IFR arrival route for a destination airport. STARs may use mandatory speeds (or speed windows) and/or crossing altitudes or provide planning information on expected clearances or restrictions. Performance-based navigation (PBN) STARs require system performance, met by GPS, DME or other precision navigation systems.

Other procedures are used for safe and efficient traffic flows. For example, a local flow traffic management program may help minimize the impact of aircraft noise by permitting departure aircraft to climb to higher altitudes and more quickly maneuvering low altitude arrival aircraft. Minimum safe altitudes (MSA) shown on instrument approach procedure (IAP) and departure procedure charts provide 1,000 feet of clearance over obstacles.

RNP Authorization Required (AR) Approach IAPs require authorization analogous to the Special Aircraft Authorization Required (SAAR) for Category II or III Instrument Landing System (ILS) procedures. Authorization Required (AR) procedures may only be conducted by aircrews meeting special training requirements in aircraft that meet the specified performance and functional requirements [77].

H. Airport Safety Practices and Safety Data Sharing with Airport Industry Organizations

Public and industry organizations provide important support and guidance regarding airport safety systems. The Airport Cooperative Research Program (ACRP), as part of the National Academies and its Transportation Research Board (TRB), reviewed airport safety reporting systems. The objective was to identify methods and systems used by Part 139 airports for safety reporting and data analysis. Airport types responding to the survey included large, medium, small, non-hub, general aviation, and joint civilian/military joint-use airports [11].

Airports often share safety data through technical and management surveys from the Airport Cooperative Research Program (ACRP), Airports Council International-North America (ACI-NA), and American Association of Airport Executives (AAAE).

IV. Airport Diagrams

Airport diagrams support the movement of ground traffic at locations with complex runway/taxiway configurations [78]. FAA policy requires that airport diagrams show important information for public-use airports, including operational runways, runways under construction, closed runways, dimensions and orientation of runways, displaced thresholds, operational and closed taxiways and their designations, and airport facilities [79], such as shown in Fig. 2 of the Harry Reid International Airport (LAS) in Las Vegas [80]. This diagram meets Interagency Air Committee specifications [78].

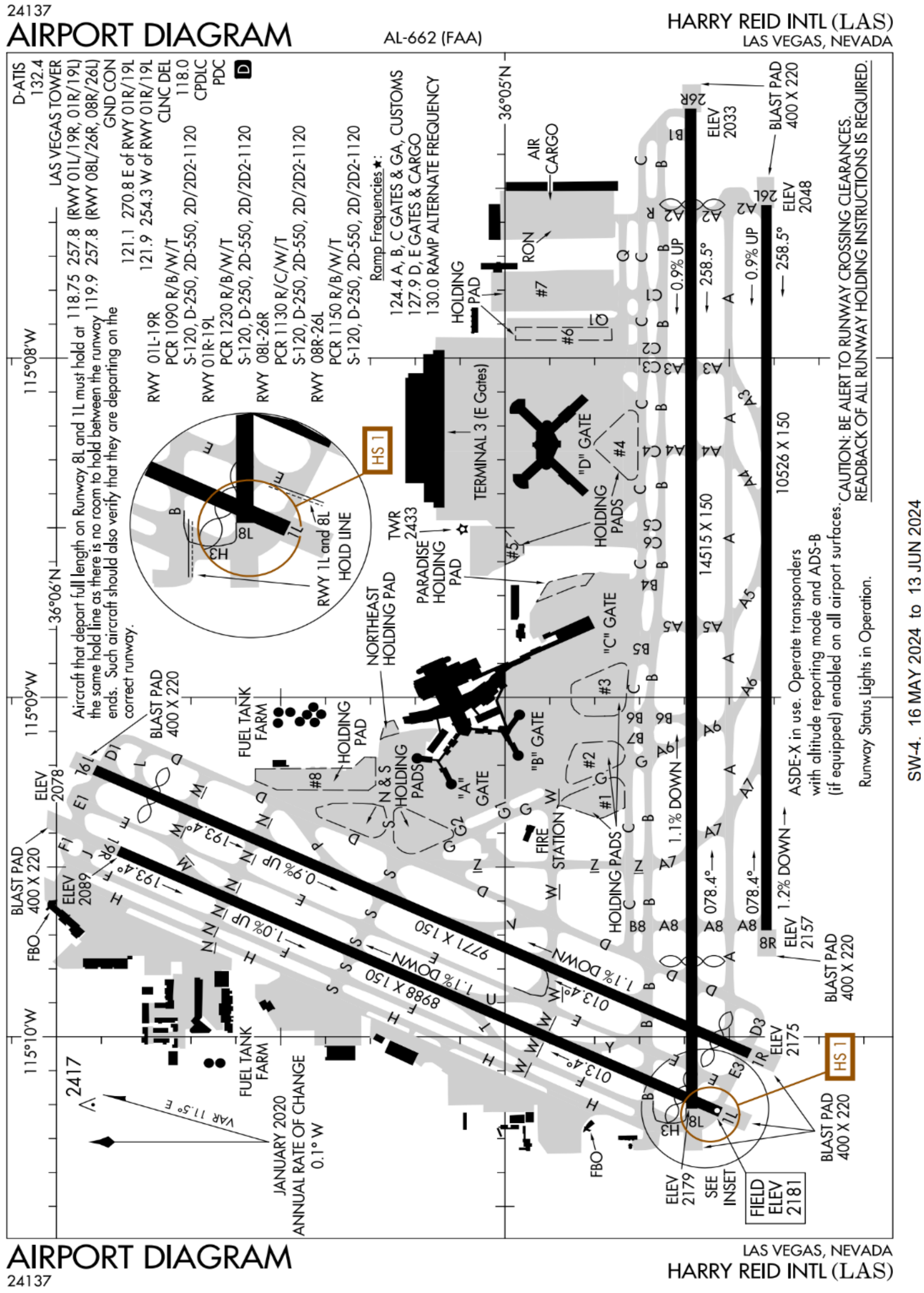

Figure 2. Airport Diagram for Harry Reid International Airport (LAS) [80].

According to the ACRP, apron and ramp markings provide accurate guidance to pilots, ground vehicle and equipment operators, and emergency first responders [81]. The terms apron and ramp are generally interchangeable and are non-maneuvering areas managed by an airport or airline operator, i.e., tower ATC communicates with the pilot when the aircraft enters the maneuvering area or in communication with ramp control, etc.). These markings denote specific categories of airport paved surfaces including commercial terminal gate areas, taxi lanes, aircraft hardstands, deicing areas, vehicle service roads, and helicopter takeoff and landing areas. Inspection of all markings, signage, and lighting is the responsibility of the certificated airport as part of their certification requirements. In its survey of airport practices, the ACRP found several challenges, e.g., inconsistent use of terminology. Airlines have different standards for terminal gate apron markings, marking aprons for aircraft of different sizes are different across airports such as using different colors for centerlines, and indications of surface-painted wingspan restrictions may use Airline Design Group measurement categories rather than feet. Pilots typically prefer lead-in lines that extend to the taxi lane centerline to reduce the amount of judgment a pilot must exercises when positioning the aircraft at the gate.

Digital chart supplements provide data not readily depicted in graphic form on airport diagrams. For the LAS airport, the remarks section provides detailed safety and other operational information, such as aircraft operating near the intersection of Taxiways S, D, G, and the north end of Taxiway Z should be prepared for closely aligned taxiway centerlines and radius turns, a large number of birds and bats seen in vicinity of the airport, and reflection of the sun from glass hotels located northwest of the airport [82].

Noise abatement procedures pertain to departures and for arrivals involve charted visual flight procedures (CVFP) that provide a pictorial display of visual arrival routes/altitudes to enhance noise abatement at some locations. Noise abatement may bring aircraft closer together on takeoff and departure as well as change trajectories in/out of airports closer to terrain and other hazards repeatedly over certain neighborhoods [83].

V. Part 139 Safety Challenges

While some safety considerations are unique to large airports, the Core 30 airports share many of the same hazards and risks with medium-sized and smaller airports. Some airport hazards, risks, and mitigations involve multiple stakeholders who may share data and information about incidents. A risk mitigation for one stakeholder could pose a hazard to another stakeholder, which underscores the importance of collaboration in monitoring, assessing, and mitigating risk. Operational safety threats and hazards that pose risk to flight, crew, worker, and passenger safety are described in the following sections.

FAA airport safety research includes annual reporting from its airport safety database and databases for FOD and wildlife strikes, paint marking reflectivity and chromaticity, and case studies of vertiport infrastructure needs such as large hubs and off-airport facilities that may affect air traffic control [84]. Other safety projects and directed studies include UAS operational applications on airports, aircraft rescue and firefighting, airport environmental and noise issues, and airports surface safety. Select safety hazards and threats, and how they are managed currently, are described next to provide case examples of the safety challenges confronting today's Part 139 airports.

While some safety challenges are common to the ecosystems of all Part 139 airports, other challenges are specific to individual airports. The following section provides an extensive listing of these Part 139 airport challenges but should not be considered exhaustive.

A. Runway Incursions

ICAO and the FAA define a runway incursion as "any occurrence at an aerodrome involving the incorrect presence of an aircraft, vehicle or person on the protected area of a surface designated for the landing and take-off of aircraft" [85, 86]. It is distinguished from surface incidents which are, "an unauthorized or unapproved movement within the designated movement area (excluding runway incursions) or an occurrence in that same area associated with the operation of an aircraft that affects or could affect the safety of flight" [86].

The FAA uses a Surface Safety Metric (SSM) to identify and assess the severity of risks in the runway environment [87]. Whereas earlier metrics were based on the number and severity of runway incursions, the SSM includes all types of relevant events that occur in the runway environment. Part of SSM development involved use of accident and incident data sources to validate algorithms using a weighting scheme to measure the outcome of accidents (e.g., injuries to people and damage to property) and probabilistically determine the severity of incidents having no outcome. The SSM has been used as a foundation for development of an airside risk model [88].

There are four categories of runway incursions not classified as resulting in a collision (accident) [86]:

- Category A – A serious incident in which a collision was narrowly avoided.
- Category B – An incident in which separation decreases, and there is a significant potential for collision (requiring time-critical corrective/evasive response to avoid a collision).
- Category C – An incident characterized by having ample time and/or distance to avoid a collision.
- Category D – An incident that meets the definition of runway incursion (e.g., incorrect presence of a single vehicle/person/aircraft on the protected area of a surface designated for the landing and take-off of aircraft) but has no immediate safety consequences.

As evidenced in Table 3, the number of runway incursions has increased over the period 2018 to 2023. This is true for both Part 139 certificated airports and non-certificated airports. The most serious category A and B incidents have increased at certificated and non-certificated airports. Please note, the following table is for illustrative purposes only, and there is a possibility that an airport was not Part 139 certified at the time the runway incursion occurred there.

Table 3. Runway Incursion by Severity, Calendar Year 2018 vs 2023 [89].

	CY 2018		CY2023	
	All Airports	Part 139 Airports	All Airports	Part 139 Airports
Severity A	4	2	8	4
Severity B	6	3	16	14
Severity C	701	557	700	495
Severity D	1069	711	1202	803
Incomplete Information to Classify	11	9	5	2
Total	1791	1282	1931	1318

Runway incursions are also classified by who was responsible: the pilot , the air traffic operation, a vehicle / pedestrian, or other. Table 4 compares runway incursions by type between 2018 and 2023 and, again, is for illustrative purposes only.

Table 4. Runway Incursions by Type, Calendar Year 2018 vs 2023 [89].

Responsible party	CY 2018	CY 2023	Increase
Pilot	1125	1201	7%
Air Traffic Operation	325	367	13%
Vehicle or Pedestrian	331	322	-3%
Other	10	41	310%

The number of runway incursions are generally rare. However, through August 2023, 985 runway incursions were recorded, reflecting a runway incursion rate of 31 per million takeoff and landings that year. In 2022 the rate was 32, and in 2021, it was 34. Over the past decade, runway incursions peaked at 35 per 1 million takeoffs and landings in 2017 and 2018 [89]. FAA runway safety technologies to improve situation awareness and alerting include:

- Runway Status Lights (RWSL)
- Airport Surface Detection Equipment, Model X (ASDE-X)
- ASDE-X and ASSC Taxiway Arrival Prediction (ATAP)
- Electronic Flight Bag (EFB) with Moving Map Displays
- Runway Safety Areas
- Runway Incursion Mitigation (RIM)
- Hot Spot Standardization (described in ICAO Document 9870, section 3.4, Hot Spots [85])
- Arrival Alert Notices
- Automated Closure Notice Diagrams

Runway incursions involving a vehicle or pedestrian are rare events but can have a serious consequence. During a 2022 training drill exercise in Lima, Peru, an Airbus A320 aircraft collided with a fire truck on the runway during takeoff, resulting in in the deaths of two firefighters [90]. The probable cause of the collision was the firetruck entering the runway without explicit authorization from the control tower while conducting a response time exercise [91]. Possibly the worst runway incursion accident in the U.S. occurred on February 1, 1991, when a Boeing B737-300 collided with a Fairchild Metroliner at Los Angeles International Airport (LAX) and resulted in 34 fatalities [92]. The probable cause of the accident was an ATC failure to implement redundant procedures, which led to "the failure of the local controller to maintain an awareness of the traffic situation, culminating in the inappropriate clearances." Over the last twelve years, there have been only 3 fatal runway incursion accidents in the U.S. causing three fatalities. All three of these accidents occurred at non-Part 139 airports without control towers. [93]

B. Runway Excursions

According to ICAO (and adopted by the FAA), a runway excursion is "any occurrence at any aerodrome involving the departure, wholly or partly, of an aircraft from the runway in use during take-off, a landing run, taxiing or maneuvering [94]. The surface events occur during aircraft taxi, takeoff, and landing, and have many etiologies, such as unstable approach or runway condition (e.g., wet runway where braking action is minimal or nil). A study conducted by the Runway Safety Initiative (a joint effort between Flight Safety Foundation and IATA) found that 97% of runway accidents were caused by runway excursions with a rate of approximately 30 events per year for commercial air carriers (25% of all accidents) [95]. The study further reported that landing excursions (79%) outnumbered takeoff (21%) excursions almost 4 to 1.

For takeoff events, the most common cause of runway excursion was rejected takeoff after the aircraft had reached the maximum speed in the takeoff at which the pilot must take the first action (e.g., apply brakes, reduce thrust, deploy speed brakes). For landing excursions, go-around not conducted was the most significant reason for the event. There are many interacting reasons underlying the causes that can be grouped by flight operations (e.g., rejected takeoff), air traffic management (e.g., failure to descend aircraft appropriately for approach), aircraft manufacturers (e.g., lack of appropriate aircraft operational and performance data information provided), regulators (e.g., inadequate regulation/oversight), and airports. Specifically for Part 139, risk factors include the following:

- Runways not constructed and maintained to maximize effective friction and drainage
- Late or inaccurate runway condition reports
- Inadequate snow and ice control plans
- Not closing a runway when conditions dictate
- Incorrect or obscured runway markings
- Failure to allow use of wind-preferential runways
- Inadequate runway end safety areas or equivalent system
- Inappropriate obstacles assessments

Runway excursion mitigations for airport operators include policies (e.g., criteria when to close a runway) and standard operating procedures (e.g., timely runway condition reports), and technology. An example of a technological solution to mitigate the severity of runway excursion are engineering materials arresting systems (EMAS), which is deployed at more than 100 U.S. airports [96] designed to address issue of runway overruns. An overrun occurs when an aircraft tries to land or abort a takeoff and in so doing passes beyond the end of the runway. One form of EMAS is a foamed silica bed made from recycled glass in a strong plastic mesh system that crushes beneath the tires and slows the aircraft. FAA regulation extends runways to provide safety areas for decreasing the probability of an aircraft overrunning the runway by giving the aircraft more space. Part 139 describes a safety area as a defined area comprised of either a runway or taxiway and the surrounding surfaces that is prepared or suitable for reducing the risk of damage to aircraft in the event of an undershoot, overshoot, or excursion from a runway or the unintentional departure from a taxiway.

One example of runway overrun occurred on October 17, 2019. A Peninsula Aviation Services Saab 2000 overran the runway at Alaska's Unalaska airport (DUT), resulting in one fatal injury and one serious injury [97, 98]. The NTSB cited that a contributing factor to this accident was the FAA's lack of consideration of the runway safety area when allowing the Saab 2000 to operate at this airport. An EMAS was considered as part of the runway safety area but found not to be practical. The NTSB did not cite the lack of an EMAS as a contributing factor, nor did it consider whether an EMAS would have mitigated the risk. Through October 2023, EMAS systems could have safely stopped 21 overrunning aircraft (Parts 121, 135, and 91), carrying 430 crew and passengers aboard [99].

Combinations of different factors can lead to other types of runway excursions. For example, Delta Flight 1086 landing at New York's LaGuardia Airport (LGA) on March 5, 2015, encountered a snow-covered runway, low ceiling, and a crosswind landing. The aircraft veered off the runway and came to rest with the nose over the berm above Flushing River. There were no fatalities, but 24 people were injured [100].

C. Foreign Object Debris

The FAA defines FOD as "any object, live or not, located in an inappropriate location in the airport environment that has the capacity to injure airport or air carrier personnel and damage aircraft" [101]. As stated in AC 150/5210-24 [101], the presence of FOD on an airport air operations area (AOA) presents a significant risk. It has potential to damage aircraft during critical phases of flight, which can lead to catastrophic loss of life and airframe and increase maintenance and operating costs. FOD can result from personnel, airport infrastructure (pavements, lights, and signs), the environment (wildlife, snow, and ice), and the equipment operating on the airfield (aircraft, airport operations vehicles, maintenance equipment, fueling trucks, other aircraft servicing equipment, and construction equipment). Some examples of FOD include [101, see page 10]:

- Aircraft and engine fasteners (nuts, bolts, washers, safety wire, etc.)
- Aircraft parts (fuel caps, landing gear fragments, oil sticks, metal sheets, trapdoors, and tire fragments)
- Mechanics' tools
- Catering supplies
- Flight line items (nails, personnel badges, pens, pencils, luggage tags, soda cans, etc.)
- Apron items (paper and plastic debris from catering and freight pallets, luggage parts, and debris from ramp equipment)
- Runway and taxiway materials (concrete and asphalt chunks, rubber joint materials, and paint chips)
- Construction debris (pieces of wood, stones, fasteners, and miscellaneous metal objects)
- Plastic and/or polyethylene materials
- Natural materials (plant fragments, wildlife, and volcanic ash)
- Contaminants from winter conditions (e.g., salt from snow and ice removal)

A study on FOD at Chicago O'Hare International Airport (ORD) characterized debris found during routine daily and monthly runway inspections on an active runway [102]; a mechanical sweeper, magnet bar, and laborers collected FOD. Findings showed that more metal items were found in winter months; samples weighed between 10 and 20 lb., with one sample weighing almost 50 lb.; winter samples found more asphalt, tar, and concrete items present; and a very small percentage of FOD items were identified as hazards that could cause or lead to aircraft damage. Current mitigations include implementation of a FOD management program (e.g., prevention awareness, training, maintenance, detection initiatives, and continuous improvement programs) and the effective use of FOD detection and removal equipment [103].

D. Wildlife Strikes

Luckily, most wildlife encounters are minor or insignificant [104]. The FAA has tracked wildlife strikes over time in a database showing almost 272,000 U.S. airport wildlife strikes (1990–2022) with about 17,000 strikes at 693 U.S. airports in 2022 alone [105]. Wildlife is a continuous hazard. For example, Part 139 airports in Florida saw 8,977 wildlife strikes and 458 damaging strikes (2011–2020). Most strikes occurred during the arrival phase of flight with the risk higher during fall and summer seasons according to a study involving Part 139 airports in Florida [106]. On March 4, 1999, a USA Jet airlines DC9-15 aircraft encountered a flock of large birds while on final approach to Kansas City International Airport (MCI). The strike resulted in a partial power loss in both engines. In response to this accident, the NTSB recommended that the FAA conduct wildlife assessments at all Part 139 airports and require the development of a wildlife management program for all appropriate airports. In addition, the NTSB recommended that the FAA require all airplane and airport operators to file mandatory occurrence reports on bird strike incidents [107]. FAA regulations for airport wildlife hazard management include guidance on when a wildlife hazard assessment must be conducted (e.g., an air carrier experiences multiple wildlife strikes). A wildlife damage management biologist conducts the assessment and the analysis of event(s), identifies wildlife species, and documents information about features on and near the airport that attract wildlife [108]. Some airports that experience frequent wildlife encounters, such as Denver International Airport, proactively develop and tailor wildlife hazard management plans [109].

E. Additional Safety Challenges

There are a myriad of hazards and threats that present significant risk to Part 139 operators and their tenants and necessitate more in-time safety tools and capabilities for airports. There are additional challenges for which cumulative safety data are not readily available. Rather, incidents tend to be infrequent or under-reported so that individual occurrences represent anecdotal instantiations of what occurred and why. These descriptions can be summarized based on available information from varied sources.

Unauthorized Drone Operations

Drones or UAS can cause significant safety concerns in an airport environment, most notably, as severe risk involving collision with other aircraft. The FAA receives more than 100 reports of drone sightings each month While it is illegal to operate around certain Part 139 airports without authorization, the FAA reported that in June 2023, there were almost 200 UAS sightings reported, most near airports [110]. FAA rules exist to protect aircraft from drones, but these are often violated either knowingly or unknowingly by drone operators. The issue of unauthorized drone activity around airports is an international problem. An example is the 2023 case of Emirates A380 flight EK77 that suffered leading-edge wing slat damage after a suspected midair collision with a UAS during landing at an airport in Nice, France [111]. Previously it was nearly impossible to locate illegal UAS operators but as of September 16, 2023, all UAS must be equipped with Remote ID, which will allow any UAS to be located and its registered operator [112]. However, there are no plans to store UAS flight data by the FAA. Intentional drone unauthorized operations are also serious threats to Part 139 airports representing substantial risk to aircraft operations (e.g., drone use for terrorism or intentional attacks) requiring SFCs to address (e.g., geo-fencing, electronic drone disablement/jamming technologies).

Un-Stabilized Approaches

The Flight Safety Foundation reported that those un-stabilized approaches involving high-energy descents (i.e., too high/fast) can result in runway overruns and runway excursions [113]. Flight handling difficulties have caused serious injuries and were a causal factor in 45 percent of 76 approach-and-landing accidents worldwide (1984 through 1997).

Near-Misses During Go-Around

Near misses may occur with departure traffic during go-arounds. For example, when arrivals and departures use the same runway, an arriving aircraft should not land before the departing aircraft lifts off from the runway to avoid two aircraft situated on the same runway. The controller would instruct the arriving aircraft to execute a go-around.

Gate Operations and Aircraft Servicing

According to the FAA AC for Airport SMS [19], hazards at the gate associated with aircraft servicing include:

- Spillage of fuel, oil, and toxins
- Mechanical hazards (e.g., ramp maintenance hazards)
- Personal hazards (e.g., slips or falls on wet external jetway stairs)
- Structural hazards (e.g., garage door closing on a service vehicle)

These hazards may also be relevant to aircraft in the apron while not in service. Accidents and injuries may occur during onboarding and deplaning of passengers and with baggage handling (i.e., loading, unloading; and transport on apron movement areas). Findings from the IATA 2023 worldwide safety audits of ground operations included the following safety challenges [6]:

- Aircraft handling and loading challenges included operational documents accessibility, ground service equipment maintenance program, operational procedures, job specific training, driving speed, airside driving training and licensing, water quality standards, lavatory services procedures/handling, and potable water servicing operations.
- Load control challenges included operational documents accessibility, manual weight and balance, load control communication, use of valid manual load documentation, job specific training, load sheet accuracy, load planning person having access to load control data, and the load itself.
- Passenger and baggage challenges included operational documents accessibility, training program, security screening equipment calibration, security event reporting, boarding pass issuance, carriage of weapons by law enforcement officer and passenger, cabin baggage size/weight/quantity, and transfer of information and data to load control.

Aircraft and Ground Vehicle Collisions

Ground vehicle collisions include colliding with an aircraft, another ground vehicle, or pedestrian. Ground vehicles include first responders (police, ARFF, and ambulance), fueling trucks [e.g., 114], tugs, baggage carts, airport operations vehicles, aircraft maintenance vehicles, and catering trucks. In the Asiana Flight 214 accident in 2013 at

San Francisco International Airport, a passenger not wearing a seat belt during landing was ejected from the aircraft and later ran over by two firefighting vehicles [115].

The layouts of some airport could present unique hazards, such as when aircraft parking ramps are placed close to runway or taxiway access.

Equipment Failures

Equipment failures most often result from power loss to critical equipment, and some may result in loss of communications or data links. Certificated airports typically have at least two main power feeds for critical systems, e.g., airport lighting with backup generators for emergencies and other situations that are time sensitive. For example, airports accepting arrivals using a Category III Instrument Landing System (CAT III ILS) must have generator support running while accepting Category III arrivals, and the lighting must be inspected so that a switch from main to generator power can be completed within no more than five to 10 seconds to support those operations. This cutover must be inspected and verified by the airport before allowing CAT III ILS approaches.

Airport Location

The physical location of an airport can itself represent a hazard. For example, in 1992, during EL AL cargo flight 1862 departure from Schiphol airport, two engines were lost (3 and 4), and, due to loss of control from asymmetric thrust, the aircraft crashed into an 11-story apartment building [116]. Fatalities included the crew and 39 people on the ground. Airports that are inside metropolitan areas can also pose a hazard (e.g., JFK, EWR, LGA, ATL, DFW, SFO). JFK is an example of an unusual airport where its "Canarsie approach" requires a steep turn over the Canarsie Very High Frequency Omni-Directional Range (VOR) transmitter around 800' AGL, which can make meeting normal stable approach criteria difficult. Washington-Dulles International (IAD) when first opened was set in a rural area outside of metropolitan Washington, DC, and over many years suburbs grew and encircled the airport.

In addition, the terrain surrounding an airport can affect safety as evidenced by the mountainous terrain at the airport in Aspen, CO (ASE). In 2014 one person was killed and two were seriously injured in the crash of a Challenger business jet arriving ASE. Contributing to the accident was the flight crew's decision to not conduct a go-around when the approach became unstable. This decision was influenced by the steep climb required to clear several mountains on a missed approach, although post-accident analysis showed the aircraft could have cleared all obstacles [117].

Adverse Weather

Adverse weather conditions can influence airport operations, and microbursts and winter/ice operations also have effects on aircraft operations. An example of a fatal accident involving a microburst during departure was Pan Am Flight 759 at Louis Armstrong New Orleans International Airport (MSY) on July 9, 1982. 145 persons on board the airplane and 8 persons on the ground were killed in the crash. The NTSB determined the probable cause of the accident was the plane's encounter during liftoff and initial climb phase with a microburst-induced windshear that imposed a downdraft and decreasing headwind [118]. The pilot would have had difficulty recognizing and reacting in time to prevent the airplane's descent before its impact with trees.

An example of a fatal accident involving a microburst during approach was Delta Air Lines Flight 191 at Dallas Fort Worth International Airport (DFW) on August 2, 1985. 134 passengers and crewmembers were killed in the crash and 29 survived. The NTSB determined the probable causes of the accident were the flight crew's decision to initiate and continue the approach into a cumulonimbus cloud observed to contain visible lightning and the lack of procedures and training for avoiding and escaping low-altitude windshear [119]. There was a lack of definitive, real-time windshear hazard information in both MSY and DFW microburst accidents.

Several accidents have been attributed to accumulation of snow and ice on airplane engines and wings. Air Florida Flight 90 crashed upon departure from Washington National Airport (DCA) in 1982 due to failure to use engine anti-ice protection [120]. 74 crew and passenger fatalities and four occupants of vehicles were killed on the bridge next to the airport. At Detroit Metropolitan/Wayne County Airport (DTW), ice accumulation on the wings combined with low airspeed and retracted flaps resulted in adverse effects on both lift and drag, leading to the crash of Comair Flight 3272 in 1997 [121].

Deicing operations can also pose hazards such as equipment striking an aircraft and deicing fluid spillage and seepage outside of the deicing area. Clearing runways and taxiways of snow can pose runway incursions from vehicle deviation hazards.

Natural Disasters

Natural disasters can wreak havoc on airport infrastructure. For example, Hurricane Katrina caused over $55,000,000 in damage to MSY, including significant damage to a concourse roof [122]. Since airports play an important role in natural disasters, such as providing a base for emergency operations during the event, in the collection and evacuation of people, and transportation of critical supplies, it is crucial to maintain the highest levels of safety possible. That said, Part 139 airports must account for natural disasters in their Part 139 airport safety management plan.

Earthquakes are another example of natural disasters that airports must address in their Part 139 airport safety management plans. A magnitude 4.8 earthquake in 2024 in New Jersey resulted in the FAA temporarily grounding all flights at Newark (EWR) and JFK Airports [123]. Internationally, earthquakes are more prevalent in occurrence and can inflict more damage on airports. For example, a magnitude 7.8 earthquake in 2023 struck Turkey splitting the only runway at the airport in Hatay Province [124]. In 2010, one of the co-authors of this paper experienced firsthand a magnitude 8.8 earthquake near Concepción, Chile and dozens of aftershocks ranging from 5.4 to 6.9 in magnitude. Within 6 months, over 20,000 more aftershocks were recorded. The earthquake and aftershocks caused extensive and severe damage to the Santiago International Airport (SCL) that closed all flight operations for multiple days [125].

During a disaster, operational risks may further escalate due to human stress and fatigue. Over the course of a pandemic, for example, an airport needs to provide a safe working environment for employees and passengers. It also needs to consider a decline in human proficiency the longer a pandemic persists, and potential issues with aircraft and other vehicles if grounded for an extended period.

Security Hazards

Security threats, while not falling under Part 139, may pose threats to airport safety, including TSA security breaches that lead to employee stress and distraction, concourse closures, and aircraft delays. If there is a security incident in a particular terminal (e.g., someone pushed a fire door open to access the ramp), the entire concourse/terminal must be emptied and everyone screened a second time, resulting in significant delays and frustrations. Cybersecurity threats are also significant potential risks that need to be assured against in Part 139 SMS and safety safeguards put in place (e.g., SFCs).

Vehicle Accidents

One of the most concerning vehicle threats is when ground vehicles strike aircraft. These accidents may result in catastrophic injury or death and can cause major ground damage. Most incidents happen when the aircraft is parked (e.g., during maintenance and loading and unloading passengers or cargo). Many incidents involve use of jetways for crew and passenger movements. The parts of aircraft that usually sustain damage in such cases are the fuselage (especially the doors) and the engines [126].

Ground damage can also occur during aircraft towing, which typically results in damage to the landing gear, wings/wing tips, or empennage. Comparatively, taxiing aircraft encounter ground events relatively less often.

Airports can have the same types of traffic accidents compared to an average downtown but with lower frequency of occurrence. This includes vehicles striking people or other vehicles that may be moving or stationary or catching fire. Low visibility conditions can result in accidents such as when driving too fast relative to apron conditions.

Airport Tenant-Related Hazards

Hazards and threatening conditions result from operations of airport tenants. For example, food and beverage service carts can pose hazards while loading and unloading carts on an aircraft. Catering carts may have weight limits to avoid potential injuries to cabin crews during turbulence. Catering service providers can be under demanding time pressure for aircraft loading and unloading as well as service vehicle operations on the airport apron. Catering service providers are confronted with rapidly changing carts to accommodate last-minute changes in aircraft, e.g., carts for a 767 are differently sized compared to carts for a 757 [127]. In addition, their employees may complete loading and unloading while exposed to adverse weather conditions.

Electronic Hazards

Electronic threats include laser strikes and GPS jammers. Lithium batteries incidents can involve smoke, fire, or extreme heat. Through May 15, 2024, there have been 22 verified incidents year-to-date, and 530 verified incidents from 2006 to April 24, 2024, with spikes in 2022 (74 incidents) and 2023 (77 incidents) [128]. Lithium battery fires are difficult to control once started.

Human Performance

Hazards related to human performance may include fitness for duty, human error, drift from operational procedures, and fatigue exacerbated by working under stress conditions over long hours in demanding situations. While FAA air traffic controllers operate most ATCTs, responsibility for tower siting and development are the responsibility of the local airport authority and, therefore, human performance concerns are also within purview. The importance of ATCT design was scrutinized when controllers at Miami International Airport (MIA) reported that the thick columns supporting the tower cab roof blocked their view of a runway, approach paths of airplanes, and ramps. The oversight cost some $5,000,000 to replace the top of the ATCT [129, 130].

Medical Emergencies

Medical emergencies may involve airport workers and passengers on an aircraft, ramp, concourse, or terminal and can pose a hazard to normal operations [131]. For example, a worker may experience a medical issue during aircraft fueling or while driving a catering truck in a movement area. Medical emergencies can lead to aircraft diversions (and their associated issues) bringing first responders into unfamiliar airport locations, and dealing with stressed family members.

Operational Tempo

The tempo or pacing of operations corresponds with the size of an airport and whether it serves as a hub for an airline. Time pressure can lead to stress and can be exacerbated when, for example, the FAA fines an airline when an aircraft sits on an apron or taxiway for excess time. Tempo may also affect gate and ramp operators and flight and cabin crews.

Baggage Handling Hazards

Multiple safety hazards may occur during baggage handling, which involves manual lifting as well as baggage handling and sorting systems and equipment. Some of this equipment may be underground, presenting challenges when airline and airport employees must access that restricted space when a bag gets stuck.

Passenger Transportation Hazards

Trams and moving walkways may pose hazards for passenger transportation. Trams will not move if a door is held open or someone purposefully or inadvertently blocks a sensor. Moving walkways may trap clothing in the mechanism or be associated with trips and falls. Courtesy carts can pose a hazard as they are driven navigating around walking and stationary people [132].

Personal Injuries and Death

Some outcomes involve injury to body parts, such as back and finger/hand injury, that are also tracked as part of the Occupational Safety and Health Administration (OSHA) requirements. Airport safety accidents and incidents can be tracked as days since last recordable incident, total of recordable incidents, and OSHA-specific number of days away from work or days of restricted work activity/job transfer [133]. There are also incidents where people have been ingested by aircraft engines and struck by propeller blades.

In summary, since airport hazards and challenges have several cross-cutting aspects, it is necessary to understand incidents and accidents more fully. While some airports share common hazards such as bird strikes and FOD, some hazards are unique to particular airports (e.g., locations of hotspots). The sharing of safety data with commercial air carriers and other tenants is necessary to ensure that a risk mitigation for one party does not present a hazard to another party. This broader perspective is critical in the identification of proactive steps and the prevention of future incidents and accidents. The IASMS intersection includes new ways of creating data systems for the future, including identifying hidden trends and precursors to proactively and predictively manage/mitigate system risks.

VI. In-Time Safety Needs for Airports

The National Academies identified the three key safety functions of monitor, assess, and mitigate critical for in-time safety management [13] pertinent to airport SMS. Monitoring the NAS involves collecting data on the status of aircrafts, ATM systems, airports, weather, and other information and data. Assessing these data may occur in real-time, second-by-second, minute-by-minute, and hour-by-hour to detect and predict elevated risk states. Data would also be assessed over longer periods of time to detect risks based on longer-term trends and to identify emergent risks. Detecting and predicting elevated risk states can result from a combination of factors, none of which would be noteworthy by itself. Assessing data is based on the nominal performance of systems and operators, historical data about the occurrence and consequence of off-nominal situations, as well as the fault tolerance of the NAS and its key elements. In-time safety assurance actions to mitigate a hazard or risk can involve recommendations for operator action or, when the risk is elevated, IASMS may be designed to initiate safety assurance action on its own to mitigate the situation.

The need to address safety must consider and integrate operational challenges (e.g., capacity constraints, congestion, delays/cancellations, etc.) with business constraints (e.g., revenue loss, competition, and markets); the faster and more effectively risks are managed, the less likely hazards and threats emerge and impact airport flow rate. The concept of "in-time" safety SFCs offers a modular, tailorable, scalable, effective, and responsive means for airport hazard mitigation, risk management, and a "learning from all operations" safety capability [134, 135, 136].

As a future vision, the FAA has developed concepts for NAS modernization, including how airport operators make increasing use digital information [137]. The FAA envisions vertiports used for electric Vertical Takeoff and Landing (eVTOL) aircraft operations will have SMSs that follow the same basic format as Part 139 SMS; NASA has extended the IASMS concept to vertiport design and operation [138]. Vertiports may be co-located at airports, located in urban/suburban/rural settings, and integrated as part of today's helipads. Vertiports of a certain size may have a vertiport operator (VO) on-site whereas smaller vertiports may have a remote VO. The FAA's concept includes continuous system-to-system communication to share location and intent information across vehicles, subsystems, and ATM stakeholders, including airports [137]. Evolving infrastructure needs include airport physical infrastructure for managed services (e.g., communications, aeronautical information, and weather services) and commercial services, such as catering. As part of the FAA vision of future urban air mobility (UAM), airport access could be coordinated by providers of services for UAM (PSUs) without direct FAA involvement on a flight-by-flight basis [139]. Airport access may also include automated systems coordinating arrivals and departures at an airport.

The NASA Sky for All vision circa 2050 envisions the future aviation system to monitor, assess, mitigate, and assure the integrated safety of the system [140]. The concept of operation achieves this by "identifying hazards, managing risk, facilitating mitigation actions, and building in Design for Safety throughout for whole system performance" [141].

VII. IASMS for Part 139 Airports

The evolution of today's SMS to the future IASMS enables introduction of advanced technology to achieve a higher level of safety performance in design and operations that helps ensure that systems perform as intended [13]. Overall justification of the IASMS is based on the critical need to augment and improve upon today's SMS for addressing future airport safety needs and to align with several areas of emphasis:

1) In-time: Through in-time integrated safety management, the IASMS creates a more responsive and expedient SMS. This will entail faster detection, identification, and mitigation of known hazards and emergent risks.
2) Effective: IASMS improves the mitigation effectiveness of SMSs. Effectiveness will be achieved if the monitor, assess, and mitigate functions are tailored to address specific risks or classes of risks. A process to identify and prioritize those risks must be one capability.
3) Scalable: The system scales for different operations tailored for the operator size, mission, aircraft, and airspace.
4) Modular/Interoperable: IASMS supports modular interoperability across different operators, service providers, original equipment manufacturers (OEMs), and the FAA for sharing data.
5) Assured: IASMS provides in-time safety assurance and resiliency in nominal and non-normal situations.
6) Teaming: IASMS improves the design and operational use of automated safety systems with the human for transparent, trustworthy, and resilient human-machine/-autonomy/-automation teaming (HMT/HAT).
7) Value: IASMS supports the safety business case for gaining FAA certification and public acceptance.

The continuous loop for in-time integrated safety management is comprised of three higher-level functions called Monitor, Assess, and Mitigate13, 15, 16]. These functions, shown in Fig. 3, involve domain-specific safety monitoring and alerting tools, integrated enhanced proactive and predictive technologies with domain-specific applications, and in-time safety threat management. These functions can be described as [142]:

- Monitoring function observes and characterizes the system state by collecting, fusing, and assessing data from a variety of sensors. Monitoring is conceptualized as a set of information services and an underlying architecture that allows for acquisition, integration, and quality assurance of heterogeneous safety-relevant data that may come from a diverse set of sources (including vehicles).

- Assessing function is enabled by sophisticated analytics functions and algorithms that (1) identify and characterize known risk states in the time frame of interest to an IASMS and (2) examine large volumes of stored flight and ground operations data with anomaly detection methods to identify and characterize emergent risks and to update IASMS risk assessment algorithms. Assessment has been defined as, "a set of tools and techniques that provide timely detection, diagnosis, and a predictive capability regarding changes in risk and hazard states. Assessment functions should be capable of spanning hazard types to judge how the overall safety margin is changing based on current context, on recent (in-flight) cascading event sequences, and on longer-term trends that can become evident with access to historical data maintained by monitoring functions."
- Mitigation is operationally defined as set of methods, tools, and procedures that provide for multi-agent or automated planning and execution of timely responses to hazardous events or event sequences when/if safety margins are observed and are predicted to deteriorate below acceptable levels which must be accomplished "in-time."

The IASMS will generate airport safety intelligence that leverages reactive safety information and data from past accidents and incidents with ongoing learning from humans' contributions to safety within a positive safety culture that encourages voluntary reporting. In addition, safety intelligence uses predictive safety systems that mine big data sets to identify leading indicators of incidents, accidents, and emergent risks. Evolving technologies that use machine learning and artificial intelligence (ML/AI) to monitor and assess data will enable operational safety. Within this construct, operators can use enhanced proactive and innovative predictive analytics and modeling to mitigate safety hazards and risk.

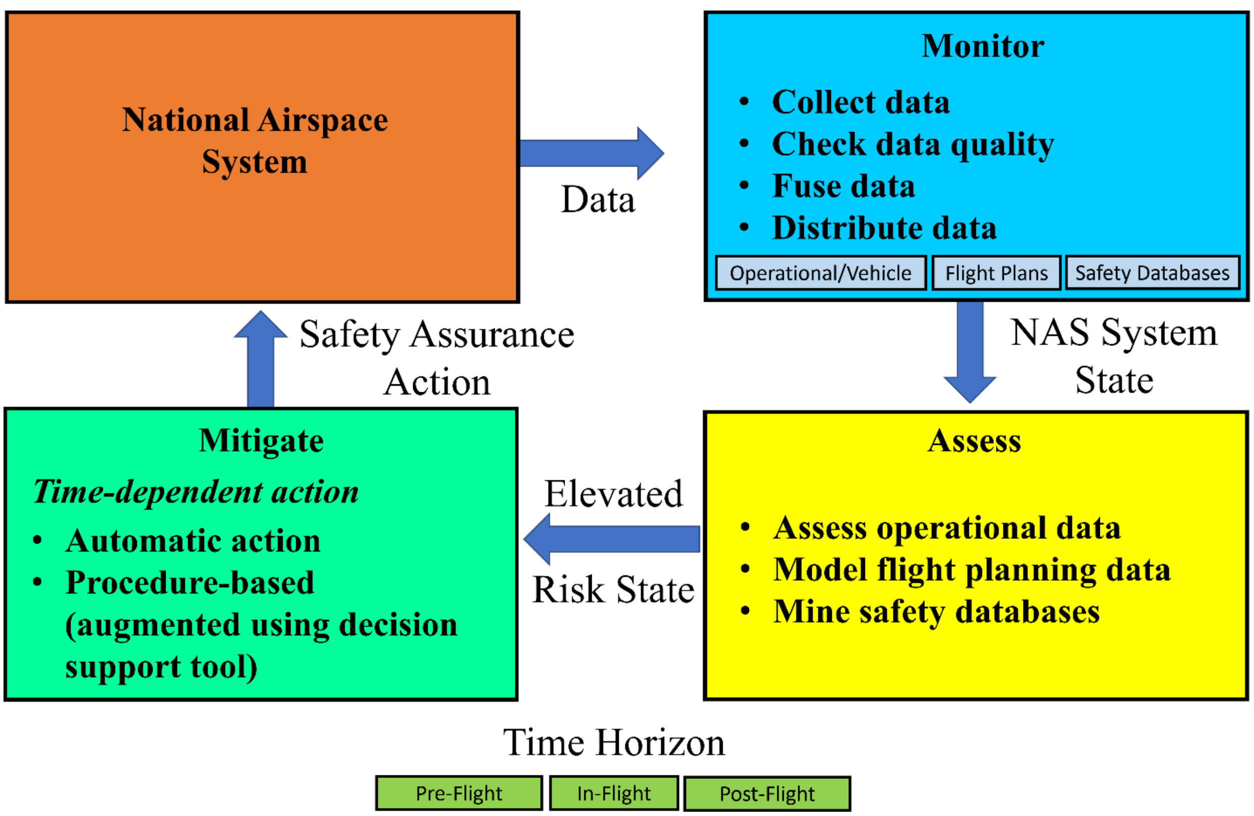

Figure 3. Relationships of IASMS functions (adapted from [13]).

VIII. IASMS System Interfaces for Part 139 Airports

IASMS system interfaces, shown in Fig. 4, represent the integration of IASMS services with vehicles (e.g., aircraft, trucks, service vehicles), operations (e.g., baggage handling, fueling, fire and rescue), industry, and proactive and predictive services managed by individual operators. In turn, these entities each share data and analysis across multiple operators. Airports play a central role in these interfaces, which connect FAA or other air navigation service providers (ANSP), commercial operators, and industry provided data services.

As NAS operations become more complex, operators will increasingly turn to SFCs that can provide for in-time risk management and safety assurance. SFCs are integrated as part of either operational systems or IASMSs, and some SFCs are cross-cutting. An assessment of SFCs was conducted for select pre-flight, in-flight, and post-flight/offline scenarios for their effectiveness to monitor, assess, and mitigate key safety risks [142]. Examples of NASA-developed reference SFCs include more capable cloud-based services, advanced weather risk models/network, and radio frequency (RF) interference monitoring and modeling. The SFCs for airports need exploration and specification based on the continuous Monitor-Assess-Mitigate functions of IASMS in relation to SRM and SA. These SFCs would include existing systems and equipment such as ASDE-X and runway status lights.

Digital twin technology can provide a virtual replica for remotely monitoring real-time operations throughout the airport. This technology will enable enhanced proactive and novel predictive views of airport operations and anticipate movements of aircraft and vehicles. ML/AI algorithms can use system performance, health, and other data from throughout the airport infrastructure to visualize, simulate, and predict normal and non-normal operational trends [143]. Cloud services facilitate sharing of selected safety data between airport operators, flight operators, service providers, and other tenants while lowering local information technology investment.

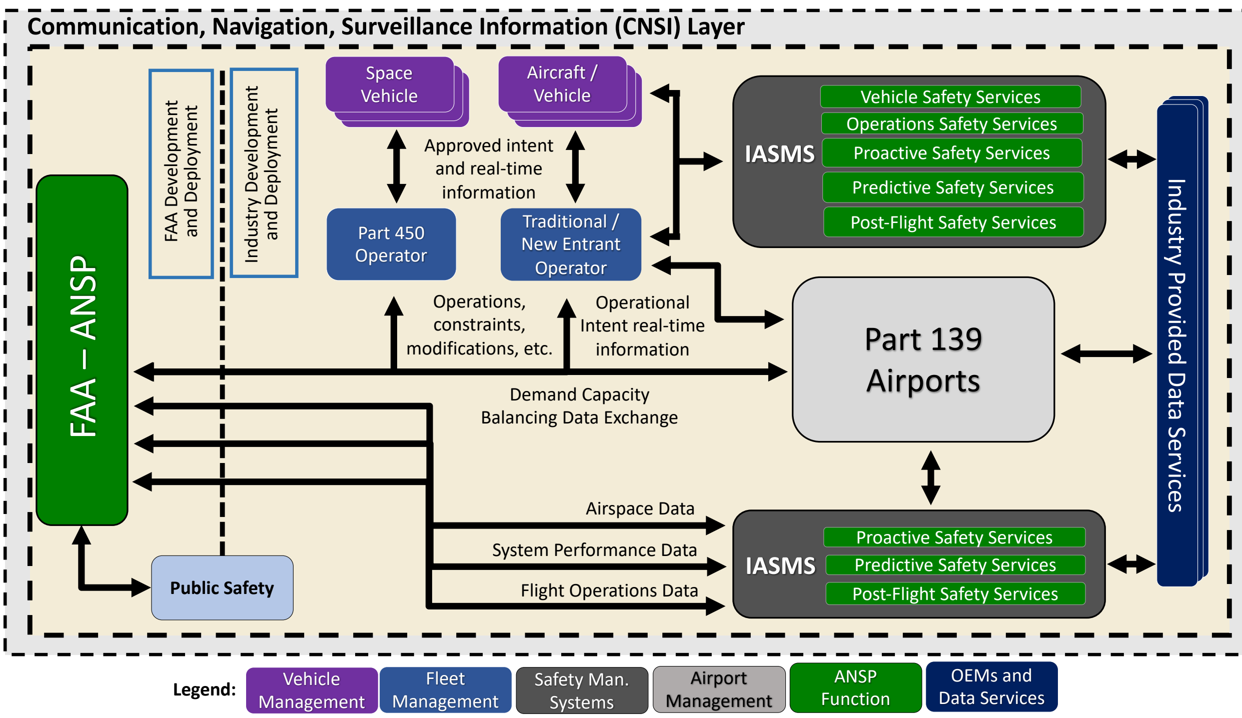

Figure 4. Interfaces of Current NAS with IASMS.

Airports need scalable and interoperable capabilities that can address a variety of hazards based on each airport's specific physical location, weather, size of runways, and other factors. SFCs must also account for various navigational aids and aircraft capabilities, as well as pilot training programs and the procedures pilots use with these aids. These combinations of airport and aircraft capabilities create multiple risk levels that will need to be analyzed in the future NAS. Through technology solutions and innovations, and understanding of how humans interact with the technology, SFCs will be key to mitigating risk to an acceptable level.

IX. IASMS Services, Functions, Capabilities for Part 139 Airports

Air transportation system safety risks can manifest as concerns already known to designers and operators and can be detected and mitigated by safety management systems (known knowns). On the other hand, emergent risks may be unknown to designers and operators (e.g., unexpected and surprising situations). However, with increasingly automated / autonomous systems, they can be understood, adapted to, and managed by safety management systems by applying machine learning or artificial intelligence (unknown known). There may also be risks recognized by designers or operators that are beyond the scope of detection and mitigation by safety management systems (known unknowns). Lastly, unforeseen risks (unknown unknowns) may not be recognizable by designers, operators, or safety management systems and require further discovery [134, 143]. The IASMS interfaces are key to SRM and SA enabled through SFCs to monitor, assess hazards and threats, and mitigate and assure potential known and unknown system safety risks providing for proactive and predictive safety intelligence.

The IASMS offers a unified approach for airlines to create a safety intelligence vision and learn from all operations. Learning from all operations aligns with the fundamental components of the ICAO SMS and presents new opportunities to enrich the pool of data available to various data repositories [135]. These data can be used to enhance risk management and safety assurance processes by providing valuable insights and lessons learned on how to mitigate risks in similar circumstances. Safety intelligence, especially enhanced proactive and newer predictive safety intelligence capability, is a pivotal component of the IASMS and its implications for various aspects of the NAS [144]. Current Part 121 air carriers can evaluate the benefits and limitations of IASMS as part of the business case for complying with SMS components [15, 145]. This encompasses the identification and prioritization of applications and improvements to predictive analytics and prototype data decision dashboards. Such capabilities empower human safety intelligence and continuous learning from all operations, thereby enhancing compliance with SMS components. This approach bridges IASMS with safety policy and safety promotion, fostering more effective advancement of organizational continuous learning strategies aimed at proactive and predictive safety intelligence. New emergent operators and those that may be required to have SMS in the future (e.g., Part 145 repair stations) can utilize tailorable and scalable SFCs and architectures that enable better interoperability across all actors and stakeholders. ICAO in development of the currently pending Amendment 2 to Annex 19, emphasizes development of safety intelligence in order to maintain and continuously improve the effectiveness of safety programs [17–18]. Guidance is expected that will provide strategy for development of safety intelligence [146].

A. Monitor-Assess-Mitigate-Assure

To identify safety risks arising from patterns in precursors, anomalies, and trends in new data types and increased data volume, SFCs are required to enable advances in in-time safety management with novel data analytical methods and innovative approaches to system safety thinking. To support in-time safety management and assurance, the IASMS high-level functions of monitor, assess, mitigate, and assure encompass domain-specific safety monitoring and alerting tools, integrated predictive technologies with domain-level applications, and in-time safety threat management. Safety assurance systems are required to enable predictive safety management with new data analytical methods and innovative approaches to system safety thinking to identify safety risks arising from patterns in precursors, anomalies, and trends in new data types and increased data volume through in-time Monitor-Assess-Mitigate-Assure SFCs—a unique feature of IASMS [142, 145, 147].

B. Services-Functions-Capabilities (SFCs)

Safety intelligence is an outcome of analyzing relevant and timely safety data and information based on current hazards and emerging risks, trends, and best practices, to support effective decision-making processes [148]. A key enabler for an effective safety intelligence strategy are SFCs. A Service is designed to address or manage hazards before they lead to harm preemptively. It becomes exceptionally crucial when hazards emerge during the design or operational stages. Services can be delivered by various entities such as the vehicle itself, the Urban Air Mobility (UAM) or Uncrewed Aircraft System Traffic Management (UTM)/Air Traffic Management (ATM) system, or other participants within the system ecosystem. Conversely, a Function relates to the tasks required by automated systems and human operators, such as maintenance personnel, ramp operators, and pilots. It involves processing multiple data streams to determine the necessary actions and timing to mitigate risks. It employs predictive analytics to identify and respond to known and emerging indicators, anomalies, and trends in system-wide performance data. Capability involves using technology, like sensors and models, to detect, validate, produce, and disseminate information across network architectures, forming the basis for the Functions and Services [142, 145, 147].

IASMS posits identification and development of SFCs to better enable airport in-time safety management. There exists a diverse set of SFCs already in use, including by Part 139 airports, that will play critical roles in future IASMS designs. Prior NASA papers have described example SFCs across different operation types (e.g., [14–16] that has their relevance here due to their use of Part 139 airports; use of similar type facilities (e.g., vertiport/vertiplex), and/or proximity of flight operations to airports presenting potential risk [138]. For example, [142–143][147] provide insights into the necessary architecture and information requirements, including SFC components, to evaluate and foresee flight safety risks in highly autonomous urban flight scenarios.

Moore, Young, et al [142] extended early definition of SFCs provided by [145] [147]. They describe identified safety critical SFCs for sUAS and air taxi operations that were tested in selected pre-flight, in-flight, and post-flight/offline scenarios for two domains: (a) highly autonomous sUAS package delivery and reconnaissance operating under 400 ft with moderate risk; and (b) highly autonomous 2-4 person occupied air taxi operations in an UAM operating less than 20 nm (pad-to-pad) with safety risk low (comparatively to Part 135 operations, but would formally be based on CFR 21.17b tailoring processing and Special Operations Risk Assessment (SORA) /Safety Assurance and Integrity Levels (SAIL) methods [149]). These scenarios were designed to assess utility and efficacy of the developed SFCs to monitor, assess, and mitigate key safety risks anticipated for these low-altitude flight operations. The authors provided the examples of the ability to check forecast winds during pre-flight planning; the ability to automatically divert to an alternate landing location during flight; and the ability to detect unsafe trends when looking across several similar flights during post-flight (or off-line) analysis [142]. Additional examples included third party casualty risk assessment, proximity to threat assessment, obstacle collision risk assessment, RF environment and interference monitoring, weather/wind/etc. prediction and forecasting services, airspace dynamic density assessment, among others]. The publication, describing three years of NASA and partner research and development (R&D), serves to help inform guidelines and recommended practices for future operational systems aimed at in-time proactive and predictive safety risk mitigation. The authors concluded that a substantial need exists to develop customized SFCs for specific operations, which may include those within and proximate to Part 139 airports (e.g., air taxi operating to/from vertiport located within and near Part 139 terminal airspace). To date, the NASA System-Wide Safety project has developed approximately 80 SFCs to support risk mitigation directly mapped to FAA Order 8040.6A specific to UAS safety risk management (appendix B, UAS Hazards, Mitigations, and Outcomes) [150]. However, significantly more R&D to develop new SFCs and mature existing ones remains an urgent need if the future safety system will be capable of managing the many envisioned changes anticipated for the future national air transportation system.

Even today's Part 139 airport operations continue to pose challenges that stress the safety envelope such as with runway incursions, runway excursions, and wildlife strikes. The IASMS roadmap identifies R&D priorities for SFCs to address a gap in the current state-of-the-art regarding specific hazards/risks and development of SFCs to mitigate and assure against the potential system risks—both at present and well into tomorrow. Future airport operations will be further challenged with introduction of new hazards and risks, such as resulting from addition of different types of aircraft such as eVTOL Concomitant with these challenges will be new opportunities for using new and underutilized sources of safety data that present both an opportunity (to yield better safety data insights) but also challenge addressing the 9 "Vs" of data challenges; namely, Veracity, Variety, Velocity, Volume, Validity, Variability, Volatility, Visualization, and Value. While hazards and risks are most relevant to the local airport and so rely on local sources of safety data, some hazard databases, such as for wildlife strikes and FOD, have shown that national data are broadly relevant to Part 139 airports. The consequence of this is that different Part 139 airports will have different SFC needs and different types of SMS/IASMS data to be collected and analyzed for proactive/predictive in-time aviation safety while other data types may be common and critical for system-wide NAS sharing. For case example of SFCs for safety risks, consider runway incursion occurrences observed today at Part 139 airports.

C. Case Example: Runway Incursions

Different technologies and combinations of technology to prevent runway incursions reflects the complexity how incursions may occur and the limitations of those technological solutions (described in earlier sections). On the flight deck, similar to Surface Awareness Initiative (SAI) that displays airport traffic to ATCT controllers without surveillance systems, moving map displays present surface traffic that can aid situation(al) awareness (e.g., surface cockpit display of traffic information (CDTI), taxi route displays, runway status indications on airport moving map displays) which can be enhanced with alerting (e.g., surface traffic conflict alerts; SURF-A) and mitigation technologies (e.g., Honeywell's SmartLanding and SmartRunway technologies) [151]. Some effective technologies are not yet fielded, such as NASA Runway Incursion Prevention System (RIPS) or equivalent visual displays (e.g., head-worn displays that may include alerting and warning requiring ADS-B IN or other increasingly implemented enabling technologies (e.g., [152–155]). However, the alarming increase in serious runway incursions at Part 139 airports, including many with highly sophisticated runway incursion prevention and surveillance systems, evince that there is far more need to be done including new SFCs to address gaps in safety nets at and around airports.

The year 2023 saw a significant increase in near misses, such as those between Boeing 737 and Boeing 777 at New York John F. Kennedy International Airport; Boeing 767 and Boeing 737 in Austin, Texas; Embraer 190 and private jet at Boston Logan International Airport; and Boeing 777 and Cessna 208B at Daniel K. Inouye International Airport. Although candidate solutions exist to prevent runway incursions at Part 139 airports, a number of serious incidents have occurred even at airports with the most sophisticated technology [68]. Today, 43 airports (of the 517 Part 139 Type I–IV certificated airports [3] in U.S. have ASDE-X package (including 12 antennas, 2 radars, ADS-B software, and displays) or ASDE-X ASSC (including flight deck traffic information displays). The 20 highest volume airports also have runway status lights (lights on runway that are triggered by algorithms based on ASDE-X or ASSC sensor data) which requires a significant number of expensive lights installed at intersections and on runways (e.g., 18 sets at Boston Logan; 34 sets at San Francisco). Despite the availability of these technologies, seven of the 25 serious runway incursions at U.S. airports (since January 2023) have occurred at five airports (BWI, BOS, JFK, SAN, SFO) that have runway status lights.

Although 15 of these 20 Part 139 airports with runway status lights have not yet experienced a serious runway incursion, the limited availability and cost to field these solutions are prohibitive. New SFC technologies are being researched, such as the Runway Incursion Prevention through Situational Awareness (RISPA) that would require fewer installed lights without traffic precision display [68]. However, as concluded by the report on “Global Action Plan for Prevention of Runway Incursions” (GAPPRE, December 2023) [156], a collaborative approach is required between aircraft operators, air navigation service providers, regulators, and aerodromes/airports to include critical needs for enhanced safety management and “enhanced technology for safe runway operations” (i.e., SFCs). These may come in the form of enhancements to existing technologies (e.g., flight deck SURF-IA) or fielding of new SFCs (e.g., NASA Runway Incursion Prevention System, virtual conformal head-worn tower displays) or even advancements in autonomous technologies (e.g., autonomous ground vehicles, autonomous aircraft taxi systems). Together with other recommendations (e.g., [156–157] and emergent solutions (e.g., better training, aerodrome markings, procedures, etc.), an IASMS for Part 139 airports is intended to provide system architectures and frameworks to build and implement innovations to collect the requisite actionable data types to enable monitor-assess-mitigate-assure SFCs for in-time system safety risk management and safety assurance. As Part 139 airport operators begin to implement mandated safety management systems and evolving future guidance is provided by the FAA, it is critical to continue the R&D necessary to ensure that requisite, safety-critical SFCs are ready to be fielded to ensure the envisioned future NAS vision transforms safely.

Development of concepts for SFCs used in airport safety management and operations and by fleet managers, aircraft operators, and air traffic controllers can be modeled and evaluated in ATCT simulation platforms. For example, the Future Flight Central tower simulation system at NASA Ames provides 360-degree full-scale, real-time simulation airport operations for airport personnel, air traffic controllers, and pilots to assess expansion plans, operating procedures, and evaluate new technologies [158]. For a recent simulation, NASA teamed with Joby Aviation, Inc. to assess how air taxi operations using eVTOL aircraft could be safely integrated into the complex, busy airspace in the DFW region using today’s ATC tools and procedures [159]. For airports siting new towers, the FAA uses its Airport Facilities Terminal Integration Laboratory (AFTIL) at the William J. Hughes Technical Center. The AFTIL supports siting studies and evaluations on interior cab design, tower orientation and height, line-of-sight studies in the terminal environment, and human- in-the-loop simulations of operational and procedural concepts [160]. The AFTIL supports 360- and 210-degree tower simulation environments.

X. Conclusions

Part 139 airports are an integral part of the NAS and are undergoing unprecedented change. Airports are accommodating increased air traffic and passenger counts, expanding and/or adding new terminals and gates (and new runways in some cases), and integrating new operations from UAS and eVTOLs carrying passengers and cargo. Addressing FAA regulation for SMS provides an important an opportunity to think about evolution of SMS towards IASMS and the benefits of in-time predictive safety.

While SMS regulation for airport SMSs is new, safety management has been long recognized as critical to the business of airport operations. Airports today use SRM and SA to identify and mitigate hazards and emergent risks, and IASMS speeds up the monitoring of safety data, assessing these data for anomalies, precursors, and trends, and mitigating hazards and risks such as through procedures, training, personnel safety meetings, and other safety promotion considerations. IASMS will accomplish this faster, cycling from data collection and analysis through SFCs designed like apps to provide timely notifications and alerts of impending risks.

Airports are complex systems comprised of multiple entities, each with their own priorities, constraints, and processes. Safety is a common top priority shared by all these entities at an airport and they realize that a hazard mitigation for one entity may pose a risk to another entity. Digital communications will empower these stakeholders to share safety information and data and to better understand interdependencies. Digital twin technology enables concurrent simulation of airport operations and will allow predictive analytics to identify precursors, anomalies, and trends indicative of increased risk potential. Predictive analytics are also critical to monitoring and assessing the overall risk threshold for the airport to improve situational awareness. Keys to this evolution are scaling safety systems for different sized operations, providing airports with digital interoperability across different safety systems and with tenants who may also have SMSs, and ensuring in-time safety management.

New concepts of operations, novel types of service vehicles with new safety SFCs, new safety data systems, and ML analysis capabilities will concomitantly require airports to monitor, assess, mitigate, and assure safety risks in equally transformative ways. Scaling these transformations will allow for selective application for meeting near-term requirements and aid in strategizing future development goals.

Research is needed to identify and specify in-time airport safety needs and may involve use of new and underutilized data sources. SRM solutions must be designed and implemented in a manner that is modular, scalable, interoperable, and assured. Within this construct, data analytics and modeling will allow airports to predict safety hazards and proactively identify risk mitigations.

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References

[1] Federal Aviation Administration. “Part 139 Airport Certification.” Last updated January 17, 2024. Accessed at https://www.faa.gov/airports/airport_safety/part139_cert.

[2] Federal Aviation Administration, “Airport Categories.” Last updated December 7, 2022. Accessed at https://www.faa.gov/airports/planning_capacity/categories

[3] Federal Aviation Administration, “Part 139 Airport Certification Status List (ACSL).” Accessed at https://www.faa.gov/airports/airport_safety/part139_cert/part_139_airport_certification_status_list.

[4] Federal Aviation Administration, “FAA Aerospace Forecast, Fiscal Years 2023-2043,” 2023. Accessed at https://www.faa.gov/dataresearch/aviation/aerospaceforecasts/faa-aerospace-forecast-fy-2023-2043.

[5] Federal Aviation Administration, “Air Traffic by the Numbers,” 2023. Accessed at https://www.faa.gov/air_traffic/by_the_numbers/media/Air_Traffic_by_the_Numbers_2023.pdf.

[6] International Air Transport Association, “Safety Overview, IATA Annual Safety Report, Executive Summary and Safety Overview, 60th Edition.” Accessed at https://www.iata.org/contentassets/a8e49941e8824a058fee3f5ae0c005d9/safety-report-executive-and-safety-overview-2023.pdf.

[7] International Civil Aviation Organization, Safety Report, 2023 Edition, Chart 4, “Historical trends for scheduled commercial operations.” Accessed at https://www.icao.int/safety/Documents/ICAO_SR_2023_20230823.pdf.

[8] Transportation Research Board, Airport Cooperative Research Program, “ACRP Report 1: Safety Management Systems for Airports, Volume 1 Overview,” 2007. Accessed at https://onlinepubs.trb.org/onlinepubs/acrp/acrp_rpt_001.pdf

[9] Transportation Research Board, Airport Cooperative Research Program, “ACRP Report 1: Safety Management Systems for Airports, Volume 2 Guidebook,” 2009. Accessed at https://nap.nationalacademies.org/catalog/14316/safety-management-systems-for-airports-volume-2-guidebook

[10] Transportation Research Board, Airport Cooperative Research Program, “ACRP Synthesis 71: Airport Safety Risk Management Panel Activities and Outcomes,” 2016. Accessed at https://ntrl.ntis.gov/NTRL/dashboard/searchResults/titleDetail/PB2016103693.xhtml.

[11] Transportation Research Board, Airport Cooperative Research Program, “ACRP Synthesis 58: Safety Reporting Systems at Airports, A Synthesis of Airport Practice,” 2014. Accessed at https://nap.nationalacademies.org/catalog/22353/safety-reporting-systems-at-airports

[12] Atlanta Department of Aviation, “Annual Comprehensive Financial Report for the fiscal years ended June 30, 2022, and 2021.” Accessed at https://www.atl.com/wp-content/uploads/2023/02/Dept.-of-Aviation-FY22-Annual-Report-83-final-1.19.23-II.pdf

[13] National Academies of Sciences, Engineering, and Medicine, "In-time Aviation Safety Management: Challenges and Research for an Evolving Aviation System," 2018. Accessed at https://doi.org/10.17226/24962.

[14] Ellis, K., Krois, P., Koelling, J., Prinzel, L., Davies, M., & Mah, R. (2021). "A Concept of Operations and Design Considerations for an In-time Aviation Safety Management System (IASMS) for Advanced Air Mobility (AAM)." 2021 AIAA Sci Tech Virtual Event. Reston, VA: AIAA. Accessed at https://ntrs.nasa.gov/citations/20205011003.

[15] Ellis, K., Prinzel, L., Krois, P., Davies, M., Oza, N., Stephens, C., Mah, R., Koelling, J., and Infeld, S., "A Future In-time Aviation Safety Management System (IASMS) Perspective for Commercial Air Carriers," AIAA Aviation, 2022. Accessed at https://ntrs.nasa.gov/api/citations/20220005918/downloads/Future%20IASMS%20Perspective%20for%20Commercial%20Air%20Carriers-AIAA%20Aviation%202022-final.docx.

[16] Ellis, K., Prinzel, L., Davies, M., Krois, P., Mah, R., Oza, N., Stephens, C., Vincent, M., Ackerson, J., and Infeld, S., "The In-time Aviation Safety Management System Concept for Part 135 Operators," IEEE Digital Avionics Systems Conference, 2022. Accessed at https://ntrs.nasa.gov/api/citations/20220009144/downloads/DASC%20IASMS%20for%20Part%20135%20Final.pdf.

[17] International Civil Aviation Organization, "Safety Management Manual," ICAO Doc 9859, Fourth Edition, 2018. Accessed at https://skybrary.aero/sites/default/files/bookshelf/5863.pdf.

[18] International Civil Aviation Organization, "Safety Management, Standards and Recommended Practices–Annex 19," in Convention on International Civil Aviation, 2nd Edition, 2016. Accessed at https://www.icao.int/safety/SafetyManagement/Documents/Annex%2019%20-%20ICAO%20presentation%20-%20self%20instruction%2024September2013.pdf .

[19] Federal Aviation Administration, "Safety Management Systems for Airports," AC 150/5200-37A, 2023. Access at https://www.faa.gov/airports/resources/advisory_circulars/index.cfm/go/document.current/documentNumber/150_5200-37.

[20] Shakya, P.R., "ICAO Annex 14 Standards and Aerodrome Certification," ICAO Workshop for Pacific Island States, December 12-15, 2016. Accessed at https://www.academia.edu/38550518/ICAO_Annex_14_Standards_and_Aerodrome_Certification_ICAO_Workshop_for_Pacific_Island_States.

[21] International Civil Aviation Organization, "Annex 14 Aerodromes, Volume I Aerodrome Design and Operations," Ninth Edition, 2022. Accessed at https://standart.aero/en/icao/book/annex-14-v-1-aerodromes-volume-i-aerodrome-design-and-operations-en-cons.

[22] International Civil Aviation Organization, "Annex 14 Aerodromes, Volume II Heliports," Fifth Edition, 2020. Accessed at https://standart.aero/en/icao/book/annex-14-v-2-annex-14-aerodromes-volume-ii-heliports-ed-5-en-12075-2020-07-01.

[23] International Civil Aviation Organization, "Airport Planning Manual, Part 1 – Master Planning," Document 9184, Third Edition, 2023. Accessed at https://www.scribd.com/document/174659903/ICAO-Doc-9184-Airport-Planning-Manual-Part-1-Master-Planning.

[24] International Civil Aviation Organization, "Aerodrome Design Manual, Part 1 – Runways," Document 9157, Fourth Edition, 2020. Accessed at https://www.academia.edu/96886363/Icao_doc_9157_aerodromedesignmanual_part1_V_2020.

[25] International Civil Aviation Organization, "Aerodrome Design Manual, Part 2 – Taxiways, Aprons and Holding Bays," Document 9157, Fifth Edition, 2020. Accessed at https://www.scribd.com/document/639043111/Untitled.

[26] International Civil Aviation Organization, "Airport Services Manual, Part 1, Rescue and Firefighting," Document 9137, Fourth Edition, 2015. Accessed at https://www.scribd.com/document/639043111/Untitled.

[27] Federal Aviation Administration, "External SMS (SMS for Part 139 Airports)." Accessed at https://www.faa.gov/airports/airport_safety/safety_management_systems/external

[28] Federal Register, Department of Transportation, Federal Aviation Administration, 14 CFR Part 139, "Airport Safety Management System," Volume 88, Number 36, February 23, 2023. Accessed at https://www.govinfo.gov/content/pkg/FR-2023-02-23/pdf/2023-03597.pdf.

[29] Federal Aviation Administration, "Airport Certification Manual," Advisory Circular 150/5210-22, 2004. Accessed at https://www.faa.gov/airports/resources/advisory_circulars/index.cfm/go/document.current/documentNumber/150_5210-22.

[30] Code of Federal Regulations, Title 14, Aeronautics and Space, Chapter I, Federal Aviation Administration, Department of Transportation, Subchapter G, Air Carriers and Operators for Compensation or Hire: Certification and Operations, Part 139, Certification of Airports, Subpart 139.5, Definitions, May 8, 2024. Accessed at https://www.ecfr.gov/current/title-14/chapter-I/subchapter-G.

[31] Federal Aviation Administration, "Airport Emergency Plan," Advisory Circular 150/5200-31C, 2010. Accessed at https://www.faa.gov/documentLibrary/media/150_5200_31c_chg1.pdf.

[32] Code of Federal Regulations, Title 14, Aeronautics and Space, Part 139 Certification of Airports, Subpart D Operations, Section 139.327 Self-inspection program, February 10, 2004. Accessed at https://www.ecfr.gov/current/title-14/section-139.327.

[33] Federal Aviation Administration, “Classes of Airports – Part 139 Airport Certification.” Accessed at https://www.faa.gov/airports/airport_safety/part139_cert/classes-of-airports#class1.

[34] Schroeder, J., “ARP Part 139 SMS for Airports: Part 139 SMS Rule Overview,” FAA SMS for Airports – Industry Day, 2023. Accessed at https://www.faa.gov/airports/airport_safety/safety_management_systems/external/FAA-SMS-Industry-Day-presentations-2023.

[35] Federal Aviation Administration (FAA), “Safety Management Systems for Aviation Service Providers,” AC No. 120-92D, 2015. Accessed at https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_120-92D_FAA_Web.pdf .

[36] Federal Aviation Administration, “Aviation Safety Information Analysis and Sharing Program,” 2019. https://www.faa.gov/newsroom/aviation-safety-information-analysis-and-sharing-program-1

[37] Federal Aviation Administration, “Air Traffic Organization Safety Management System,” Order JO 1000.37C, 2021. Accessed at https://www.faa.gov/documentLibrary/media/Order/JO_1000.37C.pdf

[38] Federal Aviation Administration, “FY 2024 ARP Business Plan.” Accessed at https://www.faa.gov/about/plansreports/arp-business-plan

[39] Federal Aviation Administration, “FY 2024 ATO Business Plan.” Accessed at https://www.faa.gov/media/76606

[40] Ayers, S., “ATL Safety Management System (SMS) Airport Overview,” FAA SMS for Airports – Industry Day: SMS Industry Panel, 2023. Accessed at https://www.faa.gov/airports/airport_safety/safety_management_systems/external/FAA-SMS-Industry-Day-Industry-Panel-2023.

[41] Thompson, S., “DIA Safety – An Environmental Partner,” Retrieved on October 27, 2023 from https://www.flydenver.com/sites/default/files/environmental/workshop_SafetyManagementSystems.pdf.

[42] Spurlock, S., “SLC Safety Management System,” 2024. Accessed at https://slcairport.com/assets/pdfDocuments/AABoard/15May2024AABPacket.pdf

[43] Hartsfield-Jackson Atlanta International Airport, “Emergency Contingency Plan,” 2023. Accessed at https://www.atl.com/wp-content/uploads/2023/12/ATL-IROPS-Update-12-2023.pdf

[44] Airport Cooperative Research Program, Transportation Research Board, National Academies, “Practices in Airport Emergency Plans,” ACRP Synthesis 115, 2021. Accessed at https://nap.nationalacademies.org/download/26077

[45] Federal Aviation Administration, “NOTAMS Back to Basics: Pilots,” 2020. Accessed at https://www.faa.gov/sites/faa.gov/files/about/initiatives/notam/what_is_a_notam/Pilots_NOTAM_primer_for_2021.pdf

[46] Federal Aviation Administration, “Airport Data and Information Program,” Advisory Circular 150/5300-19, 2015. Accessed at https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_150_5300-19.pdf

[47] Federal Aviation Administration, “FNS NOTAM Search,” 2023. Accessed at https://notams.aim.faa.gov/notamSearch/nsapp.html#/

[48] Federal Aviation Administration, “Aeronautical Information Manual,” Change 2, 2024. https://www.faa.gov/air_traffic/publications/atpubs/aim_html/

[49] Federal Aviation Administration, “Aeronautical knowledge.,” 14 Code of Federal Regulations, 14 CFR 61.155I(3), 2022. Accessed at https://www.govinfo.gov/content/pkg/CFR-2022-title14-vol2/pdf/CFR-2022-title14-vol2-sec61-155.pdf

[50] Federal Aviation Administration, “Airport Safety Database,” Version 3.2.4, 02/15/2024. Accessed at https://asd.faa.gov/home

[51] Federal Aviation Administration, “FAA Accident and Incident Data System (AIDS),” 2024. Accessed at https://www.asias.faa.gov/apex/f?p=100:12:::NO:::

[52] Federal Aviation Administration, “FAA Runway Safety Office - Runway Incursions (RWS),” 2024. Accessed at https://www.asias.faa.gov/apex/f?p=100%3A28%3A%3A%3ANO%3A28

[53] Scarborough, A., Bailey, L., & Pounds, J., “Analyzing Vehicle Operator Deviations,” Report DOT/FAA/AM-08/17, Office of Aerospace Medicine, Federal Aviation Administration, 2008. Accessed at https://www.tc.faa.gov/its/worldpac/techrpt/am08-17.pdf

[54] Federal Aviation Administration, “Ground Vehicle Operations to include Taxiing or Towing an Aircraft on Airports,” AC No. 150/5210-20A, 2015. Accessed at https://www.faa.gov/documentLibrary/media/Advisory_Circular/150-5210-20A.pdf

[55] National Transportation Safety Board, “Accident Data,” 2024. Accessed at https://www.ntsb.gov/safety/data/Pages/Data_Stats.aspx

[56] National Aeronautics and Space Administration, “Aviation Safety Reporting System,” 2024. Accessed at https://asrs.arc.nasa.gov/

[57] C. Billings, J. Lauber, H. Funkhomer, E. Lyman, and E. Huff, “NASA Aviation Safety Reporting System Quarterly Report Number 76-1, April 15, 1976, through July 14, 1976,” NASA TM X-3445, 1976.

[58] Federal Aviation Administration, "Aviation Safety Action Program," AC No. 120-66C, 2020. Accessed at https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_120-66C_(Edit).pdf

[59] Crayton, L., Hackworth, C. Roberts, C. and King, J., "Line Operations Safety Assessments (LOSA) in Maintenance and Ramp Environments," Federal Aviation Administration Civil Aerospace Medical Institute, DOT/FAA/AM-17/7, 2017. https://rosap.ntl.bts.gov/view/dot/35531

[60] Ma, M., and Rankin, W., "Implementation Guideline for Maintenance Line Operations Safety Assessment (M-LOSA) and Ramp LOSA (R-LOSA) Programs," Federal Aviation Administration Office of Aerospace Medicine, DOT/FAA/AM-12/9, 2012. https://www.tc.faa.gov/its/worldpac/techrpt/am12-9.pdf

[61] Federal Aviation Administration, "Line Operations Safety Assessments (LOSA)," June 13, 2023. Accessed May 14, 2024. https://www.faa.gov/about/initiatives/maintenance_hf/losa

[62] Federal Aviation Administration, "Operator's Manual: Human Factors in Aviation Maintenance," 2014. https://www.faa.gov/sites/faa.gov/files/about/initiatives/maintenance_hf/library/hf_ops_manual_2014.pdf

[63] Key, K., Choi, I., Hu, P., and Schroeder, D., "Validation of the FAA Maintenance Safety Culture Assessment and Improvement Tool (FAA M-SCAIT)," Federal Aviation Administration Office of Aerospace Medicine, DOT/FAA/AM-23/14, 2023. https://www.faa.gov/sites/faa.gov/files/Validation%20of%20the%20FAA%20Maintenance%20Safety%20Culture%20Assessment%20and%20Improvement%20Tool%20%28FAA%20M-SCAIT%29.pdf

[64] Huerta, M., Gilbert, P., Bolden, C., Grizzle, D., Canoll, T., and Sumwalt, R., "National Airspace System Safety Review Team: Discussion and Recommendations to Address Risk in the National Airspace System," Federal Aviation Administration, 2023. https://www.faa.gov/NAS_safety_review_team_report.pdf

[65] Federal Aviation Administration, "Air Traffic Control," FAA Order 7110.65AA Change 2, March 21, 2024. https://www.faa.gov/air_traffic/publications/atpubs/atc_html/

[66] Federal Aviation Administration, "Low Visibility Operations/Surface Movement Guidance and Control Systems (LVO/SMGCS)," AC No. 120-57C, 2023. https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_120-57C.pdf

[67] Federal Aviation Administration, "Low Visibility Operations/Surface Movement Guidance and Control System (LVO/SMGCS)." Accessed at https://web.archive.org/web/20161014061317/https://www.faa.gov/about/office_org/headquarters_offices/avs/offices/afs/afs400/afs410/lvo_smgcs/

[68] Button, K., "A New Light for Safety," Aerospace American, May 2024. https://aerospaceamerica.aiaa.org/features/a-new-light-for-safety/

[69] Federal Aviation Administration, "ADS-B Airport Surface Surveillance Capability (ASSC)." Accessed May 13, 2024. https://www.faa.gov/air_traffic/technology/adsb/atc/assc

[70] Federal Aviation Administration, "Airworthiness Approval of Enhanced Vision System, Synthetic Vision System, Combined Vision System, and Enhanced Flight Vision System Equipment," AC No.: 20-167A, 2016. https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_20-167A.pdf

[71] Federal Aviation Administration, "Enhanced Flight Vision System Operations," AC No.: 90-106B, 2022. https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_90-106B.pdf

[72] Federal Aviation Administration, "Use of Suitable Area Navigation (RNAV) Systems on Conventional Routes and Procedures, AC No." 90-108, 2011. https://www.faa.gov/documentLibrary/media/Advisory_Circular/90-108.pdf

[73] Federal Aviation Administration, "Critical_DME_List.xls," 2024. https://www.faa.gov/air_traffic/flight_info/aeronav/criticaldme/

[74] Federal Aviation Administration, "Authorization for Use of Electronic Flight Bags," Advisory Circular 120-76D, 2017. https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_120-76D.pdf

[75] SKYbrary Aviation Safety, "Low Level Wind Shear Alert System (LLWAS)," Retrieved May 10, 2024. https://skybrary.aero/articles/low-level-wind-shear-alert-system-llwas#:~:text=A%20Low%20Level%20Wind%20Shear%20Alert%20System%20%28LLWAS%29,in%20real-time%2C%20to%20warn%20pilots%20and%20aerodrome%20services.

[76] National Center for Atmospheric Research, "Low-Level Wind Shear Alert System (LLWAS)," 2024. https://ral.ucar.edu/solutions/products/low-level-wind-shear-alert-system-llwas

[77] Federal Aviation Administration, "Satellite Navigation – NAS Implementation," 2016. https://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/techops/navservices/gnss/nas/procedures/rnav_rnp

[78] Federal Aviation Administration, "United States Government Specifications: Flight Information Publication Instrument Approach Procedures and Airport Diagrams," 2023. https://www.faa.gov/air_traffic/flight_info/aeronav/iac/media/IAC4/IAC-4-13NOV2023-complete.pdf

[79] Federal Aviation Administration, “National Policy: Airport Diagrams,” FAA Order 7910.4E, 2021. https://www.faa.gov/documentLibrary/media/Order/FAA_Order_7910.4E.pdf

[80] Federal Aviation Administration, “Harry Reid International Airport (LAS) Airport Diagram,” 2023. AL-662(FAA). https://aeronav.faa.gov/d-tpp/2405/00662ad.pdf#nameddest=(LAS)

[81] Transportation Research Board, Airport Cooperative Research Program, “Airfield Apron and Ramp Surface Markings,” 2023.

[82] Federal Aviation Administration, “Supplemental Chart – Harry Reid Intl,” 2024. https://aeronav.faa.gov/afd/21mar2024/sw_392_21MAR2024.pdf

[83] Federal Aviation Administration, “Noise Abatement Departure Profiles,” Advisory Circular 91-53A, 1993. Accessed at https://www.faa.gov/documentLibrary/media/Advisory_Circular/ac91-53.pdf

[84] Federal Aviation Administration, “REDAC Read-Ahead, Submitted to the Subcommittee on Airports, 2/11/2023. https://www.faa.gov/sites/faa.gov/files/airports-mar2023-read-ahead-package.pdf

[85] International Civil Aviation Organization, “Manual on the Prevention of Runway Incursions,” Document 9870, AN/463, First Edition, 2007. Accessed at https://www.icao.int/safety/runwaysafety/documents%20and%20toolkits/icao_manual_prev_ri.pdf

[86] Federal Aviation Administration, “Runway Incursions,” 2022. https://www.faa.gov/airports/runway_safety/resources/runway_incursions

[87] Federal Aviation Administration, “Runway Safety,’ 2024. Accessed at https://www.faa.gov/newsroom/runway-safety-fact-sheet.

[88] Bati, F., Lee, F., Bollschweiler, R., Wirthington, L., Khorrami, N., Filippove, I., and Adhikari, R., “Risk Metrics to Measure Safety Performance of the National Airspace System: Implementation Using Machine Learning,” Digital Avionics Systems Conference, 2021. Accessed at https://confcats-event-sessions.s3.amazonaws.com/dasc21/papers/3032.pdf

[89] Federal Aviation Administration, “Runway Safety Statistics.” Accessed May 14, 2024. https://www.faa.gov/airports/runway_safety/statistics/

[90] Mackintosh, T., “Lima Airport: Truck Hit by Plane on Peru Runway was on Planned Drill,” BBC News, November 20, 2022. https://www.bbc.com/news/world-latin-america-63698202

[91] Flight Safety Foundation, Aviation Safety Network, Report Number CIAA-ACCID-08-2022. Accessed at https://aviation-safety.net/asndb/318723

[92] National Transportation Safety Board, “Aircraft Accident Report, Runway Collision of USAIR Flight 1493, Boeing 737 and Skywest Flight 5569 Fairchild Metroliner, Los Angeles, California, February 1, 1991, Report NTSB/AAR-91/08, 1991. Accessed at https://libraryonline.erau.edu/online-full-text/ntsb/aircraft-accident-reports/AAR91-08.pdf

[93] National Transportation Safety Board, “Case Analysis and Reporting Online.” Accessed at https://data.ntsb.gov/carol-main-public/landing-page

[94] International Civil Aviation Organization, “Runway Safety Team Handbook,” Second Edition, 2015. Accessed at https://www.icao.int/safety/RunwaySafety/Documents%20and%20Toolkits/ICAO%20RST%20Handbook%202nd%20Edition%202015%20REV2.pdf.

[95] Flight Safety Foundation, “Reducing the Risk of Runway Excursions, Report of the Runway Safety Initiative,” 2009. Accessed at https://flightsafety.org/files/RERR/fsf-runway-excursions-report.pdf

[96] Mashkani, A., “Analyzing the Efficiency of EMAS at FAR Part 139 Airports in the USA,” master’s thesis, Middle Tennessee State University, 2019. Accessed at https://jewlscholar.mtsu.edu/server/api/core/bitstreams/0f5e6fb4-e2fb-41af-b2a4-b5f2ce5d9b89/content

[97] National Transportation Safety Board, “Runway Overrun During Landing, Peninsula Aviation Services Inc. d.b.a. PenAir flight 3296, Saab 2000, N686PA,” 2021. Accessed at https://www.ntsb.gov/investigations/AccidentReports/Reports/AAR2105.pdf

[98] National Transportation Safety Board, “Aircraft Accident Investigative Update,” 2019. Accessed at https://www.ntsb.gov/investigations/Documents/PenAir-runway-overrun-Investigative-Update.pdf

[99] Federal Aviation Administration, “Engineered Material Arresting System (EMAS),” September 11, 2023. Accessed at https://www.faa.gov/newsroom/engineered-material-arresting-system-emas-0?newsId=13754

[100] National Transportation Safety Board, “Runway Excursion During Landing, Delta Air Lines Flight 1086, Boeing MD-88, N909DL, New York, New York, March 5, 2015," Accident Report NTSB/AAR-16/02, 2016. Accessed at https://www.ntsb.gov/investigations/AccidentReports/Reports/AAR1602.pdf.

[101] Federal Aviation Administration, “Airport Foreign Object Debris (FOD) Management,” Advisory Circular 150/5210-24, 2010. Accessed at https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_150_5210-24.pdf

[102] Herricks, E., Mayer, D., and Majumdar, S., "Foreign Object Debris Characterization at a Large International Airport," DOT/FAA/TC-TN14/48, 2015. Accessed at https://www.airporttech.tc.faa.gov/Products/Airport-Safety-Papers-Publications/Airport-Safety-Detail/ArtMID/3682/ArticleID/36/Foreign-Object-Debris-Characterization-at-a-Large-International-Airport

[103] Federal Aviation Administration, "Airport Foreign Object Debris (FOD) Detection Equipment, Advisory Circular 150/5220-24, 2009. Accessed at https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_150_5220-24.pdf

[104] Federal Aviation Administration, "FAA Wildlife Strike Database." Accessed at https://wildlife.faa.gov/home

[105] Federal Aviation Administration, "Wildlife Strikes to Civil Aircraft in the United States 1990-2022," Serial Report 29, 2023. Accessed at https://www.faa.gov/sites/faa.gov/files/Wildlife-Strike-Report-1990-2022.pdf

[106] Dikerts de Tella, T., and Mendonca, F., "Safety Management of Wildlife Hazards to Aviation: An Analysis of Wildlife Strikes in Part139 Airports in Florida 2011–2020," Journal of Aviation Technology and Engineering, Volume 11, Number 2, pages 18-29, 2022. Accessed at https://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=1257&context=jate

[107] National Transportation Safety Board, "Accident Number CHI99FA102, March 4, 1999," 2001. Accessed at https://data.ntsb.gov/carol-repgen/api/Aviation/ReportMain/GenerateNewestReport/45881/pdf

[108] Federal Aviation Administration, 14 Code of Federal Regulations, 14 CFR 139.337, "Wildlife Hazard Management," 2004. Accessed at https://www.ecfr.gov/current/title-14/chapter-I/subchapter-G/part-139/subpart-D/section-139.337

[109] Denver International Airport, "Wildlife Hazard Management Program at Denver International Airport," 2023. https://www.flydenver.com/about/administration/wildlife_management

[110] Federal Aviation Administration, "UAS Sighting Report," Accessed at https://www.faa.gov/uas/resources/public_records/uas_sightings_report

[111] Flight Safety Foundation, "Aviation Safety Network Occurrence # 344753, Accessed at http://aviation-safety.net/wikibase/344753

[112] Code of Federal Regulations, Title 14, Aeronautics and Space, Chapter I, Federal Aviation Administration, Department of Transportation, Subchapter F, Air Traffic and General Operating Rules, Part 89, Remote Identification of Unmanned Aircraft, May 22, 2024. Accessed at https://www.ecfr.gov/current/title-14/chapter-I/subchapter-F/part-89.

[113] Flight Safety Foundation, "FSF ALAR Briefing Note 7.1 – Stabilized Approach," 2000. Accessed at https://flightsafety.org/wp-content/uploads/2016/09/alar_bn7-1stablizedappr.pdf.

[114] ABC7 News, "Fuel truck crashes into United Airlines plane at Dulles Airport in Virginia," July 9, 2018. Accessed at https://wcti12.com/news/nation-world/fuel-truck-crashes-into-united-airlines-plane-at-dulles-airport

[115] National Transportation Safety Board, "Descent Below Visual Glidepath and Impact with Seawall, Asiana Airlines Flight 214, Boeing 777-200ER, HL7742, San Francisco, California, July 6, 2013," Accident Report NTSB/AAR-14/01, 2014. Accessed at https://www.ntsb.gov/investigations/accidentreports/reports/aar1401.pdf

[116] Netherlands Aviation Safety Board, "Aircraft Accident Report 92-11, El Al Flight 1862," October 4, 1992. Accessed at https://reports.aviation-safety.net/1992/19921004-2_B742_4X-AXG.pdf.

[117] National Transportation Safety Board, "National Transportation Safety Board, Aviation Accident Final Report," NTSB Accident CEN14FA099, 2017. Accessed at https://reports.aviation-safety.net/2014/20140105-1_CL60_N115WF.pdf

[118] National Transportation Safety Board, "Aircraft Accident Report, Pan American World Airways, Inc., Clipper 759, Boeing 727-235, N4737, New Orleans International Airport, Kenner, Louisiana, July 9, 1982," Report NTSB/AAR-83/02, 1982. Accessed at https://www.ntsb.gov/investigations/AccidentReports/Reports/AAR8302.pdf.

[119] National Transportation Safety Board, "Aircraft Accident Report, Delta Air Lines, Inc., Lockheed L-1011-385-1, N726DA, Dallas/Fort Worth International Airport, Texas, August 2, 1985," Report NTSB/AAR/86-05, 1986. Accessed at https://www.ntsb.gov/investigations/AccidentReports/Reports/AAR8605.pdf.

[120] National Transportation Safety Board, "Aircraft Accident Report, Air Florida, Inc., Boeing 737-222, N62AF, Collision with 14th Street Bridge, Near Washington National Airport, Washington, D.C., January 13, 1982," Report NTSB-AAR-82-8, 1982, Accessed at https://www.ntsb.gov/investigations/accidentreports/reports/aar8208.pdf.

[121] National Transportation Safety Board, "Aircraft Accident Report, In-Flight Icing Encounter and Uncontrolled Collision with Terrain, COMAIR Flight 3272, Embraer EMB-120RT, N265CA, Monroe, Michigan, January 9, 1997," Report NTSB/AAR-98/04, 1998. Accessed at https://www.ntsb.gov/investigations/AccidentReports/Reports/AAR9804_body.pdf.

[122] Airport Technology, "Louis Armstrong New Orleans International Airport," 2001. Accessed at https://www.airport-technology.com/projects/new_orleans/?cf-view&cf-closed

[123] Fox Business, "Earthquake Outside NYC Triggers Ground Stop at Major Airports," 2024. Accessed at https://www.foxbusiness.com/lifestyle/earthquake-nyc-triggers-ground-stop-major-airports

[124] NDTV, “Video: Massive Earthquake in Turkey Splits Airport Runway into Two,” 2023. Accessed at https://www.ndtv.com/feature/video-massive-earthquake-in-turkey-splits-airport-runway-into-two-3759029

[125] Britannica, “Chile Earthquake of 2010,” 2024. Accessed at https://www.britannica.com/event/Chile-earthquake-of-2010.

[126] SKYbrary, “Aircraft Ground Damage.” Accessed on May 5, 2024, at https://skybrary.aero/articles/aircraft-ground-damage

[127] Spark, “A Normal Day in the Busiest Airport in the World.” Accessed on May 5, 2024, at https://www.youtube.com/watch?v=lCgFXE17U3U

[128] Federal Aviation Administration, “Lithium Battery Incidents,” 2022. Accessed at https://www.faa.gov/hazmat/resources/lithium_batteries/incidents

[129] Bragg, R., “New Control Tower Being Rebuilt in Miami,” New York Times, October 7, 2000. Accessed at https://www.nytimes.com/2000/10/07/us/new-control-tower-being-rebuilt-in-miami.html

[130] Kaye, K., “New Tower Offers Clear View at Miami Airport,” Sun Sentinel, December 10, 2002.

[131] SKYbrary, “Aerodrome Emergency Medical Response.” Accessed on May 5, 2024, at https://skybrary.aero/articles/aerodrome-emergency-medical-response

[132] Leder, W., “Review of Four Alternative Terminal Passenger Mobility Systems,” Transportation Research Record 1308, 1991. Accessed at https://onlinepubs.trb.org/Onlinepubs/trr/1991/1308/1308-018.pdf

[133] Occupational Safety and Health Administration, “Occupational Injury and Illness Recording and Reporting Requirements,” 2001. Accessed at https://www.osha.gov/laws-regs/federalregister/2001-01-19

[134] Prinzel, L., Krois, P., Ellis, K., Vincent, M., Stephens, C., Oza, N., Chancey, E, Davies, M., Mah, R., Ackerson, J., Infeld, S., Kiggins, D., and Matthews, B., “The Adaptable and Resilient Safety System: The Human Factor in Future In-Time Aviation Safety Management Systems,” AIAA Sci Tech, 2024. Accessed at https://ntrs.nasa.gov/api/citations/20230016861/downloads/Prinzel%20et%20al%20SCITECH%202024%20Final%20-%20submit%20STRIVES.pdf

[135] Flight Safety Foundation, “Learning from All Operations: Expanding the Field of Vision to Improve Aviation Safety,” Flight Safety Foundation White Paper, 2021. Accessed at https://flightsafety.org/wp-content/uploads/2021/07/Learning-from-All-Operations-FINAL.pdf

[136] Burnell, J., Laursen, T., and Waites, J., “How Operators Can Create Safety in an Uncertain World,” Flight Safety Foundation Foundational Support Document,” 2022. Accessed at https://flightsafety.org/wp-content/uploads/2022/08/LAO-safety-in-an-uncertain-world_rev1.pdf

[137] Federal Aviation Administration, “Charting Aviation’s Future: Operations in an Info-Centric National Airspace System,” 2023. Accessed at https://www.faa.gov/sites/faa.gov/files/Charting-Aviations-Future-Operations-in-ICN_0%20%281%29.pdf

[138] Ellis, K., Prinzel, L., Davies, M., Homola, J., Glaab, L., Krois, P., Oza, N., Mah, R., Stephens, C., Vincent, M., Ackerson, J., & Infeld, S. (2023). “An In-time Aviation Safety Management System (IASMS) Concept of Operations for Vertiport Design and Operations.” AIAA Aviation Forum 2023. Accessed at https://ntrs.nasa.gov/api/citations/20230006104/downloads/Aviation%202023%20IASMS%20for%20Vertiports%20to%20STRIVES%5B2%5D.pdf

[139] Federal Aviation Administration, “Urban Air Mobility (UAM) Concept of Operations v2.0,” April 26, 2023. Accessed at https://www.faa.gov/air-taxis/uam_blueprint

[140] Yu, J., Engelland, S., Swieringa, K., Wing, D., Glenn-Chase, A., & Le, J. (2022). Sky for All: Ushering in a New Era of Aviation. Document 20220016651. Accessed at https://ntrs.nasa.gov/citations/20220016651

[141] National Aeronautics and Space Administration, “NASA Strategic Implementation Plan,” 2022. Accessed at https://www.nasa.gov/wp-content/uploads/2018/01/2022_nasa_strategic_plan_0.pdf

[142] Moore, A., Young, S., and others, “Testing of Advanced Capabilities to Enable In-time Safety Management and Assurance for Future Flight Operations,’ NASA/TM-20230018664, 2024. Accessed at https://ntrs.nasa.gov/api/citations/20230018665/downloads/NASA-TM-20230018665.pdf

[143] Hexaware, The Airport of Tomorrow – The New Normal,” White Paper, 2020. Accessed at https://airlines.iata.org/sites/default/files/2023-03/Hexaware_Airport_Whitepaper.pdf

[144] Chakib, M. (2023). “Developing Safety Intelligence.” International Civil Aviation Organization, Middle East North Africa Accident and Incident Investigation Regional Cooperation Mechanism Workshop. www.icao.int/MID/Documents/2023/MENA%20ARCM4/Chakib_ICAO%20Developing%20Safety%20Intelligence.pdf

[145] Ellis, K., Krois, P., Koelling, J., Prinzel, L., Davies, M., & Mah, R., & Infeld, S. (2021). “Defining Services, Functions, and Capabilities for an Advanced Air Mobility (AAM) In-time Aviation Safety Management System (IASMS).” 2021 AIAA Aviation Virtual Event. Reston, VA: AIAA.

[146] International Civil Aviation Organization (anticipated December 2024). “Safety Intelligence Manual.” Montreal: ICAO.

[147] Young, S. Ancel, E., Moore, A., Dill, E., Quach, C., Foster, J., Darafsheh, K., Smalling, K., Vasquez, S., Evans, E., Okolo, W., Corbetta, M., Ossenfort, J., Kulkarni, C., and Spirkovska, L., Architecture and Information Requirements to Assess and Predict Flight Safety Risks During Highly Autonomous Urban Flight Operations. NASA/TM-2019-000000, Hampton, VA, 2020.

[148] Nineth Meeting of the Africa-Indian Ocean Regional Aviation Safety Group (RASG-AFI/9) (November, 2023). International Civil Aviation Authority (ICAO). Accessed at https://www.icao.int/WACAF/Documents/RASG%20AFI/RASG-AFI-9/ENG/WPs-ENG/RASG-AFI9%20-%20WP04C3%20-%20Safety%20Intelligence%20to%20support%20decision%20making.pdf

[149] Joint Authorities for Rulemaking on Unmanned Systems, "JARUS guidelines on Specific Operations Risk Assessment (SORA)," Final Public Release v. 1.0, Jun. 2017.

[150] Federal Aviation Administration (2023). Unmanned Aircraft Systems (UAS) Safety Risk Management (SRM) Policy. FAA ORDER 8040.6A. Washington, DC: FAA.

[151] "SmartRunway and SmartLanding" (2024). Honeywell Aerospace Technologies, Accessed at https://aerospace.honeywell.com/us/en/products-and-services/product/hardware-and-systems/terrain-and-traffic-awareness/smartrunway-and-smartlanding

[152] Jones, D., and Prinzel, L. (2011). Simulator evaluation of runway incursion prevention technology for general aviation operations. No. NASA/TP-2011-217045.

[153] Schönefeld, D.P.F. Möller, (2012). Runway incursion prevention systems: A review of runway incursion avoidance and alerting system approaches. Progress in Aerospace Sciences, 51, 31-49.

[154] Arthur, T., Bailey, R., Williams, S., Prinzel, L., Shelton, K., Jones, D., & Houston, V. (2017). Review of head-worn displays for the Next Generation Air Transportation System. Society for Optical Engineering. Orlando, FL: SPIE. DOI:10.1117/1.OE.56.5.051405

[155] Prinzel, L., Bailey, R., Shelton, K., Jones, D., Kramer, L., Arthur, J., Williams, S., Barmore, B., Ellis, K., & Rehfeld, S. (2011). Better-Than-Visual Technologies for Next Generation Air Transportation System Terminal Maneuvering Area Operations. International Symposium on Aviation Psychology. Wright State: ISAP.

[156] Global Action Plan for the Prevention of Runway Incursions. flightsafety.org/wp-content/uploads/2021/05/GAPPRE-Parts-1-2-2021-FINAL.pdf

[157] Investigative Technologies Aviation Rulemaking Committee. Amended Sept 21, 2023. Washington, DC: FAA. https://www.faa.gov/regulations_policies/rulemaking/committees/documents/media/Amended_ARC-Charter_Investigative-Technologies_Signed-09212023.pdf

[158] National Aeronautics and Space Administration, "FutureFlight Central (FFC)," 2024. Accessed at https://www.nasa.gov/simlabs/ffc/

[159] National Aeronautics and Space Administration, "Joby, NASA Simulation Demonstrates Up To 120 Air Taxi Operations Per Hour in Busy Airspace," 2023. Accessed at https://www.jobyaviation.com/news/joby-nasa-simulation-demonstrates-air-taxi-operations/

[160] Federal Aviation Administration, "Airport Facilities Terminal Integration Laboratory," 2023. Accessed at https://www.faa.gov/about/officeorg/headquartersoffices/ang/tc/aftil