**Simple, Affordable, Flexible, and Expandable Runway Status Lights**

**(SAFE-RWSL)**

**2021 – 2022 ACRP University Design Competition**

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**Graduate Team Members:** Luigi Raphael I. Dy, McClane E. Rush

**Advisor:** Dr. John H. Mott


**Design Challenge:** Runway Safety/Runway Incursions/Runway Excursions Including Aprons, Ramps, and Taxiways F: Expanding situational awareness of pilots and ground operators on the airfield


PURDUE UNIVERSITY | School of Aviation and Transportation Technology POLYTECHNIC INSTITUTE


**Executive Summary**

While no fatal runway incursion accident has occurred involving a scheduled air carrier in the last twelve years, runway incursions have led to the death of seven individuals from 2010 to 2020. All six runway incursion accidents since 2010 involved general aviation aircraft at non-towered airports where air traffic control services are unable to provide another layer of traffic separation and collision avoidance. Despite this, most efforts in preventing runway incursions have been focused on towered airports.

Numerous technologies have been proposed and developed to tackle runway incursions, but few have been implemented. Cost, hesitancy of adoption, and complexity of implementation have been identified as the primary barriers to implementation of these technologies. As a result of these findings, Simple, Affordable, Flexible, and Expandable Runway Status Lights (SAFE-RWSL) were studied and proposed to provide a practical and feasible solution to the identified problems.

The proposed SAFE-RWSL system uses aircraft position information from Automatic Dependent Surveillance-Broadcast (ADS-B) transmissions to wirelessly activate lights that indicate runway status to aircraft taking off and landing, and to aircraft, vehicles, and pedestrians using or crossing a runway. This system will supplement see-and-avoid and radio communications at non-towered airports and reduce the probability and corresponding risk of an aircraft collision as a result of a runway incursion.

With an estimated benefit-cost ratio of 2.37 from the installation of SAFE-RWSL at nonhub primary airports based on a ten-year time horizon, the system promises to be a useful addition to runway incursion prevention solutions available to airports and the FAA.

# Table of Contents

## Problem Statement and Background

The design challenge tackled by the following proposal is challenge F: “Expanding situational awareness of pilots and ground operators on the airfield”, of the “Runway Safety/Runway Incursions/Runway Excursions Including Aprons, Ramps, and Taxiways Challenges” (Airport Cooperative Research Program [ACRP], 2021, p. 7).

### Runway Incursions

Runway incursions are events when an aircraft, vehicle, or person is inappropriately within the safety areas of a landing or takeoff surface (Federal Aviation Administration [FAA], 2020a). Such incidents have led to accidents such as the 1991 collision between a USAir Boeing 737 and a SkyWest Fairchild Metroliner at the Los Angeles International Airport that killed 35 people (National Transportation Safety Board [NTSB], 1991). The total number of reported runway incursions rose by 53%, from 1,580 reports in 2013 to a peak of 2,420 reports in 2017. This was followed by a decrease of reports to 951 in 2020, and a subsequent increase to 1,575 reports in 2021 (FAA Aviation Safety Information Analysis and Sharing (ASIAS), 2022).

#### *Runway Incursion Categories*

Runway incursions are categorized by severity as defined by the International Civil Aviation Organization (ICAO) and the FAA. In its 2008 fiscal year, the FAA changed its definitions and categorizations of runway incursions to match ICAO’s. Category A is defined as “A serious incident in which a collision was narrowly avoided” and includes accidents (FAA, 2021c, p. B-1). Category B is defined as “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”. Category C is defined as “An incident characterized by ample time and/or distance to avoid a collision”. Category D is defined as “An incident that meets the definition of a runway incursion such as incorrect presence of a single vehicle/person/aircraft on the protected surface designated for the landing and take-off of aircraft, but with no immediate safety consequences”. Category E is defined as “An incident in which insufficient or conflicting evidence of the event precludes assigning another category”.

The number of runway incursions classified as a category A or B have remained stable since 2013 with a low of 8 reported incidents in 2017 and 2020, and a high of 19 reported incidents in 2016. The number of category A and B incidents do not appear to be directly proportional to the total number of reported runway incursions per year (FAA Aviation Safety Information Analysis and Sharing (ASIAS), 2022).

Of the 1,575 runway incursions reported in 2021, approximately 66% were classified as pilot deviations, 18% as vehicle/pedestrian deviations, 14% as operational incidents (caused by air traffic control), and 2% as “other” (FAA, 2022b). This continues the trend from previous years where pilot deviations accounted for the highest percentage of runway incursions followed by similar percentages accounted for by operational incidents or vehicle/pedestrian deviations.

### ***Non-towered Runway Conflicts***

At non-towered airports, the responsibility of pilots to “see and avoid” is sometimes the only method of traffic separation. “See and avoid” has been imperfect and inadequate as shown by the occurrence of midair collisions (Morris, 2005). Position reports over Common Traffic Advisory Frequencies (CTAF) are recommended to supplement “see and avoid” but are not required (FAA, 2018a).

As runway incursions are reported by Airport Traffic Control Towers (ATCT), reports and statistics pertaining to runway incursions do not capture all runway conflicts, including all those at non-controlled airports (FAA Aviation Safety Information Analysis and Sharing

(ASIAS), n.d.). A sample of conflicts that occur at non-controlled airports is captured through the National Aeronautics and Space Administration's (NASA) Aviation Safety Reporting System (ASRS). The ASRS system compiles, processes, and analyzes voluntarily submitted reports pertaining to safety from flight crew, air traffic controllers, and other aviation personnel (ASRS, n.d.-a). These reports are confidential and cannot be used against the reporter and include some incentives for submission. The ASRS database contains reports of runway incursions and ground conflicts (classified as "critical" or "less severe") that include situations where aircraft collide or nearly collide with animals, ground equipment, personnel, or other aircraft.

A search of incidents between January 2019 to December 2019 reported to the ASRS of critical or less severe ground conflicts involving the final approach, landing, takeoff/launch, and initial climb phases yielded a total of 191 results (ASRS, n.d.-b). Of the 191 reported incidents, 108 incidents were of runway incursions or conflicts at towered airports, 60 incidents were of runway conflicts at non-towered airports, while 23 involved other reported incidents such as taxiway conflicts, terrain warnings, a runway excursion, and an aircraft collision with a deer. The most common theme of reported incidents at towered airports is of air traffic control (ATC) clearing an aircraft to takeoff or land while another aircraft is on the runway. At non-controlled airports, reports most commonly include the alleged lack of communication from another aircraft and the failure to see a conflicting aircraft leading to multiple aircraft using the same runway simultaneously. Multiple incidents of aircraft taking off or landing on opposing runways, over each other, or while an aircraft was back-taxiing on the runway were reported.

**Recent Accidents**

From 2010 to 2020, seven people have died in four accidents involving a runway incursion/conflict in the United States (NTSB, 2014a; NTSB, 2014b; NTSB, 2020; NTSB, 2021a). Two additional accidents led to serious injuries (NTSB, 2015; NTSB, 2021b). All six accidents occurred at non-towered airports and involved aircraft operating under 14 CFR Part 91 (general aviation). Three of the six accidents involved a ground vehicle. Two accidents involved aircraft landing on the same runway, and one involved aircraft operating on intersecting runways.

## Previous and Ongoing Research

Extensive research has been conducted on runway incursions, with numerous technologies proposed, and a few implemented (Schönefeld & Möller, 2012). Runway incursions/Ground collisions of aircraft was on the NTSB's Most Wanted List from its introduction in 1990 to 2012, when the list was limited to 10 issue areas at most (NTSB, 2019).

### *Technological Approaches to Combat Runway Incursions*

In response to NTSB recommendations, the FAA developed Airport Surface Detection Equipment-Model X (ASDE-X), a ground surveillance system, to assist air traffic controllers in stopping ground collisions and reducing runway incursions (Office of Inspector General [OIG], 2007). Runway Status Lights (RWSL) and Surface Movement Guidance and Control System (SMGCS) are additional systems built on deployed ASDE-X infrastructure to further reduce runway incursions.

Other technologies have been proposed to reduce runway conflicts and incursions. This includes Final Approach Runway Occupancy Signal (FAROS), Airport Movement Safety System (AMASS), Runway Incursion Prevention System (RIPS), PathProx, XL-RIAS, and Mobile Application Based Systems (MBAS) (Schönefeld & Möller, 2012).

### *Non-Technological Approaches*

Non-technological initiatives have been advanced by the FAA, such as remedial training, outreach, educational materials, and bulletins primarily targeting general aviation (GA) pilots (OIG, 2018). The Runway Incursion Mitigation Program (RIM) has also been providing data-driven site-specific improvements to airports with non-standard layouts since 2015 (FAA, 2021a).

### *Current Work*

Moving forward, the FAA plans to focus on technologies targeting small and mid-size towered airports with no surface surveillance systems, with a “right site-right size” approach to ensure that safety benefits outweigh system cost – preferring to use existing technologies rather than greenfield designs (FAA, 2021a). This includes trials of Runway Incursion Prevention through Situational Awareness (RIPSA) technology, slated to begin in 2022 (FAA, 2022a).

### *ACRP Research Recommendation*

In a 2020 ACRP Research Roadmap on Safety Issues report, movement area safety was identified as the greatest safety concern/risk by some airports (National Academies of Sciences, Engineering, and Medicine, 2020). Runway, runway safety area (RSA), and runway protection zone (RPZ) were further identified as top issues for GA airports. Runway incursions and excursions were also identified as concerns with the highest risk level, and with the most interest from industry.

## Area of Concern

Due to high costs and technical requirements, runway incursion prevention technologies are mostly available to the largest airports and to air carrier operations (Schönefeld & Möller, 2012; Ison, 2020). GA aircraft are also usually equipped with less advanced technologies and have less experienced pilots. Given that the majority of runway incursions involve a GA aircraft, airports with heavy GA traffic stand to benefit more from runway incursion prevention technologies. Solutions for these airports would be more cost-effective at reducing incursions and conflicts than continued deployment of ASDE-X and RWSL (Ison, 2020).

Often forgotten from the discussion of runway incursions, ground conflicts at non-controlled airports are a greater risk as evidenced by recent accidents and the continued reports of close calls by pilots to the ASRS. The lack of traffic services from an ATCT is an added safety layer that is not present at such airports.

**FAA Goals**

In its FY 2019 – 2022 Strategic Plan, FAA outlined its four goals of safety, infrastructure, innovation, and accountability (FAA, 2018b). While tackling the design challenge “Expanding situational awareness of pilots and ground operators on the airfield”, the following proposal kept these goals in mind (ACRP, 2021, p.7). By reducing runway incursions and conflicts, safety will be improved by reducing the probability of incidents that result in fatalities and serious injuries. Innovation was used to efficiently and effectively utilize existing technologies to improve safety, while being accountable and responsible in the use of public funds. In turn, the overall aviation infrastructure may improve with the application of this system.

## Summary of Literature Review

A literature review was conducted to grasp the technologies and issues related to runway incursions and prevention technologies as well as to understand pitfalls and areas for improvement. Previous ACRP University Design Competition (UDC) winning proposals available on the ACRP UDC website were also reviewed to see previous approaches and ideas to build on.

## Runway Incursion Prevention Systems and Initiatives

### *Airport Surface Detection Equipment-Model X (ASDE-X)*

ASDE-X combines information from multiple sources such as a surface surveillance radar, multilateration sensors, airport surveillance radars, Automatic Dependent Surveillance-Broadcast (ADS-B) receivers, and terminal automation systems to provide air traffic controllers with accurate and precise information regarding aircraft and vehicles on the airport’s surfaces (FAA, 2020c). Audio and visual alerts built into the system notify air traffic controllers of potential runway incursions, while graphic interfaces allow controllers to see the location of aircraft and vehicles in inclement conditions.

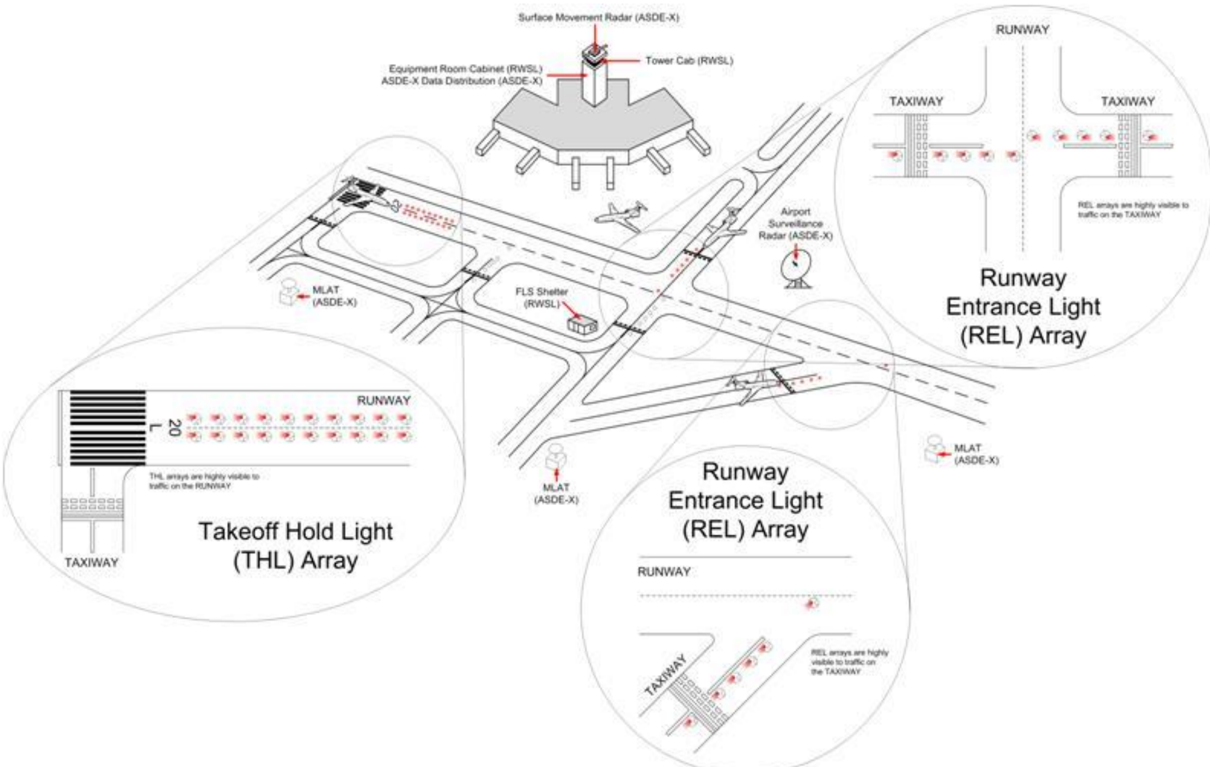
The NTSB deemed this an unacceptable response as the system does not provide direct warnings to pilots or vehicle operators, despite accounting for approximately 70% of runway incursions. The project was met with delays and budget overruns, costing more than $500 million for installation at 35 major airports (OIG, 2007; FAA, 2020c).

### *Runway Status Lights (RWSL)*

Using ASDE-X surveillance information, Runway Status Lights (RWSL) are designed to provide pilots and ground vehicle operators with visual cues as to whether a runway is occupied. Comprised of Runway Entrance Lights (RELs), and Takeoff Hold Lights (THLs), pilots and vehicle operators are shown red indications on the taxiway or runway if it is unsafe to proceed (see Figure 1) (Airport Engineering Division, 2011). The OIG of the Department of Transportation (DOT) recognized it as a viable technology in preventing runway incursions, early in its development (2008). RWSLs are currently installed at 20 US airports (FAA, 2021b).

**Figure 1**

*Diagram Depicting Runway Status Lights and ASDE-X Components at an Airport*




*Note.* From “Runway Status Lights Pilot Reference Guide” by FAA, 2015 (https://www.faa.gov/air_traffic/technology/rwsl/pet/). In the public domain.

***Surface Movement Guidance and Control System (SMGCS)***

Surface Movement Guidance and Control System (SMGCS) is an individually approved plan used at airports to aid pilots in navigating on the ground in low visibility operations (less than 1,200 feet runway visual range (RVR)) (FAA, 2020b). SMGCS requires surface movement detection equipment such as ASDE-X to allow ATC to locate aircraft and vehicles on the airport. SMGCS also stipulates the use and installation of specific airport lighting and markings such as stop bar lights and taxiway lights, depending on the conditions. Installations of SMGCS may include actively controlled lights to guide pilots navigating on the ground (Port of Seattle, 2015).

***Runway Incursion Prevention System (RIPS)***

A Runway Incursion Prevention System (RIPS) was developed by NASA to increase the situational awareness of pilots on the ground and prevent runway incidents. The system works by providing information, visual cues, and alerts of runway conflicts and deviations directly to the pilots (Jones et al., 2006). A heads-up display (HUD) overlays additional information to a pilot's view of the runway, while a moving map displays the aircraft's location, the location of other aircraft, and routing from air traffic control (Jones et al., 2001). Audible and visual alerts are triggered when an incursion or route deviation is detected, based on the position information available. During testing, a Local Area Augmentation System, a Wide Area Augmentation System, together with the aircraft's inertial navigation system was used to determine position. Surface Traffic Information Services – Broadcast, and Automatic Dependent Surveillance Broadcast (ADS-B) were used to acquire traffic data.

***PathProx***

PathProx is a runway incursion alerting system developed by the Rannoch Corporation that was tested by NASA as part of its RIPS program (Cassell, 2001). The system was designed to provide alerts to pilots through an installed cockpit display, or an electronic flight bag (EFB) when a runway incursion is imminent (Cassell et al., 2000). Aural alerts accompany the visual alerts but were proposed to be used singly when no moving map device was installed in the aircraft. The system uses information received via ADS-B and, when available, Traffic Information Service-Broadcast (TIS-B) information that contains fused data from other sources.

***Runway Incursion Monitoring, Detection, and Alerting System (RIMDAS)***

Runway Incursion Monitoring, Detection, and Alerting System (RIMDAS) is a proposed system that utilizes low-cost and low-power computers installed in aircraft called motes that communicate with each other and a centralized server to determine the probability of a runway incursion. Upon detection of a potential incursion, the system is supposed to alert pilots and air traffic controllers with an audible alert (Squire et al., 2010).

### *Final Approach Runway Occupancy Signal (FAROS)*

Final Approach Runway Occupancy Signal (FAROS) was a system evaluated by the FAA to indicate runway status to pilots on final approach (FAA, 2018a). The signal system involved a Flashing Precision Approach Path Indicator (FPAPI) that would flash when an aircraft or ground vehicle was in a location that could pose a danger to arriving aircraft. Pilots of landing aircraft that received the flashing PAPI signals were instructed to look for traffic on the runway, and contact ATC if the traffic is not acquired. Final responsibility for the decision to land however was explicitly mentioned to be the pilot's. Simulated and initial operational evaluations showed that the system was effective and promising, with more operational evaluations to follow. However, mention of the system in the Aeronautical Information Manual (AIM) was removed sometime between 2018 and 2021, having previously been section 2-1-7 of the AIM (FAA, 2018a; FAA, 2021d).

### *Other Initiatives*

Other initiatives have been pursued by the FAA, including expanding graphical NOTAMs, providing awareness training for drivers, ADS-B deployment for vehicles, promoting aural awareness from "Safe Taxi" systems in GA avionics and the use of progressive taxi instructions, reviewing radio phraseology and procedures, reviewing memory aids for air traffic controllers and pilots, and studies on incidents, airport geometries, and other new technologies (OIG, 2018).

**Previous ACRP University Design Competition Proposals**

In previous years, devices and mobile applications have been proposed to depict aircraft and vehicle movement (Arnett et al., 2019; Hammer et al., 2019). Such solutions require the aircraft operator to buy into the program. Current ADS-B-In solutions already allow pilots to receive traffic information from ADS-B-Out equipped aircraft on Electronic Flight Bags (EFBs) such as ForeFlight and GarminPilot, and other avionics (FAA, 2015a; ForeFlight, 2021; Zimmerman, 2021). However ADS-B-In capabilities are not required in aircraft. Similar applications can be used in ground vehicles to aid ground operators in seeing potential conflicts with aircraft, but still require equipment to be carried in all vehicles or operators on the ground. The use of devices in the cockpit of an aircraft or in the cab of a vehicle require consistent scanning, reducing the time the pilot or operator spends looking outside.

Another proposed solution is the improvement of airport signage and taxiway geometry. While this approach can be effective in some cases, it is expensive and can be difficult to implement (M. Blake, personal communication, February 25, 2022). This solution primarily tackles inadvertent entries onto the runway and does not tackle issues caused by the failure of a pilot to see-and-avoid other aircraft before using a runway at non-controlled airports.

The use of pilot-controlled runway status lights has also been proposed. However, this system still requires the pilot to tune and use the appropriate radio frequency correctly, which offers little additional benefits over the ability to report positions via radio as is recommended practice (Appel et al., 2010). Automated detection and triggering were suggested for the future, when cost-effective surveillance technology such as ADS-B were more mature and widespread, which it is now.

Rumble strips, a technology transfer from a road application to an aviation one was proposed and funded as FAA Partnership to Enhance General Aviation Safety, Accessibility and Sustainability (PEGASAS) project #8 (Kaste et al., 2011; PEGASAS, n.d.-a). While reminding pilots of runway entrances, it also does not tackle the failure of see-and-avoid or radio communications. This method of alerting was not adopted due to potential damage to aircraft. Although, the application of a road technology to an aviation application was thoughtful. The use of intuitive signage similar to road traffic signs were recommended in PEGASAS project #20 that studied GA runway incursions (PEGASAS, n.d.-b).

Harris et al. (2019) proposed the use of ADS-B and Differential GPS (D-GPS) to provide position data to an airport server to communicate runway incursion risks to air traffic controllers via a graphic interface. Pilots would be alerted via a device installed in the cockpit and lights installed on the airport. While this solution may be a promising attempt to provide a cost-effective solution, the system requires aircraft operator buy-in, which was a concern recognized in its received industry feedback. As a result, the applicability of the solution will only be as effective as its adoption by pilots and operators, who can benefit from similar functions built into ADS-B In devices that provide more functions, yet already face adoption issues.

**Automatic Dependent Surveillance-Broadcast (ADS-B)**

Automatic Dependent Surveillance-Broadcast (ADS-B) is an aircraft surveillance system introduced as part of the FAA’s NextGen program, designed to supplement, and improve existing aircraft surveillance methods. The implementation of ADS-B has enabled new technologies in areas such as aircraft collision avoidance and operation counts by reducing the costs of locating and monitoring aircraft (Kunzi & Hansman, 2014; McNamara et al., 2016). Costs are reduced due to the design of the system.

Equipped aircraft have transponders that transmit position information at least once per second while airborne and at least once per five seconds while on the ground. This information is then received by ground stations on the 1,090MHz and 978 MHz frequencies, eliminating the need for RADAR systems to detect and estimate the position of different aircraft (ADS-B Out equipment performance requirements, n.d.). While the installation and operation of ADS-B transponders are not required for all aircraft, it has been required for aircraft flying in and around most controlled airspace in the United States beginning in 2020 and is also required in many international airspaces (Aircraft Owners and Pilots Association, n.d.). Thus, most aircraft, especially those that operate in busier environments, are equipped with ADS-B. As of March 1, 2022, 158,562 out of the approximately 220,000 aircraft (around 70%) in the US were equipped with ADS-B transponders (FAA, 2022c).

### Swiss Cheese Model of Accident Causation

The Swiss Cheese Model, also known as the cumulative act effect, was first proposed by James Reason and Dante Orlandella in the 1990s and is used heavily in the study of aviation safety (Goetsch, 2019; Reason et al., 2009). Its name comes from the metaphor that an accident occurs when holes in different mitigating barriers/defenses of a system, line up and allow a hazard to lead to an accident. This approach to accident causation serves as justification for the proposal of an imperfect system that is expected to be effective as an added layer of safety.

## Problem Solving Approach

### Meetings and Site Visits

While the team was assembled in the Fall of 2021, work began in the Spring of 2022. The team met once a week to discuss ideas and findings of individual members from the preceding week. The weekly meeting time was also used to make key decisions and determine the direction of the project. In addition to weekly meetings, meetings with airport operators and experts were scheduled on a case-by-case basis. Team members also observed operations at the Purdue University airport, Marion Municipal airport, Fulton County airport, and during trips on scheduled air carriers over spring break through IND, IAD, and EWR. Progress on the paper took place progressively using individual time.

**Initial Ideas**

Both team members have flight experience, with one possessing a commercial pilot certificate. Drawing on their flight experiences and background knowledge, the team began to brainstorm possible technological solutions to runway safety issues. Collisions involving aircraft were established as the most significant runway issue to the team due to the severity of such incidents and personal close calls.

Inspired by the continuing development of artificial intelligence and computer vision, the team had originally thought of ways to utilize such technologies to identify runway incursions and potential midair collisions in an airport's traffic pattern with such technologies. The use of computer vision instead of other surveillance technologies such as radar or ADS-B tackles high equipment costs, and potential equipage issues that hamper their effectivity, respectively. The first concept from the team was to have a computer-vision-enabled air traffic watcher that would alert ATC (if present) and pilots via radio communications of an impending collision. The second concept from the team was the use of a camera system installed by taxiways and runways that would detect traffic, record, and alert of potential conflicts. These initial ideas highlighted two components of any traffic alerting system – surveillance and alerting.

The use of computer vision systems was discussed with the faculty advisor, and it was recognized that camera/vision-based surveillance methods have its own issues and may be susceptible to environmental conditions, including sunlight glare, rain, and snow, may require numerous deployments to be effective, and can be costly (National Academies of Sciences, Engineering, and Medicine, 2015). The use of sound/microphones for activation were also considered based on the suggestion of Dr. Stewart Schreckengast, an expert on runway incursions and safety management systems (S. Schreckengast, personal communication, February 17, 2022). However, issues such as environmental noise pose threats to the accuracy of this method. As a result of these issues that would come up, the team decided to utilize a decision-matrix (also known as the Pugh method) to guide decisions regarding the surveillance information source, and pilot/controller alerting method. The discussion with the advisor also brought up considerations of cost, effectiveness, and ease of development and use.

**Prioritization and Barriers to Implementation**

Simultaneously, the literature review on runway incursions and technologies was being conducted. While many advanced and intelligent runway incursion prevention solutions have been proposed, researched, developed, and tested in the past, a recurring theme among these solutions was that most were not implemented. Only ASDE-X, RWSL, and SMGCS have seen relatively widespread adoption. Of these, only RWSL directly tackles runway incursions caused by pilot or vehicle operator deviations, and none tackle nor are available for the identified area of concern: general aviation traffic at non-towered airports.

Hoping that their efforts were not futile, the team then realized that the most important step throughout this process was to not only understand the need, but also understand the barriers to implementation. Through the literature review, and discussions with Purdue University airport manager, Mr. Adam Baxmeyer, and Indiana Department of Transportation (INDOT) Aviation Office manager, Mr. Marty Blake, system/unit cost was identified as one of the largest barriers to implementation because of limited airport budgets, and regulatory needs when approached from an airport's perspective (A. Baxmeyer, personal communication, February 22, 2022; M. Blake, personal communication, February 25, 2022).

Another identified primary barrier to implementation was hesitancy of adoption. When assessing runway incursion prevention technologies from an aircraft operator or pilot's perspective, many require systems to be purchased, installed, carried, charged, or updated in the aircraft. This burden, unless legally required, will likely not be undertaken by all, especially those involved in GA operations who may fly less often, and have lower budgets. An example of this is how not all pilots or aircraft are equipped with ADS-B In, and some still choose to fly with no radios (handheld or installed). Moreover, even when radios are available, some pilots do not use them at non-towered airports, despite being recommended by the FAA. This issue was identified as a contributing factor in the 2018 runway collision in Marion, IN, and is a common occurrence (NTSB, 2020; M. Blake, personal communication, February 25, 2022).

Complexity of implementation was the last barrier identified. The team noticed that many proposed systems required many additional devices and systems in place to be effective, which would increase both development, and implementation costs. While advanced and technical systems may almost be foolproof and highly effective at their intended goal, such systems would likely not be cost-effective, nor efficient in the use of resources.

As a result of identifying the barriers to implementation, the team adopted a "keep it simple" design philosophy, weighing costs, development complexity, the need for aircraft operator buy-in, and effectivity to evaluate potential solutions.

**Determining the System**

Aside from the developmental goals, it was important to remember the primary function of the system being developed. The objective was to add another layer of safety to see-and-avoid, and radio communications, for uncontrolled airports (part-time or full-time). The system is supposed to prevent runway incursions that result in a close call or collision between two aircraft, which is unlike some runway incursion technologies that aim to reduce all runway incursions (such as crossing a runway accidentally).

A Pugh matrix was created to help determine the best surveillance method given the goals identified, and the information gathered through the literature review and industry interactions (see Table 1). ASDE-X was considered the baseline and was compared to other aircraft surveillance/detection methods the team had considered. Alternatives were scored subjectively on a scale from -2 to 2 based on assumptions made by the team about their cost, complexity, and effectivity. A positive score was given if it was an improvement relative to the baseline, a negative score if it was worse than the baseline.

**Table 1**

*Pugh Matrix Used to Decide the Surveillance/Detection Method*

| | ASDE-X | Cameras | Induction Loops | LiDaR | ADS-B + Mode C MLAT | ADS-B + D-GPS | ADS-B Only | Sound |
|---|---|---|---|---|---|---|---|---|
| Cost | 0 | 1 | 1 | 2 | 1 | 2 | 2 | 2 |
| Buy-in | 0 | 0 | 0 | 0 | 0 | -2 | 0 | 0 |
| Complexity | 0 | 1 | 1 | 1 | 0 | 1 | 2 | 0 |
| Effectivity | 0 | -2 | -2 | -2 | 0 | 0 | -1 | -2 |
| Total Score | 0 | 0 | 0 | 1 | 1 | 1 | 3 | 0 |

Based on the developed Pugh matrix, ADS-B only was identified as the optimal surveillance/detection method among those considered by the team. The benefits of using ADS-

B alone are its low cost and ease of use, with relatively few developmental and operational requirements when compared to the other options. Most aircraft are also already equipped with compliant transponders. The use of ADS-B alone becomes an issue when non-equipped aircraft are involved. However, it is reasonable to assume that the share of unequipped aircraft operating in the US will continue to decrease as older aircraft are retired (M. Blake, personal communication, February 25, 2022). Additionally, ADS-B data has a large legally required position accuracy margin of 0.05 nautical miles (or approximately 300 feet) (ADS-B Out equipment performance requirements, n.d.). Yet, this has not been an issue, with calculated errors being on the lower end of this range based on the experience of the team and advisor when working with ADS-B.

Another Pugh matrix was used to determine the alerting system component (see Table 2). The alerting system targets are pilots and ground vehicle operators (as these are the individuals directly involved in runway incursions). RWSL was used as the baseline system as it is the only system implemented that alerts the identified targets.

**Table 2**

*Pugh Matrix Used to Decide Alerting Method*

| | RWSL | Alert on EFB | Installed Alerting Device | Radio Alert or Transmission | Runway Barrier | Digital or Matrix Sign | Simplified RWSL |
|---|---|---|---|---|---|---|---|
| Cost | 0 | 2 | 1 | 1 | -1 | 1 | 1 |
| Buy-in | 0 | -2 | -2 | 0 | 0 | 0 | 0 |
| Complexity | 0 | 2 | 1 | -2 | -2 | 0 | 1 |
| Effectivity | 0 | 0 | 1 | 0 | 2 | 0 | 0 |
| Total Score | 0 | 2 | 1 | -1 | -1 | 1 | 2 |

Based on the developed Pugh matrix, an alert through an EFB or personal device, and a simplified runway status light system were identified as the best potential solutions. While the team recognized that a visual and or auditory alert through a pilot or driver's personal device such as an EFB would be a great method of alerting due to its low cost and complexity, this system is already available. In fact, ADS-B traffic data, combined with an alerting system through an EFB is already commonly available as discussed in the literature review. However, the issue that arises with these systems is the burden on individual pilots and operators to purchase and maintain such devices, as was previously discussed too. Thus, the team decided to move forward with a simplified runway status light system as the alerting method as it requires no buy-in from pilots and operators, and the original RWSL system has a proven record.

The primary advantage of the simplified RWSL is the ability to alert all traffic, whether ADS-B Out equipped or not, ADS-B In equipped or not, aircraft, ground vehicles, and pedestrians. Thus, this alerting method tackles both pilot deviations and vehicle/pedestrian deviations that lead to runway incursions while requiring no buy-in from anyone but the airport management and operator. The system should also be intuitive and easily seen as it is in the airport environment, where pilots, drivers, and pedestrians should be looking while navigating/driving around an airport, and not on a kneeboard or interior panel. The disadvantages of this system include the cost of installation and maintenance, that would be shouldered by the airport, and the additional information/training that would need to be disseminated to pilots.

## System Design

### *Alerting System (Status Lights)*

RWSLs already exist and are implemented at 20 US airports. However, the current light system is very costly, requiring in-pavement installation and wiring (FAA, 2018c). Due to this, the modified use of elevated runway guard lights (RGL) is proposed to indicate runway status to aircraft holding short of runways. Taking inspiration from railroad crossing lights, school bus stop lights, and emergency-vehicle hybrid beacons used for road traffic, the proposed SAFE-RWSL Runway Entrance Lights (RELs) will flash red lights on RGLs to indicate an aircraft should stop and hold at a runway entrance due to a potentially conflicting aircraft on the runway. When no conflict is detected, the RGLs will go back to flashing yellow. The use of flashing yellow and red lights to indicate “caution” and “stop” respectively, should be intuitive for most pilots who also drive. This use of intuition developed from the use of road traffic signals was further based on the conclusions of PEGASAS project #20 that studied general aviation runway incursions (PEGASAS, n.d.-b).

Other forms of elevated/above-ground lighting fixtures were considered, including single light fixtures (rather than dual-light/wig-wag style lights). However, modified RGLs were selected to reduce the need for a new or adapted lighting fixture that would need to be introduced to the airport environment. Existing RGL systems can be modified based on already-existing standards, thus reducing the number of manufacturing and regulatory changes to implement such a system. Additionally, no new fixture would be introduced to the airport environment that may confuse pilots.

The proposed position of the RELs will be the same as is currently recommended for elevated RGLs per FAA Advisory Circular (AC) 150/5340-30J. The collocation of the RELs/RGLs with the runway holding position markings will be appropriate for indicating to approaching aircraft the status of the runway. It is expected that pilots hold short of these markings when waiting and should also be able to view the lights to check the runway status when holding short (see Figure 2).

In addition to RELs, the SAFE-RWSL system will also include departure and approach warning lights (DALs) that will be located on the opposite side of the runway from the approach lighting system (Precision Approach Path Indicator (PAPI) or Visual Approach Slope Indicator (VASI)), if installed, or on either side of the runway close to the touchdown zone markings (see Figure 3). A DAL will consist of one flashing red light that will indicate runway occupancy beyond the position of the DAL. This light will be visible to both approaching aircraft and departing aircraft to suggest the possible need to go-around, or standby for departure.

**Figure 2**

*View of RGLs While Holding Short for Takeoff*


**Figure 3**

*Hypothetical DAL Location as Seen During Landing Round Out*

The RELs and DALs will be wirelessly activated by a central computer through a low-power wide-area network (LPWAN) such as LoRa. Received signals will instruct the appropriate RELs or DALs to switch color from yellow to red. While this is not possible with traditional incandescent RGL fixtures due to the use of lenses for color, this would be possible with LED RGLs installed with color changing (RGB) LEDs.

LPWANs are low-cost, low-power, and long-range networks that can be used to communicate low-bandwidth messages (such as activating RELs and DALs). The use of a low-powered wireless communication network will eliminate the need for airports to install communication cables from the lights to the central computer, reducing costs, installation complexity, and deployment time. The LPWAN's independence from existing telecommunication networks also removes the need for an airport to be covered by existing telecommunication networks – an issue that is more likely to be faced by GA airports in more remote areas. It also eliminates issues arising from network outages. Lastly, the use of an LPWAN over shorter-ranged wireless networks will ensure that airports of varying sizes can be easily covered by the system.

***Surveillance System***

The SAFE-RWSL system will receive its traffic surveillance information from ADS-B. The central computer will also serve as the ADS-B receiver and will need to be installed at or near the airport, with the appropriate antennas installed at an elevated position, with line-of-sight visibility of the airport's surfaces, and departure/approach paths (see Figure 4). Additionally, the central computer will have an LPWAN transceiver and antenna to communicate with RELs and DALs (see Figure 5). An inexpensive single board computer such as a Raspberry Pi, together with a software-defined radio (SDR) and an LPWAN module can fulfill this function (see Figure 6).

**Figure 4**

*Location of ADS-B Receiver Antenna as Installed at the Purdue University Airport*


**Figure 5**

*SAFE-RWSL System Concept*

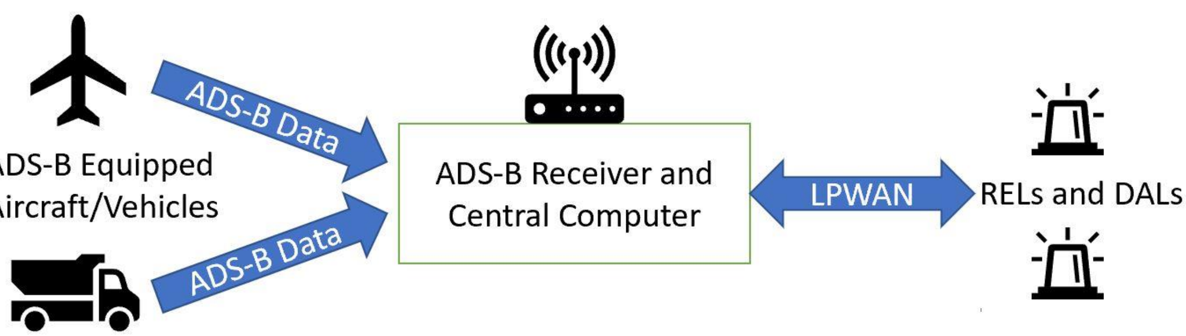


**Figure 6**

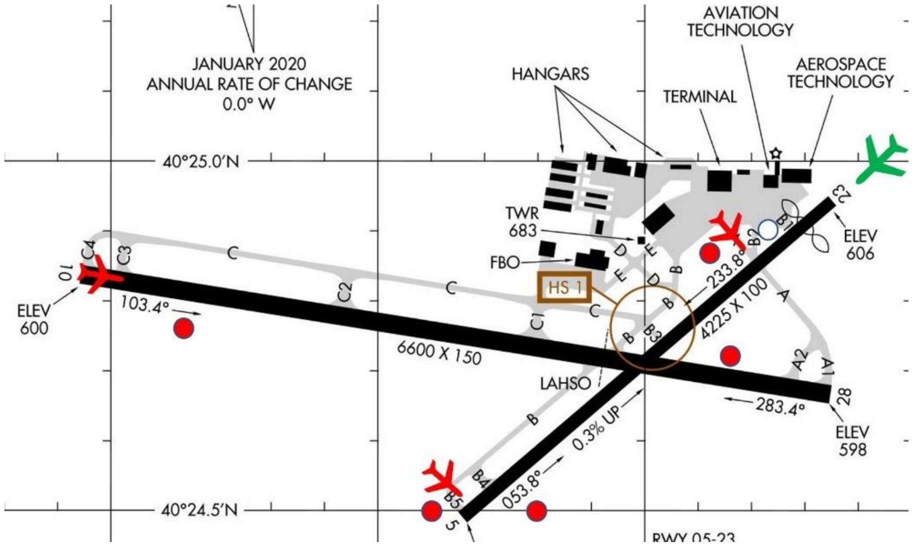
*Sample System with All Hardware Components Required of the Central Computer*

*Note.* The device is a Raspberry-Pi-based “Stratux” ADS-B receiver assembled by Crewdog Electronics that can receive both 978 MHz and 1,090 MHz ADS-B signals (hence the two long antennas). It is attached to a GSM device that gives the system the ability to communicate via cellular networks. A similar system with a LoRa instead of a GSM device can be used as the central computer.

Received ADS-B data provide aircraft identification, ground speed, ground track, pressure altitude, and GPS position data (latitude and longitude). Aircraft reporting positions within pre-determine geofenced volumes on the airport’s surfaces, and approach paths will trigger the appropriate signals to be sent out to RELs and DALs of positions with potential traffic conflicts. Using the Purdue University airport as an example, an aircraft approaching runway 23 will trigger the activation of RELs on equipped runway entrances to be activated, in addition to the DALs of the opposing runway 05, and intersecting runways 10 and 28 (see Figure 7).

**Figure 7**

*Overlaid Airport Diagram Showing DAL and REL Indications for an Approaching Aircraft*




*Note.* The image is of a hypothetical SAFE-RWSL installation at the Purdue University airport (limited tower operations). The red circles indicate a red indication on a DAL/REL at a given location. The red airplanes show aircraft in position given a stop indication, and the green airplane shows the approaching aircraft. Airport diagram adapted from "FAA Airport Diagrams" by Federal Aviation Administration, 2022 (https://www.faa.gov/airports/runway_safety/diagrams/). In the public domain.

The system can alert aircraft in all forms of runway conflicts, such as crossing during an approach/departure, opposing approaches/departures, and conflicts with intersecting runways.

Acknowledging the potential precision, accuracy, and latency issues of ADS-B, the team proposes incorporating previous work performed by a team member and the advisor, to improve the raw ADS-B data if the need arises. This includes applying a correction to ADS-B-reported altitudes and implementing a Kalman filter and interpolation algorithm to increase the quality of the position data (Dy et al. 2021; Mott et al., 2020). Research and studies on the takeoff and arrival durations of aircraft are also warranted to determine the size of the geofenced volume, adjustments for different aircraft, and how this can be implemented. Additional options such as the use of multilateration and the use of time-based estimation of conflicting aircraft can also be tested to improve performance.

**Installation and Maintenance**

For the installation and maintenance of SAFE-RWSL, the team suggests the following process. First, it would be beneficial for the airport to deploy an ADS-B receiver that will collect information about the operations of aircraft at the airport – including information pertaining to the most used taxiways and runways. This data can further support local knowledge and ensure that the RELs and DALs would be installed at the most impactful locations. The data can also be used to provide information for other applications of ADS-B data such as operation counts and noise estimation, leading to no wastage should SAFE-RWSL not be installed (Yang et al., 2019; Yang et al., 2021). After deciding on installation and priority locations, the deployed ADS-B receiver can be upgraded to serve as the central computer by adding the necessary software and LPWAN device/antenna to communicate with RELs and DALs. This step can take place after an update to the airport layout plan (ALP) for another project is required, to save on costs (M. Blake, personal communication, February 25, 2022). The appropriate geofences can also then be programmed into the system. Simultaneously, the installation of RELs and DALs shall proceed.

As RGLs are only required at the entrances of runways with precision approaches, it is expected that most installation locations will not be equipped with already existing RGLs. Due to this, it is likely as well that the prospective installation location will not have a 24/7 power source that can be used. The team learned that power is not always provided to airport lights such as taxiway lights and signs as this is how they are controlled (to adjust intensity or to switch off during day/VFR conditions) (A. Baxmeyer, personal communication, February 22, 2022). Thus, it is proposed that solar powered RELs and DALs be installed, similar to solar powered RGLs, when consistent power is difficult or expensive to connect to. The use of solar-powered RELs and DALs will also be beneficial for remote and off-grid airports.

If a runway entrance is already equipped with an RGL, a replacement RGL/REL can be installed with a simple swap out. Due to wireless capabilities, no additional wiring would be needed. The team further believes that the REL module of this SAFE-RWSL system can be adopted in the future by controlled airports. The use of the simplified REL as proposed offers RWSL benefits to runway entrances that may not already be covered by in-pavement RELs – reducing the cost of equipping the entire airport with RELs, while also plugging into an already existing system (such as an ASDE-X RWSL) by simply adding a LPWAN transmitter. The modular nature of the proposed RELs and DALs allow it to grow with any improved surveillance system that may be introduced in the future.

Maintenance for the system is expected to be minimal. The use of LEDs for the RELs and DALs should reduce the need to change out the fixture or the bulbs when compared to incandescent fixtures. System updates for the software that drives the ADS-B receiver, processes information, and transmits signals can be performed remotely with an internet connection, and would need few updates (for example, if the airport layout is changed). Parts of the system should also be inexpensive and easy to replace such as if the computer stops working, or if the antenna is destroyed. The only major maintenance need for this system would be changing the battery of solar powered RELs and DALs upon reaching its end-of-life.

**Path to Production**

The individual parts needed for the SAFE-RWSL system are mostly available off-the-shelf. The use of RGB lights in an RGL, accompanied by the wireless control system will be the only significant hardware modifications. Otherwise, the team believes that a thorough development, and testing procedure for the SAFE-RWSL system can be completed in a year and a half with the appropriate funding (the RELs/DALs are the most expensive part).

The software must also be developed to translate ADS-B data into REL/DAL instructions real-time. Testing must then follow to ensure that the system is accurate and dependable such that it is trustworthy. The effectivity of RGLs to function as RELs, and the use of DALs should also be evaluated through a pilot study at an airport and through the use of simulations.

If the system is deemed to be viable and effective, it would be important to ensure that the appropriate training and information is disseminated by the FAA through its publications such as the Aeronautical Information Manual, and advisory circulars. Despite the presence of an active traffic alerting system, pilots and drivers will be expected to stop, look, and listen for traffic at runways, similar to commercial vehicles at railroad crossings. This is because the system will not detect all traffic if using ADS-B data only. Hence, it's limitations should be clearly disseminated.

## Cost Benefit Analysis

### *Research and Development*

A cost benefit analysis was performed as recommended by Dr. Dave Byers (Virginia Space Grant Consortium, 2021). This proposal is part of the alpha test of the proposed design. It was estimated that this project has been studied for 200 hours by the time of submission. Details of estimated costs incurred so far are detailed in Table 3.

The alpha test should be followed by a beta test that includes two test airports, and the use of simulated scenarios. The two airports would allow the researchers to test different layouts and environments. Beta testing would take a year and a half. The system will be developed over the first six months, then tested for a year. Data from testing will be analyzed to make sure that the system works as designed and is simple to operate. The Purdue University airport and a nearby airport such as Delphi municipal airport could be used for testing. While the Purdue University airport is a towered airport, it is only towered part-time. Additionally, the timing of the SAFE-RWSL system can be compared to control tower instructions to determine if warning margins are excessive or not. Estimates for beta testing costs can be seen in Table 4.

**Table 3**

*Alpha Test Costing*

| **Item** | **Rate** | **Quantity** | **Subtotal** | **Remarks** |
|---|---|---|---|---|
| *Labor* | | | | |
| Labor Expenses | $25/hr. | 200 | $5,000 | 2 Students - 100hrs each |
| *Other Expenses* | | | | |
| Travel Expenses | $0.50/mi | 100 | $50 | Site visits |
| **Subtotal** | | | **$5,050** | |

**Table 4**

*Beta Test Costing*

| **Item** | **Rate** | **Quantity** | **Subtotal** | **Remarks** |
|---|---|---|---|---|
| *Labor Expenses* | | | | |
| R&D (Advisor) | $50/hr. | 640 | $32,000 | Faculty Advisor for 4 semesters (0.25 FTE) |
| R&D (GRA) | $25/hr. | 1280 | $32,000 | 1 GRA for 4 semesters (0.5 FTE) |
| Pilot testers | $10/hr. | 50 | $500 | Compensation for simulator study |
| Field Technician | $20/hr. | 100 | $2,000 | For installation of equipment |
| *Additional Expenses* | | | | |
| Hardware Expenses | $80,000 | Est. | $80,000 | 6 DALs, 4 RELs, 2 Central computers, tools |
| Simulator Use | $50/hr. | 50 | $2,500 | For use of school flight simulators |
| Travel Expenses | $0.50/mi | 2,000 | $1,000 | Drive to airports |
| **Subtotal** | | | **$150,000** | Testing at KLAF, 1I9, and on simulators |

***Production and Installation Costs***

Average production and installation estimates per system/airport are summarized in Table 5. The system should be a plug-and-play install aside from the pre-installation study to determine the locations for installation and the appropriate geofence boundaries. Estimated hardware costs are lower than preproduction estimates due to anticipated economies of scale during production and were based on similar solar-powered light fixtures. Additional labor costs from the addition of the system in an airport layout plan (ALP) were included. The estimate was based on having the system added during an ALP being performed for another reason (routine or for another project). This should allow the airport to spend less for the installation of the SAFE-RWSL system by not requiring a dedicated ALP updated just for the addition of the system.

**Table 5**

*Estimated Installation Costs*

| **Item** | **Rate** | **Quantity** | **Subtotal** | **Remarks** |
|---|---|---|---|---|
| *Labor - Manufacturing, Sales, and Installation* | | | | |
| Per Unit (average) | $100/hr. | 30 | $3,000 | Study, Assembly, Installation, and Testing |
| Marketing & Sales | $300/system | 1 | $300 | Sales (commissioned) |
| Airport Layout Plan | $2,500/system | 1 | $2,500 | Additional labor/costs incurred for addition |
| Additional Expenses | | | | |
| Hardware and Manufacturing | $20,000 | Est. | $20,000 | 2 DALs, 2 RELs, and a central computer |
| Marketing & Sales | | Est. | $150 | Approximate materials cost per unit |
| Distribution | $300/system | 1 | $300 | Shipping |
| **Subtotal** | | | **$26,250** | Installation cost at an average non-towered airport |

***Operational Costs***

Estimated costs of operations and maintenance are included in table 6. Labor costs from operator’s personnel are expected to be incurred due to the addition of the system to regular inspections. One full time technical support person is expected to be able to support all installed systems and the cost of this is spread appropriately. A visit from technical support is expected only once every five years as the system should be simple enough to troubleshoot by airport personnel alone or while on the phone with technical support. Software updates can also be patched through with an internet connection. The support visits are expected to be primarily for battery replacements.

**Table 6**

*Estimated Operations and Maintenance Costs*

| Item | Rate | Quantity | Subtotal | Remarks |
|---|---|---|---|---|
| *Labor - Operator's Personnel and Tech Support* | | | | |
| Operator's Personnel | $40/hr. | 31 | $1,240 | Average of 5 mins per day, 365 days per year |
| Technical Support Personnel | $225/yr. | 1 | $225 | Share of a full-time employee supporting 266 units |
| *Additional Expenses* | | | | |
| Travel & Per Diem | $120 | 1 | $120 | $600 travel and lodging costs; Once every 5 years |
| Battery Replacement | $300/system | 1 | $300 | Amortization of 6 batteries with 10-year service lives |
| **Subtotal** | | | **$1,885** | Per system per year |

***Cost-Benefit Summary***

The total cost of runway incursion accidents between 2010 to 2020 was $71,260,000 based on information gathered from the NTSB accident reports and values provided by Byers (2021). These accidents occurred at airports not included in the National Plan of Integrated Airport System (NPIAS), and at airports classified as nonhub primary, or nonprimary under NPIAS (FAA, 2020e). With no other practical way to classify the airports where these events happened, proposing the installation of the SAFE-RWSL system at more than 3,000 public use airports to eliminate runway incursion accidents would be impractical and not cost-effective. The team thus found and calculated the cost of the one accident that occurred at a nonhub primary airport and compared it to the cost of equipping all 266 nonhub primary airports with the SAFE-RWSL system (NTSB, 2014b). The benefit value of preventing that accident is summarized in Table 7. The corresponding cost of equipping all these airports with SAFE-RWSL system is summarized in Table 8. A cost-benefit ratio of 2.37 was calculated for the installation of the SAFE-RWSL system at 266 nonhub primary airports (see Table 9).

Note that a number of nonhub primary airports have full-time control towers, and the selection of nonhub primary airports was used to show an approximation of benefits. This is a conservative calculation as not all nonhub primary airports would need to be equipped.

**Table 7**

*Benefit Summary of Preventing the One Accident at a Nonhub Primary Airport From 2010-2020*

| **Item** | **Rate** | **Quantity** | **Subtotal** | **Remarks** |
|---|---|---|---|---|
| Value of Life (VSL) | $9,100,000 | 3 | $27,300,000 | |
| Value of Injury (VSI) | $955,000 | 0 | $0 | |
| A/C Destroyed (AVD) | $1,500,000 | 1 | $1,500,000 | |
| A/C Damaged (AVR) | $230,000 | 0 | $0 | |
| Vehicle Destroyed (VVD) | $250,000 | 0 | $0 | |
| Vehicle Damaged (VVR) | $25,000 | 0 | $0 | |
| **Subtotal** | | | **$28,800,000** | Accident cost from nonhub primary airport in the last 10 years |

**Table 8**

*Cost Summary of Installation at the 266 Nonhub Primary Airports*

| Item | Rate | Quantity | Subtotal | Remarks |
|---|---|---|---|---|
| Development (A & B Testing) | N/A | | $155,050 | |
| Installation | $26,250/airport | 266 | $6,982,500 | 266 Nonhub primary airports |
| Operations and Maintenance | $1,885/airport/yr. | 2,660 | $5,014,100 | 266 airports for 10 years |
| **Subtotal** | | | **$12,151,650** | Total 10-year cost per unit |

**Table 9**

*Cost-Benefit Summary of SAFE-RWSL Installation at the 266 Nonhub Primary Airports*

| Item | Rate | Quantity | Subtotal | Remarks |
|---|---|---|---|---|
| Value of Life (VSL) | $9,100,000 | 3 | $27,300,000 | |
| Value of Injury (VSI) | $955,000 | 0 | $0 | |
| A/C Destroyed (AVD) | $1,500,000 | 1 | $1,500,000 | |
| A/C Damaged (AVR) | $230,000 | 0 | $0 | |
| Vehicle Destroyed (VVD) | $250,000 | 0 | $0 | |
| Vehicle Damaged (VVR) | $25,000 | 0 | $0 | |
| **Total Accident Cost Prevented (Benefit)** | | | **$28,800,000** | |
| **Less Cost (Development/Installation/Maintenance)** | | | **$12,151,650** | |
| **Benefit to Cost Ratio** | | | **2.37** | **Benefit outweighs cost** |

## Other Operator and Expert Feedback

Airport operators and industry experts were consulted throughout this project. Besides those already mentioned, who contributed during the preliminary design and safety analysis phases, the group was able to receive feedback on summaries of the proposed solution from Mr. Robert Sumwalt, former chairman and board member of the NTSB, and Mr. Andy Darlington, airport manager of the Marion Municipal airport. Positive feedback on the design was received from both, and Mr. Sumwalt suggested changes to previous statements made in the introduction. In addition, feedback provided through Mr. Marty Blake included comments from Mr. Marcus Dial, Mr. Julian Courtade, and Mr. Mike Buenning from the INDOT Aviation Office (see Figure 8).

**Figure 8**

*Conversation with Mr. Marty Blake, INDOT Aviation Office Manager During a Conference*

## Safety Risk Assessment

In the deployment of a new system, it is imperative for the safety risks to be assessed as part of the safety risk management (SRM) component of a safety management system (SMS) (FAA, 2020d). In accordance with the procedures for conducting a safety risk assessment outlined in FAA AC 150/5200-37, the team identified three major hazards, determined, and assessed the corresponding risk, and provided treatments for each (FAA, 2007). The determination of risk and acceptability was made in accordance with the provided risk matrix of the same AC. The first and most significant hazard identified was the possibility of pilots falsely relying on the SAFE-RWSL system to indicate whether a runway is safe to use/cross or not. This was an issue raised during the collection of feedback with Professor Sarah Hubbard. She mentioned that pilots may incorrectly trust the system and misinterpret its purpose and reliability such as when a non-ADS-B-equipped aircraft is involved (S. Hubbard, personal communication, February 25, 2022). The worst reasonable outcome of this hazard is a runway collision. As such, the team assessed the risk of this hazard as high (probable and catastrophic), making it unacceptable for implementation without mitigation. In response to this, the team finds it critical for the system's intention, function, and limitations to be clearly described to pilots, ground operators, and pedestrians. The SAFE-RWSL is supposed to augment, and not reduce the need for pilots to see-and-avoid and use radio communications. With this mitigation procedure in place, the team assessed the resulting risk of a runway collision to be medium (extremely improbable but with catastrophic consequences). Thus, during pilot testing and implementation, this hazard should be monitored.

Another hazard identified by the team was unreliability of the system (indicates traffic when there is not, or no traffic when there is (aside from non-ADS-B-equipped aircraft)). The risk identified is the possibility of aircraft wasting time on the ground during a false positive. The team classified this as a medium risk (probable with minor consequences). The mitigation proposed for this issue is to set a quality standard for false positives. This mitigation would make it a low-risk issue (remote with minor consequences).

The third and last hazard the team identified was the total failure/shutdown of the system. The worst reasonable risk considered was requiring the pilot or vehicle operator to default using see and avoid and radio communications alone (reverting to operational procedures before

SAFE-RWSL implementation). The team determined this as a low risk (remote with no safety effect when compared to pre-installation risks).

## Conclusion

The proposed SAFE-RWSL system offers a simple, affordable, flexible, and expandable system to reduce critical runway incursions at airports. The system is simple, using technologies that already exist, requires little additional development, requires no buy-in from aircraft pilots and operators, and should be easy to maintain, in line with current FAA goals for runway incursion solutions. It is also affordable such that general aviation airports without control towers, where all runway incursion accidents have occurred since 2010, would be able to adopt a technology to supplement see-and-avoid and radio communications.

The use of wirelessly controlled status lights further provides flexibility for the system to be used with other surveillance methods (including those in development) to meet the needs of different airports and improve with technological advances. SAFE-RWSL complements the FAA's "right site-right size" approach, by providing another option for airports. With a focus on non-towered airports, it also provides a solution to airports not currently in line to receive new technologies being developed by the FAA and its partners.

The system is expandable in that additional status lights can be easily deployed as the airport grows, and as budgets can handle, without suffering from cost inefficiencies. Further, the system can be deployed at towered airports and larger hubs after further study and considerations.

With a conservative 10-year benefit-cost ratio estimate of 2.37 for the installation of the SAFE-RWSL system at nonhub primary airports, the system promises to provide a practical solution to further improve the safety of the aviation system.

## Appendix A: Contact Information

**Advisor Information:**

**John H. Mott**

765-496-3136

jhmott@purdue.edu

1401 Aviation Drive, NISW 180D, West Lafayette, IN 47907, United States

**Student Information:**

**Luigi Raphael I. Dy**

765-775-8443

ldy@purdue.edu

2604 Bristlecone Dr, West Lafayette, IN 47906, United States

**McClane Elizabeth Rush**

765-603-2174

Mclane1999@gmail.com

518 Catherine Dr, Sweetser, IN 46987, United States

## 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's without a 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, para 1-3, n.d.).

## Appendix C: Description of Industry Interactions with Industry Contacts and Airport Operators

### Marty Blake, Manager, Office of Aviation INDOT

The group met with Mr. Marty Blake to discuss the cost and potential regulations that may affect the implementation of this system. He also gave guidance on how to receive funding for the project. He provided feedback on the group's initial idea. He also shared the document with the rest of team for more feedback.

### Michael Buening, Chief Airport Engineer, Office of Aviation INDOT

Mr. Michael Buening reviewed the summary of the proposal and provided feedback from an engineering perspective. He provided his feedback through Mr. Blake.

### Julian Courtade, Airport Inspector, Office of Aviation INDOT

Mr. Courtade provided feedback on the initial idea from the group. He was able to bring his experience as an airport inspector to help the group create a more cohesive project. Marcus Dial and Mr. Courtade worked together to provide feedback to the group through Mr. Blake.

### Marcus Dial, Aviation Planner, Office of Aviation INDOT

The initial idea paper was passed on to him from Mr. Marty Blake. He was able to provide valuable feedback, such as more background on the ALP submission process.

### Adam Baxmeyer, Manager, Purdue University Airport

Mr. Baxmeyer provided insight into the costs that would come up through the course of implementation of the system. There were several costs and issues not known to the group that were relevant to the proposal. He was able to provide these insights based on his experience as the airport manager.

**Andy Darlington, Manager, Marion Municipal Airport**

Mr. Darlington provided feedback on a summary of the proposed design. He recommended that there be ways to inform pilots of conflicting aircraft or vehicles on the runway, in line with the proposed solutions.

**Sarah Hubbard, PhD, CM, Associate Professor, Purdue University**

A member of the group briefly met Dr. Hubbard to discuss the general idea proposed and to discuss her feedback and concerns on the system. She highlighted the safety concern of pilots/operators relying solely on the status lights, and potential issues of placing the lights within a runway safety area.

**Stewart Schreckengast, PhD, CM, FRAeS, Limited-term Lecturer, Purdue University**

The group provided a summary of the proposal to Dr. Schreckengast and discussed some concerns and questions with him related to the project in a virtual meeting after. Dr. Schreckengast compared the FAROS system that inspired the use of DALs to his experience landing on aircraft carriers. He also suggested investigating the use of microphones/sound for aircraft detection and mentioned other novel ideas he has heard that tackle runway incursions.

**Robert Sumwalt, Executive Director, Center for Aviation and Aerospace Safety, Embry-Riddle Aeronautical University**

Mr. Robert Sumwalt was provided with a summary of the group's proposal. He suggested an edit to a statement he did not agree with and provided the group with resources on it. He also said the proposal looked good.

# Airport Cooperative Research Program
# University Design Competition for Addressing Airport Needs
# Design Submission Form (Appendix D)

*Note*: This form should be included as Appendix D in the submitted PDF of the design package. The original with signatures must be sent along with the required print copy of the design.

University Purdue University

List other partnering universities if appropriate: ______

Design Developed by: ☐ Individual Student ☑ Student Team

***If individual student:***

Name ______

Permanent Mailing Address ______

Permanent Phone Number ______ Email ______

***If student team:***

Student Team Lead: Luigi Raphael I. Dy

Permanent Mailing Address 2604 Bristlecone Dr, West Lafayette, IN 47906, USA

Permanent Phone Number 765-775-8443 Email ldy@purdue.edu

***Competition Design Challenge Addressed:***

Runway Safety/Runway Incursions/Runway Excursions Challenge F: Expanding Situational Awareness of Pilots and Ground Operators on the Airfield

I certify that I served as the Faculty Advisor for the work presented in this Design submission and that the work was done by the student participant(s).

Signed DocuSigned by: John H. Mott 3F3555DE14054B0... Date 4/25/2022

Name John H. Mott

University/College Purdue University

Department(s) School of Aviation and Transporation Technology

Street Address 1401 Aviation Dr, NISW 180D

City West Lafayette State IN ZIP code 47906

Telephone 765-496-3136 Fax 765-494-2305

DocuSign

## Certificate Of Completion

| | | |
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## Appendix E: Evaluation of Educational Experience Provided by the Project

**Students**

1. Did the Airport Cooperative Research Program (ACRP) University Design Competition for Addressing Airports Needs provide a meaningful learning experience for you? Why or why not?

   Yes, the ACRP University Design Competition provided a meaningful experience for the team. The competition provided a venue and incentive to research, discuss, and think about problems faced by airports. The requirement to receive industry feedback forced the team to learn about the challenges faced by airports. This allowed the team to think about practical solutions that are feasible and potentially impactful.

2. Challenges did you and/or your team encounter in undertaking the competition? How did you overcome them?

   It seemed that for every one of the group's ideas there was a new cost that was a part of it. The costs to wire into the current electric grid was much more than the group had initially expected. We also had the unexpected cost of updating the Airport Layout Plan (ALP). We were able to change from wiring the lights into the current electric grid to using solar power. We also recommended that an airport that wanted SAFE-RWSL to wait until there was a need to change their current ALPs to reduce the cost of implementation.

3. Describe the process you or your team used for developing your hypothesis.

   The group originally thought of a much more complicated idea but realized that it was not feasible. There would be more room for it to fail. The group used railroad and road traffic lights as inspiration when it came time to design the system. After the initial idea was created, the group discussed it with various industry professional to further the idea along.

4. Was participation by industry in the project appropriate, meaningful, and useful? Why or why not?

All the industry interaction was really meaningful and useful. They were able to provide a perspective that the group did not have, which is especially important for proposals concerning their fields. Their years of experience provided the group with a good foundation to come up with practical and feasible ideas that solve real problems.

5. What did you learn? Did this project help you with skills and knowledge you need to be successful for entry in the workforce or to pursue further study? Why or why not?

The group was able to learn more about how to cost items and how to analyze the financial impacts of a project. They were able to go deeper into problems and find better ways to resolve them. The group's perspective on the process for changing airport technologies have been changed. There are several more steps that are involved than what had previously been considered.

**Faculty**

l. Describe the value of the educational experience for your student(s) participating in this competition submission.

The team assembled for this competition was diverse, in that it consisted of two students from different cultural and educational backgrounds. The students learned to overcome differences in their individual knowledge of the technical details of the project, as well as communication barriers both internal to the team and external with regard to the various stakeholders. I believe considerable learning occurred not only in terms of the technical aspects of imagining and realizing a project of considerable technical complexity, technology integration, and cost-benefit analysis, but also as a result of overcoming the challenges I have described here. The graduate student lead on this project has been involved in my research related to technical solutions for problems at nontowered airports, and this project was a natural extension of the concepts learned from that experience.

2. Was the learning experience appropriate to the course level or context in which the competition
was undertaken?

Yes; this project was an appropriate application of concepts and design methodologies the students learn in a graduate-level simulation course I teach at Purdue University.

3. What challenges did the students face and overcome?

One of the primary challenges associated with the project was that of developing a thorough understanding of the scope of the problem being addressed, given the large volume of literature and research that has been conducted on the subject. Other challenges were related to communication among the internal team members and external stakeholders, as described in (1). I think this competition, more so than any others with which I have been associated, helps students improve both communication and project management skills. I have been pleased to be able to see such improvement on the part of each student involved in this year's competition.

4. Would you use this competition as an educational vehicle in the future? Why or why not?

Yes; this is my fourth year of advising a team in the competition. I believe the competition provides an opportunity for the participating students to apply theoretical concepts they acquire in our undergraduate and graduate programs to the solution of practical problems, and work with industry and other faculty as they endeavor to create those potential solutions. The skills students gain by participating will serve them well as they graduate and move to positions in industry. In addition, the competition provides an opportunity for both graduate and undergraduate involvement. This is an area of research interest of mine, and I have modeled my research center, A$^3$IR-CORE, after the concept. See:

Mott, J. H. (2014). A3IR-CORE at Purdue University: An innovative partnership between faculty, students, and industry. The Journal of Aviation/Aerospace Education & Research, 24(1), 26–40. doi: https://doi.org/10.15394/jaaer.2014.1607 for more information.

5. Are there changes to the competition that you would suggest for future years

No.

**Appendix F: References**

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