Addressing Increased Runway Incursions in an Aging and Overburdened National Airspace System

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Introduction

On the evening of January 13, 2023, Delta Airlines Flight 1943 was cleared for takeoff on Runway 13L at New York's John F. Kennedy International Airport. As the aircraft accelerated down the runway, an American Airlines Boeing 777 put the lives of 308 passengers at risk when it mistakenly crossed into its path, entering the runway in front of the oncoming Delta (National Transportation Safety Board, 2024). This incident is classified as a Category A runway incursion, one of the most serious types, where a collision is narrowly avoided.

A runway incursion is defined by the Federal Aviation Administration (FAA) 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 takeoff of aircraft"* (Federal Aviation Administration, 2022, p. 1). Despite increasing awareness of the dangers posed by these incidents, incursions continue to occur at an alarming rate. In just the first five months of 2024, 24 Category A and B incursions were reported (Raphael & Mott, 2024), underscoring the ongoing safety risks in the national airspace system.

Figure 1

Total Runway Incursions: Fiscal Years 2019-2024

Note. Adapted from *FAA Runway Incursions Final Report*, by U.S. Department of Transportation, 2025. https://www.oig.dot.gov

Figure 2

Category A & B Runway Incursions: Fiscal Years 2019-2024

Note. Adapted from *FAA Runway Incursions Final Report*, by U.S. Department of Transportation, 2025. https://www.oig.dot.gov

Efforts to prevent runway incursions have been slow to implement, in part because the problem is multifaceted. While human error is often blamed, incursions result from a web of interconnected sociotechnical factors, including pilot workload, air traffic control (ATC) communication, automation systems, regulatory constraints, and outdated airspace infrastructure. To effectively mitigate these risks, a comprehensive understanding of these interactions is necessary.

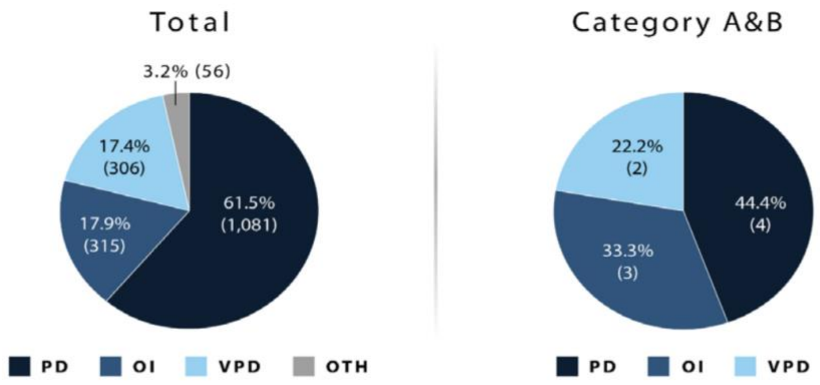
Using Actor Network Theory (ANT), this paper examines how misalignments between these actors create systemic vulnerabilities in runway safety. ANT is a sociotechnical framework that examines how both human and non-human actors, such as people, technologies, and regulations, form dynamic networks that shape systemic outcomes (Latour, 1996). By examining past incidents and the interplay between human and technological factors, this research highlights the need for integrated solutions that address both technical limitations and social barriers, such as regulatory inertia, communication breakdowns, and lapses of situational awareness.

Pilots & Flight Crew

Pilots play a critical role within the actor-network influencing runway incursions. They are, after all, the direct influencers of the controls who can inadvertently place an aircraft in a dangerous position. According to FAA data, approximately 60% of all runway incursions are caused by pilots, of which GA pilots cause 75% (Federal Aviation Administration, 2024). As shown in the diagram below representing the total runway incursion statistics during 2024, pilot deviation (PD) represents the largest proportion of blame for runway incursions across all actors involved (U.S. Department of Transportation, Office of Inspector General, 2025). The difficulty lies in the fact that these individuals act in a dynamic and high workload environment, frequently interfacing with non-human actors such as cockpit technology while simultaneously communicating with air traffic controllers or cabin crew personnel.

Figure 3

Fiscal Year 2024 Runway Incursions by Type: Total and Category A & B



OI - Operational Incident; PD - Pilot Deviation; VPD – Vehicle Pedestrian Deviation; OTH – Other
Note: Percentages may not add up due to rounding.

Note. Adapted from *FAA Runway Incursions Final Report*, by U.S. Department of Transportation, 2025. https://www.oig.dot.gov

Pilots face significant cognitive demands, especially during critical phases of flight such as taxi, takeoff, and landing. During these periods, pilots must manage multiple streams of information, including radio communications, cockpit alerts, navigational instructions, and environmental conditions. High cognitive workload increases their vulnerability to human error, as pilots may miss critical communications or misinterpret instructions. For example, high cognitive load can compromise a pilot's situational awareness, contributing to errors in navigating airport surfaces or misreading ATC clearances (DiFiore et al., 2006).

The complexity of airport environments also requires constant vigilance and situational awareness. Under heightened stress and workload, pilots can inadvertently lose track of their position, misunderstand airport markings, or mistakenly identify runway intersections. For instance, a study by Chang and Wong (2012) emphasizes that pilots often commit incursions due to memory lapses, distraction, or fatigue, leading them into protected areas unintentionally. Furthermore, in a pilot survey ranking risk factors leading to runway incursions, pilots ranked situational awareness and attention highest on the list, outpacing communication errors as a key contributor (Chang & Wong, 2012). Situational awareness, therefore, may be considered a more important factor contributing to runway incursions than miscommunication.

Pilots navigating complex taxiways in congested airports face risks of spatial confusion or misinterpretation of signage and markings, resulting in unintended runway incursions. The American Airlines incident in January 2023 represents a prime example of spatial confusion leading to a hazardous runway incursion. Furthermore, on February 25, 2025, at Chicago Midway Airport, a Flexjet Challenger 300 aircraft entered an active runway against air traffic control instructions, crossing in front of the path of a landing Southwest 737. Acting quickly and professionally, the Southwest Airlines pilots performed a go-around maneuver and avoided the

possible collision. This incident followed a series of miscommunications between the Flexjet aircraft and air traffic control, with controllers repeatedly correcting the Flexjet crew's taxi instructions prior to departure. Although miscommunication may have contributed to the incident by reflecting—and potentially exacerbating—the Flexjet pilots' breakdown in situational awareness, the event was primarily caused by their misidentification of Runway 31C as Runway 31L. This event, resulting from a direct loss of situational awareness by the Flexjet crew, highlights the human limitations that can lead to runway incursions. The National Transportation Safety Board (NTSB) is actively investigating the incident as of March 2025 (National Transportation Safety Board, 2025).

Pilots are crucial yet vulnerable nodes within the sociotechnical network of runway safety. Human cognitive limitations, especially during high-stress, high workload phases of flight, or in complex airport environments, constitute a significant systemic vulnerability.

Air Traffic Controllers

Air traffic controllers also play a critical role within the sociotechnical network responsible for runway safety. Their primary responsibilities include sequencing aircraft movements on airport surfaces, issuing precise clearances, and ensuring safe separation between aircraft during ground operations. However, despite their crucial role, air traffic controllers frequently encounter significant human limitations such as fatigue, cognitive overload, distraction, and multitasking pressures, especially during periods of high traffic and in areas of increased operational complexity. These human limitations can compromise controller performance, leading to an increased likelihood of runway incursions.

Research highlights that fatigue and excessive workload are major factors affecting air traffic controller performance. A study by Nealley and Gawron (2016) emphasized the importance of situational awareness and workload for ATC personnel. In this study, they found that operational errors were higher at periods of high workload. Furthermore, during the high workload periods, controllers appeared to pay less attention to certain aircraft and variables in order to maintain awareness of other "more important" information (Nealley & Gawron, 1998). This study suggests that reducing ATC workload can reduce human errors by ensuring controllers remain within manageable cognitive limits. However, a nationwide shortage of qualified air traffic controllers has intensified existing workload pressures, forcing ATC personnel to manage an increasing volume of flights simultaneously. This shortage makes efforts to reduce controller workload through increased staffing challenging, thereby heightening the risk of operational errors and near-collisions (New York Post, 2025).

Two notable incidents at San Diego International Airport illustrate the consequences of controller-induced errors under heightened cognitive workload conditions. In August 2023, a Southwest Airlines jet and a private Cessna Citation Excel business jet nearly collided when the controller cleared the Southwest Boeing 737 onto the runway ahead of the landing Cessna Citation. The controller, likely distracted by another operational task, temporarily lost situational awareness regarding the Southwest aircraft waiting patiently to depart. This caused the Cessna to fly approximately 100 ft from the Southwest before performing a go around (Aviacionline, 2023). This event illustrates how human factors such as multitasking challenges for air traffic controllers can significantly contribute to runway incursions (NBC San Diego, 2023). At the same airport, in October 2023, a Southwest Airlines flight nearly collided with another Southwest aircraft due to simultaneous clearance instructions onto the runway from the same air

traffic controller. This incident, only two months after the first, reiterates how distraction under high workload can create an immediate collision hazard (NBC San Diego, 2023).

Addressing ATC human factor vulnerabilities involves improving staffing levels to distribute workloads evenly, enhanced training in situational awareness, and deploying advanced support tools for ATC personnel in the form of collision prevention and workload reduction technology. By recognizing and mitigating ATC human limitations, their role within the aviation sociotechnical network can be strengthened, significantly enhancing runway safety.

Government

The Federal Aviation Administration (FAA) serves a crucial regulatory role within the sociotechnical network of aviation safety, establishing standards, procedures, and guidelines intended to reduce runway incursions and enhance aviation safety nationwide. Despite this critical responsibility, regulatory and bureaucratic hurdles have significantly impeded the timely implementation of vital safety technologies. A recent report from the U.S. Government Accountability Office (GAO) highlights that among the FAA's air traffic control systems, 51 systems were classified as "unsustainable," and an additional 54 were considered "potentially unsustainable" due to outdated technology, excessive maintenance demands, and functional obsolescence (GAO, 2024). These inefficiencies not only delay technological modernization but also exacerbate vulnerabilities in the aviation safety network.

A significant incident highlighting regulatory and technological vulnerabilities occurred in January 2023, involving the nationwide outage of the FAA's Notice to Air Missions (NOTAM) system. The NOTAM system communicates essential information regarding airport hazards, runway closures, and other critical operational changes to pilots and controllers. On

January 11, 2023, the NOTAM system suffered a major outage due to accidental deletion of crucial database files during routine maintenance, triggering the first nationwide ground stop since September 11, 2001 (Shepardson, 2023). Although not a direct runway incursion, this event underscores systemic vulnerabilities created by regulatory inertia and reliance on outdated technological infrastructure, illustrating significant potential threats to aviation safety (GAO, 2024).

Further outdated systems include the continued use of paper-based flight progress strips, requiring controllers to use handwritten and manually updated flight strips to track aircraft movements. This system could likely lead to opportunities for human error. While electronic flight strips are currently being implemented, the prolonged reliance on outdated paper-based systems well beyond their intended lifespan underscores the FAA's slow adoption of new technologies (Federal Aviation Administration, n.d.). Legacy radio communication systems, prone to signal interference, represent an additional example of technological obsolescence. If a controller issues a clearance while the radio is transmitting from another aircraft, the controllers words cannot be heard by anyone else, potentially leading aircraft to miss key information in a clearance. A significant incident occurred on February 4, 2023, in Washington D.C., where a midair collision between a civilian CRJ-700 aircraft and a military Black Hawk helicopter resulted in 67 fatalities. This incident was the first major commercial passenger flight accident in the U.S. in nearly 16 years, following Colgan Air Flight 3407 in February 2009, and the deadliest U.S. air disaster in over 23 years (Associated Press, 2025). After reviewing the Black Hawk Helicopter's flight data, National Transportation Safety Board (NTSB) Chairwoman Jennifer Homendy revealed NTSB findings showed "the portion of the transmission that stated 'pass behind the' may not have been received by the Black Hawk crew."(NBC Washington, 2025).

This is likely due to the black hawk crew “stepping” on the frequency over the controller while attempting an early response. Frequency stepping preventing clear communication during overlapping radio transmissions clearly exemplifies outdated communication technology adversely affecting airspace safety.

These technological and regulatory shortcomings lie in the context of controversial FAA resource allocation. For instance, the FAA allocated $17.5 million specifically to environmental sustainability efforts as part of its 2023 climate initiatives (U.S. Department of Transportation, 2022). Further funding has been allocated to promoting diversity, equity, and inclusion (DEI) hiring within the FAA workforce, including hiring for air traffic controllers. The FAA's Fiscal Year 2024 budget request included a $1.3 million allocation to enhance diversity and inclusion within its workforce, as part of a broader $12.7 billion Operations budget (U.S. Department of Transportation, 2023). These moves have generated criticism from experts and passengers alike, who argue that such expenditures divert resources away from critical infrastructure upgrades directly impacting operational safety. With many of these investments occurring under the leadership of Transportation Secretary Pete Buttigieg, the current administration has taken a strong initiative to “End DEI Madness and Restore Excellence and Safety within the Federal Aviation Administration” (The White House, 2025). These changes, led by President Donald Trump, come in the wake of a series of near collisions at major airports, including the catastrophic collision at Washington Reagan airport. Mentioned above, this collision was the first fatal crash of a commercial U.S. airplane since 2009, ending a nearly 16-year period without such tragedies (Isidore, 2025).

In previous administrations, government action in the form of regulatory mandates have positively influenced safety measures. Notably, under President Trump's administration, the

FAA mandated Automatic Dependent Surveillance-Broadcast (ADS-B) technology by January 1, 2020. ADS-B enhances real-time aircraft position tracking, replacing traditional radar with precise GPS-based monitoring. This mandate significantly improved airspace safety and controller situational awareness by requiring all aircraft to broadcast their position via satellite-based surveillance. Unlike previous radar-based systems, this technology enables air traffic controllers to track the precise position of all equipped aircraft in real time and allows properly equipped pilots to view surrounding traffic on their cockpit GPS displays. This mandate illustrates the critical role regulatory actors can play in enhancing or compromising aviation safety through timely technological adoption (Federal Aviation Administration, 2020).

A final and noteworthy contributor to runway incursions, for which the FAA bears responsibility, is the outdated system governing the division of ATC responsibilities and the coordination between air traffic controllers. Many airports across the United States operate multiple intersecting runways simultaneously, increasing the complexity of ground and air traffic coordination. Furthermore, these runways are oftentimes managed by multiple controllers in order to divide responsibility and reduce controller workload. However, two recent incidents have highlighted the risk that is currently posed to passengers due to conflicting instructions and lack of coordination between controllers. The first incident at Nashville International on September 12, 2024, involved an Alaska Airlines aircraft that was cleared to takeoff by one controller, while a second controller cleared a Southwest Airlines to cross the very same runway as the hurtling Alaska Airlines jet, putting the two aircraft on a direct collision course with each other and jeopardizing the safety of everyone on board (National Transportation Safety Board, 2024). A second incident, which occurred at Boston Logan Airport on April 18, 2024, involved a JetBlue aircraft that was cleared for takeoff by one controller, while just seconds later, another

controller cleared a Southwest Airlines flight to cross the same runway (CBS News, 2023). These two incidents highlight nearly identical scenarios, clearly illustrating a significant vulnerability within the current airspace control system. Although the separation of duties at major airports is crucial to reduce controller workload, the current system prohibiting clear communication between controllers creates conflicts in instruction that could lead to catastrophic collisions. This risk represents an outdated system with responsibility lying with the FAA. Although the risk has been clear for years, highlighted by numerous case studies of near collisions, the government has failed to rectify the vulnerability and has instead continued to rely on a legacy controller network.

The risk posed to passengers nationwide is a result of outdated physical infrastructure, legacy air traffic control systems, and the flawed allocation of resources. To effectively mitigate runway incursion risks, the FAA must adopt a proactive approach in streamlining bureaucratic processes, accelerating modernization, and prioritizing technological investments that directly improve airspace safety.

Solutions

Addressing runway incursion risks requires a comprehensive sociotechnical approach that involves both technological upgrades and regulatory reforms. A critical step forward involves updating and implementing advanced ground surveillance technologies at airports nationwide. For example, airports lacking updated ground radar systems such as Airport Surface Detection Equipment–Model X (ASDE-X) experience increased risks of runway incursions, especially during periods of low visibility when air traffic controllers have limited visual capabilities. Following a notable runway incursion involving a Southwest aircraft and a FedEx

cargo jet at Austin-Bergstrom International Airport in February 2023, it became evident that comprehensive ground surveillance technologies could significantly reduce risks. The event occurred when the Southwest jet was cleared for takeoff while the FedEx plane was on final approach to the same runway, with low visibility and the absence of advanced ground radar systems contributing to the controller's loss of situational awareness (National Transportation Safety Board, 2024). Since then, Austin has adopted an innovative surface situational awareness system from uAvionix. Using satellite technology (ADSB), the system uses "real-time tracking of aircraft and vehicles on the airfield" to reduce the chances of incursions (uAvionix, 2023). Although the system has been successfully implemented at airports in Austin and Indianapolis, broader nationwide adoption is essential to comprehensively enhance airport safety.

Furthermore, a recent advancement by Purdue University—the Simple, Affordable, Flexible, and Expandable Runway Status Lights (SAFE-RWSL) system—demonstrates an effective and efficient technological solution. The SAFE-RWSL is an innovative, solar-powered system utilizing existing Automatic Dependent Surveillance-Broadcast (ADS-B) data to provide real-time, automated runway occupancy alerts on airport surfaces. Developed to be cost-effective and scalable, this system has shown promising results in early testing at Purdue University Airport, accurately detecting aircraft and ground vehicle movements and visually alerting pilots and controllers of potential runway conflicts (Purdue University, 2024). An additional infrastructural solution includes implementing clearly marked and dedicated taxiways beyond runway ends, reducing runway occupancy times and minimizing taxiway-runway conflicts.

Within the actor network theory of runway incursions, air traffic controller and pilot induced incursions are similar in that their blame lies in human limitations and errors. Therefore, effective mitigation strategies should therefore directly target human factors. A potential solution

for pilots includes improved “safe-taxi” systems inside the cockpit. Safe taxi is a system which displays to the pilots their active location on the airport diagram. This system, however, currently lacks sufficient functionality to alert pilots clearly and proactively when their aircraft approaches or enters a restricted or hazardous zone on the airport surface. It’s therefore recommended that human factors experts, regulators, and additional engineers and personnel at key aircraft manufacturers work together to incorporate heightened alerting systems using cockpit safe taxi technology to make it clear to the pilots when they are entering a zone that compromises the safety of those onboard.

For air traffic controllers specifically, a study by Conversy et al. (2011) demonstrates how digital tabletop systems—interactive, computerized surfaces enabling collaborative interaction among multiple users—can significantly enhance aviation safety by improving collaboration among air traffic controllers. These tabletop systems typically consist of large horizontal touchscreen displays that allow controllers to simultaneously manage electronic flight strips, annotate critical information, and visualize aircraft trajectories in real-time. By integrating interactive elements such as electronic Post-its, task management tools, and dynamic trajectory editors, these systems restore beneficial features of traditional paper-based methods while reducing the limitations associated with manual processes. The implementation of digital tabletop systems in air traffic control operations can facilitate clearer and more efficient communication, improve controllers' mutual awareness of ongoing tasks, and support dynamic, real-time decision-making. Consequently, these improvements can reduce cognitive overload, minimize communication-related errors, and significantly decrease the likelihood of runway incursions and other safety-critical incidents, ultimately enhancing overall aviation safety.

Coupled with targeted training programs emphasizing situational awareness and effective communication, the enhancements described form an integrated sociotechnical strategy that addresses both human and technological factors. Together, these measures can significantly mitigate runway incursion risks and enhance the overall safety and efficiency of aviation operations nationwide.

Conclusion

This research examined the critical issue of runway incursions within an aging and overburdened national airspace system through a sociotechnical lens, utilizing Actor Network Theory (ANT). Key actors, including pilots, air traffic controllers, regulatory agencies, and technological systems, were analyzed to uncover systemic vulnerabilities and human limitations that contribute significantly to runway safety risks. The findings underscored the complexity of interactions between human operators, outdated infrastructure, regulatory inertia, and inadequate implementation of modern safety technologies. To address these vulnerabilities, solutions such as improved cockpit alerting systems, digital tabletop interfaces for air traffic controllers, and broader adoption of advanced runway surveillance systems were recommended. As aviation traffic continues to rise, proactive measures that holistically target both technological advancements and human factors will be essential to sustainably enhance aviation safety by reducing runway incursions, and maintain public trust in air travel.

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