Active Runway Indication System

(ARIS)

2022-2023 ACRP Design Competition

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Number of Graduate Students: 3

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Design Challenge: Runway Safety/Runway Incursions/Runway Excursions Including Aprons, Ramps, and Taxiways G: Enhancing Airport Visual Aids

Executive Summary

This paper proposes an Active Runway Indication System (ARIS) design to address the ACRP **Runway Safety/Runway Incursions/Runway Excursions Including Aprons, Ramps, and Taxiways Design Challenge**, addressing challenge G: "Enhancing Airport Visual Aids." Airports are constantly seeking improvements to mitigate the risk of runway incursions. Despite the continued efforts to mitigate this risk, runway incursions still occur without a substantial decrease. The existing signs need to convey different and enhanced information pilots. The ARIS is designed to make airports more suitable for the incorporation of more information via dynamic signs, including correct direction and runway status information. This incorporation of ARIS will improve safety, visibility of more information, and efficiency of sign design.

The project team started out by reading through ACRP and Federal Aviation Administration (FAA) documentation. To further understand airport infrastructure and sign designs and to get design input, the team consulted with industry professionals. This input was included in the method for addressing problems, the risk assessment, and the specifications for the designs. A cost-benefit analysis and sustainability assessment evaluating operational efficiency were developed. An estimated cost for the development, creation, and implementation of our proposed design is $38,236 over 10 years with a benefit-cost ratio of 37.66. The design corresponds to parts 7, 9, and 11 of the United Nation's (UN) Sustainable Development Goals (SDG).

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Problem Statement and Background

The intent of our research is to improve design challenge G: "Enhancing Airport Visual Aids", of the "Runway Safety/Runway Incursions/Runway Excursions Including Aprons, Ramps, and Taxiway Challenges" (Airport Cooperative Research Program [ACRP], 2022, p. 8).

Runway Incursions

A safe flight revolves around runway safety, beginning with takeoff and ending with landing. Air traffic controllers (ATC), pilots, and airport vehicle operators are all encompassed by the umbrella of runway safety which is a key concern for the Federal Aviation Administration (FAA). A runway incursion, as defined by the FAA, is "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" (FAA, n.d.-b, para. 1).

Most recently, between Fiscal Year (FY) 2021 and FY 2022, within the United States, there were 3,306 runway incursions recorded (FAA, 2023b). Runway incursion data between 2012 and 2017 indicates that approximately 90% of the incidents took place at towered airports, with general aviation pilots reporting more than 40% and air carrier pilots filing just 36% of runway incursions, respectively (Werfelman, 2017). 87% of incident records included references to human factors (Werfelman, 2017). "Situational awareness (mentioned in 76% of records), communication challenges (55%), confusion (53%), and distraction (31%) were among the particular human factors problems" (Werfelman, 2017).

State-Of-The-Art-Approaches

Due to runway incursions being one of the top safety concerns for the air transportation system, there are already numerous technologies in place to aid in mitigating these incidents. Runway Status Lights (RWSL), which are comprised of Runway Entrance Lights (REL) and Takeoff Hold Lights (THL), are a fully automated system designed to avoid interfering with airport operations while lowering runway incursions' frequency and severity and preventing accidents (FAA, n.d.-b). Another recent technology is the Airport Surface Detection System Model X (ASDE-X). These technologies, as well as many others, are discussed in further detail in the literature review.

Purpose

The intent of this design is to enhance airport visual aids and runway safety, by giving towered airports, which may not have the funds or facilities to install large-scale runway incursion prevention systems, the chance to possess this preventive technology. This solution augments the current runway hold sign by implementing a new system that can attach to the current runway hold short sign, which vehicles and personnel on the ground can view before entering a runway. The aforementioned technologies have only been implemented in major airports with a great deal of commercial and cargo traffic. In general, fewer runway incursions are reported at airports with more commercial operations, presumably due to the reduced general aviation (GA) activities there (FAA, n.d.-a). Even though runway incursions are an issue at all airports, only towered airports record them in the Aviation Safety Reporting System (ASRS).

Summary of Literature Review

In order to comprehend how runway incursions are at present faring, a literature review was undertaken, previous accidents, and technologies available to mitigate runway incursions. Previous ACRP submissions combined with current technologies available helped narrow down the focus to the reduction of wrong-direction intersection departures within runway incursions.

Types of Incursions

Runway incursions have four categories and increase in severity from D to A. “Category A is a serious incident in which a collision was narrowly avoided” (FAA, 2022b). “Category B is an incident in which separation decreases and there is a significant potential for collision, which may result in a time-critical corrective/evasive response to avoid a collision” (FAA, 2022b). “Category C is an incident characterized by ample time and/or distance to avoid a collision” (FAA, 2022b). “Category D is an incident that meets the definition of a runway incursion, such as the incorrect presence of a single vehicle, person, or aircraft on the protected area of a surface designated for the landing and take-off of aircraft but with no immediate safety consequences” (FAA, 2022b).

The Aviation System Reporting System (ASRS) is a way for not just pilots and ATC but all aviation professionals to report safety issues (NASA, 1976). There are 12,857 runway incursions reported since 2011, according to the ASRS database (Werfelman, 2017). There were 1,341 reports of runway incursions between 2016 and 2017 (Werfelman, 2017). Six of these incursions were classified as A and B occurrences, the most dangerous category. Leaving 1,335 incursions in the C and D categories (Werfelman, 2017). Although they are less risky, they are more frequent, making them a serious issue.

Accidents/Incidents

In 2006, Comair Flight 5191 crashed on takeoff at Lexington Bluegrass Airport. The NTSB (2007) concluded in the post-accident investigation that the crew intended to take off from the 7,003-foot-long runway 22. Instead, the crew taxied the aircraft onto and took off from the 3,500-foot-long runway 26 (NTSB, 2006). The aircraft sped to the end of the runway before it could lift off, resulting in 49 fatalities (NTSB, 2006). The two runways at Lexington had runway thresholds that were located close together. Prior to the accident, there had been two cases where aircraft attempted to take off from runway 26 while intending to take off from runway 22. In both prior cases, the pilots realized their mistakes before it was too late (National Aeronautics and Space Administration, 1993)(National Aeronautics and Space Administration, 2007).

One aircraft took off from Sharjah, United Arab Emirates (UAE), in the opposite direction it was supposed to. During the accident investigation, the UAE General Civil Aviation Authority (GCAA) found that the aircraft only became airborne after the end of the runway, where the approach light and the aircraft's landing gear were damaged. Further damage was avoided as a result of the captain applying more thrust to the aircraft (*A320, Sharjah UAE, 2018*, n.d.).

Implementation and Effectiveness of Runway Status Lights (RWSL)

RWSLs were created by the FAA as part of an ongoing technology exploration program (FAA, n.d.-b). With precise and prompt signaling of runway usage, the system seeks to enhance situational awareness among flight crew and vehicle operators. Twenty U.S. airports have installed RWSL systems (FAA, n.d.-b). The RWSL system is entirely automated; it is powered by data from traffic surveillance systems on and near runways, and the accuracy and timeliness of its processor depend on the surveillance data's track-handling capabilities (Luo et al., 2021). The RWSL system is a practical and significant technology that the FAA has developed that can reduce runway incursions. An example of this success comes from Dallas/ Fort-Worth International Airport (DFW), where this technology was first tested and implemented. As shown in Figure 1 below, at the RWSL test runway at DFW, there have been far fewer runway incursions—from 10 to 3 (or 70%) over a period of 5 years, 2002-2007 (Williams, 2008).

RWSL is a ground-breaking technology, but due to the increasingly high cost of implementation, very few airports are able to benefit from this advancement at this time. Due to higher-than-expected costs for constructing light fixtures and erecting shelters, airports' requests for more lighting than initially anticipated, and the limited availability of active runways and taxiways for construction activities, there are site-specific cost increases (Hampton, 2014). For instance, development expenditures resulted in overall RWSL installation cost estimates of $80 million and $54 million, respectively, for Atlanta and Denver airports (Hampton, 2014).

System for identifying runway position

Honeywell International was granted a patent for a process and procedure for determining the location of an aircraft during an intersection takeoff (USPTO 9117370, 2015). This design addresses one of the main shortcomings of currently available technology. Some modern flight deck displays utilize the Synthetic Vision System (SVS) to display visual cues while the aircraft is moving around the airport. SVS enables the runway designation to be displayed on the flight deck only when the aircraft is taking off from the beginning of the runway. The new Honeywell system is capable of “determining if an aircraft is headed in the right direction on a runway entered upon at a location that does not display runway identification" (USPTO 9117370, 2015). One of the main limitations of the system is that it is only compatible with modern flight deck displays and cannot be installed on older-generation aircraft.

Situational Awareness

Situation awareness (SA) is a key component of how people interpret information and is crucial to how pilots make decisions (Nguyen et al., 2019). As SA impacts all decisions and actions made during flights and during ATC operations, assuring that adequate levels of SA attained are crucial in the aviation industry (Nguyen et al., 2019). However, as defined by the

(National Academies of Sciences, Engineering, and Medicine [NASM]., 2022,) SA involves more than merely observing information in one's environment. SA consists of three levels "Perception (Level 1), Comprehension (Level 2), and Projection (Level 3)" (NASM., 2022)

These three levels can occur very rapidly and at times are not noticed by an individual, or pilot in this case. An example of these three levels in action is a pilot preparing for takeoff. In level 1 the pilot must distinguish certain things that are around them prior to takeoff such as other aircraft and a runway hold a short sign. Then, in level 2 they must comprehend what was just perceived and finally, in level 3 they must envision possible outcomes and events that could occur (NASM, 2022).

ACRP Reports

This section highlights ACRP studies that informed the team as part of the research for this design. Table 1 summarizes the reports used and what was learned from them that is pertinent to the group's research and design.

Table 1.

ACRP Reports

Report Reference	Report Title	Findings
148	LED Airfield Lighting System Operation and Maintenance	"Provides guidance for operating and maintaining light-emitting diode (LED) airfield ground lighting systems, including taxi guidance signs, elevated light fixtures, and in-pavement light fixtures." (Burns et al., 2015)
246	Airside Operations Safety: Understanding the Effects of Human Factors	"Provides a review of the current state of human factors research and the related resources that are available to U.S. airport operations personnel." (Neubauer et al., 2022)

Advisory Circulars

Table 2 displays Advisory Circulars (AC) that were examined as part of our design process. The ACs shown provide guidance to illustrate a means of complying with the regulations in place.

Table 2

Advisory Circulars

AC Number	AC Title	Findings
91-73B	Parts 91 and 135 Single Pilot, Flight School Procedures During Taxi Operations	"This advisory circular (AC) provides guidelines for the development and implementation of standard operating procedures (SOP) for conducting safe aircraft operations during taxiing to avoid causing a runway incursion." (Federal Aviation Administration, 2012)
150/5340-1M	Standards for Airport Markings	"This advisory circular (AC) change contains the Federal Aviation Administration (FAA) standards for markings used on airport runways, taxiways, and aprons." (Federal Aviation Administration, 2020a)
150/5340-18G	Standards for Airport Sign Systems	"This Advisory Circular (AC) change contains the Federal Aviation Administration (FAA) standards for the siting and installation of signs on airport runways and taxiways." (Federal Aviation Administration, 2020b)
150/5340-30J	Design and Installation Details for Airport Visual Aids	"This advisory circular (AC) provides guidance and recommendations on the installation of airport visual aids." (Federal Aviation Administration, 2018)
150/5345-44K	Specification for Runway and Taxiway Signs	"This advisory circular (AC) contains the Federal Aviation Administration (FAA) specifications for unlighted and lighted signs to be used on taxiways and runways." (Federal Aviation Administration, 2015a)
150/5345-46E	Specification for Runway and Taxiway Light Fixtures	"This advisory circular (AC) contains the Federal Aviation Administration (FAA) specifications for light fixtures to be used on airport runways and taxiways." (Federal Aviation Administration, 2015b)

Problem-Solving Approach

Approach Process

The team was formed due to a shared design idea for the ACRP competition. Runway Safety/Incursions was the design challenge chosen, with an emphasis on category G: Enhancing airport visual aids. The design/approach process was conducted in numerous stages: identifying the problem, brainstorming potential solutions, creating mock-up designs, selecting and finalizing a design.

Identifying The Problem

A top priority of the FAA is the mitigation of runway incursion in the National Airspace System. (FAA, 2023a). All members of the team have a background in the aviation industry, and two members have a flight background, all know firsthand the importance of mitigating runway incursions. Specifically, wrong-direction intersection takeoffs pose a serious threat to safety. A plane that takes off in the incorrect direction runs the risk of colliding with another one, with a vehicle on the runway, or, once in the air, with an oncoming aircraft. Another risk of an intersection takeoff from either the right or wrong direction is less available runway to take off from.

Runway incursion prevention technology is becoming more and more prevalent at major airports all around the world. RWSLs and SVS are technologies mentioned previously and they have been proven to decrease runway incursions. Yet the costs for implementing these technologies can cost upwards of $50 million depending on the size of the airport (Hampton, 2014). A comparison of current runway incursion prevention technologies are shown in Table 3 below.

Table 3

Current Technology Benefit/Drawbacks

Current Technology	Benefits	Drawbacks
RWSL	Potential to decrease incursions	Expensive - Millions of Dollars
	Completely Automated	Implementation takes a long time
	--	Light Illuminiation Errors
SVS	Determines Aircraft Position	Cannot be Installed on Older Aircraft
	Improved SA	Pilots must undergo SVS training
	Reduced Pilot Workload	Pilots may depend on SVS too much
ASDE-X	Allows ATC to track surface movements	Expensive - Millions of Dollars
	Visual and Audible alerts	Suseptable to dropped targets and outages during heavy rain
Current Runway Hold Short Signs	Cost Effective	Regular Maintenance
	Does not require training	Not able to be altered (static)

Brainstorming

Based on the seriousness of runway incursions and the need for affordable technology, the team began to brainstorm possible solutions. Initial ideas revolved around implementing technology within each aircraft, similar to SVS but it would operate via an app that pilots could use on a personal device. The second concept was to redesign the current runway hold short sign to make it completely dynamic. The sign would be able to display information pertinent to each aircraft approaching as well as airfield information that is a part of the Automatic Terminal Information Service (ATIS). This concept, however, would be very costly to implement. Our final concept would be to add an attachment to the current runway hold short sign that would display the current active runway (ARIS). When considering all of our potential designs a pugh matrix was utilized to narrow down all of our design concepts.

The current runway hold short sign was used as a baseline and was compared against three concepts. If a proposed design is an improvement to the baseline it is given a score of one (1) and if it is worse it is given a score of negative one (-1). A score of 0 is given if it is equal to the baseline. Based on the matrix conducted in Table 4 a clear frontrunner was established. ARIS will be the design chosen based on cost, effectiveness, and lack of complexity.

Table 4

Pugh Matrix

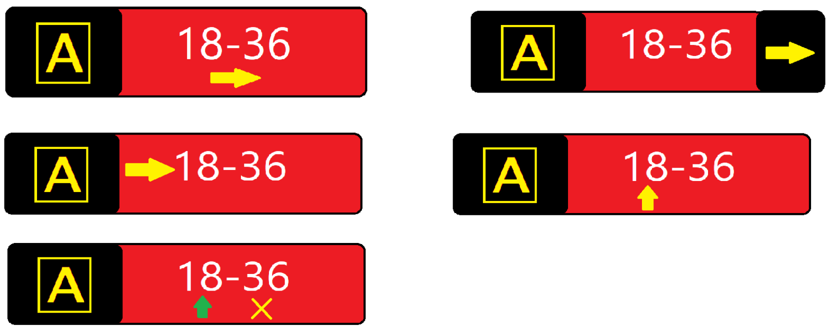
	Concepts			
Criteria	Runway Hold Short Sign	SVS App	Sign redesign	ARIS
Cost	Baseline	**1**	**-1**	**0**
Complexity		**-1**	**-1**	**0**
Buy-in		**-1**	**-1**	**1**
Effectivity		**-1**	**1**	**1**
Sum of Positive	**0**	**1**	**1**	**2**
Sum of Negative	**0**	**3**	**3**	**0**
Sum of Neutral	**0**	**0**	**0**	**2**

Potential Designs

Once ARIS was chosen as our final concept we began to sketch ideas and preliminary designs of what this technology might look like. ARIS would consist of a dynamic LED display that could attach to the current runway hold short sign. Prior to our final design, we each came up with our own concept of what ARIS could be, some designs consisted of single or multi-panel LED displays, and some designs were attached to the end or the front of the current sign. Shown below are our concepts.

Figure 1

Preliminary ARIS Design



After interaction with one of our experts, the team learned that there is a need for affordable runway incursion prevention technology, and they conveyed that our idea is feasible. Through careful consideration a design was chosen that would fit within current regulations and be the cheapest/ easiest to implement was the design shown below.

Figure 2

ARIS Final Design

Industry Interactions

The team interviewed four industry experts related to airport design and runway incursion leadership. Questions asked related to current sign design, design feedback, and implementation considerations.

Dr. Schreckengast – "is a member of the Graduate Faculty of Purdue University. He conducts undergraduate and graduate courses in aviation safety and security, along with applied research in airport development, safety management, and multi-modal security programs. In addition to his extensive knowledge of FAA regulations for airport development and safety management, he has assisted in the development and implementation of the International Civil Aviation Organization (ICAO) Annexes 1, 6, 8, 11, 13, 14, 17, and 19. He has extensive experience as a facilitator in workshops for Airport Inspections, Safety Management Systems, and Security through symposiums and training conducted for MITRE/CAASD, ICAO, FAA, University of South Australia, and Purdue University.

Dr. Schreckengast is a graduate of the US Navy Aviation Safety School, Canadian Forces Flight Safety School, Australian Transportation Safety Board, and the University of Southern California Safety Courses. He has approximately 4000 flight hours as an aircraft commander and flight instructor with extensive international experience." (Purdue Polytechnic Institute, n.d.).

After the team met with one of our experts it was found that the current runway hold short sign and hold short markings were implemented after a runway incursion at Providence, Rhode Island (S. Schreckengast, personal communication, March 2, 2023). When shown our original designs, experts suggested that the simplest solution would be to add a box on top or at the end of the existing sign (S. Schreckengast, personal communication, March 2, 2023). It was also mentioned that our biggest challenge would be complying with all the Advisory Circulars and guidelines (S. Schreckengast, personal communication, March 2, 2023). Another challenge brought up is the adverse effect of cold weather on LED displays. LED light sources do not generate as much heat as incandescent light bulbs. Therefore, snow and ice could potentially obscure the sign (S. Schreckengast, personal communication, March 2, 2023).

Adam Baxmeyer, C.M. – "is the airport operations manager for Purdue University Airport. A Purdue alum, he has also been the Deputy Director of Operations and Facilities for Bloomington Normal Airport Authority and the Airport Operations Supervisor for Cherry Capital Airport." (*Baxmeyer, Adam | Archives and Special Collections*, n.d.).

While not an airfield electrician himself, one of our experts thorough understanding of the lighting system at Lafayette Airport. Through interaction with one of our experts, a level of understanding of the complexity of circuits and controls was developed. The main challenge would be to keep the LED display at constant brightness while the intensity of other lights changes on the field (A. Baxmeyer, personal communication, March 24, 2023). An estimated cost of our design was also established thanks to our industry interactions.

When asked about cold weather issues our sign might face, the team learned that current airport signs have a curved transparent cover installed to prevent snow and ice buildup (A. Baxmeyer, personal communication, March 24, 2023). This was incorporated into the design of the LED sign.

Steven Debban - National Resource Expert for Airport Design and National Program Manager for the Runway Incursion Mitigation (RIM) Program at the Federal Aviation Administration (FAA) (*Steven Debban, P.E. - National Resource Expert for Airport Design - Federal Aviation Administration*, n.d.).

The team also learned that the need for more affordable technologies for runway incursion prevention. The team learned that existing Airport Surface Detection Equipment, Model X (ASDE-X) is costly to install and that the FAA is no longer pursuing the new installation of Runway Status Lights (RWSL) (S. Debban, personal communication, March 29, 2023).

The team realized that the design might face pushback from National Air Traffic Controllers Association (NATCA) if air traffic controllers are tasked with operating the sign (S. Debban, personal communication, March 29, 2023).

The team also gained further knowledge about the approval process for new signage and displays (S. Debban, personal communication, March 29, 2023). The team also learned that new Advisory Circulars will be drafted for new signage and displays since there is no current AC for a sign that does not exist (S. Debban, personal communication, March 29, 2023).

Marvin Woods is an FAA electric engineer specializing in airport signage and

airport visual aids (*Airport Design and Construction Branch*, 2023).

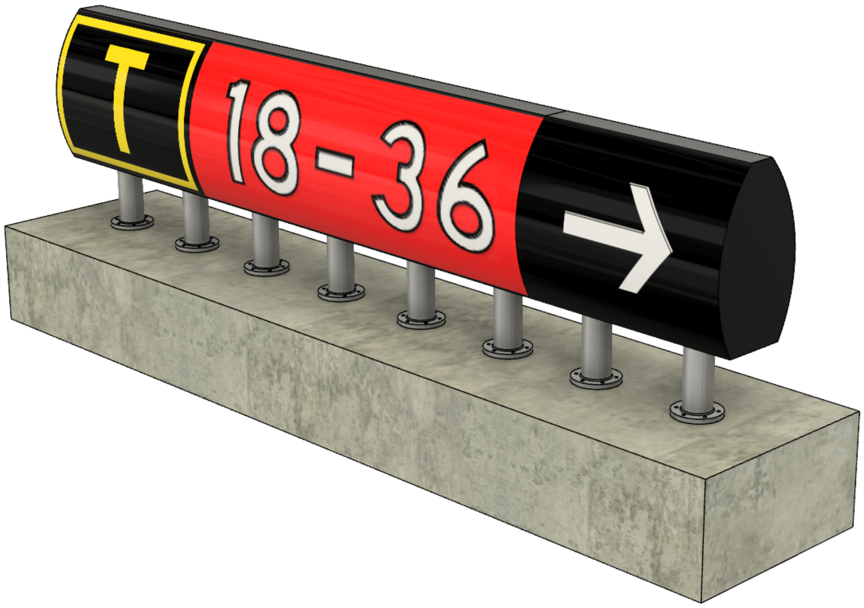
During the interaction, the team also learned that there is no current regulation regarding dynamic signage (Woods, personal communication, April 7, 2023). But dynamic signs will come in the future (M. Woods, personal communication, April 7, 2023). When shown the team's design, the team learned the importance of ensuring the sign does not lag (M. Woods, personal communication, April 7, 2023).

System Design

Our proposed active runway indication system (ARIS) design provides more information to pilots to improve safety and mitigate runway incursions. While implementing the existing design of airport taxiway signs, ARIS features were designed from expert feedback and insight. The ARIS model was modeled by the team using computer-aided design (CAD) software. A model of the ARIS system with its components is shown in Figure 3.

Figure 3

Front View of ARIS Design



From the literature review it was found that runway incursions occur substantially due to pilot deviations. Based on this, a dynamic LED display was incorporated to display the direction for pilots to take, avoiding further pilot deviations and wrong-way takeoffs. This display would provide high visibility to pilots while maintaining the design specifications for taxiway signs.

System Implementation

The design implementation of the ARIS system will depend on the airport's capabilities to improve. Based on the different geometry of airport runway and taxiway designs and with busier intersections, taxiway signs may not have room for an additional panel due to the constraints on their length. Smaller airports may not have the funding or personnel to manage this system as it would require ATC Towers to monitor and engage with the system. Steven Debban recommended that a passive system should be developed or implemented into this design for monitoring and displaying the current runway status and traffic direction to the correct aircraft. This would require more research and development in addition to the ARIS system.

Safety Risk Assessment

A safety risk assessment was conducted on the current runway hold short sign as well as the proposed design in accordance with AC 150/5200-37A (FAA, 2023c). The team identified hazards and estimated risks associated with such hazards for current and proposed designs and then developed mitigation strategies for the proposed design.

For the current runway hold short sign, one hazard identified by the team was that the light bulb for the sign could burn out. If the bulb burned out, then the enhanced centerline and runway hold short lines would still be visible to the pilot. As a result, the risk of this hazard was assessed as minor.

Another hazard identified was that pilots could enter the runway without authorization, causing a runway incursion. With the dynamic LED sign, a STOP sign could be displayed to remind the pilot to stop the aircraft, lowering the risk level to low.

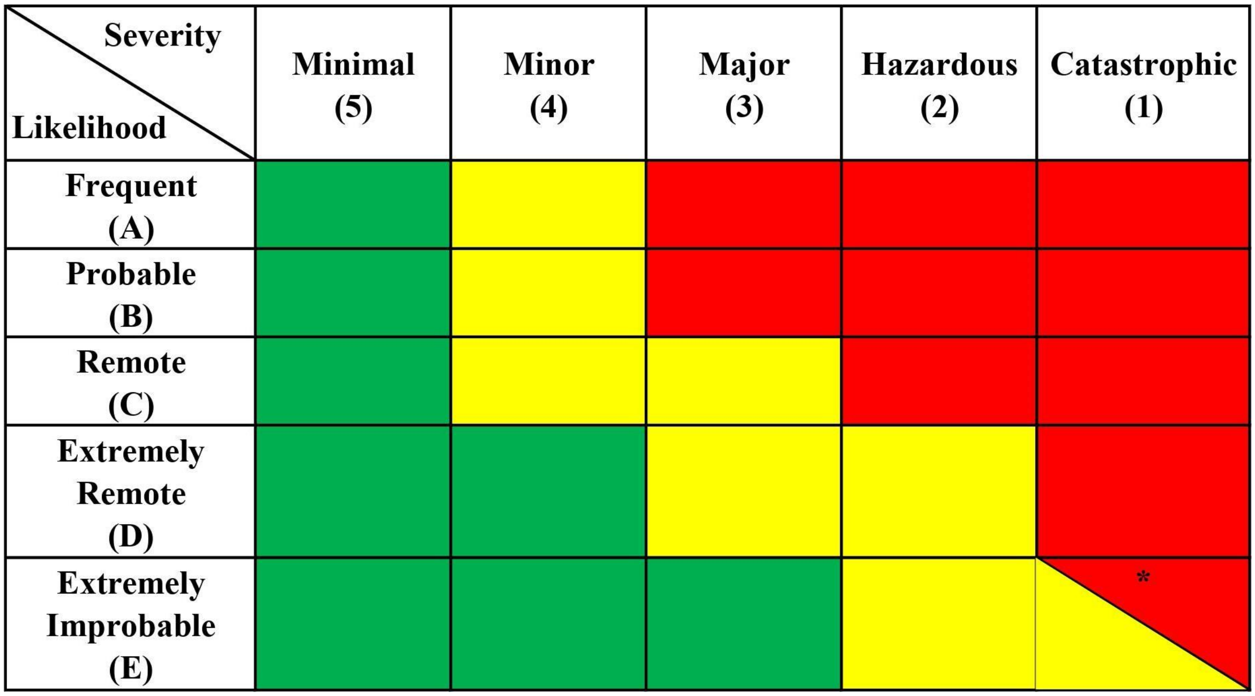
The most significant hazard for the current runway hold short sign was identified as pilots taking off in the wrong direction. As mentioned in the literature review section, the potential consequence can be catastrophic, which elevates the risk level to high. With the dynamic LED sign installed, an arrow can display the direction pilots are supposed to face when taking off. This reduces the likelihood of a wrong-direction takeoff, thus lowering the risk level to low.

The most significant hazard identified for the proposed design was that the arrow would be pointed in the wrong direction if air traffic controllers were to forget to change the display during a runway change. A delay in the display changing was brought up by FAA national expert for airport design Mr. Steve Debban (S. Debban, personal communication, March 29, 2023). The worst outcome of a wrong-direction arrow display would be a wrong-direction takeoff with insufficient runway distance. The risk of this hazard would be catastrophic and therefore must be mitigated before the implementation of the design. The team chose to segregate the exposure. Since air traffic controllers have control over the display, ground controllers will receive additional training to ensure the correct arrow is displayed to reflect the active runway in use when they record the airport's hourly Automatic Terminal Information Service (ATIS) broadcast.

The last hazard of the proposed design would be a total failure of the display. The worst outcome of this hazard would be that pilots would have to operate aircraft using the current runway hold short signs. This risk was assessed to be minimal, and mitigation was deemed unnecessary.

Table 4

Risk Matrix Chart using FAA AC 150/5200-37A (FAA, 2023c)



*High risk with single point and/or common cause failures

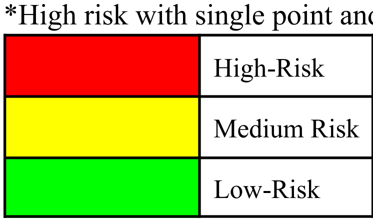


Table 5

Potential Risks Related with Existing Runway/Taxiway Sign Options using Risk Matrix FAA Order 5200.11A (FAA, 2021)

Potential Hazards	Likelihood	Severity	Risk Level	Potential Solutions	Residual Risk
Sign bulb burnt out	**Extremely remote**	**Minor**	**Low**	1. Replace Bulb 2. Replace with LED system for longer lifespan	Low
Total failure of sign	**Extremely remote**	**Minor**	**Low**	1. Replace sign 2. Perform maintenance on sign	Low
Pilot entering the runway without authorization	**Remote**	**Major**	**Medium**	Dynamic LED sign can show STOP signal as additional visual indication	Low
Pilot taking off in the opposite direction	**Remote**	**Catastrophic**	**High**	Arrow points in the direction the pilot is supposed to turn in	Low
Sign covered in ice or snow in cold weather	**Probable**	**Major**	**High**	Putting a curved cover on the sign	Low

Projected Impact of the Team's Design and Findings

Benefit-Cost Analysis

A benefit-cost analysis was used to better understand the commercial potential of this design. The analysis covers every step of the design process, from conceptualization to application of the product. An emphasis is put on practicality, affordability, and whether the design is realistic (Byers, 2021). As a part of this report and preparing cost data, the analysis is split into two development stages, alpha, and beta. The alpha stage consists of conceptual development and the labor costs behind the research and development of this design. The beta analysis consists of a more comprehensive cost analysis regarding the expenses surrounding a pre-production model and the costs associated with labor, materials, and prototype development.

Other cost analyses conducted focus on the actual production, implementation, and maintenance of our model. Production (labor and materials), marketing, distribution, installation, maintenance, and airport expenses will be considered (Byers, 2021).

Alpha and Beta Research and Development

Table 6 below shows the costs associated with the initial research and development process. Labor costs from students and an advisor encompass the initial development stages of our design and are displayed with a total cost of **$6,600**.

In the beta stage, more thorough research and development are to be conducted. The group considered the time and resources to develop a workable prototype that would later be able to be marketed. Student, faculty, and industry expert labor were estimated. Labor and the costs of product design and materials result in a Beta stage, totaling **$73,260**.

Table 6

Alpha & Beta Development Costs

Item	Rate	Multiplier	Quantity (hrs)	Subtotal	Remarks
Labor - University Design Competition (Alpha)					
Graduate Student	$20/hr	3 Students	240	$4,800	12 weeks, 20hrs/week
Faculty Advisor	$50/hr	1 Advisor	24	$1,200	Project Advisor
Subtotal				$6,000	
Overhead cost				$600	10% of project cost
Subtotal				**$6,600**	One-time Costs
Labor - Professional R&D (Beta)					
Graduate Student	$20/hr	3 Students	160	$3,200	8 weeks, 20hrs/week
Faculty Advisor	$50/hr	1 Advisor	16	$800	Project Advisor 8 weeks, 2hrs/week
Airport Director	$100/hr	1 Director	80	$8,000	8 weeks, 10hrs/week
Concept Modeling	$50/hr	1 Student	80	$4,000	2 weeks, 40hrs/week
Detailed Engineering Design	$120/hr	1 Engineer	80	$9,600	2 weeks, 40hrs/week
Prototype Construction	$150/hr	1 Unit	240	$3,600	8 weeks, 30hrs/week Materials & Labor
Marketing	---	---	---	$5,000	Advertising estimate
Subtotal				$66,600	
Overhead cost				$6,660	10% of project cost
Subtotal				**$73,260**	One-time Costs

Tangible Costs

Table 7 displays the cost to produce and distribute 10 ARIS. The total cost to produce one model is estimated to be **$1,992**. Adding additional lighting will be required as it is crucial for each airport to remain consistent with signage. Therefore it is assumed each airport will purchase 10 ARIS. Table 8 displays the yearly electrical cost to power one unit. Table 9 displays the costs to the airport to acquire, install, and operate ARIS for a period of one to ten years. The total cost to operate 10 ARIS for a period of ten years is estimated to be **$38,236**.

Table 7

Production and Sales Cost (10 Units)

Item	Rate	Multiplier	Quantity (hrs)	Subtotal	Remarks
Labor - Production, Marketing, & Distribution Expenses					
LED Display	$150	1	---	$150	LED Display Board
Body Components	$1,500	1	---	$1,500	Base Can, Frangible Coupling, Mounting Bar
Face Components	$200	1	---	$200	Panel Joint, Panel
Universal Components	$120	1	---	$120	Ground Mounting
Marketing	$5,000	---	---	$5,000	Advertisments
Distribution	$22	1	---	$22	Based on UPS ground shipping
Subtotal				**$6,992**	
Total Price for 10 Units				**$19,920**	

Table 8

Yearly Electrical Cost (1 Unit)

ARIS Specifications		Electricity Cost (1 Year)			
		Rate	Quantity	Subtotal	Notes
Runtime	8760 Hours/ Year	$0.13 kWh*	262.8 kWh	$34.16	kWh= Watts*Hours/1000
Lifespan	50,000 Hours				
Power Consumption	30 Watts				

Notes. 1) * (U.S. Energy Information Association, n.d.)

Table 9

Acquisition, Installation, and Operation of ARIS Over Ten Years

Item (Year 1)	Rate	Multiplier	Quantity (hrs)	Subtotal	Remarks
ARIS Cost	$1,992	10 Units	---	$19,920	Table 7
ARIS Installation	$500	1 Technician	10	$5,000	Cost to install and connect to the electrical grid
ATC Training	$100	1 ATC	1	$100	Operation Training
Electricity Cost	$0.13/kWh	1 Year (10 Units)	8760	$321.60	Table 8
Maintenance	$100	10 Unit	---	$1,000	Average Maintenace cost per unit (5% of ARIS Cost)
Subtotal (1 Year)				**$26,342**	
Recurring Items	**Rate**	**Multiplier**	**Quantity (hrs)**	**Subtotal**	**Remarks**
Electricity Cost	$0.13/kWh	1 Year	8760	$321.60	Table 8
Maintenance	$100	10 Units	---	$1,000	Average Maintenace cost per unit (5% of ARIS Cost)
Recurring Subtotal				**$1,322**	
Subtotal (1 Year)				**$26,342**	
Years 2 - 10				**$11,894**	
10 Years				**$38,236**	

Tangible Benefits

The main goal of ARIS is to increase runway safety, therefore benefits from our technology can range from preventing a status D runway incursion to saving a life. The value assumptions displayed in Table 10 are based on publications by the FAA that establish an economic value on life, injury, vehicle destruction, etc. It is assumed that the most likely serious accident to occur is an aircraft-on-vehicle accident. A GA aircraft with a propeller was used to determine the cost of aircraft damage and destruction due to GA aircraft having an increased number of runway incursions. The accident prevention cost was estimated at **$1,439,860** with a benefit-cost ratio of **37.66.** Both of these values can fluctuate drastically depending on the type of aircraft and the number of people involved.

Table 10

Incursion Prevention Benefits

Prevention Benefit		
Item	Rate	Remarks
Value of Life (VSL)	$9,600,000	Value of a Fatality
Value of Injury	$1,008,000	Serious Injury
Aircraft Destroyed	$1,000,000	Turbo Prop Average
Aircraft Damaged	$200,000	Turbo PropAverage (Repairable)
Accident Investigation	$38,860	GA Field
Ground Vehicle Destroyed	$250,000	Airport Vehicles
Ground Vehicle Damaged	$25,000	Repairable

Notes. 1) (FAA, 2022a)
2) (Byers, 2021)

Table 11

Risk Summary (125,000 operations per year)

Item	Unit	Quantity	Subtotal	Remarks
Operational Risks				
Risk of Aircraft - Aircraft Accident	0.02/ 1 mil	1.25mil	0.025	Risk potential over 10 years
Risk of Aircraft - Vehicle Accident	0.05/ 1 mil	1.25mil	0.0625	Risk potential over 10 years
Assumed Operational Risk			**0.0625**	Assume Higher Risk Value

Notes. 1) (Byers, 2021)
2) Assumes risk rate based on operations over 10 years
3) Average of 125,000 operations

Table 12

Benefit vs. Cost (Aircraft on Vehicle Collision)

Item	Unit	Quantity	Subtotal	Risk	Total	Remark
Cost						
Value of Life	$9,600,000	2	$19,200,000	0.0625	$1,200,000	Tables 10& 11
Value of Injury	$1,008,000	2	$2,016,000	0.0625	$126,000	Tables 10& 11
Aircraft Destruction	$1,000,000	1	$1,000,000	0.0625	$62,500	Tables 10& 11
Vehicle Destruction	$200,000	1	$200,000	0.0625	$12,500	Tables 10& 11
Accident Investigation	$38,860	1	$38,860	---	$38,860	Table 10
Accident Prevention Cost (benefit)					**$1,439,860**	
ARIS Developmet/Implementation					**$38,236**	
Benefit to Cost Ratio					**37.66**	

Sustainability Assessment

As the aviation industry strives to become more sustainable, which can be defined as creating and maintaining conditions under which nature and humans may coexist in a healthy balance that benefits both the current and future generations (EPA, 2022). Goals such as the annual improvement of fuel efficiency by 2% through 2050, or having carbon-neutral growth through 2050 within the aviation industry have been set (ICAO, 2010). A way to approach and assess whether these goals are being achieved is the EONS model, “Economic vitality, Operational efficiency, Natural resources, and Social responsibility” (SAGA, 2015). Utilizing the EONS allows the measurement of success not just not only by the conventional financial bottom line (Elkington, 1998), but also by our successes in promoting economic expansion, safeguarding the environment and our natural resources, acting responsibly as a corporation, and running facilities efficiently (SAGA, 2015).

Shown in Table 13 below is the sustainability assessment for ARIS using the EONS method. The sections from the EONS model with the largest sustainability improvements are expected to be operational efficiency and social responsibility.

Table 13

ARIS Sustainability Assessment

EONS	ARIS Sustainable Impacts	Positive (+) or Negative (-) Impact on Airport Sustainability
Economic Vitality	Reduced Maintenance	(+)
	Improved airport reputation may lead to an increase of passengers	(+)
	Increased electricity costs	(-)
	Improved lifespan of of LED signage compared to incandecent	(+)
Operational Efficiency	LEDs can be viewed more clearly in all conditions	(+)
	Increased airside efficiency through improved signage	(+)
	Potential to reduce pilot confusion	(+)
	Adds an extra responsibility for ATC	(-)
Natural Resources	Reduced energy consumption compared to incandecent	(+)
	Option to be powered by solar	(+)
Social Responsibility	Reduction in injury, death, or destruction cause by runway incursions	(+)
	Decreased active runway confusion for pilots	(+)
	Increased airport innovation (industry leader in incursion prevention)	(+)

A set of 17 Sustainable Development Goals (SDGs) was established by the United Nations (UN) to promote "peace and prosperity for people and the planet, now and into the future" (United Nations, 2015). Some SDGs are applicable to the ARIS design and are shown below in Table 14.

Table 14

Applicable SDGs for ARIS

United Nations SDG	Goal	How ARIS Meets that Goal
7 AFFORDABLE AND CLEAN ENERGY	"Ensure access to affordable, reliable, sustainable and modern energy for all" (UN,2015)	ARIS will utilize an LED display which has a longer lifespan and requires less electricity to operate
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	"Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation" (UN,2015)	ARIS is an innovitve approach to lower the risk of runway incursions
11 SUSTAINABLE CITIES AND COMMUNITIES	"Make cities and human settlements inclusive, safe, resilient and sustainable" (UN,2015)	ARIS will improve runway safety through the reduction of incursions. And allow pilots to better navigate the airfiled

Notes. (United Nations, 2015)

Conclusion

The Active Runway Indication System (ARIS) addresses the ACRP subject area "Runway Safety/Runway Incursions/Runway Excursions". Putting ARIS into action at airports worldwide would allow for an affordable, efficient, and effective tool to aid in preventing runway incursions. ARIS is a wireless ATC-controlled dynamic sign that is able to be affixed to current runway hold short signage. It will display an arrow that will indicate which runway is currently active, with the goal of reducing wrong-direction takeoffs, and incursions as a whole. The potential impact of ARIS will not only benefit the industry from a safety aspect but airports will also benefit from operational and social improvements which could in turn become economic benefits. ARIS currently is designed to be used at towered airports with a focus on airports that service GA aircraft due to GA being more likely to cause a runway incursion.

However, future improvements could be made to ARIS to allow for implementation in non-towered airports.

Through meetings with multiple industry experts, the team gained critical feedback that assisted in the development of our current design. A Safety Risk Assessment, Benefit-Cost analysis, and Sustainability Assessment were conducted to better determine the feasibility of our design. When comparing the costs over a ten-year period, to the benefits of implementing ARIS it was estimated that the benefit-cost ratio would be 37.66. This ratio could increase drastically depending on the nature of an event that was prevented.

Appendix A: Contact Information

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Appendix B: Description of the University and School

"Purdue University is a vast laboratory for discovery. The university is known not only for science, technology, engineering, and math programs, but also for our imagination, ingenuity, and innovation. It's a place where those who seek an education come to make their ideas real — especially when those transformative discoveries lead to scientific, technological, social, or humanitarian impact.

Founded in 1869 in West Lafayette, Indiana, the university proudly serves its state as well as the nation and the world. Academically, Purdue's role as a major research institution is supported by top-ranking disciplines in pharmacy, business, engineering, and agriculture. More than 39,000 students are enrolled here. All 50 states and 130 countries are represented. Add about 950 student organizations and Big Ten Boilermaker athletics, and you get a college atmosphere that is without rival.

Purdue University's School of Aviation and Transportation Technology, one of six departments and schools in the Purdue Polytechnic Institute, is recognized worldwide as a leader in aviation education. All seven of Purdue's Aviation and Transportation Technology undergraduate majors are world-class educational programs" (Purdue Polytechnic Institute, n.d., para. 1-3).

Appendix C: Description of Industry Contacts

Adam Baxmeyer - Adam Baxmeyer is the airport operations manager for Purdue University's Airport. He was the Deputy Director of Operations and Facilities for Bloomington Normal Airport Authority and the Airport Operations Supervisor for Cherry Capital Airport.

Steven Debban - Steven Debban is a National Resource Expert for Airport Design. He is the National Program Manager for the Runway Incursion Mitigation (RIM) Program at the Federal Aviation Administration (FAA). He has also served as the Airport Design Lead for the Advisory Circular AC150/5300-13B and has been involved with Runway Safety Research and the Runway Protection Zones (RPZ) policy.

Dr. Stewart Schreckengast - "Dr. Schreckengast is a member of the Graduate Faculty of Purdue University. He assisted in the development and implementation of the International Civil Aviation Organization (ICAO) Annexes 1, 6, 8, 11, 13, 14, 17, and 19. He has experience as a facilitator in workshops for Airport Inspections, Safety Management Systems, and Security" ().

Marvin Woods - Marvin Woods is an electrical engineer and the lead for airport visual aids and signage at the FAA.

Appendix E: Evaluation of Educational Experience Provided by the Project

Students

1. Did the Airport Cooperative Research Program (ACRP) University Design Competition for Addressing Airport Needs provide a meaningful learning experience for you? Why or why not?
    a. The competition provided a meaningful learning experience. The team had to look at data from multiple databases to identify a problem, communicate with industry experts to obtain insights, and read through multiple regulations and advisory circulars to ensure the final product is regulatory compliant.
2. What challenges did you and/or your team encounter in undertaking the competition? How did you overcome them?
    a. The team first encountered an issue regarding our design. It took a few trials and input from an advisor to come up with our final solution. Issues regarding contacting experts occurred as well, it took contacting numerous experts until we heard back. Finally, we struggled with determining how intricate we wanted to go with the design. As none of the group members are engineers we had challenges deciding how detailed our design should be.
3. Describe the process you or your team used for developing your hypothesis.
    a. To develop our hypothesis, we first identified the problem which was runway incursions and the cost of incursion prevention technology. Next, we looked at current technologies or policies in place and focused on current drawbacks. Once those drawbacks were identified we developed a broad idea/design for ARIS. We took inspiration from current runway hold short signs, and active lane technology

used on roads. From there we interacted with industry experts to finalize our design.

4. Was participation by the industry in the project appropriate, meaningful, and useful? Why or why not?
    a. Participation by the industry was appropriate and useful. The team was able to understand the challenges others faced in the past when going through similar processes. Industry experts also provided feedback on the idea and design.
5. What did you learn? Did this project help you with the skills and knowledge you need to be successful in entry in the workforce or to pursue further study? Why or why not?
    a. This project helped us improve our ability to find industry guidance and comply with regulations. Aviation has a complex set of regulations. Regulatory compliance is critical to the success of this project. We had to ensure all aspects of our idea and design meet the requirements set out by regulations. This is something we will have to do in the future as well.

Faculty

1. Describe the value of the educational experience for your student(s) participating in this competition submission.
    a. Many of these students make contacts that will be a resource throughout their careers. The students gain more value when they can apply newly learned design skills and sustainability skills to a project that is based on real airport needs. While they learn theoretical information, the learning that occurs through team interaction and expert interactions cannot be easily replaced.

2. Was the learning experience appropriate to the course level or context in which the competition was undertaken?
    a. This competition package is one of the choices for a project in a graduate level course in Aviation and Aerospace Sustainability. The course level and context are appropriate and a popular choice of project types.
3. What challenges did the students face and overcome?
    a. The team formed quickly and began searching for experts to contact. They began working with each other and contacting airport experts. They learned more about airport regulations and gained in-depth knowledge from experts. This alone is difficult to recreate in a text book format.
4. Would you use this competition as an educational vehicle in the future? Why or why not?
    a. I definitely will continue to use this competition as an educational vehicle. The knowledge the team gains in 12 weeks is irreplaceable through readings and shorter projects.
5. Are there changes to the competition that you would suggest for future years?
    a. I would add sustainability as an aspect of the project that should be addressed because this issue is challenging and is becoming requested by more communities and other stakeholders.

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