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Title of Design: Improving Runway Incursion Safety (IRIS)

Design Challenge addressed: Runway Safety/Runway Incursions/Runway Excursions

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Improving Runway Incursion Safety (IRIS)

Airport Cooperative Research Program

University Design Competition for Addressing Airport Needs (2014-2015 Academic Year)

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Executive Summary

In an effort to enhance runway safety, the Federal Aviation Administration (FAA) has taken action by identifying and combating contributory factors, specifically to mitigate pilot runway incursions (RIs). The prominent contributing factors for RIs are the lack of situation awareness (SA) and runway confusion, which have been caused by the following: pilot unfamiliarity with airport surfaces (i.e., runways, taxiways), pilot task overload, and lack of signage and markings.

In this report, our team proposed a way to increase SA and mitigate runway confusion in pilots and ground operators through the enhanced visibility of relevant airport visual aids. Our concept, Improving Runway Incursion Safety, or IRIS, is an airport marking methodology that consists of specific marking techniques to provide guidance for airports, which is expected to reduce RIs and improve runway safety through the use of color-coded mediums outlining the outer edge of taxiway shoulders and hot spots. Implementing IRIS will assist general aviation (GA) pilots, our target population, to compensate for the lack of guidance technologies in the cockpit or unfamiliarity with an airport. By providing additional information their position relative to runways and hot spots, IRIS is expected to save lives and avoid costly disruptions of air traffic flow.

To derive our design concept, IRIS evolved over time due to interactions with industry experts, other stakeholders, literature reviews, and collaborative, iterative design work. The IRIS design was developed specifically for the aerodrome layout of Daytona Beach International Airport (DAB); however, the medium (i.e., AvTurf, thermoplastic, paint) used can be modified for compatibility with other aerodrome design styles. The following report will describe our design and our research process in further detail.

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Abbreviations/Acronyms

ATC	Air Traffic Controller
DAB	Daytona Beach International Airport
ERAU	Embry-Riddle Aeronautical University
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FOD	Foreign Object Debris
FY	Fiscal year
GA	General Aviation
ICAO	International Civil Aviation Organization
IRIS	Improving Runway Incursion Safety
MDW	Midway International Airport
NAS	National Airspace System
NOTAM	Notices To AirMen
OE	Operations error
OI	Operational incidents
ORD	Chicago O'Hare International Airport
PD	Pilot deviations
RI	Runway incursion
RSA	Runway Safety Area
RSAT	Runway Safety Action Team
RWY	Runway
SFB	Orlando Sanford International Airport
SME	Subject matter experts
SRM	Safety Risk Management
TXY	Taxiway
VMC	Visual meteorological conditions
VPD	Vehicle/pedestrian deviation

1. Background

In the United States, airports with Air Traffic Control services are required to report any incident that occurs in an aerodrome to the FAA (FAA, 2012). Incidents at an aerodrome involving the incorrect presence of an aircraft, vehicle, or person on the protected area of a surface designated for the landing and takeoff of aircraft are classified as RIs (FAA, 2014a).

To indicate the "potential for a collision, or the margin of safety associated with an event", incursions are categorized by the severity of their outcome (FAA, 2007a). In October 2007, the FAA adopted standard definitions from the International Civil Aviation Organization (ICAO) for classifying RIs based on severity (see table 1; FAA, 2012); Figure 1 illustrates the order of severity for non-collision categories from least to greatest.

Table 1. FAA Runway Incursion Severity Rating Definitions

Category	**Definition**
Accident	An incursion that resulted in a collision
Category A	A serious incident in which a collision was narrowly avoided
Category B	An incident in which separation decreases and there is a significant potential for collision, which may result in a time critical corrective/evasive response to avoid collision
Category C	An incident characterized by ample time and/or distance to avoid a collision
Category D	Incident that meets the definition of runway incursion such as incorrect presence of a single vehicle/person/aircraft on the protected area of a surface designed for the landing and takeoff of aircraft but with no immediate safety consequences

Note: Adapted from "Runway Safety: Runway Incursions" by the Federal Aviation Administration, 2014.

Figure 1. Order of Incursion Severity Type. Adapted from "Runway Incursions: A Call for Action" by Air Line Pilots Association, 2007.

The FAA further categorizes incursions by error type: operational incident (OI), pilot deviation (PD), and vehicle/pedestrian deviation (VPD; FAA, 2014a). The incursion error type is identified on the "basis of who was determined to be most at fault" (ALPA, 2007). When the incursion is the result of an error made by an Air Traffic Controller (ATC), the incursion is identified as an OI (FAA, 2014a). If the pilot is found to be the most at fault, the incursion is categorized as PD; a PD is distinguished as the action of a pilot that violates any Federal Aviation Regulation (FAR; FAA, 2014a). A VPD incursion is the result of pedestrians or vehicles entering any portion of the airport movement areas (i.e., runways/taxiways) without authorization from ATC (FAA, 2014a).

In FY 2014, RIs totaled 1,265 (FAA, 2014b). Of the 1,265 RIs reported in FY 2014, 257 were itemized as OI, PD accounted for 767, and 233 were the result of VPD; the remaining 8 were itemized as *other* (FAA, 2014b); see Figure 2.

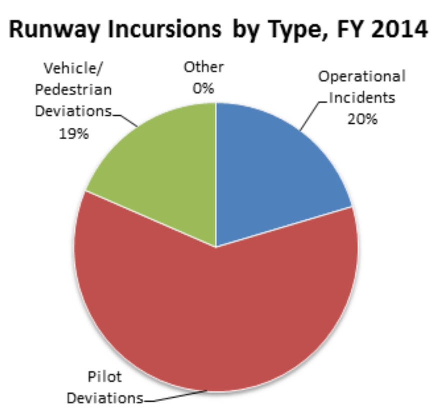

Figure 2. Runway Incursions by Type, FY 2014

The FAA classifies RIs by error type in order to help identify the leading cause(s) of an incursion; however, by additionally considering the other factors that influenced the cause(s), more effective measures may be employed to reduce the severity, number, and rate of RIs and to improve safety (FAA, 2007a). Table 2 lists example contributory factors for each error type; it identifies miscommunication, working memory decay, disorientation, interruption, and/or lack of SA as some of the factors that contribute to how and why each error type occurs (Adams, 2008).

Table 2. A Variety of Error Type Contributory Factors

Error Type	**Contributory Factors**
OI	1) Momentarily forgetting about: a) an aircraft; b) the closure of a runway; c) a vehicle on the runway; or d) a clearance that had been issued; 2) Distraction; 3) Workload; 4) Experience level; 5) Inadequate training; 6) Lack of a clear line of sight from the control tower; 7) Incorrect or inadequate handover between controllers; and 8) Breakdown in communication
VPD	1) Failure to obtain clearance to enter the runway or comply with ATC instructions; 2) Lack of airside vehicle driving training; 3) Lack of appropriate equipment; 4) Communication errors; 5) Inaccurate reporting of position to ATC and 6) Lack of knowledge of aerodrome signs and markings.
PD	1) Inadequate signage and markings (particularly the inability to see the runway-holding position lines); 2) Controllers issuing instructions as the aircraft is rolling out after landing (when pilot workload and cockpit noise are both very high); 3) Pilots performing mandatory head-down tasks, which reduces situation awareness; 4) Pilots being pressed by complicated and/or capacity enhancement procedures, leading to rushed behavior; 5) A complicated airport design where runways have to be crossed; 6) Incomplete, non-standard or obsolete information about the taxi routing to expect; and 7) Last-minute changes by ATC in taxi or departure routings.

Note: Adapted from “Manual on the Prevention of Runway Incursions” by the International Civil Aviation Organization, 2007.

2. Problem Statement

The focus of this project is to address issues affecting runway safety; specifically, issues that contribute to runway incursions (RIs). An incursion is classified as "any occurrence at an aerodrome involving the incorrect presence of an aircraft, vehicle, or person on the protected area of a surface designated for the landing or takeoff of aircraft" (FAA, 2014c). Between fiscal years (FYs) 2010 and 2013, there were 4,311 RIs (FAA, 2014a); in FY 2014, pilot deviations (PDs) were the foremost type of RI (FAA, 2014b). In an endeavor to mitigate pilot RIs, the FAA has taken action by identifying and combating the contributory factors; two of the most prominent contributing factors for PDs are lack of situation awareness (SA) and runway confusion (ICAO, 2007).

SA is the "perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" (Endsley, 2004, p.13). In other words, SA is a person's awareness of what is happening in the environment around them (Endsley, 2004, p. 13). In a study of major airline accidents due to human error, 88% could be attributed to problems with SA (Endsley, 1995).

Runway confusion, a subset of runway incursions, leads to the incident in which the pilot accidentally takes off or lands on a taxiway or the wrong runway (Mrazova, 2014). Runway confusion is believed to occur due to the lack of stimuli highlighting the difference between runways and taxiways, especially for aerodromes with parallel runway and taxiway systems (Mrazova, 2014).

For a pilot unfamiliar with an airport, distinguishing between taxiways and runways can be difficult. The resulting runway confusion may cause the pilot to enter an area for which they do not have proper clearance by mistake, resulting in an RI. When multiple RIs have occurred at a particular location of a given airport, that location will be identified as a *hot spot* by the airport. A hot spot is a location on an aerodrome movement area with a “history of potential risk of collision or runway incursion and where heightened attention by pilots and drivers is necessary” (FAA, 2014e; ICAO, 2007). Hot spots are generally located at complex or confusing taxiway/taxiway or taxiway/runway intersections (FAA, n.d.b; FAA, 2014d); thirty-three percent of RI occurrences transpire at taxiway/runway intersections (Mrazova, 2014). The marking of hot spot locations begets attention to potentially confusing aerodrome areas and alerts pilots to exercise caution (FAA, 2012); however, hot spots are only communicated to pilots in a Notice to Airmen (NOTAM) and illustrated on the FAA airport diagram. Some airports utilize wig wag lights as an additional solution to notify pilots of hot spot locations (FAA, 2012).

Our team looked at FAA safety support requirements for all regulated airports and the supplemental methods employed by local airports. Current methods used by airports to support ground navigation and meant to capture the pilot’s attention at a specific instance include: signs with taxiway or runway names, ground markings of runway/taxiway names, alert systems, hold short lines, lighting, and Air Traffic Controller (ATC) communications (FAA, 2012).

Our team is proposing a way to increase SA and mitigate runway confusion in pilots and ground operators through the enhanced visibility of relevant airport visual aids. Our concept, Improving Runway Incursion Safety, or IRIS, is expected to reduce RIs and improve runway safety through the use of color-coded mediums outlining the outer edge of taxiway shoulders and hot spot locations.

Prior research on color utilization in displays has found that color is effective at (1) increasing visibility of cues or alert symbols, (2) locating, grouping and separating items, (3) improving learning of visual materials, and (4) decreasing workload at high information levels (e.g., Reynolds, 1994; Hughes & Creed, 1994). The ability for people to relate to colors as important identifiers has led to the common associations of yellow meaning caution and red equaling danger, stop, or hot.

The FAA already utilizes the color red to signify danger and yellow for caution (FAA, n.d.a); as such, the team has chosen these colors to signify taxiways and hot spot locations. Taxiways that may be confused for runways or connect to runways will be outlined in yellow, while hot spot locations will be outlined in red and white stripes.

3. Literature Review

The team referred to several documents and resources during the development of the IRIS design concept. These documents provided the team with a better understanding of design goals. The FAA's (2010) *Certification of Airports* Part 139, which contains regulations to ensure safety in air transportation, provides guidance for the markings, signage, and lighting of FAA certified airports. The FAA (2014) *hotspot list* gives the number and location of hotspots identified across different airports around the country and gave the team an understanding of types and severity of runway safety issues. The FAA (2012) *runway safety report* lists all the categories of reported incursions and provides statistics for runway incursions that took place between the years 2010 and 2012. The report also identifies initiatives being taken to improve runway safety.

In *Steven's Handbook of Experimental Psychology*, Macmillan (2002) presents signal detection theory as the way relevant information is detected by the observer, and factors affecting detection. The theory suggests that acquiring more signal information makes a decision easier. Consistent with the theory, IRIS adds another visual marker to the runway to enhance the signal information and thus, help pilots detect critical information in their environment; Derefeldt et al. (1999) work is an example of color facilitating the processing and use of visual information. The authors note that the detection, location and comprehension of information are important parts of situation awareness and that color coded displays are advantageous as less cognitive effort is required to search for and acquire information from them. Savage-Knepshield (2001) identified color palettes containing colors that could be distinguished by people with a color blindness. In a field as safety sensitive as aviation, the choice of color is of great concern. She also found that redundant coding is important. Through this article, the team was able to finalize which colors would be used to effectively mark the runways/taxiways and hotspots such that the color blind pilots could also perceive the signals clearly.

4. Problem Solving Approach

4.1 Concept of Operations

IRIS is an airport marking methodology that consists of specific marking techniques to provide guidance for airports. By using IRIS, airport managers would decrease incursions through the use of colored mediums along the shoulder of taxiways. IRIS will assist general aviation (GA) pilots, our target population, to compensate for a potential lack of newer guidance technologies or unfamiliarity with an airport. Although commercial airline pilots receive extensive training on the layout of their destination airports, most GA pilots must rely on reviewing preflight items such as airport diagrams and NOTAMs. However, the use of preflight items does not always produce familiarity with a new airport, and leads to difficulty in maintaining SA. IRIS should also reduce the number of taxiway landings. The 24-inch thick color borders will have high salience and so will be seen by pilots flying into the airport under Visual Flight Rules (VFR) conditions. The colored borders will attract pilot attention and increase awareness of taxiway boundaries and hotspot locations. Yellow was chosen as the color for taxiway edges to promote caution. Red has been associated with stop and danger (Savage-Knepshield, 2001); thus, red and white striped borders will replace the yellow taxiway border when a pilot approaches a hotspot. Colored borders are not used on the runway in order to avoid pilot confusion during take-off and landing.

Airport operations management will choose from one of three mediums to use for the color border, and should make this decision based on their current layout and the local environment. Local environment factors to consider include whether there is grass against the taxiway, or if there are several feet of extra pavement along the taxiway shoulder. The choices for mediums are: artificial turf approved by the FAA, thermoplastic, and FAA approved paint. As an example of how IRIS could benefit runway safety, a prior scenario involving a DAB hotspot will be used.

DAB has a hotspot located at intersection taxiway (TWY) Whiskey and TWY Sierra, just 50 feet before Runway 7 (7R). The airport labeled this area as a hotspot due to a high rate of pilots missing their turn and driving onto an active runway. Pilots are issued instructions to go down TWY Whiskey and turn right onto TWY Sierra, then stop at the hold short line for 7R. However TWY Whiskey's intersection with TWY Sierra is located approximately 50 feet before its intersection with 7R. Pilots who have lost situational awareness will tend to pass TWY Sierra and turn right onto 7R instead, or cross 7R completely. Implementing IRIS would mean incorporating colored borders on the shoulder of all taxiways, thus providing a clear indication to pilots of their location on a taxiway versus a runway. A pilot traveling down TWY Whiskey at DAB would be surrounded by yellow, and as they approach 7R and enter the hotspot location, he or she would suddenly be flanked by red and white stripes. The IRIS marking strategy will decrease the number of pilots entering 7R from TWY Whiskey, and give pilots an opportunity to identify TWY Sierra.

4.2 Systems Development Process

Our team selected the agile system development (ASD) approach to develop our design. Value in ASD is built upon successful communications, functional prototypes, involvement of the customer and resilience of the team (Boehm, 2002). These values influenced the development of our final design. Our team approached the IRIS solution by participating in weekly meetings as well as logging all major milestones and supporting tasks as they were completed. Design activities followed an iterative process of: researching, analyzing, assessing flaws and risks, and improving the design on both an individual and collaborative level.

The most informative portion of the research process consisted of industry interactions and the Design Review Meeting which are elaborated on in the remaining portions of Section 4. These events provided insights about the current and future state of our design. The Design Review Meeting helped assess what risks we had failed to account for, as well as strengths and weaknesses of our design, which are discussed throughout Section 4. Although difficult challenges surfaced through iterations and the Design Review Meeting, we managed to adapt our activities to improve our relevant knowledge base of key areas (e.g., FAA Standards for Airport

Markings, FAA Safety Management System, FAA Guide to Ground Vehicle Operations, etc.), and keep the project on schedule, which is characteristic of true agile development.

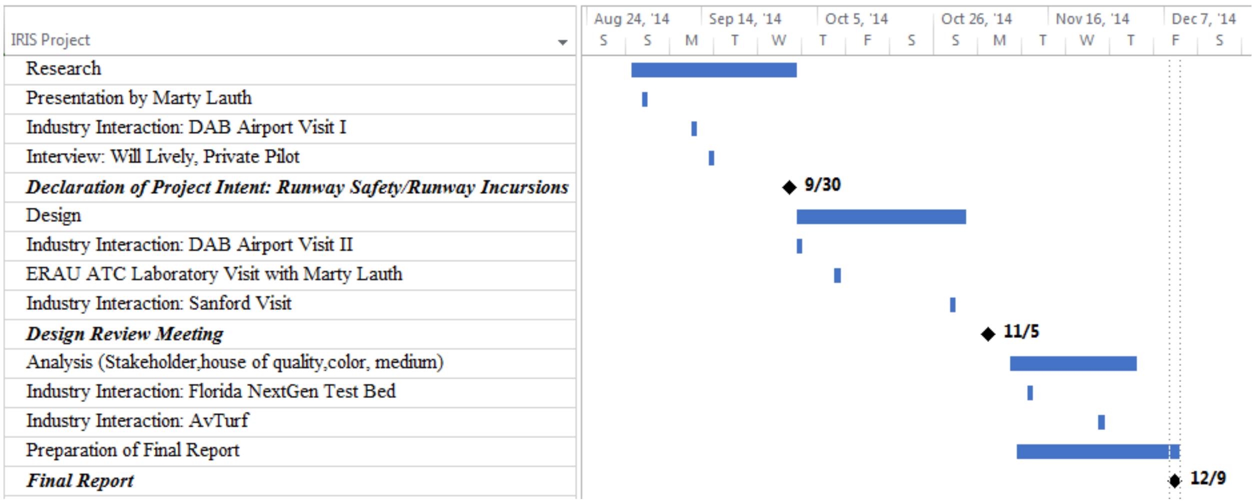

Figure 3. IRIS Gantt chart. Tasks and milestones are listed on the left hand side of this figure. Milestones are indicated by points.

4.3 Overview of Research Process

The IRIS design concept evolved over time due to interactions with industry experts (described in Section 4.4), other stakeholders (to be identified in section 4.5), literature reviews, and collaborative, iterative design work. With a wide range of categories to choose from for the FAA design competition, the IRIS team began exploring past projects in nearly every competition category (material composition of pavement, mobile applications for runway navigation and travel anxiety, wildlife, etc.). Major areas of focus for the team included pilot, situation awareness, runway incursions and hot spots. Our team looked into current measures being taken at airports to improve runway safety by targeting situation awareness. These measures did not seem to include the marking of hotspots on or near the runways. Thus, the goal of improving the salience of hotspots and helping pilots distinguish taxiways from runways emerged, a goal that benefits pilot situation awareness and has several additional benefits for the airport which are discussed in the later parts of this report. Our team's analysis activities included a review of FAA-approved colors to determine which are appropriate to use on runways and an evaluation color application mediums. These analyses are presented in sections 4.6 and 4.7 respectively.

4.4 Description of Interactions with Industry Experts

Our first industry interaction took place at the Daytona Beach Airport, where we met with Mr. John Murray, Director of Public Safety, and his colleagues (see Table 3). This meeting provided insights into current airport operations and areas for improvement. During the airport tour we had the opportunity to enter the aerodrome and see the conditions of the pavement and surface markings, which the airport personnel had stressed as being expensive and frequently in need of repair. As a result of this interaction, we focused our studies on airport operations, pavement and hot spots.

Table 3. Daytona Beach International Airport Personnel who met with the IRIS Team

DAB	Position	Contact Information
John M Murray	*Director of Operations*	jmurray@volusia.org
Tom Vannieuwenhoven	*Airside and Landside Manager*	tvannieuwenhoven@volusia.org
Carl Schweizer	*Projects Engineering Coordinator*	cschweizer@co.volusia.fl.us
Tammy Patten	*Finance Manager*	tpatten@volusia.org
James R. Ford	*Airport Security Coordinator*	jford@volusia.org
Rhett Bradley	*Fire Commander*	rbradley@volusia.org
Rick Lovell	*Support Specialist*	richard.a.lovell@faa.gov

After conducting research on airport diagrams, airport operations and communications, we conducted an interview with William E. Lively, a Private Pilot. During the interview we discovered the significance of hot spots and how pilots learn about these areas at a given airport. Lively reminded us that the airport diagram is the only *visual reference* pilots use to learn about hot spots and that no additional visual cues are present on airport surfaces. Taking Lively's guidance, we pursued hot spots and potential mediums that can be used to mark them (e.g. paint, thermoplastic, artificial turf) as areas for further study. We then developed the idea of highlighting the perimeter of the airport surfaces in different colors. The color scheme idea was presented to Marty Lauth, Associate Professor of Applied Aviation Science, and one of our team advisors, during our visit to the Air Traffic Control Laboratory, in the Embry-Riddle College of Aviation. Mr. Lauth agreed with our proposal to highlight the perimeter of the airport surfaces and encouraged us to continue our research.

Later the team chose to look into the concept of improving the salience of current markings and signage through the use of artificial turf. Our faculty advisor, Mr. Lauth, previously worked as an ATC for Orlando-Sanford International Airport (SFB) and informed the team that SFB had installed artificial turf. Mr. Lauth helped the team contact George Speake, Vice President of Operations at SFB, to learn more about the SFB's installation of artificial turf. Mr. Speake explained that SFB had chosen to install artificial turf to reduce wildlife on the airport grounds. The most notable benefit was a reduction of the endangered gopher tortoise which would burrow holes around SFB's taxiways and runways. That problem had the potential to cause more damage to aircraft during runway excursions because the holes weaken the ground around taxiways and runways. The artificial turf, however, made it difficult for the tortoises to burrow, causing them to go elsewhere.

The design concept at this point was to use artificial turf as our method for improving ground navigation markings; Mr. Speake endorsed this design concept. According to Mr. Speake, it would be easy, but expensive, to replace grass with artificial turf, and it would help airports deter most wildlife on and around runways and taxiways due to the loss of food and shelter the grass provided, as they had found during SFB's AvTurf installation. He gave us the contact information for Daniel McSwain of AvTurf, LLC, with whom we were able to discuss the product and obtain purchasing information for use in the Cost Benefit Analysis of Section 6.2.

Our group then held a Design Review Meeting with several professionals from Embry-Riddle Aeronautical University (ERAU). Meeting participants helped us identify potential shortcomings in the design concept. The attendees, in addition to the project team, were as follows:

- Nicola M. O'Toole, *Certified Flight Instructor (CFI), Department of Aviation*
- Marty Lauth, *M.A.S., Department of Air Traffic Management*
- Kelly Neville, *PhD, Department of Human Factors and Systems*
- Dahai Liu, *PhD, Department of Human Factors and Systems*
- William E. Lively, *Pilot, M.S. Student, Department of Human Factors and Systems*
- Sarah Sherwood, *Ph.D Student, Department of Human Factors and Systems*

During the design review, the team was reminded that some airports have pavement instead of grass along the side of runways and taxiways. In addition, larger airports have complex designs that include many taxiways crossing in one area which influences the reliability of the color border strategy, which was intended for traditional, straight lined taxiways. Feedback from this meeting enlightened us to the idea that highlighting both runways and taxiways would provide too much stimuli and may contribute to confusion or detrimental error. This led to our final revision of the design concept, which we would name IRIS.

The team was also given the opportunity to tour the Florida NextGen Test Bed (FTB) facility near ERAU with Todd Waller, FTB Demonstration and Test Coordinator. We were presented with information about future capabilities of NextGen and received feedback about our design strategy from Mr. Waller in the process. Mr. Waller agreed with the IRIS concept, and offered a further method of improvement: not only should the taxiways and hot spots be marked outside of the aircraft, but future technologies (e.g., GPS systems) could possibly incorporate the colors to assist pilots in navigation from the cockpit. The team chose to refrain from modifying the IRIS strategy due to the additional cost associated with implementing such a design.

4.5 Stakeholder Analysis

The stakeholders for IRIS include the following: FAA, National Transportation Safety Board (NTSB), airports, general aviation (GA) pilots, commercial pilots, commercial airlines, ATC, airport maintenance personnel, suppliers for mediums (e.g., Avturf), installers for mediums, unions, and environmental protection groups (EPG). A stakeholder analysis was conducted by interviewing personnel from DAB, SFB, and FTB.

The team interviewed several representatives from a subset of selected stakeholder groups to get a better idea of their interactions and influences on the overall aviation system. Information about the stakeholders is visible in Figure 4 below. In Figure 4, these stakeholders are plotted on a graph to show the extent of their influence over the IRIS concept adoption. They are also plotted against the second dimension of IRIS's impact on them.

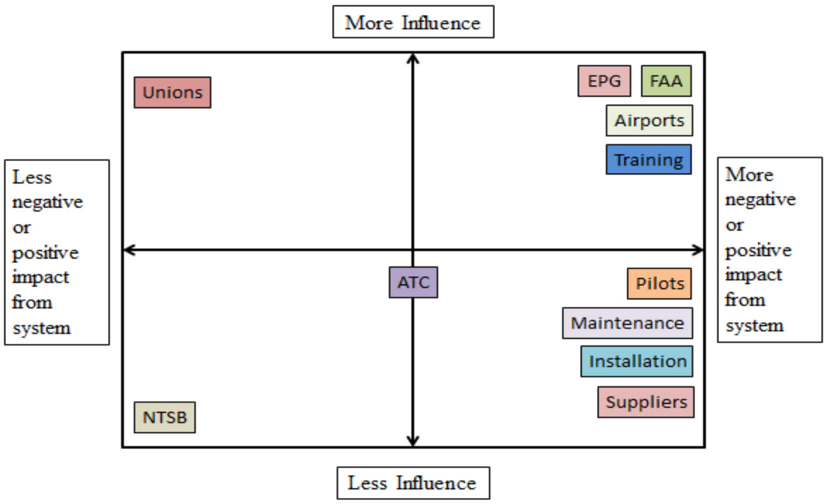

Figure 4. Stakeholders in terms of influence on and impact of the system.

To further support IRIS stakeholders, the team developed a House of Quality analysis (see Figure 5 below), which maps stakeholder needs and desires against system design features. Specifically, the House of Quality in Figure 5 identifies key goals and benefits (i.e., needs and desires) of stakeholders, and show ratings of the importance of each. It also contains ratings of how well goals and benefits are met by various border marking choices, including the two color choices for taxiways and hotspots and the three medium choices, which was derived by understanding each color marking and medium choice through literature reviews and research. It suggests that, in general, airports will tend to benefit most from artificial turf with red and white stripes to mark hotspots. A medium-specific version of this House of Quality could assist airport operators and other stakeholders when they must identify the best mediums to use at their airport.

House of Quality	Marking Choices						
Goals/Stakeholder Benefits	Importance	2 Color Marking Choices:		3 Medium Choices:			**Totals**
		Yellow to Mark Taxiways	Red & White Stripes to Mask Hot spots	Paint on Pavement	Artificial Turf	Thermoplastic	
Distinguish taxiway from runway	5	5		3	4	3	**20**
Identify hot spots in real-time	5		5	3	4	3	**20**
Relatively quick to install	3			5	2	4	**14**
Low maintenance	4			2	4	3	**13**
Low cost	5			4	1	3	**13**
Decrease pilot uncertainty and mental workload	5	3	3	3	4	3	**21**
Increase pilot situation awareness	5	4	4	3	4	3	**23**
Ratio of lifespan to cost	4			3			**7**
Hot spot markings stand out from other markings	2	3	5		5	3	**18**
Totals	**38**	**15**	**17**	**26**	**28**	**25**	
Note: 1=Low, 5=High. Ratings were derived by the IRIS team, but a future analysis of this House of Quality should be completed by stakeholders.							

Figure 5. House of Quality

4.6 Color Assessment

Several colors that have been approved by the FAA for use in airport markings and signage were considered for use in IRIS markings. Table 4 lists all the colors that were considered for IRIS. The usability of colors on runways was compared on the basis of AC 150/5340-1J Standards for Airport Markings, and AC 150/5340-18D Standards for Airport Signs Systems, and through the observation of colors currently being used at airports. The colors recommended by the IRIS design team are yellow and red, as shown in Table 4.

Table 4. Color assessment for IRIS design

Color Analysis			
FAA Approved Color	**Federal Standard Color Chip #**	**Chosen for IRIS?**	**Reasoning**
Yellow	22538	Yes	Represents caution & used on taxiways
Green	34108	No	Too similar to the color of grass
Black	37038	No	Utilized on pavement borders
Blue	35180	No	Utilized for night time lights
Red	31136	Yes	Represents warnings & danger
White	37925	Yes	Utilized on runways to indicate hold short/outline shoulder
Reference: U.S. Dept. of Transportation, Federal Aviation Administration (n.d.)			

4.7 Medium Analysis

The IRIS design can be applied at the airport runways using the following mediums: artificial turf, thermoplastic which could be either hydrocarbon or alkyd based, and paint. Artificial turf is an artificial grass surface that is widely used in athletic fields and is now finding application in the aviation industry. Thermoplastic is a heat-applied road marking compound based on either alkyd or hydrocarbon resins and containing a significant portion of premixed glass beads, paints are the usual paints applied on runway pavement.

The advantages and disadvantages of the mediums are discussed in Table 5. The mediums differ from each other in terms of their cost, durability and maintenance. It is up to authorities at a given airport to decide which medium to choose for IRIS.

Table 5. Medium Analysis

Medium Analysis		
Medium	**Pros**	**Cons**
Artificial Turf	Easily seen in comparison to natural grass	Most expensive solution
	Replaces grass - no lawn maintenance needed	Slow install
	Promotes salience of airport signs	
	Emits heat/warms environments: good for cold climates	Absorbs heat: bad for warm climates
	Maintenance once every 10 years	
	Reduces wildlife, specifically birds such as cattle egrets, near taxiway and runway	Attracts other wildlife (e.g. coyotes)
	Enhances drainage	Temperature dependent (melts in high heat)
	Durable (expected 15 years enduring jet blast and UV degradation)	Deforms under high stress
Hydrocarbon Thermoplastic	Good retroreflectivity, even on wet surfaces	Tape markings have a 4-8 year lifespan, depending on roadway conditions and proper installation
	Produces audible/rumble noise	Epoxy markings tend to have a 2-4 year lifespan, depending on roadway conditions and proper installation
	Does not contain Volatile Organic Compounds (VOC)	May produce toxic fumes when heated
	Faster installation in comparison to paint	Performs worse on concrete pavements (versus concrete only)
	More heat stable, in comparison to alkyd	Poor adhesion of material to pavement surfaces in cold climates (drawback during installation)
	Can apply new thermoplastic directly over older thermoplastic markings	
Alkyd-based Thermoplastic	Good retroreflectivity, even on wet surfaces	4-8 year lifespan, depending on roadway conditions and proper installation
	Audible/rumble noise	Epoxy markings tend to have a 2-4 year lifespan, depending on roadway conditions and proper installation
	Does not contain Volatile Organic Compounds (VOC)	Temperature dependent (melts in high heat)
	Can apply new thermoplastic directly over older thermoplastic markings	Deforms under high stress
		May produce toxic fumes when heated

		Performs worse on concrete pavements (versus concrete only)
		Poor adhesion of material to pavement surfaces in cold climates (drawback during installation)
Paint	Most affordable pavement marking material, especially for smaller airports	Pollutants may spread due to application (e.g. overspray, spills)
	Can be installed on pavement shoulder (minimizing disruption of traffic on airport surfaces, thus good for large airports that experience a lot of traffic)	1-2 year lifespan; 1 year or less for waterborne paints
	Waterborne paints are more environmentally friendly than solvent based paints	Maintenance intensive over time
		Reliant on pavement maintenance
		Not visible under certain climate based conditions
		Loss of retroreflectivity after exposure to high traffic and abrasive winter weather and snow removal activities
References: AvTurf (2014), Jiang (2008)		

4.8 Human-System Integration

Haskins et al. (2010) defines Human-System Integration (HSI) as "the interdisciplinary technical and management processes for integrating human considerations within and across all system elements" (pp. 328). Incorporating HSI into our design was paramount to promoting safe interactions of pilots and other vehicle operators with the IRIS solution. A major HSI concern is ensuring that the humans in a system that undergoes change receive support in adapting to that change. The IRIS solution is recognized as a National Airspace System (NAS) change, which is defined as "a modification to any element of the NAS that pertains to or could affect the provision of air traffic management and communication, navigation, and surveillance services" (FAA, 2014e, pp. 24). Due to the classification of IRIS as a NAS change, the assessment of vehicle operators' response to IRIS will be a continuous focus throughout the lifecycle of our solution. To coincide with this initiative, a training plan has been prepared.

As part of this education and training plan, all airports that plan to implement the IRIS solution must update their FAA airport diagrams prior to implementation. FAA airport diagrams must indicate the location of IRIS markings and contain a key or note to reinforce the meaning behind IRIS. Hot spot areas should be depicted in a red font color, instead of the currently used brown color, to reinforce the meaning and color selection for the border. The DAB FAA airport diagram with IRIS specification is included in Figure 6. The existing preparatory flight action methods, for pilots, will be utilized for training and awareness of the IRIS solution. As directed in 14 CFR Part 91, pilots are required to review pertinent flight information prior to pre-flight (e.g. taxiing, pre-takeoff) as well as prior to approach and landing. Preflight activities include, but are not limited to: reviewing weather data, NOTAMs and an FAA airport diagram, via radio announcements, airport call-in number, and the FAA website or mobile application that aggregates flight information. During these activities, pilots are informed about hot spots on the audio announcements and in updated visual references (e.g. FAA airport diagrams). In accordance with the latest FAA (2014) *Guide to Ground Vehicle Operations*, all ground vehicle operators are encouraged to become familiar with the locations of runways and taxiways along with the significance of airport surface markings. To support the changes introduced by IRIS, ground vehicle operators must review the latest FAA airport diagram prior to entering the operations of an airport where IRIS has been installed. In addition to the training provided to ground operators and pilots, Air Traffic Control must review the latest FAA airport diagram in order to direct and improve situation awareness during airport surface movements. Educating ground operators, pilots, ATC and other airport personnel would be low cost since it is already required that they review the latest FAA airport diagram prior to the use of airport surfaces. Formalized training for IRIS could be incorporated into one of the routine training sessions held at the airport to alert all personnel of the IRIS installation on the airport surface. Training should be conducted prior to construction and installation.

In addition to HSI considerations for education and training, HSI will be further supported by a long-term risk management plan that identifies and addresses risk to pilots throughout the life cycle of our system. Airport Runway Safety Action Team (RSAT) meetings and other local airport meetings will be utilized as a means for recording and aggregating all safety issues related to IRIS.

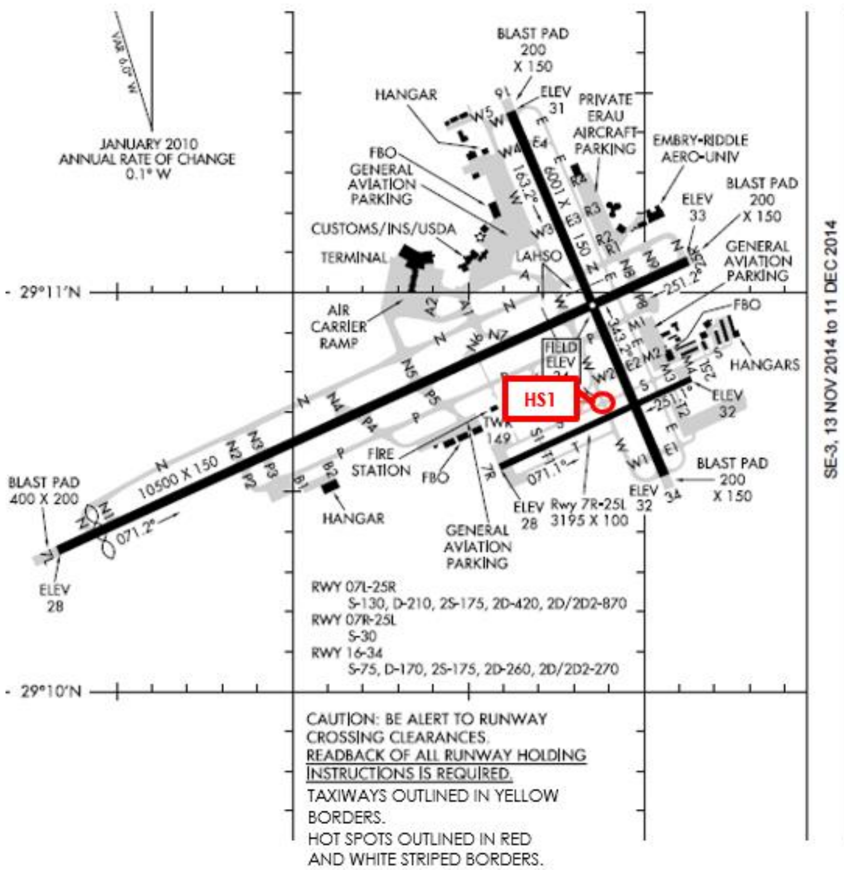

Figure 6. DAB Airport Diagram with IRIS specification.

Note: The Airport Diagram includes IRIS color key for taxiway and hot spot borders (e.g. Taxiways outlined in yellow borders. Hot spots outlined in red and white striped borders.). Hot spot areas are depicted in red to reinforce the meaning of and color selection for the border.

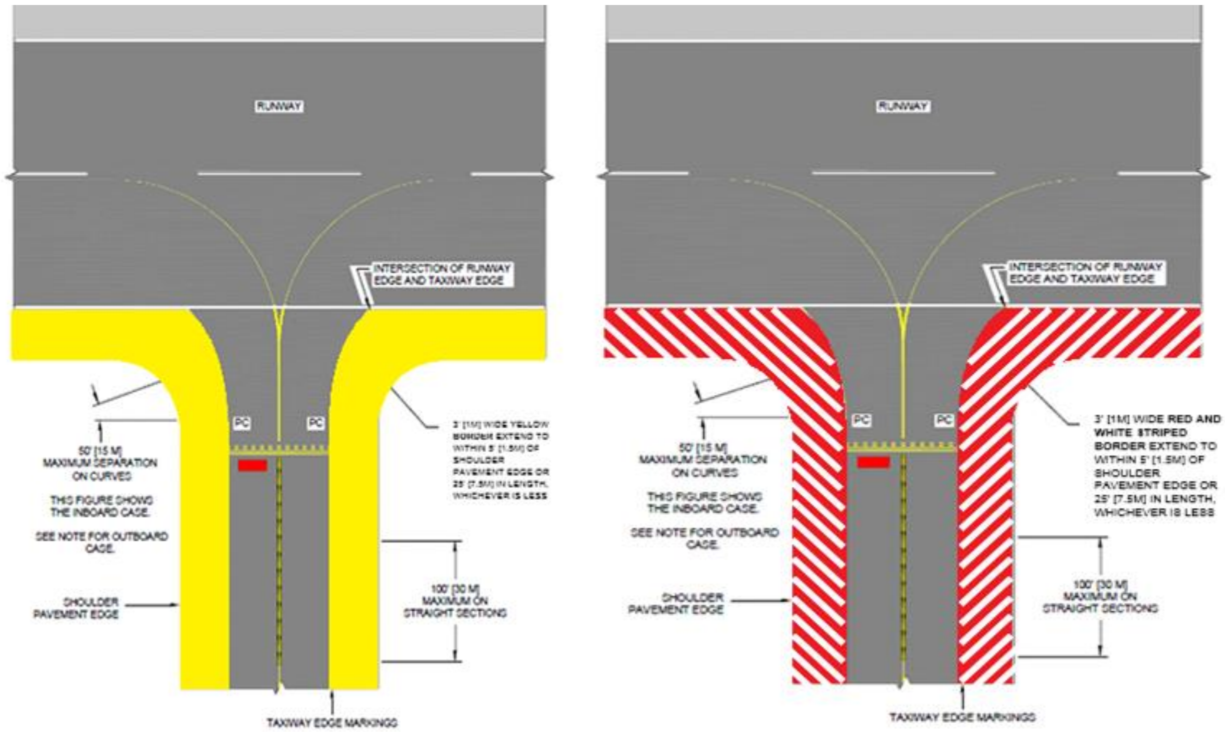

Figure 7. Depiction of IRIS concept.

Note: Adopted from Figure A-23 of Standards for Airport Markings. Taxiways are outlined in a yellow border. Hot spots are outlined using a red and white striped border.

5. Safety Risk Analysis

This section identifies safety hazards that may need to be identified and assessed regarding the use of colored mediums to find appropriate mitigation. We will be basing the safety assessment on the FAA's Safety Risk Management (SRM) process (see Figure 8, FAA 2007b, 2014e).

Describe the System

The system must be described and modeled in ample detail to allow a safety analysis to continue to the hazard identification stage. The description of the system needs to accurately explain the system without ambiguity, error, or omission. Everything stated is required to be essential and specified at the appropriate level of detail for serving as the basis for hazard identification.

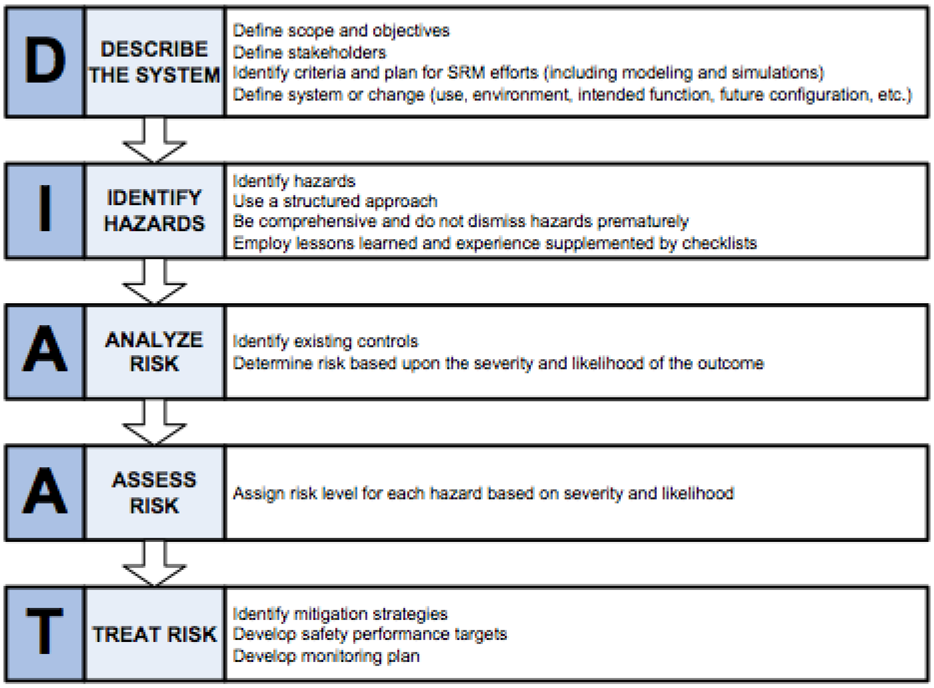

Figure 8. Safety Risk Management Phases from the "Safety Management Systems Manual (Version 4.0)" by the Federal Aviation Administration, 2014.

Note: The FAA's Safety Management System (SMS) is a tool used to identify and address hazards (FAA, 2007b, 2014d).

Identify Hazards

Once the system is described, hazards are identified. A hazard is defined by the FAA as "any real or potential condition that can cause injury, illness, or death to people; damage to or loss of a system, equipment, or property; or damage to the environment" (FAA, 2014d, p. 25).

During this phase, the possible things that could go wrong and their causes are identified and recorded, which was done during numerous assessments of our design. As our idea evolved, we had to reevaluate and alter our possible hazards. There is always the potential for creating hazard and consequently increasing risk, so documenting each hazard to acknowledge risks, assess its risk level, and specify specific mitigations is required.

Analyze Risk

The evaluation of each hazard, and the states of the system it potentially affects, is required to determine risk prevention or reduction tactics that minimize the hazard's effects or occurrence. Analyzing each hazard involves assessing the severity and likelihood of the risk to determine a hazard risk level. The assessments were done during the design review meeting with Embry-Riddle Aeronautical University professionals described in Section 4.

Assess Risk

In order to assess risk, each hazard's risk level is plotted on a risk acceptability matrix (see Figure 9) to help prioritize treatment and mitigation. The placement of each hazard on the matrix is determined by the assessed severity and likelihood of the risk.

Hazard		**Category**				
Severity / **Probability**		**A**	**B**	**C**	**D**	**E**
		Catastrophic	**Hazardous**	**Major**	**Minor**	**Minimal**
LEVEL	**Frequent**	**A1**	**B1**	**C1**	**D1**	**E1**
	Probable	**A2**	**B2**	**C2**	**D2**	**E2**
	Remote	**A3**	**B3**	**C3**	**D3**	**E3**
	Extremely Remote	**A4**	**B4**	**C4**	**D4**	**E4**
	Extremely Improbable	**A5-1** / **A5-2**	**B5**	**C5**	**D5**	**E5**

High **Medium** **Low**

Figure 9. Risk Acceptability Matrix. Adapted from the "Safety Management Systems Manual (Version 4.0)" by the Federal Aviation Administration, 2014.

Treating Risks

In order to treat the risks, methods to mitigate or manage the safety risks are identified. With the risk matrix indicating the priority for the treatment of risks, the highest risks are given the most consideration. Our team created a risk treatment plan that involved deciphering whether the risk should be avoided, mitigated, transferred, or accepted. The risk treatment plan documents the safety requirements, designates safety performance targets, and predicts residual risk level. Through numerous meetings, we developed strategies to reduce the estimated likelihood of each hazard, thus reducing the initial risk.

5.1 IRIS and Risk Analysis and Management

Following the FAA (2007b, 2014d) SMS and using the Risk Acceptability Matrix (see Figure 9), our team identified and assessed hazards relating to the implementation, operation and maintenance of IRIS. We considered the IRIS repercussions on potential users within the aerodrome environment and with existing systems that results in injury or death. In a prioritized order, plausible hazards and their results are shown in Table 6 and described in the paragraphs that follow.

Table 6. Possible IRIS Risks, Assessment Results, and Mitigation Priorities

Hazards	Probability	Severity	Assessed Risk Category	Mitigation Priority
Pilot confusion of colors	Extremely Remote	Hazardous	B4	High
Incompatibility with existing systems	Extremely Improbable	Major	C5	Medium
Malfunctions & failure in equipment	Remote	Minor	D3	Medium
Failure to produce situational awareness	Remote	Minimal	E3	Low

Note: Use Figure 9 to find the placement of the Assessed Risk Category on the Risk Acceptability Matrix.

The highest priority hazard as determined by the risk analysis is the possibility for pilots to become confused about whether runways or taxiways have the colored border. This hazard was assessed as extremely remote but hazardous with a risk level of medium. Risk prevention activities we recommend are implementing a color key for taxiway and hot spot borders in the FAA airport diagram for mitigation. Although assessed severity is hazardous, the initial likelihood of extremely remote is further reduced by ensuring pilots are familiarized with and educated about the change.

The incompatibility of IRIS with existing systems implemented in the aerodromes and overall FAA system is another hazard identified in the risk analysis. This hazard was assessed as extremely improbable but major with a risk level of low. We recommend prototyping, operational testing, and evaluation to further reduce the assessed likelihood of extremely improbable. These activities will facilitate the development of a compatible IRIS with current systems; thus, reducing the risk of failure to support the system's mission that could potentially lead to the cause of injury or death.

Malfunctions and failure in the equipment used to implement IRIS could also be a source of hazard to the users. This hazard was assessed as remote, but minor with a risk level of low. The proper type of application materials must be chosen in order for the system to resilient enough to endure weather and foreign object debris (FOD). Due to the option to choose among different materials to employ IRIS so that it is compatible with the surrounding environment and budget of the airport, the risk of this hazard would be reduced; however, it is still imperative to test the materials and equipment before deploying the system in order for the design to be safely implemented and used.

There is also a potential for IRIS to fail to benefit SA; that is, failure to provide pilots with useful information involving hotspots and airport location. This hazard was assessed as remote but minimal with a risk level of low. If IRIS fails to provide this boost to SA, it would not be considered a negative safety effect due to the current system that alerts pilots of their desired or current destination. IRIS is a system that is redundant and not the sole stimuli for SA; it is there for reinforcement, not replacement of runway safety equipment.

6. Commercial Viability

6.1 IRIS Implementation

The impact that IRIS will have on enhancing situation awareness and reducing runway incursions was driven by stakeholder needs, advisory circulars and aviation industry recommendations. The IRIS implementation plan consists of three stages: Planning, Installation, and Education; all of which will be described in the sections that follow.

6.1.1 Planning

The preliminary research has revealed the need to bring awareness to areas on airports that are prone to runway incursions. The FAA has published airport diagrams that indicate hotspots on airports nationwide (FAA, 2014f). The intention of IRIS is to translate known hotspots from paper to the airport's physical surface. Red and white striped edges on a taxiway island and taxiway shoulder will denote a hot spot. Extended yellow edges on the taxiway island and on the taxiway shoulder will help distinguish a taxiway from a runway. IRIS can be installed through three different mediums: thermoplastic, paint and also artificial turf. Initially, individual airports, with help from IRIS's team, will need to evaluate the needs of the airport to determine which medium would fit best. Thermoplastic and paint would be the best option for those airports that only want to focus on reducing RI’s. Artificial turf is an upgraded option that would reduce runway incursions through visual enhancement and also aid in soil erosion, reduction of foreign object debris (FOD), lawn maintenance, jet blast, drainage control and wildlife deterrence (FAA, 2006).

The IRIS planning stage takes into consideration the concerns of airport stakeholders and produces a recommendation for the best medium. Our airport surface design is tailored to DAB. The concerns of stakeholders at DAB are expressed in Table 7. RI’s, wildlife, and maintenance were the general problems voiced by stakeholders at DAB. IRIS will be most efficient if artificial turf is used as the medium of choice at DAB. IRIS would partner with AvTurf, a company that provides high quality artificial turf, to produce and implement IRIS’s visual enhancement patterns.

Table 7. IRIS Airport Medium Recommendation

Name	**Title**	**Concern(s)**	**Best Medium**
John Murray	Director of Public Safety	The negative interaction between migrating birds and aircraft at the southeast part of the airport. Foliage, grass, trees provide a feeding habitat and living environment for wildlife.	Artificial Turf (wildlife deterrence)
Tom Vannieuwenhoven	Operations Supervisor	The need to expedite the maintenance of taxiway islands. Sign visibility is hindered, especially in Florida, because grass and weeds grow extremely fast. Safety is also jeopardized if the lawn is being mowed in close proximity of an active runway. FOD hidden in overgrown lawn threatens ground operations safety as well.	Artificial Turf (maintenance, FOD, visual enhancement)
Carl Schweizer	Projects Engineering Coordinator	Runway incursions are a problem with beginner and advanced pilots, especially at the merging of Taxiway W and Taxiway S.	Paint, Thermoplastic, Artificial Turf (runway incursions, visual enhancement)

Note: Stakeholder concerns are paired with mediums to produce the best fit for airports.

6.1.2 Installation of Mediums

Artificial Turf

IRIS, airport managers and contractors must take great care to minimize interference with the airport operations during the artificial turf installation process. This can be done through explicit and open communication between all stakeholders, including pilots and ATC. NOTAMs will be issued by airport managers to alert pilots and ATC on construction site dangers.

Surface preparation is an important initial step for installing artificial turf. Before installation, the area around the hot spot needs to be excavated approximately 12 inches in order for artificial turf application to begin (FAA, 2006). To prevent grass and weed from growing up through the artificial turf, geotextile weed barrier will need to be placed on the top of the excavated soil. The pre-cut artificial turf is installed over the desired area and anchored to the ground. The excess artificial turf is “tucked” under the adjoining pavement to assure a cleanly sealed edge (AvTurf, 2014). The IRIS team, airport management and AvTurf will oversee the installation process.

Paint and Thermoplastic

While this report focuses on artificial turf as a medium for IRIS at DAB, other airports may find that paint or thermoplastic is the best solution. For those airports, IRIS has also put together a guide for paint and thermoplastic installation. A precautionary NOTAM should be issued during construction.

Surface preparation is also an important first step for installing new paint markings on taxiways for visual enhancement. Some airport surfaces are glossed with a curing compound that ensures paint is properly bonded to the pavement. In preparing airport surfaces, it is the contractor's responsibility to remove the curing compound for optimal paint application. If the pavement is new, it is recommended that the contractor waits 8-12 weeks before applying new markings to the concrete to avoid gas bubbles from erupting through the paint (Innovative Pavement Research Foundation (IPRF), 2008). The surface should also be cleaned thoroughly by the contractor to remove contaminants, like mud, that can affect the bonding properties of the paint and the pavement. The contractor should specify a coverage rate that is appropriate for the surface type, high or low rates of paint application typically result in low quality runway markings and can add to cost. Also, recommendations by the IPRF (2008) on application for textured surfaces will be considered, as grooved and porous surfaces can alter the appearance of the airport markings. Before application, the contractor will outline the airport marking with chalk to assure airport marking accuracy. Checking the equipment and materials will also be important. The paint applicator, whether an airless system or pneumatic atomized system, must be consistent with the specifications in Advisory Circular, 150/5340-1L. The paint type must be consistent with Federal Standard 595b. All federal standards will be verified and confirmed by IRIS, airport managers and contractor.

Excess materials on airport property will be cleaned by the contractors. Clearing FOD from the installation process is also the responsibility of the contractors. However, airport operations and maintenance should independently assure that FOD is clear of the construction and surrounding areas before airport activities resume.

Paint installation can also produce hazardous byproducts: solvent, epoxy, and methyl methacrylate paints require special handling. Contractors should be in compliance with Environmental Protection Agency (EPA) and Occupational Safety and Health Administration

(OSHA) standards and wear the appropriate personal protective equipment when handling hazardous materials (EPA, 2014 & OSHA, 2014).

Before and during installation it will be important to inspect the airport markings and/or artificial turf for quality control and maintenance reasons. A log quantifying the completed work on a daily basis and a log calculating material usage will be kept by the IRIS consulting team. The following will also be inspected and confirmed by IRIS and contractors:

- ❏ Location of markings on airfield are accurate (FAA 150/5340- I Standard)
- ❏ Dimension is measured and within specified length and width (FAA 150/5340- I Standard)
- ❏ Paint achieves uniform thickness (IPRF)
- ❏ Glass beads are distributed evenly on paint with magnifying glass (IPRF)
- ❏ Color is consistent with Federal Standard 595b color chips (can be measured with colorimeter) (Table 4)

6.1.3 Education

Airport managers, ATC and pilots will need to understand benefits and risks associated with IRIS. This can be established through distribution of this report, NOTAMs, updated airport diagrams, and airport management meetings. Airport managers need to know where IRIS should be deployed to be most effective. ATC must understand the purpose of IRIS so they can direct pilots who are unfamiliar with airport layout to the correct location. A separate educational campaign needs to target pilots to make them aware of the purpose and usage of IRIS. Pilots should learn to associate IRIS's red and white striped edges with an area of high traffic and to be aware of other planes, ground vehicles, or pedestrians within the area.

6.2 Cost-Benefit Analysis

IRIS has the goal of improving SA and reducing runway confusion through the use of color-coded mediums outlining the outer edge of taxiway shoulders and hot spot locations. Airports would have as options the following three mediums: artificial turf, thermoplastic, and paint. The best medium for a given airport would be dependent on aerodrome layout and budget.

To determine the feasibility and choice of medium, a medium cost-benefit analysis was conducted. The team gathered data on the costs for the three chosen mediums, shown in table 8. The data for each medium were compared against each other and the resulting comparison chart can be used by airports to determine the best medium to use.

Table 8. Itemized Cost of Items Used in Design

	Artificial Turf	Thermoplastic	Paint
Material Cost	$1.50*	$0.194*	Quote inspection required
Installation Cost	$4.09**	Quote inspection required	Quote inspection required
Operating & Maintenance (O&M) Cost	< $2,000 per year***	Quote inspection required	Quote inspection required
Life Expectancy	20 years	3 – 5 years	Varies per airport

Note: * Size: Per sq. ft. Artificial Turf cost estimate by AvTurf. Thermoplastic cost estimate by Ennis-Flint HotTape
**** Size: Per sq. ft. Unit price provided by vendor based on more than 1,000,000 sq. ft. For a smaller quantity, a 20% surcharge is added for a resultant unit price per square foot of $4.91. Cost estimate by AvTurf**
***** O&M Cost Basis: (Hours to maintain each taxiway) x (2 times per year) x (# of taxiways) x (maintenance operator hourly wage) x (# of maintenance operators). Cost estimate by AvTurf; dependent per airport.**

According to Mr. Speake from SFB, artificial turf has a life expectancy of 20 years. The AvTurf representative, Daniel McSwain, stated the return on investment would occur in a span of five to seven years due the mitigation of landscaping maintenance costs alone. According to

Mr. McSwain, for an airport AvTurf installed artificial turf for in 2002, the airport spent approximately $54,100 in annual landscaping maintenance costs for the runway safety area (RSA) alone; this annual cost included labor, fuel, equipment replacement, and equipment maintenance. Alternatively, the cost to maintain artificial turf in the RSA would be less than $2,000 per year.

While material cost, installation cost, and O&M costs could not be priced per square footage for paint, several of our SMEs have stated the utilization of paint can be costly. Many variables must be considered when developing the cost estimate of paint: bead type selection, total footage, contractor pricing practices, labor days, and surface preparation - which is site specific and requires physical inspection (Andrews, Estes, Moertl, & Olmos, 2005). Life cycle maintenance costs vary across airports; some airports may need to repaint their markings more frequently than others (Andrews, Estes, Moertl, & Olmos, 2005). DAB found that the white paint on their aerodrome would turn yellow due to the chemical reaction of iron in the asphalt and paint, which caused marking discoloration and required constant maintenance. According to DAB's Airside and Landside Manager, Mr. Vannieuwenhoven, DAB spends approximately $100,000 every two to three years to repaint their current aerodrome markings; total that cost over the lifespan of artificial turf, DAB would spend approximately $700,000 in O&M costs over the span of 20 years. An additional downside to choosing paint, other than cost, is the visibility issues associated with it. Mr. Vannieuwenhoven stated that pilots and other vehicle operators have difficulty seeing paint markings on pavement surfaces under certain weather and lighting conditions which could lead to potential safety hazards (e.g., RIs).

As for thermoplastic, while thermoplastic material costs may be much cheaper than artificial turf, Mr. Vannieuwenhoven informed us that the material has the potential to cause pavement damage during removal. According to the FAA Advisory Circular AC 150/5340-1H, pavement markings that are no longer needed should be physically removed by sandblasting, chemical removal or other means; not painted over. Any damaged pavement would have to be repaired, which would be an additional cost of up to $200 per linear foot to resurface GA airport asphalt, or $360 per linear foot to resurface commercial airport asphalt (Florida Department of Transportation, 2011). Considering that thermoplastic has a life expectancy of three to five years, airports could pay a substantial amount of extra costs on top of the medium's O&M costs; the same fees would apply if airports chose paint.

Smaller airports have less revenue coming in; however, their overall cost of installation may be offset by the lack of O&M costs for 20 years. The lack of maintenance costs gives smaller airports time to save revenue and to be able to afford maintenance costs when the 20 year mark approaches. Table 9 summarizes the cost benefits for each medium below.

Table 9. Summary of Cost Benefits per Medium.

	Artificial Turf	Thermoplastic	Paint
Advantage	▪ Low O&M costs ▪ Higher life-cycle expectancy ▪ Rate of return on investment low; within 5 to 7 years	▪ Material costs per sq. ft. are low ▪ Higher reflectivity and visibility than paint ▪ Higher life-cycle compared to paint	▪ Material costs may be low
Disadvantage	▪ High initial installation costs	▪ High O&M costs ▪ Low life-cycle expectancy compared to artificial turf ▪ Low, or no return on investment ▪ High potential to damage pavement during removal ▪ Potential for extra costs during O&M	▪ High O&M costs ▪ Low life-cycle expectancy compared to artificial paint and thermoplastic ▪ Prone to discoloration ▪ Low visibility under poor weather and lighting conditions ▪ No return on investment ▪ High potential to damage pavement during removal ▪ Potential for extra costs during O&M

6.3 Potential Real-World Impact of Proposed Solution

General aviation airports would need to cooperate with the FAA to receive funding to implement the design, as the initial costs of installing artificial turf or paint can be quite expensive. However, the benefits of installing IRIS are projected to offset the cost and may even generate revenue.

Some airports are already utilizing similar astroturf-based methods to visually enhance airport surfaces. Chicago O'Hare International Airport (ORD) and Midway International Airport

(MDW) have installed artificial turf to improve perception of runway and taxiway boundaries (FAA, 2006). Initially, ORD painted an island green so pilots wouldn't accidentally overshoot a taxiway; the paint eventually chipped which led to the green artificial turf installation. Occasionally at MDW, aircraft would accidentally veer off onto grass islands and onto runways because it was hard to distinguish contrast between concrete from grass; MDW recently installed green artificial turf. IRIS would further enhance pilots' SA and reduce runway incursions by creating a sharper visual distinction between concrete and grass, and runway and taxiway.

IRIS will impact pilots' SA and reduce runway incursions by providing additional information about their position relative to runways and hot spots. This could contribute to a number of mishaps avoided, thereby saving lives and avoiding costly disruptions of air traffic flow. If pilots are alerted that they are coming up to a hot spot, through IRIS, they may be more likely to stop and look for oncoming traffic. ATC and airport managers may also benefit from the added layer of defense that IRIS provides; it may be that ATC will feel more secure in knowing that if the other runway incursion safeguards fail, IRIS markings will be conspicuous enough for pilots to notice they are approaching a hot spot.

6.4 Commercialization

IRIS could find a niche in multiple markets. The aviation industry has already started to utilize artificial turf to enhance visual cues. However, no airport utilizes IRIS to further enhance visual distinction between surfaces. For those airports that are implementing artificial turf, IRIS provides distinct markings developed by the utilization of human factors that would greatly assist visual enhancement.

Turf runway markings could provide value by generating funding from industry (George Speake, personal communication, 2014). More specifically, funding could be generated by using airport marking materials to display advertisements. A potential partnership could be forged between the FAA, airports and local businesses to offset the cost of implementation through advertising. Air carriers, like Delta, or local companies such as NASCAR can help provide some of the money to fund the implementation of IRIS. In return, these companies will receive a non-movement, non-safety area on the airport where they can advertise using the turf. The advertisement would not interfere with the operations but would be noticeable by passengers in the air or the ground.

Sports industries could also benefit from IRIS. In coverage of big sporting events, blimps or other aircraft, circle football, baseball and racecar driving arenas to capture the excitement of competition. IRIS could be extended outside aviation to help companies design advertisements into turf or other surfaces that stand out to spectators and home audiences. Big events like the Super Bowl, World Series or even the Daytona 500 draw millions of home viewers each year. The revenue made off IRIS's advertisements would be sizeable and could fund other FAA or airport projects.

Appendix A. Team Contact information

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Appendix B. Embry-Riddle Aeronautical University

"At Embry-Riddle, our mission is to teach the science, practice and business of aviation and aerospace, preparing students for productive careers and leadership roles in service around the world." -- Mission of Embry-Riddle Aeronautical University

Orville and Wilbur Wright made history in 1903 with their first successful flight of a controlled, power sustained aircraft. Twenty-two years later, following in the progress of aviation, John Paul Riddle and T. Higbee Embry founded the Embry-Riddle Company. In the ninety years since its establishment, the institute has expanded to become known as Embry-Riddle Aeronautical University and has since become the world's oldest and largest accredited university that specializes in aviation and aerospace.

At its residential campuses in Daytona Beach, Florida and Prescott, Arizona and at its 150 Worldwide Campus locations around the globe and online, Embry-Riddle offers its students a wide variety of undergraduate and graduate degree programs in aviation, business, engineering, and related high-tech fields. In recent years, the institute has expanded its research activity and launched Ph.D. degree programs in Aerospace Engineering, Aviation, Engineering Physics, Human Factors, and Mechanical Engineering.

As aviation and aerospace continue to evolve, so does Embry-Riddle Aeronautical University; in collaboration with the FAA and industry leaders, Embry-Riddle has become widely recognized as one of the nation's leaders in the development of next-generation air traffic management technology. It is the institute's pledge to "commit to the expansion of opportunities for students to work more closely with the aviation industry in the United States and in other nations".

Appendix C. Description of Non-University Partners

Not Applicable

Appendix E. Educational Experience of Students and Faculty

For the students:

1. Did the FAA Design Competition provide a meaningful learning experience for you?

Why or why not?

The FAA design competition provided a means for each student on our team to experience our field in a real world setting. The team is composed of graduate human factors students, with backgrounds in engineering and psychology.

2. What challenges did you and/or your team encounter in undertaking the Competition?

How did you overcome them?

Our initial visit to DAB provided us with a wealth of information, but left us feeling like we did not have a complete understanding of airport operations. The experience benefitted us by helping identify areas that we could focus our research on and that we needed to utilize FAA standards to guide us through the design process.

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

The team went through several iterations of our design concept throughout its development. The team actively shared potential additions to the design with each other, and with professionals in the field.

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

Our experience interacting with the industry was appropriate, meaningful, and useful to the development of our design. By using all of the details and experiences each industry professional provided us, we were able to grasp the issues currently faced in airports and the National Airspace System, essentially leading us to our design.

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?

This project not only helped us expand our understanding of systems engineering, but we developed skills about teamwork and communication. Because increased knowledge of system development and skills to work with a diverse group, this experience has provided us the ability to implement what we've learned and be successful for entry in the workforce, as well as pursue further study.

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