Thermal Detection System

For Mitigating Runway Incursions at Non-Towered Airports

April 2022

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

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2 Executive Summary

Runway incursions are a growing focus for the Federal Aviation Administration (FAA). The greatest cause of runway incursions is pilot deviation (Green, 2013). Pilot complacency and lack of situational awareness cause the majority of the pilot deviations at non-towered airports because more responsibility is placed on pilots to be attentive to surroundings (Aviation Safety Reporting System, 2002). Runway incursions are generally higher at non-towered airports because pilots are responsible for "seeing and avoiding" other air traffic due to the absence of a control tower (McClellan, 2002). Current strategies to mitigate runway incursions at non-towered airports include pilot education, additional pavement markings, and signage. While these strategies can be effective, they often do not meet expected safety increases and can create safety concerns of their own, including reduced friction on taxiway intersections. Non-towered airports are often hindered from implementing effective solutions to improve safety due to cost.

The team is proposing a solution to improve safety by decreasing runway incursions and increasing pilot awareness at non-towered airports. Utilizing thermal imaging technology, the team proposes a system to identify air traffic, vehicle/pedestrian deviations, and wildlife on the runway and in the runway safety area. The Thermal Detection System (TDS) includes two thermal imaging cameras, a computer, and two L-804 guard lights. The two thermal imaging cameras detect use of the runway and send the data to the computer via ethernet. A computer interprets the camera data, sends information to the lights, and stores the runway incursion data. An L-804 guard light across from the hold short line at each outer taxiway alerts pilots of incoming aircraft or vehicles/pedestrians using a flashing red light and wildlife using a yellow light. The Fitch H. Beach Airport (KFPK) in Charlotte, MI was used to model the TDS. The TDS will initially cost about $20,000. Annually the TDS will cost $200 including maintenance and electricity costs. Federal and state grants are expected to assist in financing the initial cost of the system. The annual costs are the responsibility of the airport. In 2015, the average general aviation aircraft accident cost $105,911 (FAA, 2015). The average aircraft accident costs significantly more than the initial and annual costs of the TDS. While there are some additional safety risks associated with the TDS, many of these risks can be mitigated with preventative measures such as daily inspections. The additional risks of the system need to be considered; however, the overall improvement to safety outweighs the potential risks. The TDS indicates runway availability to reduce runway incursions and increase the safety of non-towered airports.

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3.1 Table of Acronyms

Acronym	*Meaning*
BWE	Built World Enterprise
FAA	Federal Aviation Administration
MOR	Mandatory Occurrence Report
MTU	Michigan Technological University
NOTAM	Notice to Airmen
REL	Runway Entrance Light
RWSL	Runway Status Light
TDS	Thermal Detection System
THL	Takeoff Hold Light

4 Problem Statement and Background

4.1 Runway Incursions

Runway incursions pose significant safety risks at all airports. While most runway incursions are near misses or minor accidents, their rate of occurrence is frequent. The FAA estimates that roughly three runway incursions occur per day between all towered airports across the United States (FAA, 2020a). A runway incursion 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 take off of aircraft" (FAA, 2020a). More specifically, runway incursions are defined by four different categories based on risk: A, B, C, or D. Category A is the highest risk and Category D is the lowest (FAA, 2008). Runway incursions have been identified as a significant safety concern by the FAA since the 1990s. The number of runway incursions continue to increase despite the FAA's considerable mitigation efforts (Further Actions, 2001). Figure 1 shows the increase in runway incursions from 1997 to 2016.

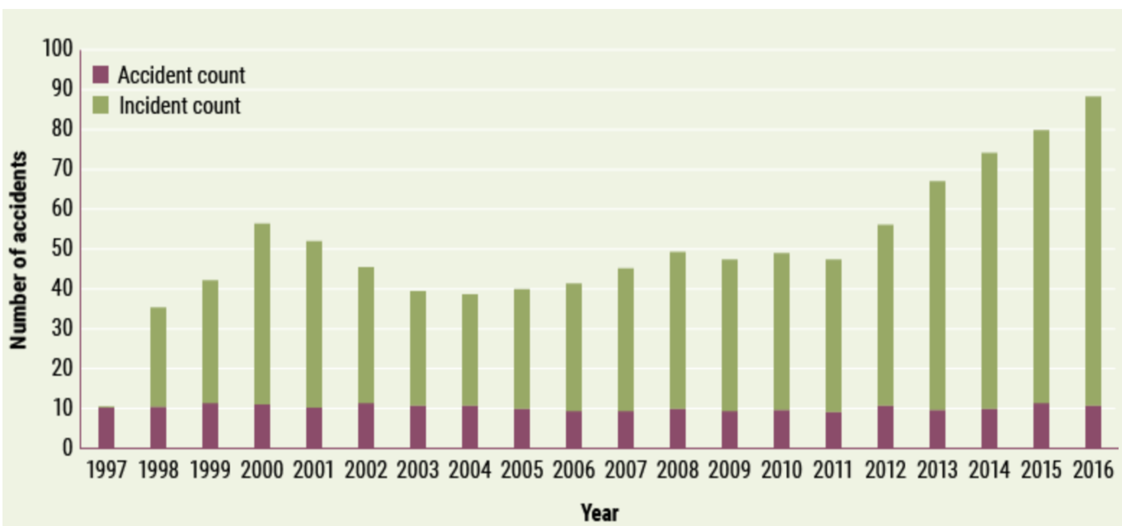

Figure 1 Runway Incursion Count from 1997 to 2016 (Welferman, 2017)

4.1.1 Types of Runway Incursions

The three types of runway incursions are: pilot deviations, operational errors/deviations, and vehicle/pedestrian deviations (FAA, 2008). Pilot deviations cause 72% of runway incursions (Green, 2013). At non-towered airports, more responsibility is placed on the pilot for knowing when taxiways and runways are available. The oversight and direction of a control tower is absent at non-towered airports (McClellan, 2002). Lack of situational awareness and communication are the two main factors contributing to pilot deviations (Welferman, 2017).

Mitigation efforts to decrease pilot deviations involve increasing pilot education, adding additional pavement markings and signage, and eliminating problematic and nonstandard taxiway geometry. The FAA has stated that "non-standard taxiway/runway geometry [is] a contributing factor in many runway incursions and wrong runway takeoffs/landings" (Vitagliano et al., 2018). Non-standard geometry can cause pilot confusion. One of the ways to reduce pilot confusion is installing a control tower, which increases communication and decreases the responsibility of the pilot to identify when entering a runway or taxiway is safe. Although the majority of runway incursions are pilot deviations, operational errors/deviations still occur when aircraft do not leave adequate spacing or when aircraft land on closed runways (FAA, 2008). Vehicle/Pedestrian deviations occur when unauthorized vehicles and pedestrians enter the runway and other protected areas without proper approval. Fences, increased security, and additional managerial support has been effective in decreasing vehicle/pedestrian related runway incursions (Maharaj, 2020).

4.2 Current Runway Incursion Mitigation Strategies

Runway incursions have been prevalent throughout aviation history, and many solutions and strategies have been created to counter them. Mitigating a source of runway incursions can have positive, rippling effects on the overall safety of the airport. Current solutions at towered airports to reduce runway incursions focus on adding technology and identifying the causes of human error (Wilt, 2016). Runway Entrance Lights (RELs) are a warming system where lights are embedded into the pavement to indicate utilization of the specific runway. RELs have been implemented at large airports and have been effective but include a high implementation cost (Ison, 2020). Due to cost barriers, non-towered airports are prevented from implementing runway incursion mitigation strategies involving technology and warning systems. Non-towered airports rely on increasing visibility through additional pilot education, signage, pavement markings, and other low cost solutions, which are often insufficient in increasing safety (Ison, 2020).

4.2.1 Pilot Education

The FAA provides education and literature to pilots to reduce runway incursions. The FAA's primary ways of decreasing runway incursions for pilots includes reading pertinent Notices to Airmen (NOTAMs), understanding Air Traffic Control instructions, using proper radio technique, and understanding airfield layout, markings, and signage. Utilizing appropriate exterior lighting and following the Line Up and Wait Procedure increases situational awareness at airports during inclement weather (FAA, 2017). While education is helpful, the FAA focuses on increasing situational awareness specifically during inclement weather and low visibility. The runway incursion data indicates runway incursions are more likely to occur during pleasant weather with good visibility and low traffic volumes (Aviation Safety Reporting System, 2002). While pilot education is vital to new and existing pilots, education is not the most effective way to address runway incursions at non-towered airports.

4.2.2 Additional Pavement Markings

Pavement markings can be added to runways and taxiways to increase visibility, attention stimuli, and identify hot spots. Paint is inexpensive and easy to implement on pavement, which makes additional markings desirable. While there are positive impacts of adding more pavement markings, adding too many can cause inattentional blindness (Speidel, 2008). Additionally, effective pavement markings require good workmanship and quality paint to increase safety and be cost effective. Pavement markings are often under-monitored for compliance with specifications, resulting in either over or under maintained markings (Speidel, 2008). Glass beads present in the paint causes reduced friction and makes the pavement marking more slippery, especially when ice is present (Minnesota Department of Transportation, 2021). Furthermore, pavement markings and their maintenance becomes another responsibility for the airport manager to deal with, adding more work and tasks to be completed (Speidel, 2008). Pavement markings can be effective, especially in identifying hot spots; however, reduced friction and additional maintenance work for the airport manager are significant downsides.

4.2.3 Installation of a Control Tower

Airport Traffic Control towers increase safety by requiring pilots to seek permission before entry onto taxiways and runways. However, due to the high costs involved in building and running a traffic control tower, most smaller airports do not feature them. Airports are required to request a control tower from the FAA. Each control tower request involves an investment of $150,000 in human factors specialists to confirm a control tower is needed and to determine the specific characteristics of the tower. The average cost of a control tower is about $400,000 (Baker, 2006). Furthermore, the process of obtaining approval for a control tower is lengthy, costly, and the outcome of whether the airport receives the control tower is very uncertain (Aircraft Owners and Pilots Association, 2005). Due to high costs and the lengthy approval process, the FAA only constructs on average seven new control towers each year (Baker, 2006).

4.2.4 Runway Status Lights

Various towered airports around the country use the Runway Status Light (RWSL) system to indicate whether a runway is safe to enter, depending on the color of light used. The RWSL system uses RELs to indicate a runway is unsafe to enter or cross. RWSL systems also use takeoff hold lights (THL), which indicate if a runway is not safe for departure. Both of these lights illuminate red to indicate unsafe conditions (FAA, 2018a). During an initial test of the RWSL system at the Dallas-Fort Worth International Airport (DWF), RWSL systems were shown to decrease runway incursions by 70% (Ison, 2020). RWSL is still not commonplace, due in part to the time it takes to implement such a system. For instance, testing a RWSL system at Los Angeles International Airport (LAX) received approval from the FAA in 2009, but finally became fully operational in 2013 (Ison, 2020). Additionally, RWSL systems have not been implemented at non-towered airports because “the technical and financial constraints for most of the general aviation aircraft and smaller airports limit the use of runway incursion prevention technology” (Möller and Schönefeld, 2012).

4.3 Challenges at Non-Towered Airports

4.3.1 Monetary Challenges at Non-Towered Airports

Non-towered airports often lack monetary funds to implement upgrades and safety improvements. Internal sources of revenue for non-towered airports include commercial land and hangar leases, fuel flowage fees, and landing and ramp fees (FAA, 2009). Non-towered airports without commercial status are prohibited from implementing a Passenger Facility Charge fee. The majority of revenue at non-towered airports comes from government funds. The Airport Improvement Program and other federal and state grants provide funding for fixed costs at non-towered airports including runways, taxiways, aprons, and safety upgrades (Ecola et al., 2020). Between internal and external funding, non-towered airports are often inadequately funded.

4.3.2 Wildlife Incidents at Non-Towered Airports

Wildlife incidents are another challenge at non-towered airports. A wildlife incident is defined as when a bird or another animal collides with an aircraft while in the air, during takeoff, or landing operations (US Department of Agriculture, 2020). These incidents damage aircraft and potentially cause serious injury or loss of life. Larger towered airports have employed a variety of methods to mitigate wildlife hazards, such as flight operation modifications, habitat modification and exclusion, repellent and harassment, and removal (Cleary & Dolbeer, 2005). Non-towered airports, however, tend to lack the resources and funds to use these effective methods, exacerbating the chance of wildlife incidents occurring, and overall increasing the risk of incidencts involving wildlife.

5 Summary of Literature Review

5.1 Runway Incursion Reporting Form

If a runway incursion occurs, it is the responsibility of the pilot, Air Traffic Controller, or other involved party to report the incursion to the FAA through completing a Mandatory Occurrence Report (MOR). The MOR needs to be completed within an hour of when the runway incursion occurred, which can be unreasonably expected in many situations (Bhargava & Marais, 2020). The MOR is an extensive document to complete and requires personal information including name, aviation experience, and other information the applicant may not want to divulge in the report. Runway incursions often go unreported due to the lengthy documentation process and in depth information required when submitting a report. Additionally, pilots and airport staff often do not want to get others in trouble when filing a MOR. Furthermore, a study of runway incursion reporting at General Aviation airports found a lack of supervision and management to be a large cause of under reporting runway incursions (Maharaj, 2020). Under reporting runway incursions makes airports appear safer and increases the difficulty of identifying and solving runway incursion causes.

5.2 Thermal Imaging

Thermal imaging detects objects by measuring the level of thermal radiation given off by an object to identify hot spots (Karp, 2020). The use of thermal imaging in aviation is still experimental; however, it is growing due to the increase in drone usage (Kraus & Štumper, 2015). Airports can use thermal imaging for surveillance to detect unauthorized personnel and foreign drones (Kraus and Štumper, 2015). Thermal imaging is used in surveillance because visual clearance is not required for the detection of objects. Airports need surveillance to scan perimeters and detect the arrival and departure of aircraft. Thermal imaging is a useful technology which can improve the existing functions at airports.

5.3 Runway Signage and Lighting

5.3.1 Runway Signage Types and Standards

There are a variety of runway signs used at airports. Location signs indicate the location of an intersection by using a two symbol code, with a letter for the taxiway and a number for the runway. These signs use yellow text on a black background. Mandatory instruction signs inform pilots of entrance onto a runway, critical area, or non-aircraft area. These signs have white text on a red background. Both direction and destination signs have black outlines on yellow signs with black text, and are used to show where taxiways lead (FAA, 2017).

The FAA has signage regulations specifying the size, distance from the runway, and the height of signs in the runway safety area. The print size determines the size of the sign and how far it is from the runway. However, typical airport signage standards suggest that signs should have a height ranging from 2.5 feet to 3.5 feet above the runway surface. Signage height recommendations ensure that signs are one foot below aircraft wings. Guidance on distances from the runway vary from a 10 foot minimum to a 60 foot maximum distance (FAA, 2020b).

5.3.2 Runway Lighting

Lighting systems on the side of the runway must adhere to certain standards to be approximately uniform between different airports. Lights on the side of the runway are white and spaced at most 200 feet apart. Runway edge lights should be placed between two and ten feet from the edge of the runway (FAA, 2018a). The FAA has recommended design specifications for runway edge lights, including a 14 inch height requirement with a frangible coupling and a disconnector plug (FAA, 2018a). A frangible coupling is a purposefully designed weak connection intended to break away cleanly in the instance of impact with an aircraft or other vehicle. The only time where white edge lights are not used is at the end of instrument runways, where the last 2,000 feet or half of the runway uses yellow lights. Instrument runways are not implemented at smaller airports; non-towered airports use visual runways. Visual runways use white lights as edge lights around the entire perimeter (FAA, 2018a).

6 Team's Problem Solving Approach

The team used the design thinking process to define problems and develop solutions relating to the TDS. Design thinking is defined as "a non-linear, iterative process that teams use to understand users, challenge assumptions, redefine problems, and create innovative solutions to prototype and test" (Interactive Design Foundation, n.d.). Within the framework of the process are five steps: empathizing with the relevant parties, defining the scope of the project, ideating to determine solutions, prototyping, and testing.

6.1 Initial Steps

The team initially chose to improve runway safety at airports. After reaching out to multiple contacts, Derek Rausch, a private pilot, suggested improving the safety at non-towered airports. Rausch has experienced many instances of pilots failing to check the availability of the runway before entering resulting in runway incursions. After further research, the team found that lack of situational awareness at non-towered airports is a widespread issue (FAA, 2018a). These initial ideas fell under ACRP Runway Safety Category F: "Expanding situational awareness of pilots and ground operators on the airfield".

6.2 Problem Solving Approach

Throughout the project, the team was in communication with Rausch and other pilots and aviation engineers to receive advice and feedback. Rausch suggested a radar based system at non-towered airports that could inform pilots before entering the runway from the hold-short line. Rausch expressed the great need for the system at non-towered airports due to the absence of air traffic control professionals to identify clear conditions. The team began to investigate a radar-based runway detection system. By empathizing with professionals, the team defined the problem as a lack of situational awareness, causing runway incursions at non-towered airports.

The ideate phase involved brainstorming solutions with low cost and minimal maintenance requirements. Non-towered airports seldom have additional financial resources (Maharaj, 2020). The team considered several runway detection system options, including thermal versus radar detection technology, and how to inform the runway user of runway utilization.

6.3 Defining the Final Solution

The team met with Professor Dave Nelson, a professor of airport design at Michigan Technological University (MTU), to discuss the characteristics of the TDS. Thermal detection cameras were quickly chosen over LiDAR (Light Detection and Ranging), as the heat emitted from aircraft, vehicles, pedestrians, and wildlife can be detected with this technology. The team decided to implement two thermal imaging cameras located centrally on the runway with each camera pointed in opposite directions. This camera placement was chosen because runways switch landing and takeoff directions in accordance with the wind direction. Using an aircraft, vehicle, pedestrian, and wildlife algorithm, the camera would detect utilization of the runway.

The next part of the design phase was determining how to alert pilots and other runway users of runway utilization. After discussion with airport professionals and researching current runway marking standards, the team concluded that the best location for the runway guard lights would be across from the taxiway, directly in front of the hold-short line. The team then created a decision matrix collectively to evaluate the need for accompanying text with the indicator lights and an option to do nothing, as shown in Table 1. Table 2 contains the rating scale used to complete Table 1, and Table 3 provides explanations for each category.

Table 1. Evaluating Need for Text

Category	Weight	Indicator with Text	Indicator with No Text	Do Nothing
Initial Cost	1	1	2	5
Pilot Training	1	4	3.5	5
Maintenance Cost	1	2	3	4
Impact to Normal Operations	1	4	4.5	5
Comprehensibility	2	4	3	5
Signage Congestion	1	2	4	5
Attention Stimuli	2	4	3	0
Improvement to Safety	2	5	5	0
Ability to Implement at Various Airports	2	2	4	5
Environmental Concerns	0.5	4	4.5	5
Totals		45	49.25	46.5

Table 2. Rating Scale Used in Table 1

Rating Scale
1 - Least Effective, Most Cost
5 - Most Effective, Least Cost

Table 3. Explanations of Categories in Table 1

Explanations	
Initial Cost	The monetary amount required when installed. This includes both material and labor costs.
Pilot Training	Costs associated with training pilots and operators to use the system. Includes time and hours worked
Maintenance Cost	Monetary amount needed over time to ensure the system remains functional. Includes labor, repairs, etc
Impact to Normal Operations	Amount of attention and maintenance this system requires from airport staff
Comprehensibility	The ability for relevant parties to understand the meaning and intention behind the design
Signage Congestion	If there is overcrowding of signs, or too many signs in one location at airfield. Increased signage congestion decreases safety.
Attention Stimuli	How well the attention/focus of relevant parties is captured
Improvement to Safety	The reduction rate of runway incursions
Ablity to Implement at Various Airports	The ease of implementation at airports with different runway layouts and aircraft
Environmental Concerns	The potential risks our design has on the surrounding environment

In order to reach an appropriate conclusion, each team member determined ratings for Table 1 independently and then came together to compare values. Taking into account category weights, an indicator with no text proved to be the most effective and least costly option.

7 Description of Technical Aspects

The thermal detection system is essentially an automated control tower. Two thermal cameras positioned at the center of the runway scan the runway to identify aircraft, vehicles/pedestrians, and wildlife on the runway. A guard light across from the hold short line at each outer taxiway indicates if the runway is utilized. A red light is illuminated if an aircraft or a vehicle/pedestrian are on the runway and a yellow light if wildlife is on the runway.

7.1 Light Fixtures

The TDS will use an L-804 Elevated LED Two Bulb Guard Light, as shown in Figure 2, to display if the runway is safe to enter. LED lighting was chosen over halogen bulbs because LEDs are cheaper, brighter, and have greater longevity than halogen lights (Bloudicek, 2017). The left bulb will use a traffic signal red lens, and the right bulb will use an ICAO yellow lens. These lenses will have to be changed out after purchase because the L-804 comes with identically colored lenses (Flight Light Inc., 2013). Minor adjustments in programming will be made to allow for the lights to both flash and remain solid. The current lighting mechanism for the L-804 involves alternate flashing lights.

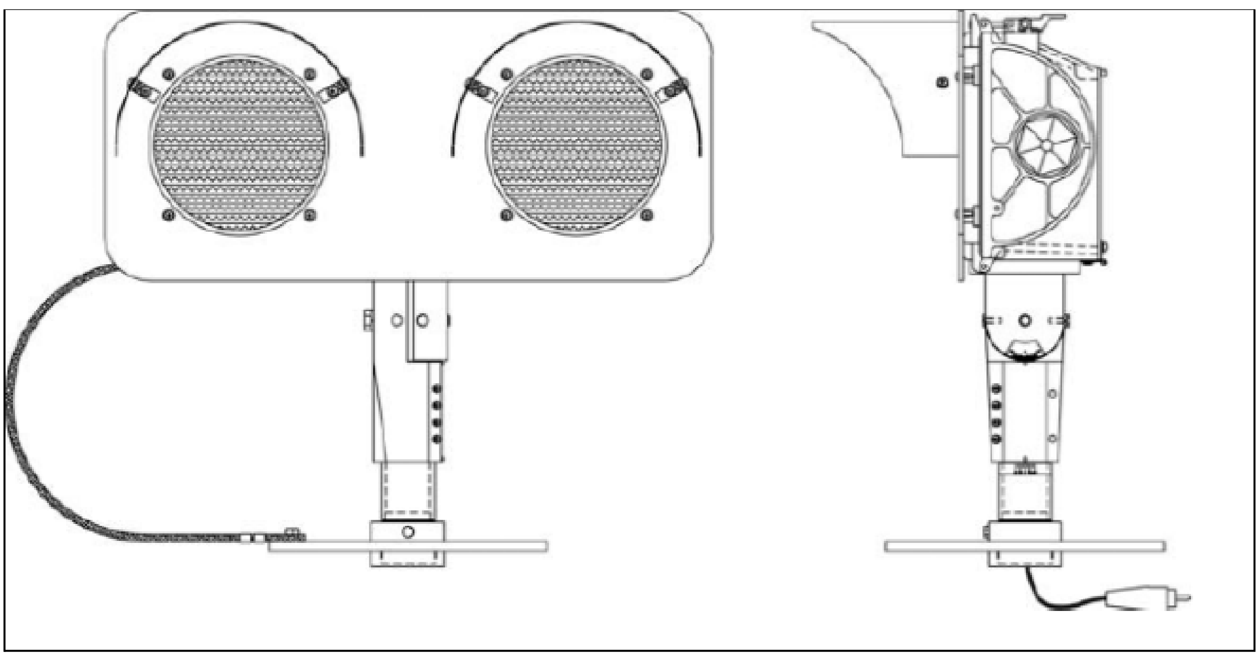

Figure 2 L-804 LED Runway Guard Light

The L-804 requires that the power supply and electrical hookups are below ground. Many non-towered airports have existing electrical infrastructure below ground. The lights are adjustable and can stand up to 26 inches from the ground. The L-804 uses a frangible column and a frangible coupling. These brittle connections are employed to mitigate damage and safety hazards in the instance of a collision between the L-804 and a plane or operator vehicles (Flight Light Inc., 2013). A model of the L-804 is shown in Figure 2.

7.2 Thermal Imaging Camera

The thermal imaging camera that was chosen for the detection system is the Flir A50. Flir is an American thermal imaging company, whose cameras have been used in airport applications (A. Finkelstein, personal communication, February 16, 2022). This camera can detect heat signatures ranging from -20°C to 175°C. Moreover, this camera is designed for the purpose of constant streaming. The A50 can be connected to the internet via ethernet or wifi. The visual resolution is 1280x960 pixels and an IR resolution of 464x348, creating a very clear image. Because of the camera's shape, the A50 can be easily mounted in various positions. The camera has three field of view options: 29°, 51°, and 95°. The TDS layout uses two fixed 95° cameras which is essential for total detection of aircraft, vehicles, and wildlife. Having an IP66 rating, the A50 can withstand extreme temperatures, rain, snow, and wind. For additional protection, Viper Imaging created a rigid enclosure that can be easily installed around the camera. Furthermore, Viper Imaging manufactures a sunshade built specifically for the A50, which can reduce glare and heat signatures from the sun. Airports can purchase a sunshade if the need arises (2022). A picture of the A50 is shown in Figure 3.

Figure 3 Flir A50 Thermal Image Streaming Camera (Without Rigid Enclosure)

7.3 Location and Positioning of the TDS

As the aim of the TDS is to ensure that entering aircraft and other vehicles are alerted to potential runway intrusions, warning lights will be placed on the outside taxiways. Placement at this location ensures that regardless of the direction of takeoff on a given day operators can be warned. The taxiways in the middle will not feature warning lights, because aircraft typically need the entire runway to take off. Additional warning lights can be added at the discretion of the airport if the need arises. A sample layout of the TDS at the Fitch H. Beach Airport is shown in Figure 4.

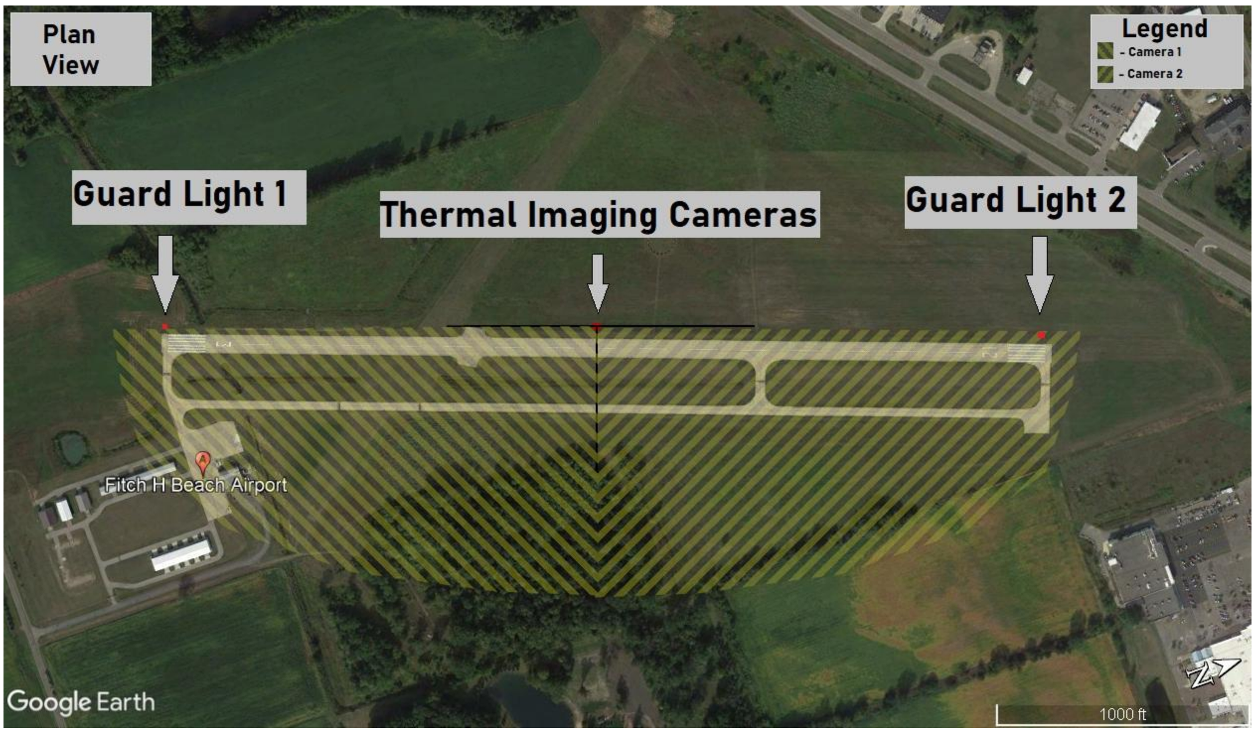

Figure 4 Design Plan View at Fitch H. Beach Airport

The thermal imaging cameras will be in a centrally located position, with each camera pointed at a different end of the runway. The specifications for the Flir A50 state that the field of view of the camera is approximately 90 degrees, which allows for a complete view of the runway. The cameras are positioned in this way to prevent any potential blindspots, ensuring full coverage of the runway. While field testing is outside of the scope of this project, refinement and adjustment of the thermal imaging camera angles should be conducted to ensure accurate view of any incoming aircraft. Some of these refinements could include algorithmic disregarding of airport heat signatures.

7.4 Environmental Concerns

The light bulbs on the L-804 Guard Light have an expected lifespan of 10 years (ADB Safegate, 2020). Depending on the weather conditions, other electrical components may fail over time and should be replaced. The light bulbs and other electrical components of the L-804 can be recycled by sending them to the product's manufacturer, ADB Safegate. Existing weather and moisture protection on the cameras should be sufficient protection against weather and precipitation.

Wildlife concerns are relatively small. Although runway surfaces and technologies are often mildly disruptive to the local ecosystem, implementing new technology in close proximity to existing wildlife habitats will have little additional impact compared to the existing interference. One potential issue that could arise would be birds perching on top of either the thermal imaging camera post or the warning lights. Bird spikes can be installed if bird interference is an issue. Similarly, the guard lights are rated for outdoor use and can withstand wildlife interference.

7.5 3D Simulation

The TDS was modeled utilizing flight simulator software to allow the team to gain a perspective of potential users, including pilots and runaway operators. Additionally, the ability to demonstrate the team's proof-of-concept design in a simulated setting allows for improved feedback from industry contacts. To accomplish this, the team utilized the free flight simulator GeoFS (2022). Several features, including the ability to select any airport, including non-towered airports, and the diverse selection of aircraft to choose from allowed the team to assess the design in a practical scenario. For these purposes, three small-to-medium sized aircraft were chosen to represent the types of aircraft typically present at non-towered airports. Cessna and AlphaJet PAF aircraft were simulated and placed at the hold-short line, and the guard lights were composited into the image. As discussed earlier, the Fitch H. Beach airport in Charlotte, Michigan was chosen due to its standard runway layout. Figures 5 through 7 show cockpit views from these aircraft.

Figure 5 AlphaJet PAF Cockpit View

Figure 6 Cessna Cockpit View

Figure 7 Opposing Taxiway View

The placement of the warning lights should ensure that entering aircraft operators are able to understand if any potential runway intrusions are occuring. Additionally, the guard lights' location at the taxiways on both ends of the runway ensure that regardless of takeoff direction, pilots will be informed.

7.6 Data Recording and Storage

Using either ethernet or wifi connections, the Flir A50 camera feed will be connected to a computer in the airport, where the appropriate personnel can monitor it. The TDS is designed to be as automated and self sufficient as possible, thus an airport personnel is not needed to monitor the system more than about once an hour. Software would be created to analyze the video to recognize if there is a hazard on or approaching the runway. A Raspberry PI with an attached receiver will be connected to the Brite Remote Control on the L-804 Guard Light (ABD Safegate, 2001). When the software detects an obstruction and determines whether the object is a aircraft, vehicle, or wildlife, the information will be sent to the Raspberry PI via the receiver, which will result in the appropriate color flashing on the guard light.

The software created to analyze the thermal camera video stream will also be used to record runway incursion data. When an incursion is detected, the software will record the date, time, location, and the video of the incident. There will be an option for airport personnel to review the recorded incursions and subsequently classify whether the incident was truly a runway incursion or a falsely recorded malfunction. Because runway incursions at non-towered airports are underreported, the TDS will be able to collect runway incursion data that can be used toward future mitigation tactics.

8 Safety Risk Assessment

8.1 Defining the Risk of the TDS

Safety is vital to ensuring successful air transportation. While the TDS increases safety by increasing situational awareness for pilots, there are additional risks associated with the implementation of the TDS. The additional risks associated with the TDS can be separated into three sub-categories: mechanical failures, environmental impacts, and human impacts.

Mechanical failures are classified as any problem or malfunction associated with the components of the TDS. Two examples of mechanical failures would be false negatives and false positives. False negatives are significantly more problematic, as they occur when a plane is incoming but the TDS does not detect the inbound aircraft. There are a number of situations that would cause a false negative. A failure to detect an aircraft by the TDS would cause a false negative. Other mechanical failures that would result in a false negative would be the loss of power to the TDS, the bulb in the guard light not working, or material fatigue on other parts of the system. False positives can occur when the TDS indicates an aircraft in it's absence. False positives are much less dangerous than false negatives in the short term. False positives are mostly an inconvenience to pilots. However, in the long term, false positives can lower confidence in the TDS, which could lead to pilots ignoring the system when there is an aircraft coming in.

Environmental impacts occur when wildlife, debris, and weather affect the TDS. Wildlife and debris can obscure sections of the TDS. A false positive can occur if wildlife obscures the camera since a heat source would be directly in front of the camera. Wildlife or debris obscuring the guard light would cause pilots to have difficulty interpretting the bulb illumination. Inclement weather, which includes intense precipitation and high winds, could damage the TDS and obstruct the pilot's view.

Human impacts involves the interference of pilots, airport personnel, passenger, and the general public. A pilot at the hold short line observing the guard light indicating an incoming aircraft, could enter the runway regardless. Pilots might ignore the TDS either due to a lack of knowledge of the system or belief that the pilot knows better. The TDS could be damaged by airport maintenance working in the vicinity. Passengers might find the thermal imaging camera of the TDS to be alarming, but airports can minimize concern by distributing informative material on the TDS. Hacking is the theft of information from the cameras and would reduce the comfortability of pilots and passengers interacting with the TDS.

8.2 Mitigation Strategies

A majority of the safety issues that can occur with the TDS can be mitigated through daily inspections of the system. Daily inspections for the TDS would include a recalibration of the detection component and examination for damage or wear on the detection and signaling components of the TDS. Daily inspections would address power outages to the TDS, material wear, calibration error, and visual obstructions to the camera, which would reduce false negatives and positives. Airport personnel would be trained in these procedures through a maintenance manual, learning how to operate around the system to reduce potential damage. The TDS is designed to be weather resistant, with the option of additional weatherproof covers for the camera as needed. Hacking would be addressed by the use of ethernet to communicate between the detection component and the computer in the staff office to create a closed loop of information within the system. Pilot training would reduce misenterpetion or ignorance of the TDS due to not knowing what the signal means. The TDS is about two feet tall and utilizes frangible couplings to reduce damage to aircraft in the event of a collision between an aircraft and the system. With these mitigation strategies in place, the TDS still reduces runway incursions and increases safety at non-towered airports.

8.3 Safety Risk Matrix

Figure 8 shows the matrix used to determine the levels of severity for the various safety risks associated with the TDS. Each severity level has a code from A (insignificant) to E (catastrophic), and the likelihood of an event occurring ranges from on to five. The safety risks associated with the TDS listed in Table 4 are labeled with severity and likelihood codes corresponding to Figure 8.

TDS		Severity				
		Insignificant (A)	Minor (B)	Moderate (C)	Major (D)	Catastrophic (E)
Likelihood	Almost Certain (1)	1A	1B	1C	1D	1E
	Probable (2)	2A	2B	2C	2D	2E
	Possible (3)	3A	3B	3C	3D	3E
	Unlikely (4)	4A	4B	4C	4D	4E
	Rare (5)	5A	5B	5C	5D	5E

Figure 8. Safety Risk Matrix

Table 4. Safety Risks and Codes

Risks	**Severity and Occurrence Rating**
Mechanical Failure	
False Negative	4C
Power Outage	4B
Burnt Out Bulb	2B
Material Fatigue/Failure	4C
False Positive	3A
Environmental Impacts	
Wildlife/Debris Obstruction	3B
Inclement Weather	5E
Human Impacts	
Pilots Ignoring/Not Understanding/Not Noticing	3D
Incursions Involving System - Maintenance	4C
Passenger Impact	2A
Hacking	4C

As shown in Table 4, the primary concerns are a burnt out bulb on the signaling component and pilots disregarding the system. Burnt out bulbs would result in the equivalent severity of a false negative, but a bulb burning out is significantly more likely than a false negative. Daily inspections of the TDS would also address many complications of the system, such as removing debris from the guard light, power outage, burnt out bulbs in the signaling component of the TDS, hacking, and addressing material fatigue of the TDS. Pilots not noticing the TDS or not understanding the information portrayed by the TDS would be addressed through pilot training on the system and overall of success. False negatives and false positives would also be reduced by occasionally monitoring the camera's live feed by airport personnel. The TDS should have minimal impact on passengers, as the guard lights are similar to the traffic lights used in other transportation systems.

9 Cost Benefit Analysis

9.1 Cost of Thermal Detection System

The cost of the TDS is $20,000 initially and maintenance costs of about $200 per year after installation. The elements in the TDS are broken down in Table 5. The main costs of the system are material, labor, and maintenance. Due to the implementation at non-towered airports, federal and state grants are proposed to offset financial barriers of the initial cost. Maintenance costs will be the responsibility of the specific non-towered airport. The team applied the TDS to the Fitch H. Beach Airport in Charlotte, MI to illustrate a layout of the system and a cost estimate. The Fitch H. Beach Airport was chosen to base the Cost Benefit Analysis off of due to the common runway geometry, translating to smooth application to other non-towered airports.

Table 5 Initial Cost Breakdown

Item	Unit Cost	Quantity	Total Cost
Flir A50 Thermal Imaging Streaming Camera	$6,950	2	$13,900
L-804 Elevated LED Two Bulb Light	$1,450	2	$2,900
Connection Materials/Computer Setup (wires, cables, connection to computer)	$1,500	-	$1,500
Installation Labor	$25/hour/worker	8 hours, 3 workers	$600
Sub Total			$18,900
Contingency	5%		$945
Total			$19,845

The material costs are the majority of the initial and maintenance costs. The most expensive material is the two thermal imaging cameras. The Flir A50 Thermal Image Streaming Camera was chosen due to its weather resistant cover, integration of thermal imaging, and temperature alert. The temperature alert indicates to the user when an object is detected. Care should be taken to identify wear and tear by observing the outer surfaces since the thermal imaging camera is the most expensive item to replace. An L-804 guard light was selected for indication of runway status to the pilot. There will be two L-804 guard lights installed, one at each outside taxiway. Most air traffic uses the outer taxiways. More guard lights can be implemented if the need arises. The light bulbs will need to be replaced every 50,000 hours (Elevated LED, 2013). Connecting the camera, computer, and guard lights will cost about $1,500. Cables will need to bring electricity to the thermal imaging cameras, and an ethernet cable will send detection data to the computer. The computer will analyze and store the detection data and send the information to the L-804 guard lights if runway presence is detected. The two L-804 guard lights placed at each outside taxiway will receive electricity and illuminate the bulbs if the computer sends information. The quantity of cables depends on the size and layout of the airport and the computer setup changes depending on the preferences and existing technology at the airport. A five percent contingency was added to cover unforeseen costs. Each airport will need to train personnel and pilots on the TDS. NOTAMs will be distributed to pilots flying in and out of the airport to ensure awareness of the system. The TDS is designed to be straightforward to use and understand so the expected training is minimal.

Labor costs for the installation of the TDS is estimated at $500. Construction equipment rental is not included in the cost estimate. No special training or requirements are needed for installation and maintenance of the system. Labor costs will vary depending on the size, layout, and location of the airport.

Maintenance costs of the TDS is estimated to be $200 per year. Using $0.128 per kilowatt hour as the electricity cost, $100 dollars is expected to be used to power the system. The electricity cost used for the estimate is based on the cost in Charlotte, MI, though the cost will vary depending upon location. An additional $100 is expected for replacing worn out parts including LED bulbs and other necessary repairs.

9.2 Comparison to Alternatives

The purpose of the TDS is to increase situational awareness of pilots to more accurately identify runway availability. Existing ways to increase pilot awareness of runway status is increased pilot education, additional signage and pavement markings, RELs, and the presence of a control tower. Increased pilot education is a low cost alternative but is not as effective because education mainly focuses on new pilots and does not address the more experienced pilots. Adding more signage and pavement markings is another low cost option; however, signage and pavement markings do not always solve the problem. Installing more signs increases signage congestion near the runway. Additionally, signs only remind pilots to check the availability; they does not indicate availability. The quality of pavement markings is often inconsistent resulting from the desire to save time and money and the subjectiveness of identifying pavement marking maintenance. RELs are effective at decreasing runway incursions by identifying availability of the runway; however, they are expensive even for large towered airports. Additionally, RELs are embedded in the pavement and require airports to have paved runways. Many non-towered airports have grass and dirt runways making installation of the lights impossible. Control towers are another way to identify runway availability but they are expensive to install and staff. Furthermore, non-towered airports often do not have the traffic volumes to justify both the initial and maintenance costs of a control tower. Amid significant safety improvements, RELs and control towers are too expensive to be widely implemented at non-towered airports.

9.3 Benefit Analysis

In 2021, 1,575 runway incursions were recorded at airports in the United States and 1,033 were caused by pilot deviation (FAA, 2022). Runway incursions endanger the safety of airport personnel and passengers and can incur millions of dollars in damages. The TDS increases the safety of humans involved and benefits the airport since pilots are more likely to fly into and out of airports with higher safety ratings, increasing the traffic volumes of airports with the TDS. In 2015, the average damage cost from a general aviation aircraft accident was $105,911 (FAA, 2015). The TDS decreases the chances of a runway incursion occurring, reducing the costs incurred from aviation accidents. The initial and maintenance costs of the TDS are minimal compared to the cost of aviation accidents. The TDS pays for itself if even one aviation accident is prevented.

10 Interactions with Aviation Professionals

10.1 Derek Rausch

Derek Rausch is a private pilot located in Iowa who flies private charters. Rausch assisted the team by expressing challenges faced at non-towered airports for pilots, and proposing improvements to increase safety at non-towered airports. Receiving feedback on initial designs and ideas improved efficiency and readability of the final solution. Rausch discussed his personal experiences of pilots failing to check runway availability while stopped at the hold short line of non-towered airports. Rausch's experiences showed why and how runway incursions at non-towered airports are a large safety concern and provided helpful feedback to develop a practical solution.

10.2 David Nelson

David Nelson is a professor in the Civil, Environmental, and Geospatial Department at MTU. Nelson specializes in airport design and construction and assisted the team by providing background into runway layouts. Further, Nelson assisted the team in implementing a solution applicable to a variety of different airports and configurations.

10.3 Heidi Spangler

Heidi Spangler is a State Block Grant Engineer working in Michigan Department of Transportation's Aviation division after working in traffic and safety roles on roadway projects. Spangler provided insight from a traffic and safety engineer standpoint on signage and user interpretation. Additionally, Spangler provided contacts and resources to assist the team.

10.4 Kaitlyn Wehner

Kaitlyn Wehner is a private pilot and Civil Engineer specializing in airport construction and design. Wehner relayed her experiences at airports both as a pilot, construction inspector, and designer. Further, Wehner provided resources on current standard runway signage regulations, including use of frangible couplings.

10.5 Indira Maharaj, PhD

Dr. Indira Maharaj wrote her PhD dissertation on runway incursions at general aviation airports and the experiences of airport managers in running general aviation airports. Dr. Maharaj advised the team on the structures of general aviation airports, the importance of dealing with runway incursions, and the FAA's practices involving general aviation airports.

11 Projected Impacts

11.1 Meeting FAA Goals

The overall goal of the TDS is to help reduce runway incursions at non-towered airports. This fits within "Strategic Objective 1: Systemic Safety Approach" listed in the FAA Strategic Plan for 2019-2022 (FAA, 2018b). One of the main points of this objective is to "improve surface safety by reducing runway incursions and wrong surface operations caused by vehicle/pedestrian deviations or by pilot error as well as improve Runway Safety Areas" (FAA, 2019). The TDS is designed to reduce runway incursions by using a visual light system to alert pilots or other stakeholders of runway conditions and allow them to make decisions that will decrease runway incursion risks. In addition to alerting pilots of the utilization of the runway, the TDS stores runway incursion and wildlife interference data. By collecting more data, the specific causes of runway incursions and wildlife presence at a specific airport can be identified and directly addressed. Non-towered airports often do not have the resources to implement and maintain a control tower leading to significant safety risks. The TDS is both a control tower and data collection system for non-towered airports at a fraction of the cost of a traditional control tower. The safety of non-towered airports needs to be increased and implementing a TDS is an effective way.

11.2 Other Potential Uses

Besides the primary focus, the thermal imaging camera utilized within the TDS has multiple potential applications. Thermal imaging can be used to identify wildlife hazards around the airport that would pose a threat, while collecting data to improve methods that airports use to mitigate wildlife hazards. Outside of solely aviation-related use, thermal imaging technology can be used for security purposes to identify foreign drones or other security threats and alert the appropriate parties. Thermal imaging technology is common in high-profile security cameras today as they give an additional method of detection besides the visual imagery collected by the camera.

Appendix A

List of Complete Contact Information

Faculty Advisor:

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Students: The team consists of four undergraduate students. Three undergraduate students are working on Bachelor of Science degrees in Civil Engineering and one student is pursuing a Bachelor of Science degree in Environmental Engineering.

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Appendix B

MTU is an ABET accredited four year university located in Houghton, MI. There are 16 degree programs within the College of Engineering. The university offers an enterprise program where students work with professionals to solve real-world problems and experience the expectations of the workplace. The team participating in the Airport Cooperative Research Program is part of Built World Enterprise (BWE). Founded in the spring of 2019, BWE is one of 25 different enterprise programs at MTU. BWE addresses civil, environmental, and geospatial engineering challenges.

Appendix C

Airport operators and industry experts contacted:

Derek Rausch

David Nelson

Heidi Spangler

Kaitlyn Wehner

Indira Maharaj, PhD

Appendix E

Student Questions

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?

The ACRP competition was a meaningful experience for the team by providing more opportunities to create professional contacts, write a technical report, and learn more about runway incursions.

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

Through completing the competition, the team was challenged by the process of finding runway incursion data and general information for non-towered airports. Without sufficient data, identifying specific causes of runway incursions at airports was more difficult. We overcame the challenge by speaking with aviation professionals who work with non-towered airports and requesting additional resources and information.

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

The team utilized Design Thinking to develop an effective solution. First, the team communicated and empathized with aviation professionals to learn challenges and concerns they are experiencing. Next, the team used the feedback from professionals to define the problem of runway incursions at non-towered airports. The team then created two prototypes to decrease runway incursions and used a decision matrix to evaluate and eventually choose the most effective solution. The design was then sent out to professionals to provide feedback and suggestions.

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

Feedback from professionals in industry was helpful and impactful on the project. By speaking with professionals early on, the team was able to identify a real problem faced by the aviation world.

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?

Through completing this competition, the team reinforced many important skills relevant to the workforce. The team improved the conciseness and effectiveness of their technical writing and practiced discussing their project solution with both aviation professionals and other students.

Faculty Questions

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

The students chose the topic to address, which pertains to runway incursion and wildlife mitigation on runways. This topic is significantly outside of the topics covered by the courses in the undergraduate civil engineering program curricular. The risk aspect of the project is particularly eye opening for students as they may not have thought about the risks associated with the facilities or processes they design.

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

Our participants are undergraduate students. As they are able to set the scope of work and the problem they solved, the learning experience was appropriate to the course level and context of the competition. Moreover, the more experienced students mentor the junior students, which is a valuable experience for all involved.

3. What challenges did the students face and overcome?

As usual, it can be a challenge to identify industry professionals who are willing to provide feedback to the students. In particular, we encourage our students to use the Stanford D. School Design Thinking process and it is always a challenge to have the students apply the model to develop the best solution.

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

As long as students are interested in exploring challenges that exist at airports, I will continue to support their participation in the ACRP challenge.

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

I have none. I think the competition is well thought out and organized. I like the electronic submission approach adopted during COVID and I hope that remains into the future.

Appendix F

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