Runway Intersection Markings:

For Increasing Situational Awareness and

Decreasing the Frequency of Runway Incursions

April 2020

Design Challenge: Runway Safety/Runway Incursions/Runway Excursions: Enhancing airport visual aids, improved lighting, marking, and signage for runways, taxiways and the airport apron.

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02 Executive Summary

Runway incursions are increasingly the focus of organizations that seek to improve runway safety. As the most common type of unsafe runway incident, they are a natural focus. The International Civil Aviation Organization (ICAO) identifies incursions as a "high risk global safety priority" in their Global Runway Safety Action Plan from 2017 (ICAO, 2017). A few years earlier in 2015, the Federal Aviation Administration (FAA) began a program dedicated to mitigating runway incursions by using data compiled in an incursions database ranging from 2007 onwards (Vitagliano, Canter & Aland, 2018). They were able to identify that confusing geometries are a major contributing factor of runway incursions. The root of this is pilot confusion, and ultimately human factors. Current strategies to mitigate these causes include modifications to airport geometry, lighting, signage, and more pilot training. However, these solutions are often costly--particularly for smaller and general aviation (GA) airports. Although there is no data on runway incursions at non-towered airports, it is likely that incursions are just as much of a concern at these airports as at larger ones. This is due to inexperienced pilots primarily using these airports.

In this report, the team proposes a nonstandard runway intersection marking that would increase pilots' situational awareness at hot spots and problematic geometry locations. This marking would be located between the hold short line and the runway edge and consist of red and white stripes at 30° from the hold short line. Inspired by the red bus lanes that cities across the United States implement to reduce bus lane incursions, the runway intersection marking was refined to increase salience and ultimately effectiveness. The team worked with airport operators, engineers, and a psychology professor who specializes in aviation to develop a marking that would catch pilots attention and decrease the risk of them incurring on the runway. Furthermore, the implementation of this marking would be cheaper than many of the current mitigation strategies and is able to be implemented at both towered and non-towered airports. By using paints that are already in use on the airfield, the additional costs and risks associated with implementing this marking are minimized. As a whole, the runway intersection marking is an incursion mitigation solution that is accessible to a wide range of airports and has great potential to decrease the dangers of runway incursions.

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03.1 Table of Acronyms

Acronym	*Meaning*
ADM	Aeronautical decision making
ATC	Air Traffic Control
BWE	Built World Enterprise
EB	Engineering Brief
FAA	Federal Aviation Administration
FOD	Foriegn Object Debris
FSF	Flight Safety Foundation
GA	General Aviation
GIS	Geographic Information System
HS	Hot Spot
IATA	International Air Transportation Association
ICAO	International Civil Aviation Organization
KABQ	Albuquerque International Sunport
KACT	Waco Regional Airport
KATL	Hartsfield - Jackson Atlanta International Airport
KCLE	Cleveland - Hopkins International Airport
KFCM	Flying Cloud Airport
KFXE	Fort Lauderdale Executive Airport
KGRB	Austin Straubel International Airport
KJVL	Southern Wisconsin Regional Airport
KLAF	Purdue University Airport
KOPF	Miami - Opa Locka Executive Airport
KTUL	Tulsa International Airport
MAC	Minneapolis Airport Commission
MTU	Michigan Technological University
NAS	National Aerospace System
NPIAS	National Plan of Integrated Airport Systems
NTSB	National Transportation Safety Board
NYCDOT	New York City Department of Transportation
OP	Operational Incident
PD	Pilot Deviation
RELs	Runway Entrance Lights
RIM	Runway Incursion Mitigation
RWSL	Runway Status Lights
RWY	Runway
THLs	Takeoff Hold Lights
TWY	Taxiway
UN	United Nations
US	United States
V/PD	Vehicle/Pedestrian Deviation

04 Problem Statement and Background

04.1 Background of Aviation Safety

In the National Aerospace System (NAS), safety is always a concern: pilots and ground crews are trained in safe practices, aircraft are maintained to ensure safety, and a large portion of aviation research focuses on safety. In their 2017 Global Runway Safety Action Plan, the International Civil Aviation Organization (ICAO) identifies steps that runway stakeholders—such as the United States (US) Federal Aviation Administration (FAA)—can take to mitigate these risks (ICAO, 2017). With this responsibility, the FAA provides many documents and training opportunities to pilots, manufacturers, engineers, airport operators and others. Specifically for pilots, the Pilot's Handbook of Aeronautical Knowledge provides a vast amount of information, including a section on aeronautical decision making (ADM). ADM is defined as a methodology for pilots to determine the adequate course of action for a given situation (FAA, 2016). ADM is included in pilots' training so that they can better "understand how personal attitudes can influence decision making and how those attitudes can be modified to enhance safety in the flight deck" (FAA, 2016). In addition to safety in the sky, the FAA focuses on ground operation safety for pilots and vehicle operators by publishing various guides such as the FAA Guide to Operations, A Comprehensive Guide to Safe Driving (FAA, n.d.) on the Airport Surface and Pilots Guide to Airport Signs and Markings (FAA, n.d.).

04.2 Background of Runway Incursions

ICAO, which operates as a part of the United Nations (UN) and partners with other aviation organizations across the world, has identified runway incursions and runway excursions as the two highest runway safety risks (ICAO, 2017). A runway incursion is an event where there is "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, 2015). Runway incursions generally occur when a pilot fails to hold short of a runway surface or hold short markings (FAA, 2017). There are three main causes of incursions: operational incidents (OIs), pilot deviations (PDs), and vehicle/pedestrian deviations (V/PDs). Of these occurrences, the most common cause of runway incursions is PDs. In 2018, 63% of incursions were due to PDs, 19% to OIs, and 18% to V/PDs

(FAA, 2018). The top factors that contribute to pilot error have been identified as communication issues, confusion, and inattention (FAA, 2017). Other factors that increase the risk of an incursion include poor weather conditions and increased traffic.

04.3 Current Incursion Mitigation Strategies

Though runway incursions are typically caused by multiple overlapping factors, successfully mitigating any individual factor can make a big difference at an airport. Nonstandard runway and taxiway geometry is a factor that is both easily identifiable and practical to mitigate. The FAA has concluded that "nonstandard taxiway/runway geometry [is] a contributing factor in many runway incursions and wrong runway takeoffs/landings" (Vitagliano et al., 2018). The contribution of nonstandard geometries to incursions is addressed in AC 150/5300-13A "Airport Design" and Engineering Brief (EB) 75, but most recently addressed through the Runway Incursion Mitigation (RIM) program in 2015. Through the program, airports are annually reviewed for nonstandard geometries as identified in the Problematic Taxiway Geometry Study Overview, as seen in Figure 1. By mitigating these nonstandard geometry factors, the RIM program aims to reduce the number of runway incursions (Vitagliano et al., 2019). At the end of 2018, there were 135 active RIM locations at 79 airports across the US, with each location in a different stage of mitigation (Vitagliano et al., 2019). The RIM program recommends various mitigation strategies, which can include airport geometry changes, lighting improvements, improved signage and markings, and changes to operational procedures. The circumstances around each problematic geometry are unique to the airport, so there is little generalization about how best to promote safety. However, case studies can illuminate how various airports approach mitigating these geometric hot spots.

Geo Code	Problematic Geometry Definition
0	No geometry issues
1	Y-shaped taxiways crossing a runway
2	Wrong runway events
3	Wide expanses of taxi pavements entering or along a runway
4	Convergence of numerous taxiway types entering a runway
5	High-speed exit crossing a taxiway
6	Two runway thresholds in close proximity
7	Short taxiways (stubs) between runways
8	Direct taxiing access to runways from ramp areas
9	An aligned taxiway entering runway ends
10	Nonstandard markings and/or signage placement (e.g., overlapping holdbars, nonstandard holdbar placement, runway intersections with multiple hold lines)
11	Greater than three-node taxiway intersection
12	Taxiway connection to V-shaped runways
13	Taxiway intersects runway at other than a right angle
14	Short taxi distance from ramp/apron area to a runway
15	High-speed exits leading directly onto another runway
16	Taxiway coinciding with the intersection of two runways
17	Using a runway as a taxiway
18	Unexpected holding position marking on parallel/entrance taxiway
99	Miscellaneous: • Nonsequential taxiway designation schemes • Absence of full-length parallel taxiway • Taxiway intersection along the middle third of a runway • Runway intersection sign and marking standards

Figure 1. Geocode Listing (Vitagliano et al., 2018)

Albuquerque International Sunport (KABQ) airport in Albuquerque, New Mexico provides analysis of their FAA identified hot spots and other risky geometries in their 2018 master plan draft. Chapter 4 of the master plan identifies where their airport layout differs from design standards outlined in AC 150/5300-13A, while Chapter 5 describes multiple mitigation alternatives for each of these locations (Sustainable Airport Master Plan, 2014). In this analysis, KABQ considers how pilots would interact with the proposed changes--in one case noting that though "this [proposed] layout does meet design standard, [...] it could still be somewhat confusing to pilots" (Sustainable Airport Master Plan, 2014). This user-based approach to the design of their solution is critical to its success as a measure to increase runway safety. Furthermore, the writers of KABQ's master plan discuss their interactions with airport and air traffic control operators to see what changes to the airfield geometry these stakeholders believe would be useful. All of the proposed hot spot alternatives discuss the balance between increasing runway safety and not decreasing airport capacity. While this case study did not illuminate any innovative mitigation techniques for nonstandard runway geometries, KABQ's Master Plan described the considerations made for each design alternative and outlined their approach to mitigating these hot spots.

Waco Regional Airport (KACT) located in Waco, Texas utilized RIM strategies to mitigate incursions at a few locations across the airport. KACT also utilized AC 150/5300-13A on Airport Design to redesign a nonstandard taxiway. Some of the best practices in taxiway design highlighted at KACT include intersections at 90 degrees; the "three-node concept", where pilots are ideally only given the option to turn left or right at 90° angles or to go straight; and avoiding confusing access from runways directly onto a parallel apron. In the 2015 Waco Master Plan Chapter 3, several problematic taxiway geomeometries were identified, with the most critical being where taxiway (TWY) B3 to runway (RWY) 32 extended into RWY 1-19 at a nonstandard angle (Waco Regional Airport Master Plan, 2015). This intersection was not labeled as a hot spot; however, due to several incursions, KACT decided to redesign this taxiway geometry to meet standards. The new design removed the pavement connecting RWY 32 to RWY 1-19. Although the solution prevents incursions from PDs, there is now a risk of aircraft with a wing span of larger than 79 feet obstructing RWY 1-19 from TWY B3. Due to this risk, an additional procedural mitigation technique was put into place: aircraft with large wingspans will not use RWY 32, unless RWY 1-19 is closed.

Tulsa International Airport (KTUL) in Tulsa, Oklahoma completed a taxiway reconstruction project in August of 2018. As part of the project, TWY J and TWY C were reconstructed and TWY H was removed. Prior to reconstruction, the area was an identified RIM nonstandard geometry location and was designated as a hot spot. Prior to reconstruction, the angles of the runway and taxiway intersections were not 90° and included a wide expanse of pavement--both of which are listed as nonstandard geometries by the RIM program. In the 2015 Master Plan Update for the airport (Mead & Hunt, 2015), it was mentioned that this taxiway intersection should be improved to follow the three-node concept. As seen in Figure 3, the current airport diagram shows that TWY J now joins the runway at a 90 degree angle and the wide expanse of pavement that included TWY J, C, and H was removed.

Figure 2. Tulsa International Airport Problematic Geometry Area

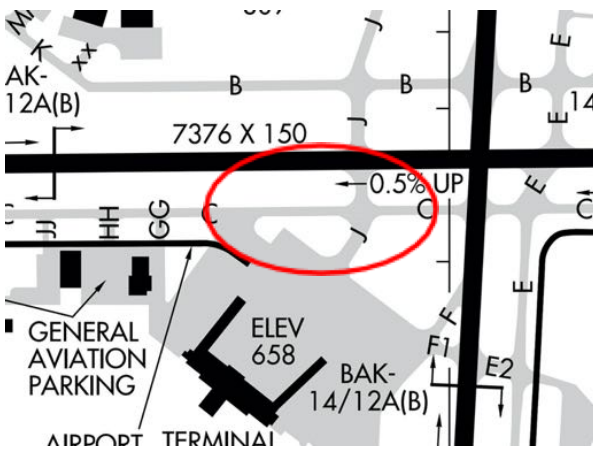

Figure 3. Tulsa International Airport Diagram Post Reconstruction

Other than pavement reconstruction, which is an expensive mitigation measure, other mitigation strategies can be implemented by airports. An example is Fort Lauderdale Executive Airport (KFXE) in Fort Lauderdale, Florida. In 2015, the Fort Lauderdale Aviation Advisory Board discussed three runway and taxiway intersections identified through the FAA's RIM program. A rehabilitation project was planned and executed to upgrade airfield lighting through the installation of LED lights to improve visibility (Aviation Advisory Board, 2015). This example provides insight into the mitigation strategies of improving signage, markings, and lighting to reduce runway incursions.

Another strategy recently implemented by the FAA are Runway Status Lights (RWSL). Currently the system is operational at 20 US Airports (FAA, 2019). RWSL are in-pavement lights that warn vehicles and pilots of high speed activities taking place on a runway. There are two RSWL systems: runway entrance lights (RELs) and takeoff hold lights (THLs). RELs are placed along the taxiway centerline to the runway edge. When the runway has activity, the lights illuminate red and when it is safe, the lights are turned off. THLs operate similarly to the RELs, but are located on either side of the runway centerline. When the lights are illuminated red, it indicates to not take off and when it is appropriate to takeoff, the lights are off. It is important to note that the system operates independently of Air Traffic Control (ATC); for example, if the lights are off, it does not give ATC clearance to cross the runway or to takeoff (FAA, 2019).

The RIM program illuminates a handful of strategies for mitigating runway incursions, though they are not accessible to all airports. The most direct method for alleviating problematic geometries is reconstruction, which is both costly and greatly impacts an airport's daily operations. RWSLs are another more drastic change that can be implemented, but they similarly have a high up-front cost and require extensive construction. Smaller airports may not have the resources to pay for these types of projects. The solutions that are less prohibitive are also less effective. While increased lighting and signage may help remove confusion, it does not drastically impact the pilot's perception of the hot spot or problematic geometry. When attempting to mitigate areas of the airfield prone to runway incursions, it is vital that the solution directly impacts how a pilot choses to navigate through the space.

05 Summary of Literature Review

Both aviation and ground transportation organizations are invested in minimizing the presence of unwanted vehicles in designated spaces. The FAA has focused its mitigation of runway incursions through the RIM program. In various publications, they reference the importance of considering human factors and situational awareness when attempting to reduce the frequency of incursions. Furthermore, there are some instances when the FAA will allow a nonstandard pavement marking in order to increase situational awareness at hot spots. However, nonstandard pavement markings are much more common in ground transportation. In 2011, New York City began pioneering the use of nonstandard red pavement in bus rapid transit lanes with the goal of reducing incursions into these lanes. Examining the implementation of red pavements in bus rapid transit systems across the US can provide valuable insight to what the implementation of red pavements might look like on airfields.

05.1 FAA Incursion Mitigation

The FAA RIM program reviews nonstandard geometries at airports. As a part of the program, the FAA conducted the Problematic Taxiway Geometry Study, which was completed in January, 2018. This study draws from a geographic information system (GIS) database that inventories all PD and V/PD incursions at towered airports. Each entry in the database is composed of four layers: aerial imagery, georeferenced airport diagrams, hot spot and problematic geometry locations, and incident locations. This tool allows for airports and the FAA to identify nonstandard geometries and incident rates at towered airports in the National Plan of Integrated Airport Systems (NPIAS) (Vitagliano et al., 2018).

Prior to the Problematic Taxiway Study, EB 75 was created in 2007 to respond to preliminary research linking runway incursions to airfield design. EB 75 lists various recommendations and considerations to improve taxiway and runway geometries, which are implemented in AC 150/5300-13A. Some of the recommendations include avoiding wide expanses of taxi pavement, limiting runway crossings and dual purpose pavements, increasing visibility of holding position signs, and eliminating taxiways that lead directly from an apron to a runway (Jacobs, 2007). As seen in Figure 1, there are many similarities between the details in EB 75 and the focus of the current RIM program.

05.2 Human Factors

There are many things that affect pilots while operating an aircraft, including fatigue, complacency, inattentional blindness, and stress. All these conditions can be attributed to human factors, which directly causes or contributes to many aviation accidents (FAA, 2016). In the Pilot's Handbook of Aeronautical Knowledge, pilots are educated on human factors and the risks that they may pose (FAA, 2016). Runway incursions have been analyzed extensively in human factors studies since the first conducted by Bellatoni and Kodis in 1978 (Torres et al., 2011). From these studies, quantifiable causes for incursions can be addressed to improve mitigation strategies.

Situational awareness is one aspect of human factors that is frequently discussed when examining runway incursions. A survey of pilots in 2012 revealed that pilots consider situational awareness to be one of the most important, but not the most achievable objective to mitigate runway incursions (Chang & Wong, 2012). According to the FAA Call to Action in 2015, a large proportion of runway incursions involve experienced pilots with 1,500+ flight hours. Experienced pilots can cause incursions due to inattentional blindness, which occurs when a person's eyes miss something directly in their line of vision due to distractions. Confirmation and expectation biases cause pilots to subconsciously disregard mistakes by what is expected or perceived as normal. Contrarily, general aviation (GA) pilots are another large contributor to runway incursions due to their inexperience, which may cause them to either miss or ignore runway signage (FAA, 2015). To pilots, perception, understanding, planning, and decision analysis are the crucial aspects of enhanced situational awareness (Airbus, n.d.). Emphasizing situational awareness can significantly decrease incursions at hot spots.

05.3 Nonstandard Markings at Airports

AC 150-5340-1L on Standards for Airport Markings emphasizes the importance of situational awareness at taxiway and runway intersections. Enhanced taxiway centerline markings are required by 14 Code of Federal Regulation Section 139.311 at all taxiway intersections that only lead directly to a runway holding position (FAA, 2013). Enhanced taxiway centerlines are not specific to RIM identified locations or hot spots; however, AC 150-5340-1L section 5.15 defines an additional nonstandard surface marking for these spots (FAA, 2013). Although nonstandard surface markings are not always permitted, the occurrence of multiple taxiway landing incursions allows for the exception of surface marking “TAXI” to be put onto taxiways. Under section 5.15, the runway intersection marking would also be classified as a nonstandard design solution that applies specifically to areas with a heightened risk of incursions.

05.4 Colored Lanes in Bus Rapid Transit

Beyond airports, incursion mitigation is also applied to bus rapid transit systems. Throughout the US and the world, cities are looking to improve bus transit systems by reducing travel times. One method of achieving this is to give buses designated lanes that are not to be used by other vehicles for driving or parking. However, bus lanes are frequently not as effective as desired due to many cases of illegal parking or driving in the lane. To increase efficiency, the idea of red painted bus lanes was introduced. In 2011, the New York City Department of Transportation (NYCDOT) conducted a study to determine if the red colored bus lanes would discourage unauthorized vehicles from impeding and ultimately enhance bus service (NYCDOT, 2011). As a result of this study, it was found that the number of vehicles driving in the designated bus lanes decreased by 55.4% once they were “treated” with the red color (NYCDOT, 2011). With the success of the New York bus lane experiment, additional cities implemented red bus lanes, including Seattle, San Francisco, Minneapolis, Pittsburgh, and Denver (Portland Bureau of Transportation, 2019). Overall, by treating the pavements with the red color, situational awareness for drivers is enhanced and prompts them not to impede on the bus lane.

After it was shown that red bus lanes are effective, there was further research into how to properly treat the surfaces. When testing application methods, the NYCDOT considered high visibility, durability, safety and skid resistance, low cost, ease of installation, and ease of patching (Carry et al., 2012). In order to achieve the colored surface, they considered street paints, epoxy and aggregate products, asphalt concrete-based micro surfaces, and Portland cement-based micro surfaces. As a result of various field testing and lab testing, it was concluded that epoxy street paint provides a reliable and durable option for new asphalt surfaces; meanwhile, portland cement-based micro surfaces are not deemed effective.

Studies conducted in other cities support that the use of pigments on the surface is more effective than blending pigments with Portland cement (Akkari & Burnham, n.d.). The pigmented concrete underwent early deterioration compared to regular Portland cement concrete. Though microcracking deterioration has not been directly correlated to the colored pigments, minimizing premature deterioration in pavements is an important consideration (Thomas et al., 2013).

06 Team's Problem Solving Approach

06.1 Investigating the Problem

The team consists of students majoring in Civil Engineering, so a major consideration when selecting a problem to research was the possibility of civil design. Initially, their focus was Challenge B: "optimizing safety through improvements to and redesign of existing runways and taxiways" (Airport Cooperative Research Program, 2019). From this starting point, the team found information about the FAA RIM program and problematic taxiway geometries that contribute to runway incursions.

After investigating the runway incursions aspect of runway safety, the team broadened the scope of their research. They investigated runway excursions as an alternative area for innovation. There is significantly less research present in the area of runway excursions. While the FAA keeps a database of runway incursions, there is no such database for excursions (FAA, n.d.). This means that the causes and mitigation strategies of runway excursions are less widely understood, and that researchers tend to use a smaller sample size of excursions when discussing them. Furthermore, the number of runway excursions has not significantly decreased in the past decade (FAA, n.d.). This knowledge prompted investigation of runway excursion mitigation.

06.2 Problem Solving Approach

The team compiled the proposed solutions after researching incursions and excursions through a design thinking process. Foremost, a brainstorming session was conducted to develop as many solutions as possible to mitigate incursions and excursions. Solutions were divided into categories as the following: colors for different surfaces, marking visibility in bad weather, aircraft navigation systems, condition reporting improvement, operations and administrative tools, and drainage. From there, each of the three team members voted on their top three favorite solutions/categories. The top scoring solutions were colors for different surfaces and condition report improvement.

Once all ideas were collected, it was easier to see how the team approached this challenge. The problem in mind was redefined to fit the scope and relevance of the team's research. A common area of focus was incursion and excursion events due to pilot error. In order to address this specific problem, the team decided that human factors should be considered in the final design. In order to do so, steps must be taken to gain relevant perspective from the users on the proposed solution.

06.3 Selecting the Top Solution

The team found that the issue of condition reporting had largely been solved through the runway condition assessment matrix (FAA, n.d.). The team confirmed that this solution has much improved the problem through correspondence with an airport manager and pilot.

The other top solution — colors for different surfaces — is what the team decided to pursue. This solution is inspired by red bus lanes implemented in major US cities used to decrease bus lane incursions (NYCDOT, 2011). By differentiating surfaces, specifically the surface between the hold short markings and runways, the solution effectively addresses the refocused problem of reducing pilot error by increasing pilot situational awareness.

After additional research, the team chose to proceed with the solution of colors for various airfield surfaces, which falls under the competition category of Runway Safety/Runway Incursions/Runway Excursions with Challenge G: "enhancing airport visual aids through improved lighting, marking, and signage for runways, taxiways and the airport apron" (Airport Cooperative Research Program, 2019). This varied from the original scope the team was focusing on; however, the team felt that this challenge better encompassed the solution they were designing.

06.4 Distinguishing the Best Prototype via Decision Matrix

Once the team decided on the proposed design solution, two different marking patterns were considered. The original design entailed a solid marking from the hold short line to the edge of the runway, giving it the name runway intersection marking. However, the team added an alternative of a red striped marking with the same positioning after gaining perspectives of industry professionals. In particular, the staff at Austin Straubel International Airport (KGRB) in Green Bay, Wisconsin voiced concern about having a large expanse of painted area. Since KGRB is located in a cooler climate and often exposed to icing and snow, Ronald Sampson, Airfield Operations Supervisor, suggested a striped marking to combat friction losses that a large expanse of solid markings would entail.

Dr. Kelly Steelman from the Cognitive and Learning Sciences department at Michigan Technological University (MTU) also provided insight on the striped versus solid markings decision. Dr. Steelman shared the importance of increasing salience from a pilot's viewpoint. Hence, a striped marking would provide a stronger orientation contrast, increasing pilot situational awareness. Color contrast is another element of salience that Dr. Steelman emphasized. Human attention is increased by stark color contrast and association of a color's meaning in other applications. Dr. Steelman's insight led to the addition of another potential design with alternating red and white stripes, creating a solid marking with increased visual contrast.

The team compiled the feedback pertaining to design considerations using a decision matrix, as seen in Figure 4, to appropriately address important elements of each design. Solid markings, striped red markings, striped red and white markings, and no additional markings were evaluated. For each design, friction, salience, maintenance, and pilot interpretation were evaluated. Friction, salience and maintenance were evaluated on a scale of 0 (lowest safety factor) to 10 (highest safety factor). Friction was given a weight of two. Salience was given a weight of three, due to the sub-elements evaluated: color contrast, orientation contrast, and luminance, which were all given a weight of one. Maintenance was given a weight of one. Pilot interpretation was broken into four categories with different levels of understanding. The interpretations that could lead to an incursion, worst case and base case, were given a weight of negative one. Contrarily, the best case and medium case were given a positive weight of 1 with the scale of 0 (least likely to occur) to 10 (most likely to occur). After completing this analysis, the team decided that the striped red and white markings would provide the most desirable outcome of the objective to decrease runway incursions.

Pavement Marking Pattern Decision Matrix										
		Alternatives								
		Solid Markings		Striped (Red) Markings		Striped (Red & White) Markings		Do Nothing (Just Hold Short Marking)		
Category/Topic	**Weight**	**Rating**	**Score**	**Rating**	**Score**	**Rating**	**Score**	**Rating**	**Score**
Friction	2	5	10	7	14	5	10	10	20
Salience: color contrast	1	6	6	8	8	10	10	0	0
Salience: orientation contrast	1	5	5	10	10	10	10	0	0
Salience: luminance	1	8	8	7	7	10	10	0	0
Maintenance	1	6	6	5	5	4	4	10	10
Pilot Interpretation: Best Case	1	6	6	8	8	10	10	4	4
Pilot Interpretation: Medium Case	1	8	8	6	6	6	6	5	5
Pilot Interpretation: Worst Case	-1	4	-4	5	-5	5	-5	7	-7
Pilot Interpretation: Base Case	-1	6	-6	5	-5	3	-3	8	-8
			39		48		52		24

Rating System
0 - Lowest Safety Factor, Least likely case to occur
10 - Highest Safety Factor, Most likely case to occur

Pilot Interpretation Explainations (HOW LIKELY is this case to occur) based on unfamiliar airport
Best Case: Understand fully, stops and reassures (asks) clearance, associates clear bias of stop and approaching runway
Medium Case: Pilot notices the marking but is confused, asks for clarification, incurs on marking
Worst case: Pilot notices and makes bad decision, incurs on runway
Base case: Pilot does not notice markings, incurs on runway

Salience (Definition: Quality of being particulary noticeable or important; prominance (Oxford Dictionary))
Color contrast: visibility of the color in a variety of lightings
Orientation contrast: How much the marking is a visually different pattern to those around it
Luminance: the intensity of light emitted from a surface per unit area in a given direction (Oxford dictionary)

Friction Explaniation
Friction: In colder climates, markings can increase icing and can decrease friction

Maintenance Explaniation
Maintenance: Cost and time to maintain the markings

Weight Description
Pilot Interpretation (Total Weight = 4): How a pilot interprets that marking
Salience (Total Weight = 3): What the pilot physically sees in the marking
Friction (Total Weight = 2): Pavement Markings can decrease friction in cold weather climates
Maintenance (Total Weight = 1): The cost to maintain the markings

Figure 4: Pavement Marking Pattern Decision Matrix and Descriptions

07 Description of Technical Aspects

07.1 Implementation Location

The runway intersection marking would cover the area between the runway hold short marking and the runway edge marking. As mentioned in Section 06, the team's use of decision matrix demonstrated that the best solution was to implement red and white stripes on this runway intersection marking. In order to best comply with FAA regulations and Advisory Circulars, the runway intersection marking would be classified as nonstandard. Implementation of the marking is recommended to occur at non-towered and towered airports. However, the marking should only be implemented at hot spots or FAA RIM problematic geometry locations. Though it may seem beneficial to implement at all runway intersections, this can create confirmation and expectation bias among the user, ultimately making the marking less effective.

07.2 Marking Geometry Design

Though the geometry of the pavement area where the marking will be implemented will vary, the geometry of the runway intersection marking is standardized. The team recommends that the striped markings start at a 30 degree angle from the hold short line, and that each stripe have a width of 15 feet, as seen in Figure 11.

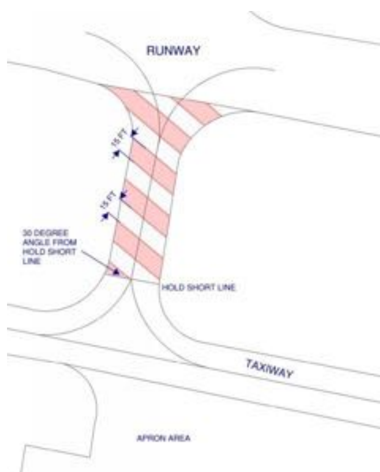

Figure 5: Runway Intersection Marking Standard Detail

07.3 Implementation Variations

After determining the best solution, the team analyzed five airports listed in the RIM inventory of locations. The five airports analyzed have different NPIAS Classifications and different problematic geometries. Airport information and the locations of geometries that were analyzed are shown in Figure 6.

Airport Name	Airport Identifier	Location	NPIAS Classification	Geometry Analysis Location	Problematic Geometry Geocode	Airport Designated Hot Spot
Hartsfield - Jackson Atlanta International Airport	KATL	Atlanta, Georgia	Large Hub	RWY 8L-26R/ TWY C, D Intersection	10	HS 1
Cleveland - Hopkins International Airport	KCLE	Cleveland, Ohio	Medium Hub	Five point intersection of Taxiways J,L,S, and Runway 6R/24L Five point intersection of Taxiways R, L,A, and Runway 6R/24L	11, 1	HS 2
Flying Cloud Airport	KFCM	Minneapolis, Minnesota	National, Reliever Airport	Hold position bar For RWY 10L/28R on TWY C	14	HS 2
Miami - Opa Locka Executive Airport	KOPF	Miami, Florida	National, Reliever Airport	Hold Short Bar on TWY T8 at approach end of RWY 30	3, 8	
Purdue University Airport	KLAF	Lafayette, Indiana	Regional, General Aviation Airport	Intersection of Taxiways B,B3, C, and RWYS 10/28 and 5/23	1	HS 1

Figure 6: Selected RIM Locations

The team identified the problematic geometry of nonstandard markings and/or signage placement to exist at Hot Spot (HS) 1 at Hartsfield - Jackson Atlanta International Airport (KATL). Additionally, the location is located on the north side of the airport near the GA operations area. Figure 7 shows how the runway intersection marking would be implemented there, as well as an approximation of the area to be covered by the marking.

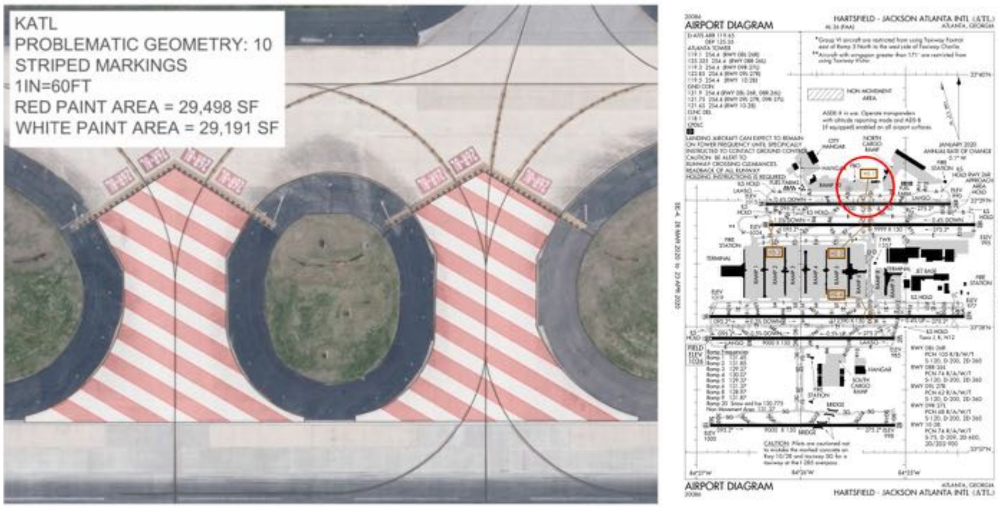

Figure 7: KATL Runway intersection marking implementation at HS 1

Cleveland - Hopkins International Airport (KCLE) is classified in the NPIAS as a medium hub airport, making it smaller than KATL. The team identified Y-shaped taxiways crossing a runway and a greater than three node taxiway intersection at the RIM program location, as shown in Figure 8.

Figure 8: KCLE Runway intersection marking implementation at HS 1 and HS 2

Neither Flying Cloud Airport (KFCM) in Minnesota and Miami - Opa Locka Executive Airport (KOPF) in Florida are commercial service airports, and they are both listed as GA National and Reliever Airports. They experience significant amounts of business and private aircraft activities. Figure 9 shows HS 2 at KFCM, which was identified by the team to have a short taxi distance from ramp/apron area to a runway. The area shown in Figure 10 for KOPF is not listed as a hot spot but is identified as a part of the FAA RIM Program inventory. The team identified the problematic geometry at this location to be wide expanses of taxi pavements entering or along a runway as well as direct taxiing access to runways from ramp areas.

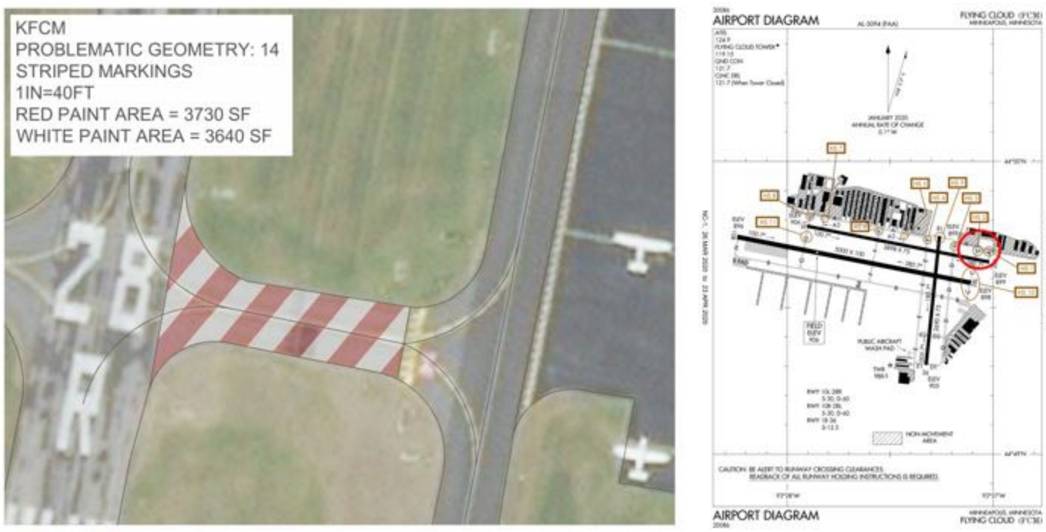

Figure 9: KFCM Runway Intersection Marking implementation at HS 2

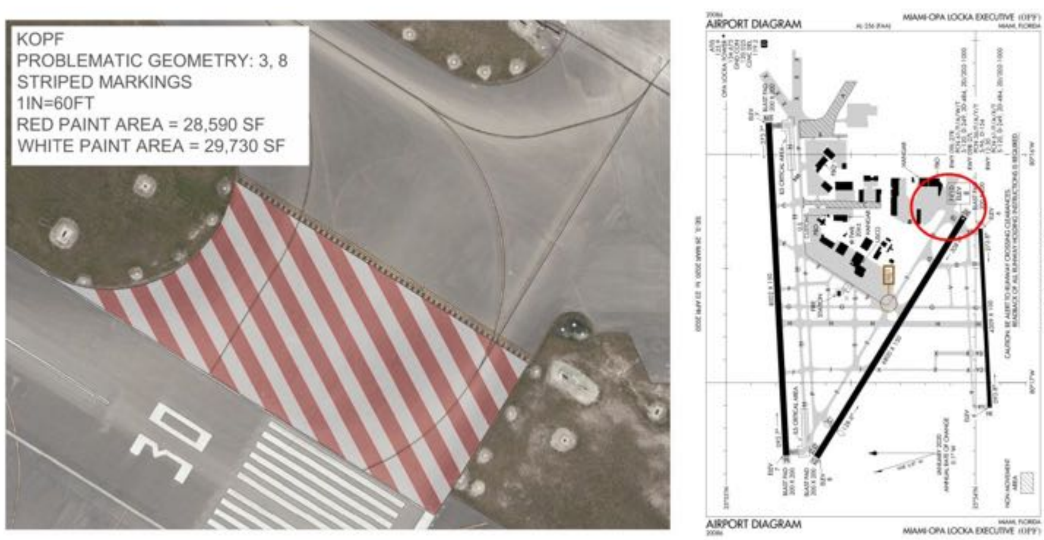

Figure 10: KOPF Runway intersection marking implementation

Purdue University Airport (KLAF) in Indiana is listed as a regional GA airport, implying it does not receive commercial service flights. The regional classification implies the airport does not see a significant number of business or private national flights. KLAF serves as an example that smaller airports are not resilient to runway incursions and may have problematic geometry locations. At KLAF, the team identified Y-shaped taxiways crossing a runway.

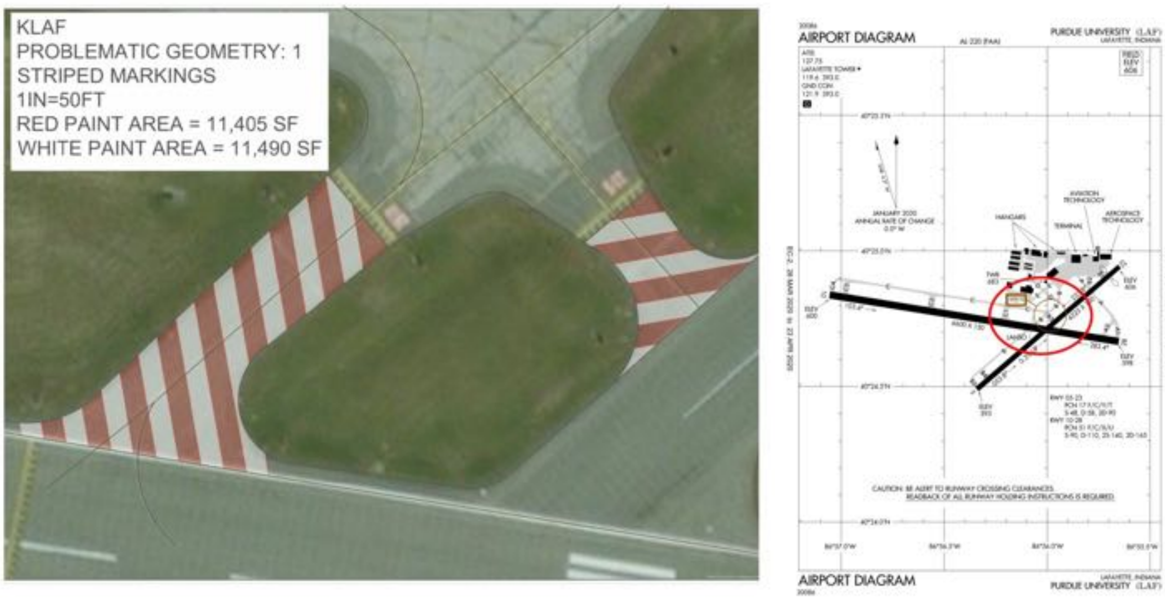

Figure 11 : KLAF runway intersection marking implementation at HS 1

No matter the classification or taxiway geometry of an airport, the runway intersection marking can be implemented, ultimately increasing safety for airport users and operators.

07.4 Paint Type

Currently, the FAA recommends the use of waterborne, epoxy, methyl methacrylate, or preformed thermoplastic paint for pavement markings. For the runway intersection marking, the use of a waterborne paint that contains glass beads is recommended. Upon talking with airport managers, the team discovered that many airports currently use waterborne paint for their markings. By maintaining consistency with current paint types, the implementation and maintenance of the new marking is not anticipated to cause any unique or unmanageable challenges.

07.5 Environmental Implications

Upon consideration and consultation, the team does not foresee any significant environmental impacts that arise through the implementation of the runway intersection marking. The paint the team recommends is currently in use at airports across the US and has not shown any major environmental impacts. Though the recommended paint contains glass beads, which can be worn down and released into the environment, they pose no significant impact because they are chemically inert, meaning the beads will not react with anything in the environment. Additionally, the solution proposed by the team eliminates the necessity to complete total reconstruction. Reconstruction of a taxiway can pose many environmental hazards such as dust and runoff pollution Additionally, the procurement and shipping of materials for a reconstruction pollutes the environment.

07.6 Maintenance

According to airport managers the team contacted, standard practice is that markings are repainted twice annually at commercial service airports and every two years at general aviation airports. The team reccomeneds that the new markings be repainted at the same frequency as other airfield markings. The runway intersection marking proposes a greater area of paint with more detail; however, once implemented, the maintenance of the markings is not anticipated to pose significant impacts.

08 Safety Risk Assessment

08.1 Defining the Risk of Project

Safety is an imperative initiative of the FAA, especially when considering runway incursions. The RIM program, safety conferences, and safety training are some of the ways that safety is emphasised throughout the FAA. Although mitigation of runway incursions is the ultimate goal, the unpredictability of human interaction makes complete mitigation challenging. Many incursions can be attributed to a lack of situational awareness, since 63% of runway incursions are due to PDs (FAA, 2018). The goal of the runway intersection marking is to maximize the situational awareness of pilots at hot spots where a higher risk of incursion is present.

The risk of pilot confusion was broken into four resulting categories: disregardance of markings, avoidance of taxiway, minor incursion, and major incursion. Disregarding the markings would entail not registering the increased caution and incurring on the markings, but not the runway. Complete avoidance of the taxiway would result in a pilot changing their route if the markings were perceived as a closure of that taxiway. A minor incursion would involve a pilot failing to ask ATC for clearance. A major incursion would entail an incursion despite instructions form ATC.

Reduced friction, low visibility, and foreign object debris (FOD) were also assessed. Reduced friction would result in a loss of control and increase the potential for an incursion. Low visibility could occur from inattentional blindness, adverse weather conditions, or night conditions. The runway intersection marking creates a potential hazard for increased FOD, as the marking could chip and create excess debris on the runway. The Safety Risk Matrix, seen in Figure 12, rates each potential hazard on a scale of severity and likelihood of occurrence. Furthermore, the colors on the chart rank the risk level of each item at hand — green being the lowest risk, and red being the highest.

Runway Intersection Marking		Severity				
		Insignificant	Minor	Moderate	Major	Catastrophic
Likelihood	Almost Certain					
	Probable	FOD				
	Possible	Avoidance of Taxiway	Disregardance of Markings			
	Unlikely		Low Visibility	Minor Incursion		Reduced Friction
	Rare				Major Incursion	

Figure 12: Runway Intersection Marking Safety Risk Matrix

08.2 Mitigation Strategies

If a pilot disregards the markings, the risk of incursion is no different than if the markings were not there. This is a base case for assessment, comparative to the most common type of incursion. There are four levels of incursion severity ranging from category A to D. Category A is a nearly avoided collision, with Category D there is no risk of an accident. 97% of incursions are in category C or D (FAA, 2017). These categories are a medium to low risk of incursion. Since this marking is nonstandard, it is possible that a pilot would not understand the meaning and disregard the marking; however, it is more probable that the pilot would ask for clarification in this situation.

Another way a pilot could interpret the surface markings is as a taxiway closure. A pilot might ask for clarification, choose not to use that runway, or simply stop without knowing where to go. This especially applies to pilots who are foreign to the airport and not familiar with the markings. In order to mitigate this from occurring, proper education about this type of nonstandard marking must be initiated.

A minor incursion might occur if a pilot perceives the markings as a place where asking for clearance is not necessary due to the added precaution. This risk would look different for a towered and non-towered airport. Again, educating pilots on this surface marking is critical to increasing pilot understanding.

A major incursion would occur if the pilot consciously and intentionally ignores the surface marking. This would be a rare occurrence, due to very poor communication between ATC and the pilot. Initiating a clear procedure to cross a runway intersection marking would decrease this risk.

The potential hazard of reduced friction due to a large expanse of pavement markings could be catastrophic. This issue especially applies to northern airports that must combat icing of runway and taxiway surfaces. This risk is the most severe because the pilot would no longer be in control and be unable to make a decision to influence the outcome of an event. With the addition of glass beads to the surface markings, friction is less likely to be an issue. However, if the markings are not maintained regularly, the effectiveness of glass beads might decrease. Diligent maintenance would be necessary to keep reduced friction at an unlikely possibility of occurrence.

To mitigate the risk of low visibility, especially in nighttime conditions, white stripes were added to the design. Since color is more difficult to distinguish during the nighttime, the alternating colored stripes add orientation contrast and color contrast to decrease the risk (American Optometric Association, 2015). Furthermore, white is particularly high in brilliance, which makes it easier to see at night. The lighting surrounding the taxiways where the markings would be implemented makes visibility less of a concern, as the lights would comply with AC 150/5340-30J - Design and Installation Details for Airport Visual Aids (FAA, 2018). All of these elements combine to make low visibility an unlikely situation. If a pilot wasn't able to see the markings, the severity would be the same as disregarding the markings.

In order to mitigate the risk of FOD due to the large surface area of the marking, AC 150/5210-24 - Airport Foreign Object Debris (FOD) Management should be referenced (FAA, 2010).

The most critical part of implementing an effective Safety Management System for runway intersection markings would be to adamantly promote the definition of the nonstandard marking, so that pilots associate a clear bias with increased risk of incursion. This duty would fall primarily upon senior management. Appropriate incorporation into training would also be implemented. Refer to AC 150/5200-37 for more safety risk management planning (FAA, 2007).

09 Cost Benefit Analysis

09.1 Cost of Markings

The cost of implementing our marking is calculated similarly to the cost of other markings that are currently implemented on the airfield. This cost can effectively be split into material costs and labor costs.

Material costs include waterborne airfield paint and the glass beads. In AC 150/5370-10H, the FAA establishes guidelines for estimating how many gallons of paint are necessary to cover a given area of pavement, as seen in Figure 13. They additionally specify how many glass beads are necessary to mix into the different types of waterborne airfield paint (FAA, 2018). Our team reached out to Ennis Flint to acquire the costs of the types of paint per gallon. Using this information, the cost of implementing our marking on any given airport hot spot can be calculated given the area that needs to be covered. Additionally, our estimations of the cost of the marking are overestimates. In practice, airports buy airfield paint and the other associated supplies in bulk. By attempting to isolate the cost of our marking, the savings associated with buying larger quantities of the paint were lost.

Labor costs would similarly be grouped into the cost of painting all of the markings on an airfield. A benefit to this design is that the implementation of the marking requires no specialized training above the skills already necessary to implement other markings on the airfield.

Paint		Glass Beads		
Type	Application Rate Maximum	Type I, Gradation A[1] Minimum	Type III Minimum	Type IV[1] Minimum
Waterborne Type I or II	115 ft^2/gal (2.8 m^2/l)	7 lb/gal (0.85 kg/l)	10 lb/gal (1.2 kg/l)	--
Waterborne Type III	90 ft^2/gal (2.2 m^2/l)	7 lb/gal (0.85 kg/l)	8 lb/gal (1.0 kg/l)	
Waterborne Type III	55 ft^2/gal (1.4 m^2/l)		6 lb/gal (.8 kg/l)	5 lb/gal (.7 kg/l)
Solvent Base	115 ft^2/gal (2.8 m^2/l)	7 lb/gal (0.85 kg/l)	10 lb/gal (1. 2 kg/l)	--
Solvent Base	55 ft^2/gal (2.2 m^2/l)	--	--	5 lb/gal (.7 kg/l)
Epoxy	90 ft^2/gal (2.2 m^2/l)	15 lb/gal (1.8 kg/l)	20 lb/gal (2.4 kg/l)	16 lb/gal (1.9 kg/l)
Methacrylate	45 ft^2/gal (1.1 m^2/l)	15 lb/gal (1.8 kg/l)	20 lb/gal (2.4 kg/l)	16 lb/gal (1.9 kg/l)
Methacrylate Splatter-Profile	24ft^2/gal. (0.6 m^2/l)	8 lb/gal. (0.1 kg/l)	10 lb/gal. (1.2 kg/l)	10 lb/gal (1.2 kg/l)
Temporary Marking Waterborne Type I or II	230 ft^2/gal (5.6 m^2/l)	No beads	No beads	No beads

Figure 13: Application Rates for Paint and Glass Beads (FAA, 2018)

09.2 Comparison to Alternatives

The cost of the runway intersection marking is substantially less than other incursion mitigation strategies currently encouraged by the FAA. The total cost of implementing the marking depends on the specific hotspot that is being mitigated. However, one can examine hot spots that have already been mitigated to compare the cost of the executed mitigation with the cost of implementing the marking. KABQ began reconstruction of their HS 1 in March of 2018. This hotspot was an identified RIM location, and our team identified it as having problematic geometries 6 and 11 (Vitagliano et al., 2018). According to KABQ's 2019 Quarterly Fiscal report, the reconstruction of HS 1 cost $197,659 (City of Albuquerque, 2018)). Accounting for inflation, this is equivalent to $203,619 in 2020 (Staff, 2020). Conversely, the implementation of the pavement marking over the 46,440ft^2 of HS 1 would have cost between \$5,100 and \$11,700, depending on the type of waterborne paint selected, as is demonstrated in Figure 14. This is an order of magnitude less than the reconstruction option. Additionally, the runway intersection marking is less disruptive to the normal function of the airport and leaves the area closed for a shorter period of time. The timeline for KABQ's reconstruction project was March 2018 to April 2020 (City of Albuquerque, 2018). While HS 1 was not the only project that is described in this timeline, the overall effect of reconstruction on KABQ's airfield is significant. Alternatively, the implementation of the pavement markings could take place on the scale of days as opposed to months and years.

Type Of Paint		Type of Beads	Total Cost
Fast Dry	Type I & II	Type I	$5,119.40
	Type III.i	Type I	$6,616.40
	Type III.ii	Type IV	$10,423.25
High Build	Type I & II	Type I	$5,749.40
	Type III.i	Type I	$7,441.40
	Type III.ii	Type IV	$11,705.75

Figure 14: Cost of Runway Intersection Marking at KABQ HS 1

One of the relatively newer methods for mitigating runway incursions is RWSLs. As previously mentioned, RWSLs are LED lights embedded in the pavement along runways and taxiways adjacent to runways that help indicate to pilots if a runway is currently in use by another aircraft. The program was developed by the FAA between 2008 and 2012. Most of the airports that currently have active RWSLs had them installed and operational before 2017. While this technology was still developing and growing in 2010, the FAA requested that $117,300,000 of their budget be allocated to RWSLs (FAA, 2010). Of this money, about $60,5000,000 was described as being just for the construction costs of implementing RWSLs at a few test airports (FAA, 2010). In 2020, this cost would be equivalent to $717,700,000 (Staff, 2020). This is clearly a very expensive strategy to decrease runway incursions. The list of airports with active RWSLs is reflective of this, as the 16 airports with RWSLs as of 2017 are all fairly large airports with more funding available to them. These factors make RWSLs an infeasible mitigation strategy for many medium and smaller airports across the US.

09.3 Benefit Analysis

All of the solutions above aim to prevent runway incursions, and ultimately accidents. The costs associated with accidents includes the damage to the aircraft, the injuries sustained by the people involved, and the opportunity cost of the airport operations that are impacted by the accident. The team chose to focus on the damage to the aircraft sustained in accidents, as it is the most quantifiable. However, one should keep in mind the value of human safety when examining incursion mitigation.

The National Transportation Safety Board (NTSB) classifies aircraft accidents as causing "no damage," "minor damage," "substantial damage," or being "destroyed" (FAA, 2015). The FAA publishes the costs associated with restoring "substantial damage" or replacing an aircraft that has been "destroyed," as the first two categories do not contribute to a significant portion of the costs incurred by airfield accidents. For commercial passenger air carriers, the average cost of an accident in 2014 was $280,000,000, or 21% of the value of the aircrafts involved, as seen in Figure 15 (FAA, 2015). In 2020, this is equivalent to $305,000,000 (Staff, 2020). For GA aircraft, the average cost was $105,911, or 20% of the aircrafts' value, as seen in Figure 16 (FAA, 2015). This is equivalent to $115,727 in 2020 (Staff, 2020). The cost of a commercial accident significantly outweighs any of the mitigation strategies above, making the cost of the runway intersection seem completely insignificant. While GA accidents are much less costly, they are still orders of magnitude more expensive than implementing runway intersection markings. If the marking could prevent any accident resulting in substantial hull damage or destruction of an aircraft, its benefit will have significantly outweighed the cost of its implementation.

Table 5-4: Restoration Costs – Passenger Air Carrier Aircraft

Aircraft Category	Col. 1 Number of Accident Aircraft	Col. 2 Average Loss Percentage	Col. 3 Weighted Average Current Market Value (millions) of U.S. Fleet	Col. 4 Average Loss Value for U.S. Fleet
Wide-body more than 300 seats	82	11%	$35.00	$3.80
Wide-body 300 seats and below	113	15%	$29.70	$4.40
Narrow-body more than 160 seats	49	8%	$19.30	$1.50
Narrow-body 160 seats and below	343	22%	$14.00	$3.10
RJ more than 60 seats	45	28%	$14.00	$3.90
RJ 60 seats and below	36	19%	$2.90	$0.50
Turboprop more than 60 seats	51	20%	$11.00	$2.10
Turboprop 20-60 seats	141	30%	$2.70	$0.80
Turboprop under 20 seats (Part 23)	84	26%	$1.70	$0.40
Piston engine (Part 25)	3	36%	NR	NR
All Aircraft	**947**	**21%**	**$13.50**	**$2.80**

Source: Ascend Flightglobal Consultancy
Col 1: Number of aircraft involved in accidents that met the criteria outlined in section 5.2.2
Col 2: The average loss percentage sustained by the aircraft described in column 1
Col 3: The weighted average current market value of the U.S. fleet, as described in column 2 of Table 5-1
Col 4: Column 2 multiplied by column 3

Figure 15: Passenger Carrier Restoration Cost (FAA, 2015)

Table 5-10: General Aviation Restoration Costs ($2014)

Aircraft Category	Certification	Col. 1 Average of Hull Value	Col. 2 Average of Hull Damage	Col. 3 Damage/ Value
Piston engine airplanes, 1-3 seats	Part 23	$33,201	$9,624	29%
Piston engine airplanes, 4-9 seats one-engine	Part 23	$59,768	$12,065	20%
Piston engine airplanes, 4-9 seats multi-engine	Part 23	$125,372	$30,008	24%
Piston engine airplanes, 10 or more seats	Part 23	$87,330	$9,151	10%
Turboprop airplanes, 1-9 seats one-engine	Part 23	$714,179	$145,546	20%
Turboprop airplanes, 1-9 seats multi-engine	Part 23	$675,523	$137,668	20%
Turboprop airplanes, 10-19 seats	Part 23	$1,068,640	$7,845	1%
Turboprop airplanes, 20 or more seats	Part 25	$1,903,301	$387,884	20%
Turbojet/turbofan airplanes, <= 12,500 lbs.	Part 23/25	$1,840,114	$375,007	20%
Turbojet/turbofan airplanes, > 12,500 lbs. and <= 65,000 lbs.	Part 25	$5,144,237	$1,059,169	21%
Turbojet/turbofan airplanes, > 65,000 lbs.	Part 25	$17,006,419	$1,038,907	6%
Rotorcraft piston <= 6,000 lbs.	Part 27	$206,934	$42,172	20%
Rotorcraft turbine <= 6,000 lbs.	Part 27	$1,185,951	$241,691	20%
Rotorcraft piston > 6,000 lbs.	Part 29	NA	NA	NA
Rotorcraft turbine > 6,000 lbs.	Part 29	$3,321,674	$676,942	20%
Other		NA	NA	NA
Experimental		NA	NA	NA
Light Sport		NA	NA	NA
All Aircraft		**$519,695**	**$105,911**	**20%**

*Average Hull Value=Average Market Value from table 5-7; Average Hull Damage="Damage/Value" for *All Aircraft* (~20%) multiplied by Average Hull Value; "Damage/Value"="Damage/Value" for All Aircraft.
NA = Not Available
Col 1: Average aircraft hull value for each economic values category.
Col 2: Column 1 times Column 3.
Col 3: Average of restoration cost as a percentage of hull value for this Category in 2007 Economic Values report. Based on claims in databases from Airclaims and AVEMCO.

Figure 16: GA Restoration Cost (FAA, 2015)

10 Interactions with Airport Operators

10.1 Aaron Stewart, P.E.

Aaron Stewart is an airport engineer at OMNNI Associates, a Westwood company, in Appleton, Wisconsin. Stweart has been doing airport engineering for over twenty years and has participated in many projects throughout the state of Wisconsin.

In the initial stages of determining a solution, the team proposed the idea of colored pavements to Stewart. Immediately, he raised a concern about the FAA regulations and marking design standards. He then proceeded to discuss how the FAA is focusing on runway incursions through problematic taxiway geometries. He informed the team about reconstruction projects he is involved in at non-towered airports designed to fix the problematic geometry areas. After this discussion, the team decided to focus on nonstandard pavement markings to better fit FAA guidelines and to incorporate the markings at hotspots and problematic geometry locations at both towered and non-towered airports.

10.2 John Wehner

John Wehner is the airport manager at Fond du Lac County Airport, a non-towered field. He is also a pilot holding both a private and instrument certificate. The team contacted Wehner in the initial idea stage and asked his opinion about mitigating runway incursions through the incorporation of pavement markings. Being a pilot, he believed that the pavement markings would be very beneficial at many airports where the taxiways are confusing. He mentioned that many private pilots do not have as much technology as the airlines, nor the experience to adequately and safely taxi through confusing areas. Additionally, he mentioned that the colored markings would be beneficial for airport vehicle drivers as well, increasing overall situational awareness.

10.3 Greg Cullen

Greg Cullen is the airport director for Southern Wisconsin Regional Airport (KJVL) in Janesville, Wisconsin. KJVL is a towered airport with an identified hot spot at the end of two runways. The team asked Cullen about the area and what he does to mitigate incursions. Cullen indicated that there were additional lights on the taxiways. Additionally, the hotspot is discussed during drivers training. Cullen believed that the current signage was working to mitigate risks at this hot spot.

10.4 Austin Straubel International Airport Staff

The team contacted the Airport Director Marty Piette, the Assistant Airport Director Rachel Engeler, and the Airfield Operations Supervisor Ronald Sampson at Austin Straubel International Airport (KGRB) in Green Bay, Wisconsin. In a phone discussion with the group, these staff raised concerns pertaining to ice buildup and snow removal on pavement with additional paint markings. Engeler mentioned that in the winter weather, the paint is the first to show signs of icing, and from an operational perspective the airport must be vigilant for ice on painted areas. Sampson, also showing concern about icing, suggested using striped markings, which help by breaking up areas of the solid paint. The group of professionals recommend that the team remain focused on implementation at hot spots for the idea to possibly be eligible for FAA funding.

10.5 James Thomas

The team contacted James Thomas -- a Boeing 777 international airline pilot from Fond du Lac, Wisconsin -- after establishing the initial ideas for the proposed solution pertaining to pavement markings. From his perspective in the cockpit at major international airports, safety and taking time to analyze taxi clearances is always a concern; however, external pressures such as keeping a schedule and not slowing down other airport operations can compromise this. Thomas believes that the solution will improve safety at airports because of the visual recognition. He predicted that identifying the runway intersection marking will become a learned trait and can prompt pilots or drivers to ask the ground/tower if they are cleared to cross the runway. Additionally, Thomas mentioned that the implementation of the runway intersection marking is not going to directly increase radio congestion. Finally, he mentioned that in his experience the red color implies caution and areas to slow down in the operation of the aircraft.

10.6 Joe Harris

Joe Harris is the director of Minneapolis Airport Commission (MAC). The MAC manages a group of seven airports in the Twin Cities metropolitan area of Minnesota. When the team shared the proposed design, Harris echoed the importance of incursion mitigation and shared some approaches that his team has taken. KFCM is an airport under Harris' supervision that has had an ongoing struggle with incursions. Some of the challenges that have come up at KFCM include the changing definition of incursions over time, lack of space to expand where current taxiway geometries should be reconfigured, and the unpredictability of the type of pilot to commit an incursion. KFCM has proposed and implemented various mitigation strategies with differing levels of success. Educating student pilots and the public on proper nomenclature, bright orange flyers given out while pilots fuel up, and increased signage and surface markings have already been implemented. If the problem persists, Harris predicts more drastic measures such as relocating the tower might be implemented. This conversation helped the team understand the scope of current runway incursion mitigation strategies and the limitations that exist when implementing them. Furthermore, the runway intersection marking would be feasible at KFCM even within the constraints, as seen in section 7.

10.7 Dr. Kelly S. Steelman

Dr. Kelly Steelman is a Professor in the Cognitive and Learning Sciences department at MTU with a background in aerospace engineering who researches human attention models with respect to aviation safety. Steelman helped the team further analyze the decision to implement a striped or solid marking. Based on the main visual properties of salience — color contrast, orientation contrast, and luminance — the use of a striped marking would be more likely to catch a pilot's attention.

Another design consideration that Dr. Steelman emphasised was inattentional blindness. If a risk associated with a warning is frequently absent when a person sees that warning, their vision can unintentionally block out the warning when the risk is present due to complacency. This is why limiting the design solution to hot spots would be more effective than a standardized marking. According to Dr. Steelman, attention "is drawn by expectations and values." Hence, the color of the markings is important, as it ties in with a pilot's preconceived association with that color. Perception of the markings can also change based on the time of day, as human vision is structured so that there is a small range of colors that appear bright during the day and are also bright during the nighttime. Reflective materials in the paint were stressed as an important aspect of visibility of the final design.

11 Projected Impacts

11.1 Meeting Goals

The overall goal of the runway intersection marking is to increase airport surface safety by reducing runway incursions through increased situational awareness. As a part of the FAA Strategic Plan for 2019-2022, the FAA outlined a number of multi-year strategies to prevent and reduce aviation injuries and fatalities. One of the strategies listed was to "improve surface safety by reducing runway incursions and wrong surface operations caused by vehicle/pedestrian deviations or by pilot error" (FAA, 2019). Because the striped marking was designed to catch the attention of the user, it is expected that the runway intersection marking will improve surface safety by reducing runway incursions caused by all deviations. In the research and development of the runway intersection marking, mitigating PDs was of primary focus. However, the marking is also expected to be beneficial in mitigating V/PD deviations as well.

11.2 Design to Implementation Process

The placement, color, and pattern of the runway intersection marking do not meet FAA pavement marking standards outlined in AC 150/5340-1M *Standards for Airport Markings*. Since the runway intersection marking is a new design, it would have to be proposed to and approved by the FAA. The classification as a nonstandard marking is recommended because the team suggests that the runway intersection marking is only placed at hot spots and problematic geometry locations. This is to prevent expectation and confirmation bias among the user; if implemented at all intersections, the marking will be perceived as "normal" and it would no longer be an effective strategy to increase situational awareness. Before widespread implementation of the runway intersection marking, it is expected there will be testing determining the effectiveness of the markings as well as how users will react. Testing is expected to be done both virtually in simulators and through implementation at select airports. In addition to the testing of the marking, educational information for users will need to be produced and distributed.

11.3 Commercial Potential

As a part of the FAA RIM Program, mitigation of runway incursions is being addressed by removing problematic geometry locations. The runway intersection marking is recommended to be implemented at hot spot or problematic geometry locations at both towered and non-towered airports as a permanent or temporary solution. As addressed in Section 9, the runway intersection marking is more affordable than reconstruction or implementation of RSWLs at an airport. Additionally, as addressed in Section 7, the runway intersection marking poses decreased environmental implications than complete reconstruction. As a whole, the runway intersection marking has versatile applications for increasing situational awareness at airports across the US.

Appendix A

List of Complete Contact Information

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Students: The team consists of three undergraduate students. Two of the undergraduate students are working on Bachelor of Science degrees in Civil Engineering. The other undergraduate students are working on a Bachelor of Science degree in Civil Engineering and Mathematics.

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Appendix B

Michigan Technological University is a four year public school located in Houghton, Michigan. The largest unit at Michigan Tech is the College of Engineering, which includes 16 degree options. The University has developed the Enterprise Program, which provides undergraduate students the opportunity to get real world experience before going into a professional environment. It is a hands-on program that applies skills learned in the classroom. There are 24 different enterprise teams, each with a different focus. The team pursuing the Airport Cooperative Research Program is part of the Built World Enterprise (BWE), which started in the spring of 2019. Previously, the enterprise program lacked a civil and environmental engineering focused group.

Appendix C

No non-university partners were involved in this project.

Appendix D

See attached page that follows.

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?

Yes, this project undoubtedly helped the team learn and grow. There are limitless opportunities in the world of airport design. All while focusing on the topic of runway safety, the team learned a plethora of information. We were able to grow as a team in more than just knowledge. Each team member found their specialty and was able to contribute uniquely to the final solution. Furthermore, our participation in MTU's Enterprise program gave us an experience similar to working on a project in industry.

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

One of the challenges we faced was contacting airport professionals. In order to do so effectively, the team reached out to over 50 airports to cover a wide range. Many of the airports that were contacted did not respond; however, we were still able to compile a variety of professionals to encompass a range of opinions across the field. The team was persistent in order to gain different perspectives; we also built off of connections in the aviation industry to reach out to more individuals.

Another challenge was deciding on what pattern and colors to use for the runway intersection marking. By assessing a decision matrix as individuals, then compiling our decisions as a team, we were able to appropriately find the solution we thought was best. However, we did not feel confident in our logic behind the ratings. After we met with human factors professor Dr. Steelman, we revised the decision matrix to better reflect the factors we considered through a psychology lense. This helped us reassess and confirm the decisions we were making about the design of the marking.

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

The team used a process called design thinking to develop a hypothesis. We used this method after attending a workshop with Dr. Brett Hamlin, a member of the engineering faculty at MTU. The design thinking method was developed at Stanford University with the following steps: empathize, define, ideate, prototype, and test. This process is described in detail in section 6.2 Problem Solving Approach. Our biggest takeaway from this experience was redefining our problem in order to fit the need that we found was the most appropriate and attainable for our team to address.

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

The industry participation was a crucial part of this project. We included many of our design considerations based on the applied perspectives of individuals with many years of experience. Our connections helped us build a well rounded viewpoint on the project. The perspectives we received were both in favor and against the runway intersection marking. From the critical feedback, we reevaluated the implementation and design to best accommodate the concerns.

Furthermore, interacting with industry experts contributed to our confidence in our design. As undergraduate students, we are aware of the limitations of our knowledge and expertise. However, many of the professionals assured us that we were demonstrating adequate critical thinking, problem solving, and researching skills.

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?

Yes, the team gained many valuable experiences while working on the project. Over the course of the project, all team members developed their ability to complete technical research and effectively review literature. Our technical and professional communication skills were strengthened through our connections with members of industry. The process of refining our solution gave us opportunities to apply new brainstorming methods and work on collaborative problem solving. All of these skills will be of great use to us as we become engineers in industry. Additionally, the ACRP provided a great platform to obtain exposure to potential career paths.

Faculty Questions

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

The students learned about airport operations and specifically about incursions and processes that influence airport design and geometries that create incursions. On a big picture level, I believe the students learned about research, developing research statements, the process of developing solutions, and communicating the solution.

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

The Enterprise Program is open to students who are in the second semester of their first year up to graduating students. As such, the students possess a large range of knowledge about civil engineering and airports in particular. Many students had never flown before initiating these projects so their knowledge gap was larger than I anticipated. However, the time at which we launched the projects plus the external resources the students located enabled them to overcome the knowledge gap. So I do believe the learning experience was appropriate to course level because the students made it so.

3. What challenges did the students face and overcome?

Our remote location is a challenge in that we do not have engineers working in airport planning and design located near us. As such, the students made a lot of cold calls and some of the calls turned out positively; however, many did not. The students did the best they could.

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

Absolutely. I found the topic rigorous but not so much so to prevent our freshman and sophomore students from participating.

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

Not at this time.

Appendix F

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