COVER PAGE

Title of Design: Pilot-controlled Alert Lighting System ("Air PALS")

Design Challenge addressed: Runway Safety/Runway Incursions

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Executive Summary

This paper proposes the Pilot Controlled Alert Lighting System (Air PALS) to mitigate the risk of runway incursions by enhancing pilots' situational awareness (SA) while operating at small airports. Runway incursions (RIs) are typically considered a greater risk to large airports, but RIs are not uncommon at smaller, nontowered general aviation (GA) airports, which make up about 90 percent of U.S. airports. As examples, a 1996 fatal two-aircraft collision at Baldwin Field in Quincy, Illinois and similar incidents in Deland, Florida in 1999 and in Westerly, Rhode Island in 2003 serve as reminders to the aviation world that runway safety during nontowered airport operations should not be taken lightly. The cost effective Air PALS system builds on the concept of pilot controlled lighting (PCL) systems to help pilots better coordinate their runway usage and to improve pilot situational awareness when operating around nontowered airports. Drawing on stakeholder interviews, a literature review, and a study of related technologies, the team designed Air PALS around the constraints and safety improvement needs of airports conducting flight operations without the benefit of tower control. Air PALS adds a distinct visual cue to reinforce pilots' verbal communications currently used to deconflict runway usage. The visual cue signals runway intentions, situationally engaging other aircraft operating in the vicinity of the runway environment. The prospects for Air PALS successful implementation are positive. Analyses revealed that implementation and maintenance costs would be recouped within five years and that hazards associated with introduction of Air PALS are generally low in probability and amenable to mitigation. Local airport officials expressed interest in Air PALS and assessed it as a viable option provided that its costs could be kept low. The down-the-road extensions of Air PALS capabilities – for example, to provide more specific runway usage information – would build on established successes to further support safe runway operations at nontowered airports.

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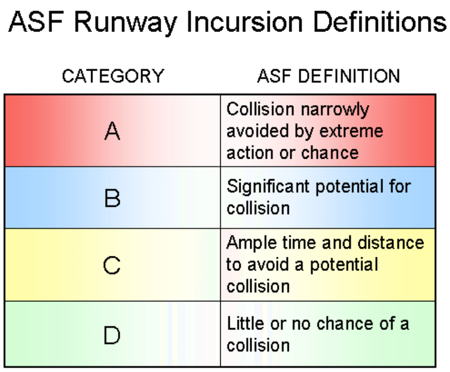
1 Problem Statement and Background

A runway incursion (RI) is defined 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 and takeoff of aircraft" (Federal Aviation Administration [FAA], 2009). In layman terms, a runway incursion is best explained as a close call between two aircraft in the airport's "runway environment," defined as the "protected area of a surface designated for the landing and takeoff of aircraft" (FAA, 2009). (Note: Incursions can be between an aircraft and a ground vehicle or a pedestrian as well, but these incidents are less frequent and not the primary focus of this study.) The current RI definition was first adopted by the International Civil Aviation Organization (ICAO) on November 2004. Subsequently, the FAA adopted this definition in October 2007. Before the FAA adopted this definition, incidents which involved an error that did not infringe on traffic separation requirements between aircraft were alternatively categorized as surface incidents. For example, if an aircraft was cleared by ATC to land on the runway but landed instead on a parallel taxiway, this would have been a surface incident under the old FAA definition if no other aircraft had to maneuver to avoid the landing aircraft. Under the new definition, this description would be considered an RI solely due to the fact that the aircraft landed in the wrong place.

After a runway incursion is reported, the investigating FAA representative assigns the event an incursion category. The FAA categorizes RIs by severity (Class A through D, with Class A being the most severe) and also by type of the runway incursion. These type categories are: Pilot Deviation (PD), Operational Error/Deviation (OE/D), and Vehicle/Pedestrian Deviation (VPD). Cardosi (2005) explains in detail the various ways which runway incursions can be attributable to errors on the parts of air traffic controllers, pilots, vehicle drivers, or pedestrians. The AOPA's Air Safety Foundation (ASF) presents the following chart showing how the FAA categorizes RIs according to their severity:



ASF Runway Incursion Definitions

CATEGORY	ASF DEFINITION
A	Collision narrowly avoided by extreme action or chance
B	Significant potential for collision
C	Ample time and distance to avoid a potential collision
D	Little or no chance of a collision

Figure 1-1. Runway Incursion Categories (AOPA)

In the sections that follow, we discuss the problem of runway incursions, the focus of our efforts to develop a design for reducing runway incursions, and the factors that influenced our choice of focus.

1.1 Focus of Study: Nontowered Airport Runway Incursions

In 2008, 71 percent of RIs involved general aviation (GA) aircraft, including 10 of 12 serious (category A or B) runway incursions (FAA, 2009). The majority (63 percent) of these incursions were attributable to pilot deviations. Although the reasons why GA pilots seem to be involved in more incursions are debatable, the fact is that the nature of GA flying is very from other aviation operations – air transport and military. One major difference is that GA aircraft are the primary users of small to mid-sized airports. Most of the smaller airports in the U.S. are nontowered airports, meaning that they are not serviced by an air traffic controller (ATC). Pilots and vehicles operating at nontowered airports must maintain their own separation. (Note: For purposes of this paper, nontowered airports refers to both the 24-hour operations at approximately 20,000 U.S. airports which do not have an operational control tower, and the tower-closed operations at airports which close their towers during a portion of the night and operate under nontowered airport flight rules during these [typically low volume] periods.) To maintain separation during nontowered operations, pilots typically communicate their intentions to each other via radio using a Common Traffic Advisory Frequency (CTAF). In some cases, auditory communication of intentions is not possible, as aircraft operating at nontowered airports are not required to be radio-equipped. At larger airports, in contrast, aircraft must be radio-equipped and pilots benefit from the oversight functions provided by ATC. Larger airports are also more likely to undergo frequent infrastructure improvements and employ new technologies specifically aimed at minimizing incursions.

The number of serious (Class A or B) RIs in the United States has declined steadily between 2000 and 2009 and the majority of this decline comes from reductions in commercial aviation RIs (FAA, 2009). This is highly attributable to mitigation strategies such as airport-specific outreaches (e.g., identifying hot spots), improvements in airport signage, and technological improvements at larger airports such as introduction of the Airport Movement Area Safety System (AMASS) and Runway Status Lights (RWSL; Green, Otero, Barker, & Jones, 2009). Despite these advances, it seems unlikely that the technology, outside of airport signage improvements and RI awareness campaigns, will reach smaller GA airports in the near future.

Large airports handle a greater volume of air traffic, meaning their incursion countermeasures have greater impact potential compared with countermeasures at their less sophisticated small-airport counterparts. Every runway incursion is one too many, however, and 627 runway transgressions at uncontrolled airports were voluntarily reported to the Aviation Safety Reporting System (ASRS) between 1991 and 2001 (ASRS, 2003). The number 627, although large, does not convey the true extent of the problem due to the voluntary nature of ASRS reporting. This design proposal will suggest a relevant cost-effective solution that is easily used and understood by pilots to mitigate runway incursions at small airports. By improving pilot situation awareness and aircraft coordination at nontowered airports, our design may substantially reduce runway incursions in uncontrolled airport operations, thereby reducing the overall runway incursion rate.

1.2 Background

A NASA callback study examined 51 pilot safety reports provided to their Aviation Safety Reporting System (ASRS) database of runway transgressions at nontowered airports from October 2000 through

September 2001. The data showed that communication issues and lack of situational awareness were most commonly cited as factors contributing to the runway incidents (ASRS, 2003).

Endsley (1995) describes situation awareness as “the perception of the elements in the environment within a volume of time and space and the comprehension of their meaning” (p. 36). Unlike tower-controlled airports, at nontowered airports there is an additional requirement placed on the individual pilots to pick up perceptual cues to decipher where other aircraft are and what the best course of action is. The frequency of runway incursions at small, nontowered airports indicate that pilots are still making errors in picking up these cues, which served as a catalyst for developing this system (ASRS, 2003).

A 1996 runway incursion at Baldwin Field provides a vivid example of how communication and situation awareness failures led to an actual accident. On November 19, while landing on Runway 13 at Baldwin Field in Quincy, Illinois, a United Express Beechcraft 1900 collided with a King Air which was taking off on Runway 4. The collision took place where the two runways intersect. Both planes caught fire and all twelve aboard the United Express and the two of three people aboard the King Air were killed. The accident occurred during day visual meteorological conditions. The NTSB faulted the King Air pilots’ failure to use proper communications and “see-and-avoid” procedures at an uncontrolled airport as there were problems with the physical locations of the airplanes and the communication between the pilots (Landsberg, 1997). The NTSB (2007) reported the official cause of the crash was communication errors. It was found that the pilots in one of the aircraft were not monitoring the traffic advisory frequency, nor were they appropriately scanning for traffic. Also, there was a pilot in a third aircraft who interrupted a critical radio transmission, which contributed to the entire misunderstanding. These factors resulted in the aircraft on the ground taking off as the other aircraft was landing. To demonstrate that the Baldwin Field accident was not an isolated incident, our team reviewed NTSB accident data between 1999 and 2003 and identified 40 aircraft collisions that had occurred in runway environments at nontowered airports, resulting in 16 fatalities. Additionally, all of these accidents occurred during the daytime, in visual meteorological conditions (NTSB, 2009).

Our team set out to design an aircraft coordination support system to help pilots using nontowered airports deconflict their runway use intentions by means of centralized visual cueing. Our design, the Pilot-controlled Alert Lighting System, or Air PALS, is an airport lighting system that uses flashing runway lights as a cue to increase pilots' awareness of the runway intentions of other pilots. As a system that can be used redundantly with the established radio communication protocol for signaling runway-use intentions, Air PALS provides an additional and needed source of aircraft coordination. Further, when activated, Air PALS' visual lighting cues may jar pilots out of complacency and reinforce a runway safety attitude.

Redundancy of important perceptual information is a fundamental human factors design principle. Human factors research suggests that when a message is presented via more than one modality (e.g., via visual and auditory modalities), the message is more likely to be correctly perceived (Wickens et al., 2004). Redundancy is particularly effective when one type of alert is degraded, as radio communications can often be. Therefore, complementing the auditory cue (CTAF communications) with a visual cue (Air PALS runway lighting cues) will help ensure that the pilots correctly perceive information about runway usage.

The Baldwin Field accident is a good example of why having a redundant system is necessary for nontowered airports. If Air PALS had been in place at the Quincy airport, perhaps one of the aircrafts' pilots would have realized that the runway was about to be used. Abrupt changes in the visual environment tend to capture attention automatically (Jonides & Yantis, 1988; Yantis & Jonides, 1984, 1990). In the situation like this when the auditory cuing system (i.e., normal aircraft-to-aircraft radio communications) fails, well-positioned flashing runway lights could have visually alerted the aircraft about to takeoff that another aircraft was inbound to land. Immediately, either pilot could then take whatever deconfliction measures were necessary to avoid the collision. Because the collision occurred during a period when the airport was experiencing a high volume of traffic and radio communications, it is apparent that the pilots' situation awareness was reduced. The flashing lights would have pierced through the perceptual noise of the busy runway environment to grab attention, improve situational awareness, and improve aircraft coordination. Thus, the pilots would have been able to notice critical changes in their environment and would have been more aware of the entire situation.

1.3 Existing Technology

A number of systems that reduce the risk of runway incursions have been developed over the past 20 years. For example, the Traffic Alerting and Collision Avoidance System (TCAS) improves pilot situation awareness in the air and has been mandatory for commercial aircraft to use since 1993. Controller situational awareness is benefitted by Airport Surface Detection Equipment (ASDE), developed to help controllers monitor aircraft on the ground, and the AMASS controller alerting system, which makes use of ASDE to enhance controllers' ability to detect potential incursions. Another recent initiative is the Final Approach Runway Occupancy Signal (FAROS), an automated system which flashes approach guidance lights to warn landing aircraft that the runway ahead is occupied. Even with new, promising safety systems such as these in place, runway incursions are still a significant problem. No system by itself eliminates the problem of runway incursion risk; each system has its limits. For example, if buildings or other objects are in the path of ASDE radar, this creates blind spots where the ASDE is unable to detect aircraft. As exemplified by the FAA's Runway Safety Management Strategy (2009), incursions can best be reduced by means of multiple complementary initiatives.

The number of existing and promising, under-development RI systems made it difficult to identify new, complementary systems, but at the same time this helped to focus the team on some basic RI mitigation concepts. Two systems that were particularly influential in shaping Air PALS are the Runway Status Light (RWSL) and Pilot-Controlled Lighting (PCL) systems. The remainder of this section will focus on describing these two important systems.

A prototype RWSL was installed and tested at the Dallas Fort-Worth International Airport (DFW) in 2003. The RWSL system works by placing rows of red lights at departure ends of runways and at every intersection along runway and a taxiway. The red lights illuminate automatically when the system detects high speed traffic on or approaching the runway (inside two miles from the airport), alerting other pilots not to cross the active runway. This system in not intended to replace communication between controllers and pilots, but only to act as another safety barrier. This system is especially helpful in preventing errors during hazardous situations such as when there is poor airport visibility, the pilot is unfamiliar with an airport layout, or the controller confuses the locations of aircraft on the taxiway.

In a test trial of a RWSL at DFW, the FAA determined that a rate of no more than one system error in every 2,000 operations would be acceptable. "This rate corresponds to approximately one such error every four days for a busy runway, or an error rate on the order of 0.03 percent of all light illuminations." During testing, RWSL system exceeded this target, producing an error rate of 0.001 percent. In 2005, DFW reported approximately 27,000 departures and landings and 36,000 total runway crossings. Of the 63,000 processes there were 114 system anomalies. Of the 114 anomalies, 40 percent were attributed to missed detections, 50 percent were false activations, and 10 percent were interferences (Eggert et al., 2006). Pilots exposed to RSWL operations at DFW received a survey from the FAA to glean feedback on the system (Eggert et al., 2006). A total of 220 responses were collected and analyzed. The results indicated the majority of pilots had a positive reaction to the RSWL with 92 percent of the respondents choosing the survey response, "Runway Edge Lights (RELs) would help reduce runway incursions." In addition, 88 percent felt the system should be installed at other airports. Only 6 percent of the respondents felt the system was a bad idea, but the survey did not glean any additional information regarding why this was the case.

Although DFW's RWSL is automated and much more advanced than Air PALS, the basic concepts of this commercial system can be applied to our system's design. First, RWSL demonstrates that a visible, ground-based light is a tested, effective way to gain the attention of pilots (and other airport operators and personnel), either taxiing on the ground or in the air, and during day or nighttime. Since there are not any air traffic controllers at nontowered airports and pilots rely solely on radio communication and visually acquiring other aircraft to ensure landing or takeoff separation, our concept would provide the additional function of alerting ground personnel and non-radio equipped aircraft of a moving aircraft in the runway environment. Second, RWSL emphasizes the central importance of runway lights to all airport operations, a concept which was integrated into our design. At airport locations where taxiways intersect runways, the modified runway edge lights would flash red as a method to signal taxiing aircraft that the runway is not clear to cross or use – either an aircraft is approaching or taking off on the runway.

FAA data for FY2009 showed that most serious types of "runway incursions" – those in which a crash was narrowly avoided or a significant potential for collision existed – dropped from 25 in 2008 to 12 in 2009. This corresponded to a similar drop in close calls at DFW. Given this success at one of the busiest commercial airports in the world, our team agreed that RWSL conceptually had potential to prevent incursions at any airport with some changes. One of these changes would be cost driven. The RWSL system is a multi-million dollar automated project and even a scaled down version, say, one-tenth the size of the version at DFW, does not eliminate heavy investment into integrated airport surveillance radars (ASRs), surface detection radars, and transponder multilateration information from the ASDE-X surveillance system, not to mention the labor and runway downtime of installing in-pavement lighting at 8 to 10 locations around the airport. Our work-around to this dilemma was to propose a pilot controlled version of RWSL, one which builds on the existing lighting infrastructure at the airport without significant construction costs.

The second airport system, the Pilot Controlled Lighting (PCL) system, is already in use at most airports. Designed to save energy costs at night when the airport is not operating under ATC control, the system self-arms via photoreceptor cells so that any arriving or departing aircraft can activate the runway and taxiway lights by clicking their radio a certain number of times on the airport's common radio frequency (CTAF). The PCL system is also accessible in daytime poor visibility conditions, such as fog or heavy rain. Pilots may turn the lights on at full brightness by clicking the radio microphone (mike) seven times in five seconds, medium brightness by clicking five times in five seconds, and low brightness by clicking three times in five seconds. After each pilot activation, the PCL stays on for fifteen minutes. The radio control boxes are fairly standard and just require some wiring attached to the main circuit board powering the runway and taxiway lights.

Air PALS will borrow from the PCL infrastructure, adding a lighting scheme that would be used in both day and nighttime conditions to communicate runway use intentions. In addition, Air PALS operations were deconflicted from PCL operations. Specifically, both systems rely on mike clicks to activate runway lights. Because three, five, and seven clicks are taken by PCL systems, Air PALS is designed to activate after four clicks within five seconds. While our team could not find any specific explanation regarding the origins of the existing click designations, in discussions with pilots, the consensus was that the number of clicks are just to make it easy to differentiate between clicking the mike to activate various airport lighting levels and clicking the mike to transmit a voice communication. Full brightness (seven clicks) was the most common setting the pilots we spoke to used. The pilots also agreed that the more clicks that pilots make, the more likely the pilot is to make an error. For these reasons and so as not to make the clicking overly laborious, our team decided that four clicks would be quick, simple, and adequately differentiable from the existing system.

2 Summary of Literature

Our team used myriad resources to gather as much credible information as possible to validate a system that would effectively increase situational awareness of pilots at nontowered airports, increase aircraft-to-aircraft coordination, and decrease RIs. In the earlier conceptual stages, a large concentration of research was placed on literature. The team compiled information on runway incursions from a variety of resources. We reviewed pertinent FAA, NTSB, NASA, and industry technical reports and associated fact sheets available online. The FAA’s Advisory Circulars 90-42F “Traffic Advisory Practices at Airports without Operating Control Towers” and 90-66 “Recommended Standards Traffic Patterns for Aeronautical Operations at Airports without Operating Control Towers” helped to equip team members without an aviation background with knowledge of some basic airport operating procedures. As the design evolved, the team consulted publicly available technical data from commercial airport lighting manufacturers, including data on existing PCL, FAROS, and RWSL systems. Information on the RWSL systems (i.e., operational evaluations, engineering briefs, etc.) all helped to provide our team with a strong idea what we wanted our design to accomplish. The design team also used scholarly journal articles to investigate the perceptibility and interpretability of different runway lighting-based cuing schemes. Our primary conclusions from the literature review were:

1. The exact frequency of runway incursions at nontowered airports is largely speculative, but the self-report and accident data (ASRS, 2003; NTSB, 2009) suggest runway incursions are both frequent and sometimes deadly at these airports. Data suggest a major contributing factor is the greater discretion pilots have at these airports – they operate without any supervision and fall under more lenient communication requirements. For example, there are reports of aircraft landing on the same runway in opposite directions. This is a problem unique to nontowered airport operations.

2. Federal funding for smaller GA airports to receive existing and proposed runway safety management technologies (e.g., RWSL) will probably not be made available for many years, but the basic functions of these technologies may have simpler applications that are transferrable to GA airports on a smaller scale.

3. Abrupt onsets of visual information reliably capture attention (e.g., Jonides & Yantis, 1988; Yantis & Jonides, 1984, 1990). Flashing runway lights are a form of repeated abrupt onset and thus represent a reliable form of attention capture.

4. If a stimulus is distracting, a person will suppress or inhibit attention to it after an initial attentional capture by the stimulus (Tipper, Driver, & Weaver, 1991). Therefore, the team

recommends a slow flash rate that will capture attention via lighting onsets and discourage attentional inhibition of the lights. The team recommends a rate of one flash every 3 seconds, a rate that will not conflict with other approach lighting or airport emergency lighting systems.

3 Problem Solving Approach

Because our team had approximately 13 weeks in the semester to develop a design and project proposal for the competition, we conceded early on that following a comprehensive system development process was not practical. Instead, we opted for a simpler, more rapid development plan that applied core principles from two well-known and highly-regarded software development strategies – Agile Software Development and Lean Software Development – to the project's design and development.

One of the characteristics of the team structure was that not everyone was from the same academic degree or background. Using the Agile motto of "individuals and interactions over processes and tools," the team encouraged self-motivated research through brainstorming and bringing new ideas to weekly meetings where other team members provided constructive feedback which helped to refine and improve the idea (Beck et al., 2001). Another focus of the team coming from Agile was to concentrate on customer needs – i.e., ways to prevent or reduce a number of runway incursions at nontowered airports around the U.S. Because the objectives of the FAA competition were broad, the team was free to explore and be creative to come up with a unique and viable solution. Furthermore, though actual prototyping was not possible due to various constraints – mainly budget-wise and student workload – each week was, in essence, a development iteration in which everyone would provide various sketches, articles, and notes to depict possible design prototypes. As part of this process, each week the team would explore various aspects of the working design, to include feasibility measures and risk controls.

3.1 Research Process

As explained in the previous section, the literature review was an important early step in ensuring the team understood the problem and the existing solutions. As our focus switched from conceiving to developing an idea for a formal system, the research and system design process evolved down several simultaneous paths. The first goal we set was to contact local small airports to discuss ideas for mitigating runway incursion risks at their airports. While these interviews were underway, each team member took turns leading a weekly group session in which we analyzed the conceptual design in the context of using a specific system design tool, theory, or process. The various design techniques, functional flow diagrams, and system modeling language tools we employed as design exercises are explained in the following sections.

3.1.1 House of Quality

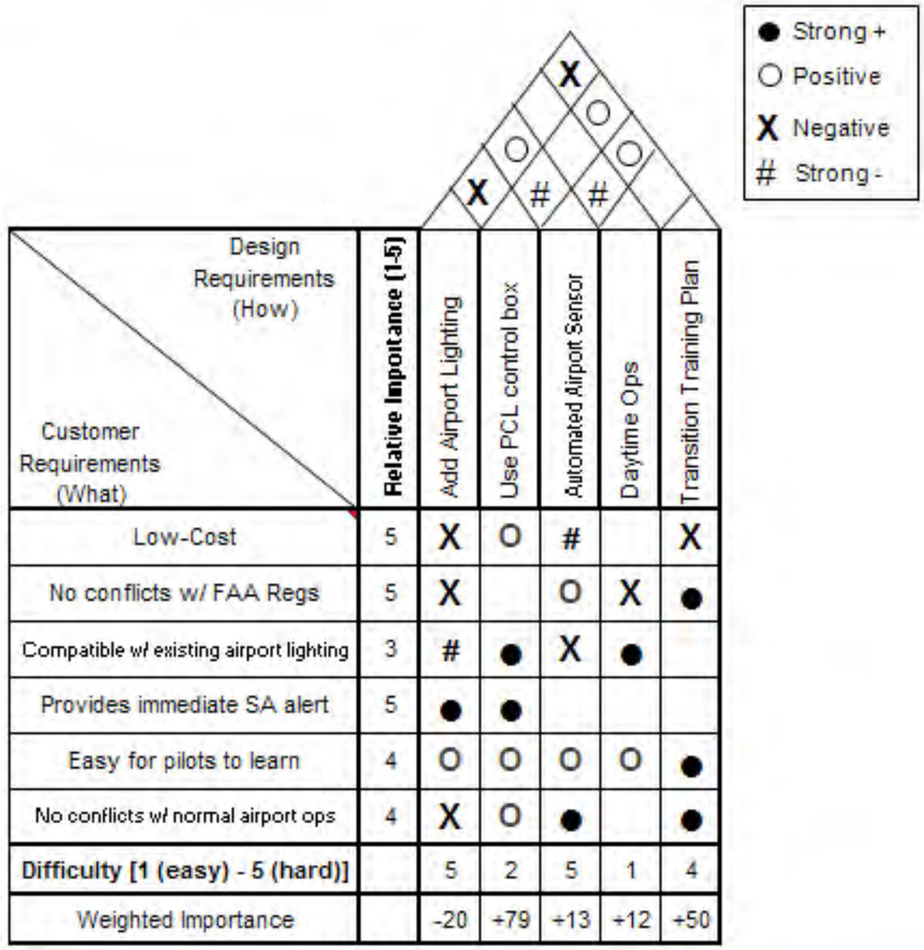
The House of Quality (HoQ) is a design matrix that provides a conceptual map providing the means for interfunctional planning and communications (Hauser & Clausing, 1988). While it was conceived as a system to help designers organize a quantifiable plan to change a product, it has since become a multipurpose framework, one that can be used in product development to prioritize initiatives, examine customers' needs, mitigate risks, and engage stakeholders in the design process (Brynjolfsson, Renshaw & Van Alstyne, 1997).

For this project, the HoQ became useful about a month into the project, once our team had deliberated with local airport managers and FAA officials and had gained insight into what the requirements for a functional system such as the runway alert lighting system truly were. Repeatedly in interviews, local airport managers and operators voiced “low cost” and “operational simplicity” as functional necessities. Contacts in the FAA shared many of the same opinions and provided an effective counterbalance to the more ambitious requirements small airports had brainstormed in the context of cost not being an issue. Prioritizing cost, simplicity, and other user-based needs, our team utilized the HoQ design tool to compare what the airports (users) needed to the potential design options capable of meeting the user needs within the scope of the time and nature of the project. The HoQ analysis encouraged the identification of multiple design goals and design options. Given the complex nature of airport systems, the need to develop a comprehensive pilot and airport operator education program is an example of a critical, yet easily overlooked, design element that was identified using a HoQ analysis.

Not only did the exercise in creating the HoQ help our team to organize its ideas, the real benefit was that it allowed us to choose between design priorities. For example, while the group agreed that we wanted this system to function at smaller, nontowered airports, there was significant debate over whether or not to pursue a more automated system, such as one which activated the runway lights without pilot input, or one that provided a noise or visual alert as feedback to the cockpit of the initiating aircraft. The HoQ (Figure 3-1) clearly demonstrated the negative relationship between adding and/or automating airport lighting and incurring additional costs which, as a result, directed the overall plan back towards a manually-initiated one. Early on in the process, the existing functionality of the PCL seemed like it had potential to develop into something usable during the day as well, but our team could not quantify this educated guess. As the HoQ demonstrates, the simplicity of the PCL system related well with many aspects of the existing airport operations and infrastructure and became one of the options we agreed on from the onset of the project.

In summary, HoQ is a user-focused method which helped us organize our objectives, prioritize our goals, and identify potential conflicts as we moved into the later planning stage of this project. The HoQ shown here takes the six most important user needs we identified from a front-end analysis and compares them to five potential design solutions. Building the HoQ to formulate quantifiable priorities to then share with stakeholders was extremely beneficial. Additionally, the HoQ correlation matrix provided evidence that the team's design idea – augmenting the capabilities of the existing nighttime PCL system by adding a method to alert pilots of potential runway activity – can be achieved while safely interacting with most other airport operations. (This is depicted in Figure 3-1 by the lack of negative interactions in the column under "use PCL control box".)

The HoQ depicted below compares the relationships between small airports' needs with the team's evaluations of the most practical design methods/capabilities available to the industry to meet these needs. The weighted importance is calculated by multiplying the relative importance score in each row by the relationship factor in each box (e.g., strong positive is 5, positive is 3, strong negative is -5). The columns are then summed to generate the weighted importance. The difficulty row refers to the difficulty the team assigned to each design method.



Design Requirements (How) / Customer Requirements (What)	Relative Impoitance [1-5]	Add Airport Lighting	Use PCL control box	Automated Airport Sensor	Daytime Ops	Transition Training Plan
Low-Cost	5	X	O	#		X
No conflicts w/ FAA Regs	5	X		O	X	●
Compatible w/ existing airport lighting	3	#	●	X	●	
Provides immediate SA alert	5	●	●			
Easy for pilots to learn	4	O	O	O	O	●
No conflicts w/ normal airport ops	4	X	O	●		●
Difficulty [1 (easy) - 5 (hard)]		5	2	5	1	4
Weighted Importance		-20	+79	+13	+12	+50

Figure 3-1. House of Quality shows relationships between airport needs and design requirements

3.1.2 Stakeholder Analysis

Stakeholders involved with the implementation of a pilot controlled runway safety lighting system could include:

- Federal Aviation Administration (FAA)
- Pilots
- Aircraft owners
- Nontowered airports
- Airports which operate tower-closed during overnight hours
- Pilot unions (e.g., Air Line Pilots Association [ALPA])
- Aircraft manufacturers
- Installation personnel (i.e., airport lighting technicians)
- Airport maintenance personnel
- Airport lighting system manufacturers (Cooper Crouse-Hinds, ADB Airfield Solutions, etc.)

Each stakeholder that would be involved in our system has different interests and levels of involvement during phases of the life cycle on the system. Each stakeholder also has a certain level of importance and influence on the system that must be taken into account in order to create a successful lighting system. The stakeholder analysis for our FAA competition project is displayed in Tables 3-1 and 3-2.

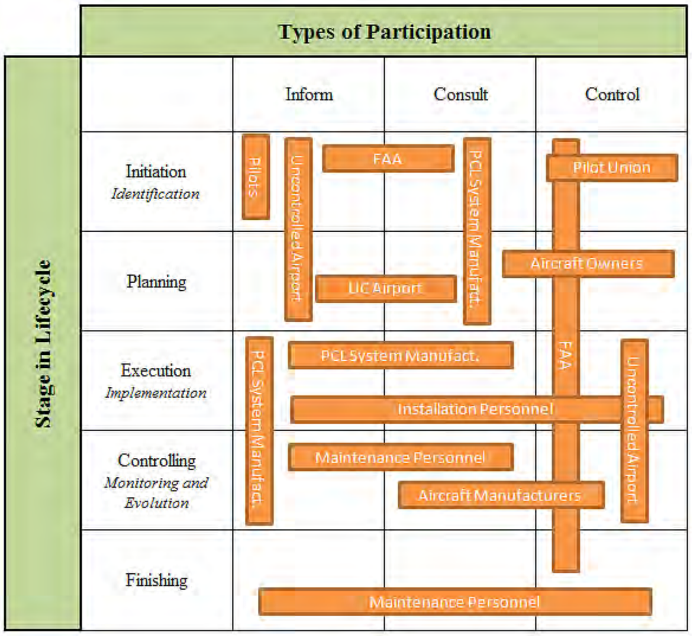
Table 3-1 shows the stakeholders that would be involved and what their areas of interests are in our lighting system. By determining what aspects of our system the stakeholders will be interested in, we are able to cater to them in those areas.

Table 3-1. Stakeholder interest areas

	Interest Areas					
Stakeholders	Legal and Regulations	Serviceability	Integration	Finance	Usability	Operational Changes
FAA	●	●	●	●		●
Pilots					●	●
Uncontrolled Airports	●			●		●
Aircraft Owners	●			●		
Pilot Union	●				●	●
Aircraft Manufacturer	●	●		●		
PCL system Manufacturer	●		●	●		
Installation Personnel	●		●			
Maintenance Personnel	●	●				●

Table 3-2 shows what type of participation the stakeholders will have in the system during the different stages of the system's life-cycle. The exercise of designing this table was very helpful to our team because it allowed us to see when each stakeholder should be involved with Air PALS. It is important to keep in contact with the stakeholders and the table clearly displays at which stages we should communicate with them.

Table 3-2. Stakeholder participation at different stages of the system's lifecycle



3.1.3 Activity Diagrams

Activity diagrams are a method of explaining what you would like to accomplish and how your system is going to work. Displaying a workflow using a series of activity building blocks and nodes, activity diagrams can show when decisions must be made, what trigger conditions must be met, what information should flow where, and more. Although not an accurate final depiction of Air PALS but rather a demonstration of a design tool the team used, an activity diagram for a modified pilot controlled light communication system is shown in Figure 3-2. The Air PALS activity diagram is broken down into three different “swimlanes” representing three different areas of interrelated activity. In the center ‘Lighting System’ swimlane of the diagram, the PCL system is lighting the runway when a trigger from the ‘Pilot Needing Runway’ swimlane causes the PCL system to transition to a sequence of flashes which, in turn, triggers a change in behavior in the third swimlane. The cycle begins and will ‘loop’ through this activity diagram after the flashing lights stop after 15-20 seconds and conditions in the ‘Pilot Needing Runway’ swimlane are met. When pilots need to land or take off, they simply click their microphone four times to activate our lighting system which will tell others to stay away and wait until the lighting changes back to normal. For sake of this diagram, the process described here pertains to a situation in which neither aircraft is aware of the other aircraft through normal radio voice communications. (Again, this diagram represents an earlier version of Air PALS and is presented to demonstrate a design possibility the team considered. For example, the final version of Air PALS uses separate runway lights, not the “lighting system currently in place”, as the diagram portrays.)

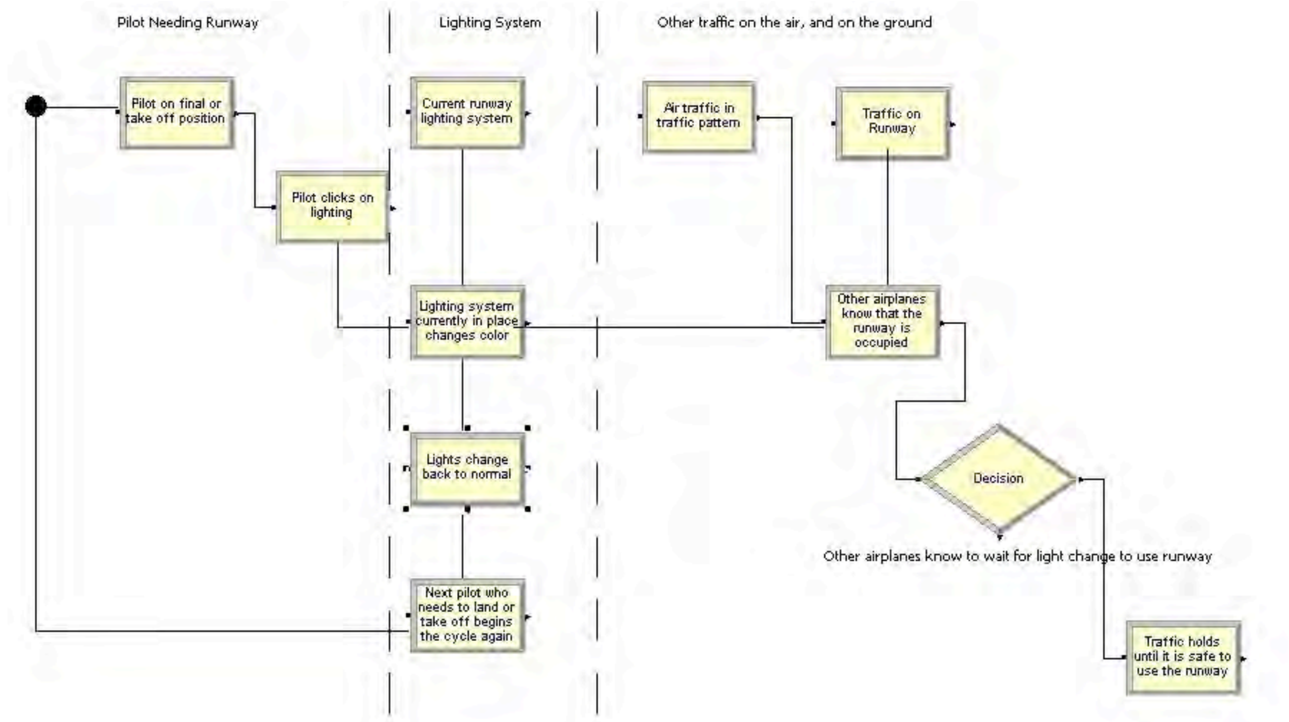


Figure 3-2. Preliminary activity diagram of modified pilot-to-pilot communication system

3.1.4 Human Systems Integration

The design team employed a Human Systems Integration (HSI) approach focused on key user issues to integrate human considerations across all system elements to define and strengthen our system requirements. HSI promotes a "total system approach which includes humans, technology, the operational context and the necessary interfaces between and among the elements to make them all work in harmony" (Haskins, 2007, p. M-1). An example of unharmonious system integration would be if the airport lights flashed too dimly to be visible during the day and too bright to be useful to pilots at night. While there are additional stakeholders (humans) involved in our overall system design, for the HSI activities, we defined the "users" in our system specifically as pilots and airport managers. For the pilots we identified usability, usefulness, effectiveness, trainability, and consistency with pilot practices as the top HSI issues. For the airport managers and staff, we identified maintainability, reliability, ownership costs, and understanding the technological elements as the top issues (Haskins, 2007). To optimize system performance with respect to HSI goals, our team considered accommodating the various characteristics of the population affected by aspects of the system. For example, during interviews, private pilots discussed the ways that, in-flight, their visual attention resources were split between scanning inside and outside the aircraft and running through checklists. Because attention may be focused inside the aircraft or on a checklist when Air PALS flashing begins, we decided that the runway lights would have to flash at least 15 to 20 seconds to be at least reasonably sure the flashing lights catch the attention of the pilots. Training is another area which can be overlooked in design processes which ignore the users. Pilot training would not consist of much more than providing them with a basic system understanding through publicity and outreach so as to avoid any cockpit confusion when pilots spot the new flashing lights. Airport management and maintenance may have to go through some additional training to comprehend the system's sustainability and maintenance requirements and how to manage a system failure. In this case, in alignment with HSI principles, the system is fail-safe in that in the event of a failure, the red lights remain off (open circuit design) and the airport reverts to operations under the previous rules. HSI integration is an ongoing activity and would be a part of modeling and prototyping this system throughout its life-cycle.

4 Description of Technical Aspects

4.1 Description of Air PALS Design

Air PALS is designed to increase pilots' awareness that a runway is either about to be occupied by either a departing or landing aircraft by providing an easy-to-use tool for pilots to visually alert each other of their intentions prior to these critical phases of flight. Recent technologies the FAA has employed to promote runway safety have mostly focused on automated systems, which have undoubtedly prevented hundreds of RIs at larger airports. The concern for the smaller nontowered airports and pilots who operate at them is that these programs, in their current or proposed configurations, have little or no likelihood of being employed there in the near future. Air PALS can change that. With Air PALS, the layer of safety the ATC controllers provide at towered airports, e.g., instructing taxiing aircraft to "hold short", "exit the runway", or "expedite your takeoff", is partially reinstituted. The example of this is a situation in which an aircraft on a short (1 mile) final approach just made a radio call of his/her intention to land and sees an aircraft holding short of the runway he/she is about to land on. The pilot may assume the pilot of the aircraft on the ground sees his or her aircraft coming in to land, but maybe the pilot has not heard anything on the radio to confirm this. The landing pilot clicks their radio and watches the lights flash as they complete the approach and land uneventfully. After he/she lands and clears the runway, the other aircraft lines up and takes off, at which time the other aircraft makes a comment like, "Hey, N999WD, it's a good thing you flashed the lights, I didn't see or hear you coming in and I almost took the runway as you were landing!" Air PALS can save lives. Air PALS consists of a radio control box that will be installed in line with existing PCL-configured radio control boxes and the current runway edge lights. It will be programmed to operate on the same common frequency as the PCL system. When activated, the alert lighting system immediately signals the intended occupancy of the runway to all aircraft operating within eyesight of the runway or runways.

This system is designed to build a runway safety mindset and raise awareness of the runway safety protocols. Air PALS is compatible with daytime and nighttime operations. During the daytime at nontowered airports, the PCL system is disabled, but Air PALS would be active. Given the higher frequency of daytime runway accidents and the high operations tempo at nontowered airports, this system required daytime functionality. In addition to the radio control box, Air PALS would consist of red, omnidirectional, high-intensity elevated lights installed along the runway edges (but not runway thresholds) every 200 feet, and on either side of taxiway/runway intersections (i.e., hold short zones). The FAA standard is to have these lights elevated 14 inches from the ground (see Figure 4-1). Upon activation the lights would flash – 3 seconds on, 3 seconds off, etc. – for 21 seconds, at which time they would extinguish and remain armed for next activation.

Whether the aircraft is taking off or landing, the pilot clicks the microphone four times to activate the lighting system. The radio control box receives the signal and sends a signal to the modified (bulb change only) runway edge lights through existing circuits and wiring. The lights in this system will be installed along the edge of the runway and flash red for 21 seconds to let other aircraft in the air and on the ground know that the runway is about to be occupied.

At night, Air PALS would operate independently of PCL. Typically, a pilot using the airport will activate the taxiway and runway lights (PCL) prior to activating Air PALS, and then activate Air PALS at the appropriate time prior to takeoff or landing. The Air PALS controls would be programmed to illuminate the lights at a lower intensity (50 percent of daytime) during nighttime operations so as to alert, yet not potentially interfere with pilots' vision during a critical landing or takeoff phase of flight. Although the existing radio control box technology and sensitivity controls could not prohibit pilots from activating Air PALS from a distance greater than 10 miles (based on altitude, costs to redesign existing PCL radio receivers, and radio strength of the transmitting aircraft), it is unlikely that transmissions from distant (20 miles or further) airport would trigger Air PALS, according to airport lighting officials.

One initial design concern would be how to program the radio controller to account for a situation in which two pilots are simultaneously clicking their radios to activate Air PALS. Similar to the existing PCL system, if a second pilot began clicking as a first pilot completed his/her clicks, the proper activation click count (4 clicks in 5 seconds) would be off, and the lights would not activate. The pilots would not see the runway lights flash in response to their mike clicks and this should cue them that someone else is attempting to activate Air PALS at the same time. Current technological limitations of analog VHF radios and push-to-talk radios make it difficult to resolve an issue such as the unlikely event two pilots initiate clicks at the same time and precise cadence. The way airband radios work is that when one person keys their microphone, they transmit and everyone else receives (listens). Pilots become fairly skilled at recognizing when someone else has keyed the mike. In the context of Air PALS activation, a pilot keying their microphone on and off creates an instantly recognizable scratchy tone in the headsets of the other pilots, which deters additional communications, according to several pilots we spoke to. Unless two pilots clicked their microphones in perfect synchronization four times, the likelihood that the pilots would not recognize something was amiss is unlikely.

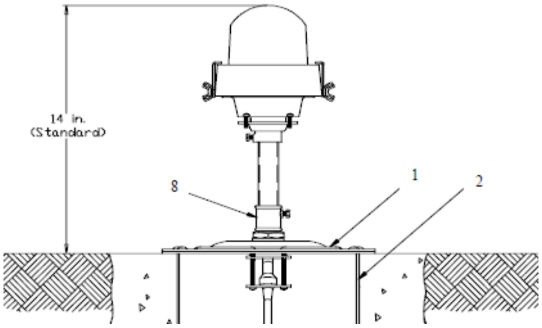


Figure 4-1. Elevated runway edge light (REL)

In discussions with licensed pilots of varying experience levels, we determined some basic parameters and operating guidelines we would use in initial pilot training and system testing. If the aircraft is landing, the pilot would click the microphone four times about 45 to 60 seconds prior to landing to activate the lighting system. If the aircraft is taking off, the pilot would click the microphone four times about 30 seconds in advance of taking the runway to activate the lighting system. In either scenario, the runway has finished flashing and any immediate follow up radio calls or immediate avoidance maneuvers (exit runway or waveoffs) can occur prior to the initiating aircraft entering the runway environment. Using this lighting will help pilots in all stages of their training, especially novice aviators, to establish and develop good communications and situational awareness at small airports. This system would also send a signal to GA pilots that the FAA is serious about improving runway safety at small airports.

To depict the various "what if" scenarios, our team examined four of the most common RI scenarios in the context of a generic single runway airport. These scenarios were formed based on RI frequency data published by Cardosi (2001) and ASRS (2003), and accident data from non-towered airports (NTSB, 2009). The first "what if" scenario we propose is when aircraft "A" is preparing to take off at the end of the runway, while there is another, aircraft "B", approaching a runway intersection (see Figure 4-2).

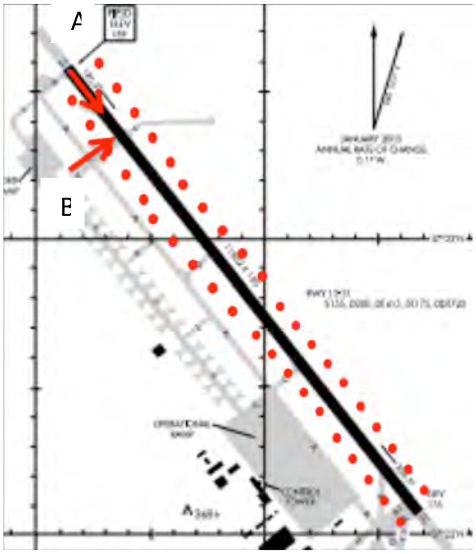


Figure 4-2. Example of runway light system

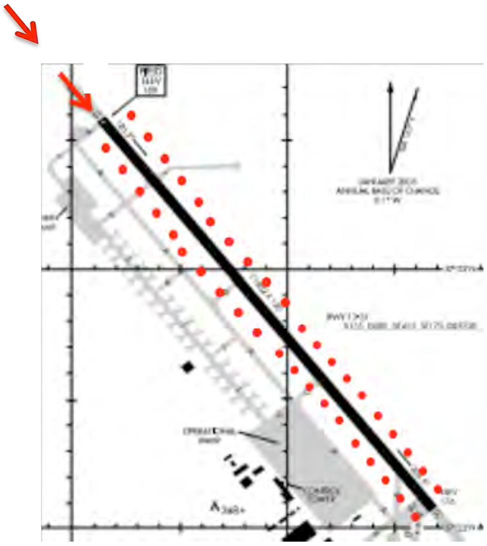


Figure 4-3. Two aircraft landing on the same runway

The two arrows represent the aircraft, and the red dots are the runway edge lighting system. Thirty seconds before the aircraft enters the runway, pilot “A” clicks his or her microphone to activate the active runway edge lights. The lights will flash, signaling to aircraft “B” (approaching the intersection) that the runway is about to be occupied. The lights would gain the attention of pilot “B”, in case he or she was not aware of the other aircraft and in sufficient time to stop short of the runway until aircraft “A” took off. Air PALS’s main goal is to provide additional perceptual cues identifying the existence of other aircraft which can then function as an effective alert in many of the most common situations leading to RIs (e.g., landovers, crossing, etc.). In any of the following scenarios, the system will lessen the likely of RIs.

In Figure 4-3, there are two aircraft converging to land on the same runway at about the same time. The closer aircraft “A” has the right of way, and should have keyed the microphone first, alerting the pilot of the following aircraft “B” to keep an eye out for another aircraft attempting to land or takeoff. This may cause a need for the latter aircraft to “go around” to avoid an incursion. Because right-of-way rules state that the aircraft landing has priority, the pilots should abide by that rule. The pilot in aircraft “B” should yield and break off the approach. This scenario is most important when the aircraft are equidistant from the runway and would impact on final without some intervention (this a frequent cause of accidents at nontowered airports). In this case, the signal would alert both aircraft to each other so hopefully they could revert to physical avoidance or, if time permitted, to the right-of-way rules which state that the aircraft below the other (or to the right, when level) has priority (General Operating and Flight Rules, 2009).

Figure 4-4 displays a scenario that has happened and could only occur at nontowered airports – two aircraft, shown by the red arrows, are attempting to land on opposite ends of the same runway. According to ASRS data (2003), nearly one-third of incursions at nontowered airports in 2000-2001 involved aircraft landing in opposite directions on the same runway. When either aircraft activates the lights, the other will be alerted to the presence of another aircraft and should follow-up with a radio call or waveoff as necessary. Both aircraft would be more likely to perceive, process, and respond to the overall situation and avoid an accident or incident.

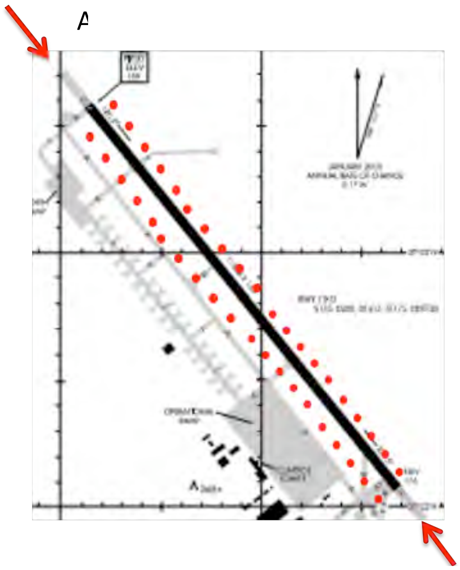


Figure 4-4. Two aircraft landing on opposite ends of a runway

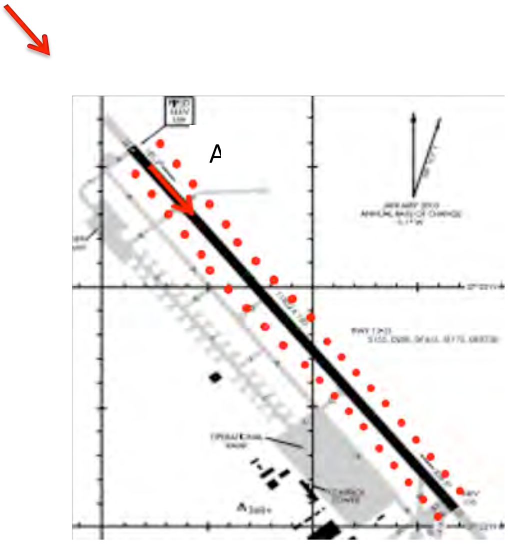


Figure 4-5. One aircraft taking off while the other is landing

A

Our final “what if” scenario (Figure 4-5) shows aircraft “A” on the active runway about to take off, while aircraft

"B" is coming in to land and neither aircraft sees the other. Ideally the aircraft taking off would have heard on the radio or spotted the aircraft coming into land and yielded to that aircraft, but this does not always happen. This is where Air PALS comes into play, alerting the landing pilot that another aircraft does not see him/her and is taking the runway. When the aircraft taking off activates the lighting, the aircraft on final would be made fully aware that the runway is about to be occupied, and would be able to analyze the situation and attempt to communicate over the radio to resolve the situation in advance of colliding with the other aircraft. As explained in section 1.2, these scenarios can and do occur at nontowered airports.

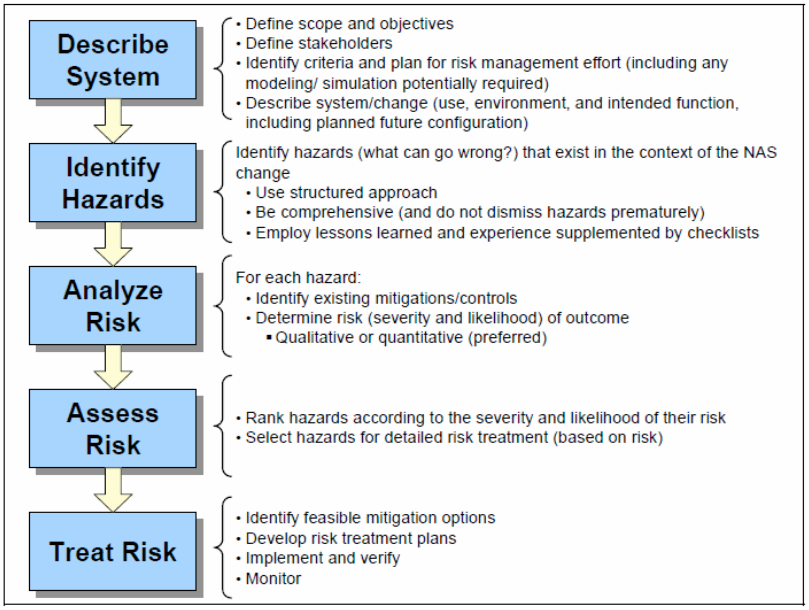
4.2 Safety & Risk Management

Our design team implemented a rigorous risk management and risk assessment program to comply with the FAA's Safety Management System (SMS) Manual (FAA, 2008a). Each Air PALS-configured airport will be different in at least a few ways – e.g., runway length, layout of taxiways and parking areas, existing airport lighting configuration, etc. Because of the variability of environments and scope of operations, this document aims to outline the proper process for identifying hazards, analyzing risk, assessing risk, and treating risk rather than make specific cases that would not apply universally. All airports that use Air PALS will comply with the FAA SMS.

While there is a monumental amount of variability between different airports and how risks are created, there are some concrete definitions that apply. FAA Advisory Circular (AC) 150/5200-37 has set definitions for certain terms that are commonly used when assessing the safety of a system:

- *Hazard:* A condition, object or activity with the potential for causing damage, loss, or injury.
- *Risk:* The chance of loss or injury measured in terms of severity and probability.

The standard flow for the FAA's Safety Risk Management (SRM) process for recognizing and mitigating hazards in any runway in the National Airspace System (NAS) is illustrated in Figure 4-6. In the remainder of this section of this report, we discuss the risk analysis of Air PALS through the first three phases of the SRM process.



- Define scope and objectives
- Define stakeholders
- Identify criteria and plan for risk management effort (including any modeling/ simulation potentially required)
- Describe system/change (use, environment, and intended function, including planned future configuration)

Identify hazards (what can go wrong?) that exist in the context of the NAS change
- Use structured approach
- Be comprehensive (and do not dismiss hazards prematurely)
- Employ lessons learned and experience supplemented by checklists

For each hazard:
- Identify existing mitigations/controls
- Determine risk (severity and likelihood) of outcome
  - Qualitative or quantitative (preferred)

- Rank hazards according to the severity and likelihood of their risk
- Select hazards for detailed risk treatment (based on risk)

- Identify feasible mitigation options
- Develop risk treatment plans
- Implement and verify
- Monitor

Figure 4-6. FAA's SRM Analysis Phases

4.2.1 System Description

The first phase of the SRM analysis process involves describing the Air PALS system, which has been presented throughout this report, primarily in section 4.1. It is most important to understand this system is designed to augment safety systems in place, specifically, the FAA's general operating rules for nontowered airports, not change them. In other words, this system is another layer of safety designed to prevent a seemingly minor error – such as a missed radio call or an aircraft unintentionally lining up on a different runway then the rest of the aircraft in the pattern – from leading to a serious RI or worse, a deadly accident.

4.2.2 Hazard Identification and Risk Analysis

In this section, we address the second and third phases of the FAA SRM. In implementing change there is always the potential for creating hazards and consequently for increasing risk.

While the types of hazards associated with Air PALS are fairly consistent from airport to airport, it is important to note that their risk levels, as calculated by severity multiplied by probability, greatly vary. Although the risks' *severity* may remain constant, other factors (traffic volume, airport capacity, runway length, taxiways, location, and scope of operations) differ significantly, impacting the probability of these hazards manifesting themselves.

Our team identified hazards that could occur with the implementation of Air PALS and grouped them into four hazard categories. The four hazard categories are described below. Within the hazard category descriptions, we address the severity and probability components. We do not go so far as to assign risk values, however, because of the unnecessary complexity this adds to the project at this stage.

- **Human-to-Human Integration Hazards**: Relevant scenarios include two pilots signaling the lights at once, or multiple pilots making approaches in immediate succession that do not allow the system to reset. We analyzed and assessed this hazard as carrying a low probability, but a high severity. Aircraft operations at nontowered airports are rarely busy, in fact, about half of the RIs in one study occurred during a reportedly low activity level at the airport. Still, this figure jumps to 84 percent when moderate activity levels are included, indicating that only a small percentage of RIs occur during high activity-level times at small airports (ASRS, 2003). To minimize the probability of human-to-human integration hazards, if two pilots attempted to activate Air PALS at the same time**,** the control box would recognize and count the additional radio clicks, which would interfere with the number and timing of the clicks required to activate the lights, and the system would not respond. When the pilots do not see the runway lights flash in response to their microphone clicks, this should cue them that someone else may be attempting to activate the lights at the same time, providing feedback and should raise the pilots' attention and situation awareness, signaling the pilot that there is likely other traffic to avoid. Since there are hundreds of specific potential RI scenarios that could occur in the runway environment, Air PALS is designed with a large amount flexibility to provide pilots with a visual cue that alerts them to a potential hazard and allows them to hone in their visual scans on critical areas of the runway *from* *their perspective* to assess the risk so that they can use their piloting skills or communications systems to resolve the situation.

- **Human-System Integration Hazards**: These hazards occur by incorrect interfacing of the human element with system technologies and procedures. Potential human-technology conflicts could result from (1) inadequate training and lack of pilot "buy-in" (intentional non-use) with the system, (2) implementation of sensory incompatible light types or lighting sequences that confound pilots, and (3) implementing system procedures that are incompatible with existing practices. These types of hazard presents the biggest risk because associated errors are common in new systems and can be of greater severity (Sarter, Woods, & Billings, 1997). Operational testing and evaluation will mitigate these risks to an extent. Specifically, prototyping the Air PALS light intensity and flashing frequency would need to be performed at a single airport to work out potential kinks in the program. Beyond this, NOTAMS, Advisory Circulars, other published FAA documents and information recorded on weather transmissions will include notifications and alerts of Air PALS availability. Another feasible risk we can mitigate is one in which complacent pilots use Air PALS as the sole method of conveying runway use intentions instead of using it in conjunction with the proper (and required) radio communications protocol. An FAA-led publicity campaign must emphasize that basic airport flight rules remain in place, and that pilots are encouraged to use Air PALS' flashing lights to bolster situation awareness. It is also important to note that the system defaults to a failsafe condition and that in the absence of the system, the airport would function normally just as it does today without it.
- **System-System Integration Hazards**: These types of hazards occur when the design of our system conflicts with systems inherent in the overall FAA Air Traffic Control system. Such hazards include conflicting function flows in the new and pre-existing system, as well as the new system directly impeding the productivity or safety of the FAA system. As explained in Section 4.1, we considered interference between Air PALS and PCL a low risk, but the issue will need to be continually assessed throughout the evaluation and implementation stages.

- **Mechanical Hazards:** Faults or failures in the actual hardware of the system could result in unwanted actions and repercussions. The physical lighting structures we plan to use are already in use across the country and have proven to be resilient to weather and temperature issues in outdoor environments. Given the nature of light bulbs and electrical equipment, however, maintenance and airport operators will schedule inspections of the lighting system periodically per manufacturer specifications.

5 Interactions with Airport Operators & Industry Experts

As our team was wrapping up our initial literature review, the concentration of efforts was guided towards interviewing and presenting ideas to SMEs of various backgrounds and disciplines. We consulted airport managers, air traffic controllers, runway safety specialists, academics, pilots (both fixed wing and rotorcraft), and airport lighting specialists to provide out team with a very comprehensive understanding of potential uses for Air PALS. Using a variety of specialists helped us to understand the technical and practical aspects of runway incursion mitigation strategies at small airports. The aviation industry experts we interviewed as sources are listed in Table 5-1. Our interactions with them are summarized in the paragraphs that follow.

On September 10, 2009, the project team participated in a brainstorming session at Embry-Riddle Aeronautical University (ERAU). Our team posed questions to ERAU researcher and airport and airspace operations planning expert Carlos Castro, who discussed runway safety design challenges and provided an overview of airport operations and airport signage. Much of the discussion focused on pilot-to-controller communications and the upcoming capabilities associated with the FAA's NextGen project. Primarily, this initial meeting helped our group to define some of the needs that the various airport stakeholders would have in designing a system to prevent runway incursions. Additionally, this conversation reinforced our perception from the literature review that automation technologies to prevent incursions at large airports (such as ADS-B, WAAS, and RWSL) are underway and advancing rapidly.

As a team, we began to consider implementing an incursion mitigation strategy/system compatible with a small-to-midsized airport.

During the latter half of September, members of our group reached out to airport managers in the local area and initiated discussion to identify their perceptions of runway incursion risks at general aviation airports. Roy Sieger, airport manager at Flagler County Airport, Florida, whose nontowered airport handles 190,000 operations per year, described the Pilot Controlled Lighting (PCL) system, some of the methods which airports control and manage it, and various equipment associated with lighting systems at smaller airports with one or two-runways.

Our team took these ideas and spoke with Dave Massey, airport manager at Massey Ranch Airpark, and George Speake, Vice President of Operations at Orlando Sanford International Airport, to generate additional ideas for simple, yet effective ways to utilize airport lighting to help to mitigate runway incursions. Both men appreciated the idea of a pilot controlled alert lighting system for use during uncontrolled hours of operation, and offered insight into lighting system costs. Both experts provided ideas describing how to possibly integrate Automated Surface Observing Systems (ASOS) capabilities into the feedback and system monitoring functions of our design. George Speake detailed many probable RI scenarios (e.g., two aircraft landing on the same runway in opposite directions) faced at a medium-sized airport like Orlando Sanford and helped our team brainstorm several potential mitigation strategies.

On October 14, our team contacted Vincent Cimino with the FAA and discussed the idea of a pilot controlled runway alert lighting system. His feedback proved to be extremely useful in ensuring that our solution did not duplicate features provided by existing solutions such as FAROS and Runway Guard Lights (RGL). Also, he provided insight into the actual cost of these systems, described the process behind research, development, and funding, and explained how these factors affect the implementation of safety systems at U.S. airports.

On October 27 and November 16, our team met with FAA Runway Safety expert Dan Cilli who provided us with guidance regarding the practical execution and evaluation of the project. He offered some practical lessons regarding lapses in situational awareness at airports and related them to small, general aviation airports, the focus of our system. His expertise also pointed us towards a customer-oriented focus and developing as inexpensive a system as possible to improve marketability given the bleak state of local and state budgets for funding airport improvement projects.

On November 10, our team interviewed Perry Suganuma, an airport lighting sales manager, and Phil Rakowski, an airport lighting field service technician, in regards to the integration of lighting systems. They provided background on the hardware needed to deploy our proposed system (radio controllers, circuit boards, constant current regulators, etc.), some associated prices for this equipment and labor to install additional lighting if the system required it. Basically, they explained the technical intricacies of how we would integrate an airport's existing airport lighting and PCL radio-controlled system with Air PALS. There were considerations like how lighting timers work and the overall wattage requirements which our group still needed clarification on in our design discussion and these SMEs were especially valuable to develop our discussion of these issues.

Table 5-1. List of Professional Contacts

Airport Operators and Industry Professionals

Name	Company	Title
Roy Sieger	Flagler County Airport	Airport Manager
George Speake	Orlando-Sanford Airport	VP of Operations
David Massey	Massey Ranch Airport	Airport Manager
Carlos Castro	Embry-Riddle Aeronautical University	Senior Researcher, College of Aviation
Vince Cimino	Federal Aviation Administration	Runway Safety Program Manager, Eastern Region
Dan Cilli	Federal Aviation Administration	Runway Safety Office, South Region
Phil Rakowski	Krause-Hinds	Field Service Technician
Perry Suganuma	Allen Enterprises	ADB Regional Sales Manager

6 Projected Impact of the Design

6.1 Advancement/Commercial Potential

In our discussions with three local airport officials, all expressed legitimate interest in implementing Air PALS at their airports. Two of these three are nontowered airports and one is tower-controlled during most of the day and tower-closed from 9 p.m. to 7 a.m. The primary concern they expressed to the team in regards to the theoretical lighting design was the costs associated with the system. Specific design costs will be addressed in the section 6.2, but generally speaking, we operated under the premise that small airports operate on very tight budgets and receive almost no federal funding, unless the airport is in desperate need of safety (e.g., signage) or infrastructure improvements. A secondary concern was the training of the system – i.e., would the system be mandatory or voluntary? Could the flashing lights confuse pilots? Training is addressed in sections 3.1.4 and 6.1.1 and would be satisfactorily addressed as part of any FAA prototype implementation, such as was used for the FAROS implementation at Long Beach Airport and for RWSL at Dallas-Fort Worth International Airport.

Although we consider the simple “on-off-on-off” lighting function featured with Air PALS as a strength, there is significant potential for future advances for this system. One advancement of this system would be to design a method to alert pilots which runway direction is being used, as this is clearly a cause of small airport incursions and not currently a specific feature of Air PALS. The proposal would be to sequentially flash the runway edge lights in the requested direction for takeoffs and landings. This could possibly be achieved by using a series of radio receivers which could determine which part of the airport the activating aircraft was closest to. For example, if an airplane activate Air PALS while on the west side of the airport facing east ready for takeoff, each runway edge lights would illuminate sequentially from east to west indicating the direction the aircraft was planning to take off. Because of the obvious similarities this has to existing approach lighting systems (ALS), this system would have to be differentiable in some respect from the existing sequenced ALS at airports. By having this technology in place, however it would allow other airport personnel to know more specifically the intentions of the aircraft either about to take off or land. Sequential lighting would increase the situational awareness of other airport personnel in the area by directing their scan/attention in the appropriate direction.

Another similar concept would be to redesign Air PALS as a smart system – Air PALS could interact with the automated weather reporting systems at airports and, based on wind direction, the airport lights would sequentially flash on the recommended departure/arrival side of the runway to make it clear to inbound aircraft which direction they should land. Also, this system would help aircraft identify where to look in the airport vicinity to locate the other aircraft. These advancement ideas stemmed from conversations with airport managers and, according to them, could be included in later versions of Air PALS.

6.1.1 Deployment Timeline and Training Plan

Months 0-6: Purchase, install, and test hardware. Red, omnidirectional light fixtures w/ LED lights will need to be installed along the runway perimeter. The radio control box will need to be customized to respond to a prescribed number of radio clicks. The existing constant current regulator (the type used at most small airports) will require additional wattage relative to the existing PCL system to sustain the flashing requirements. A list of lessons learned will be developed from this process for future Air PALS implementations.

Months 5-6: Provide online training to airport personnel regarding system maintenance and, once active, training on how to activate system from airport vehicles, as needed. Also, develop “FAA Fact Sheet: Air PALS” and develop an online training module as the initial phase of FAA’s test and evaluation process.

Months 6-12: Initiate airport outreach; issue a Notice to Airmen (NOTAM); begin operational test and evaluation at a single airport; solicit post-flight feedback from pilots, particularly in respect to usability, comfort with number of clicks, and light visibility (especially during the day); and ensure the NOTAM is included in the automated (AWOS/ASOS) broadcast at airports.

6.2 Financial Analysis

As previously mentioned, cost is a significant factor in any potential airport upgrade at a small airport, in fact, in these “belt tightening” times, airport development projects are oftentimes the first to get cut by local governments. We conducted a cost-benefit analysis to make an economic case to implement Air PALS.

First, based on interviews with airport managers and lighting system experts, the cost of Air PALS installation is the sum of the initial cost of the pilot controlled lighting system radio control box, associated wiring costs, and the installation of new red runway edge lights (see Table 6-1). Using the same sources, our team estimated an average annual electrical bill and maintenance costs as recurring costs. To further develop the costs associated with the system, we arbitrarily chose to outfit 1,000 airports with Air PALS, representing about one-quarter of all of the paved, non-towered airports in the U.S. A few other costs and some estimates that assume the work would be given to an FAA contractor include: (1) publicity campaign: $75,000 first year, $25,000 subsequent years; (2) online training development: $150,000, $75,000 for subsequent years; (3) fact sheet creation: $25,000; (4) test and evaluation (data collection and analysis at 3-5 target airports): $250,000.

The team proposes that Air PALS’ benefits should be measured in terms of preventing fatalities and crashes. The team used the FAA’s 2008 Airport Improvement Program grant decision-making figures in this process. Because of the aforementioned challenges of FAA-derived RI data reflecting operations at nontowered airports, we used data from nontowered airport accident reports for our cost-benefit analysis. To do this, the team reviewed five years of accident data from NTSB accidents reports spanning from January 1999 through December 2003 (as mentioned in Section 1.1). Accidents the team considered had to occur between two aircraft at nontowered airports, within the runway environment (accidents of the non-movement or FBO ramps were not included). The team identified 16 fatalities, 5 serious injuries, 22 completely destroyed aircraft, and 33 substantially damaged aircraft from a total of 40 collisions on or in close proximity to the runway (NTSB, 2009). These figures were divided by five to derive an annual estimate of deaths, injuries, and damages as a result of aircraft collisions at nontowered airports. Next, we assigned estimated values to each of these variables: $5.8 million for a human life, $333,500 for serious injuries, $172,000 for a totaled GA aircraft, and $35,000 for substantially damaged aircraft (average cost to repair hull damage to GA aircraft) (FAA, 2008b; GRA, Inc., 2007). Once totaled, the NTSB data provided our team with estimated benefits of implementing Air PALS under the premise that these accidents would not have occurred if the aircraft had seen each other.

Clearly, a portion of aircraft mishaps at nontowered airports involve aircraft in which neither aircraft has a radio and may not be able to activate Air PALS. With this in mind, we subtracted a percentage of the "benefit" figure to account for this and other potential limitations of the Air PALS system – in reality, mishaps still will occur because the system was used improperly, too late, or was not seen by the pilots because of a distraction or for some other reason. We estimate this would result in at least a 20 percent drop off in the mishap prevention rate of Air PALS. In other words, for purposes of this cost-benefit analysis, we will consider this system capable of effectively reducing the risk of incursions and incursion-related accidents at nontowered airports in 80 percent of RI occurrences. The team understands that because the Air PALS system is a conceptual system only at this point, we accept that this cost-benefit analysis is highly subjective and tentative.

Nonetheless, given the incorporation of accident data from nontowered airports, this analysis is highly revealing. You can see that although the installation costs would exceed the benefits for the first three years, the very low recurring costs work in favor of the system, amortizing within just 4-5 years. The potential human and property savings alone over 10 years could purchase an additional 1,800 Air PALS systems. Stakeholders could use this data in several ways to either advance more quantities of the system or keep the quantities down and boost the functions of the system.

Table 6-1. Estimated/Projected Annual Costs of Air PALS

Item	Estimated Costs	Estimated Benefits	Total Benefit
PCL Radio Control Box	$2,500		
Red Light Emitting Diodes	$10,000		
Annual Electrical Bill	$1,200		
Light Installation	$30,000		
Annual Maintenance	$2,000		
Total Initial Costs (Approximate)	$45,700		
Total for 1,000 GA airports	$45,700,000		
Training/publicity	$500,000		
First year total	$46,200,000		
Annual costs (train, maint, etc)	$3,300,000		
3.2 Lives saved/year		**$18,560,000**	
4.4 GA aircraft saved/year		**$756,800**	
1 Serious injury avoided/year		**$333,500**	
6.6 Damaged aircraft/year		**$231,000**	
Total Benefit		**$19,881,300**	
80% ROI		**$15,905,000**	
1-Year (B - C)*			**-$30,290,000***
2-Year (B - C)	**$49,500,000**	**$31,810,000**	**-$17,690,000**
3-Year (B - C)	**$52,800,000**	**$47,720,000**	**-$5,080,000**
5-Year (B - C)	**$59,400,000**	**$79,530,000**	**$20,130,000**
10-Year (B - C)	**$75,900,000**	**$159,050,000**	**$83,150,000**

***Figures rounded to nearest $10,000**

7 Conclusion

Air PALS is a system intended to proactively mitigate runway incursions at nontowered airports by providing pilots flying or taxiing near an airport the ability to send and receive visual cues about runway use intentions. Beyond the obvious coordination benefits of this system, there is much more embedded in the Air PALS concept. For example, the runway lighting-based cues reinforce the runway safety mindset and jar pilots out of the complacency that can develop during routine flights. One of the major hazards the FAA has identified as leading to serious pilot errors is acute fatigue as a result of monotony (FAA, 2008b). To mitigate this, the activation and use of Air PALS can help break the monotony of a seemingly routine flight and increase pilot alertness.

Air PALS is a user-centered design concept for several reasons. First, Air PALS was conceived based on discussions with a variety of SMEs and pilots. Second, it is as simple and low-workload to use as clicking a radio mike. Third, Air PALS can bring situational awareness into the cockpits of thousands of small GA aircraft in a very cost-effective manner that other available technologies could not have done. It is our team's hope that the simplicity, affordability, and usefulness of Air PALS will allow it to gain acceptance among even those GA pilots who are averse to new technology. The benefits of Air PALS and its consistency with current pilot practices may sway change-averse pilots and improve their willingness to accept additional changes that will be introduced in coming years.

Appendix A – Contact Information

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Appendix B – Description of University

At Embry-Riddle Aeronautical University, what we do – and do best – is teach the science, practice, and business of the world of aviation and aerospace.

Since it was founded just 22 years after the Wright brothers' first flight, the University and its graduates have built an enviable record of achievement in every aspect of aviation and aerospace. The curriculum at Embry-Riddle covers the operation, engineering, research, manufacturing, marketing, and management of modern aircraft and the systems that support them. The University engages in extensive research and consulting that address the unique needs of aviation, aerospace, and related industries.

Residential campuses in Daytona Beach, Florida, and Prescott, Arizona, provide education in a traditional setting, while Embry-Riddle Worldwide provides instruction through more than 130 campuses in the United States, Europe, Canada, and the Middle East, and through online learning. All academic programs at Embry-Riddle are approved for veterans' educational benefits and are accompanied by personalized academic advisement.

ERAU prides itself for the diverse education its students receive. Academics at ERAU include aviation operations, meteorology, human factors psychology, systems engineering, software engineering, humanities, international relations, communication, mathematics, aerospace engineering, physics, business, and much more. The university community is additionally proud of the quality of the education obtained. Class size at both the Daytona Beach and Prescott, AZ campuses averages 24 students and the overall undergraduate student-faculty ratio at these campuses is 16 to 1. Low class sizes make possible the use of interactive and authentic approaches to learning, such as project-based learning approaches.

The university values community diversity and actively encourages diversity by means of programs aimed to support and provide education about minority groups, including ethnic minorities, gender-identity minorities, religious minorities, students with handicaps, and so forth. The ERAU Office of Diversity Initiatives was created by current ERAU President, Dr. John P. Johnson, to help build a positive climate in which all students, faculty, and employees are encouraged in their professional, social, and intellectual pursuits. Among its many efforts, the ERAU Office of Diversity Initiatives is involved in community outreach programs designed to foster interest in science, technology, engineering, and math among women and underrepresented groups in the K-12 educational system. Pilot projects include a GEMS (Girls Exploring Math and Science) Camp during the summer months and the introduction of an aviation/aerospace program for all 6th graders at Campbell Middle School in Daytona Beach. Both ERAU campuses participate in the Ronald McNair Scholars Program, a program that seeks to increase the number of Ph.D. degrees obtained by students from underrepresented segments of society.

Appendix C – Description of Non-University Partners

Not applicable.

Appendix E: Team Reflections

E-1 Dr. Kelly Neville, Faculty Advisor

The Air PALS team is one of two teams that participated in the FAA's 2009-10 design competition as part of my master's-level Systems Concepts, Tools, and Methods course. Every single member of this eight-person team took the FAA project and their responsibility to their teammates seriously. The Air PALS team demonstrated how much can be achieved and learned when members of a team invest in the joint effort and pull together.

Members of the Air PALS team listened to each other's ideas, questions, and relevant knowledge and, in doing so, they learned about each other's areas of expertise. This diverse team included just two members who know the world of aviation. These two aviators taught their team about aviation and patiently and respectfully made sure their teammates understood the issues so that each member's work and contributions could be useful and on target. A master's level student in computer engineering contributed useful experience about how to work well as a relatively small project team facing a deadline. Other team members—from safety, experimental psychology, and human factors backgrounds—likewise shared their experience, ideas, and knowledge during design brainstorming sessions and in their report contributions. Further, it seemed that team members who had experience writing successful project reports gave the rest of the team confidence and helped them understand how their efforts could all come together into a well-organized, professional-quality report.

The knowledge these students gained about each other's areas of expertise and their receptiveness to learning about the others' areas of expertise were possibly the most fulfilling aspects the FAA design competition for me as the course instructor. I was also pleased to see students on this team making connections between their project work and other course content. For example, one team member wrote an essay for class in which she described strategies she had read about and that the Air PALS team was using. Specifically, she noted their use of 'miniature milestones' and their strategy of reusing and building on good ideas and good system designs versus starting from scratch with a brand new completely untested system design. I believe the team members also gained insight into the uses and relatively usefulness of different engineering analyses and artifacts.

Typical project challenges, such as scope management, deadline adherence, and teammates who aren't doing their part, did not seem to emerge as problems for this team. The team seemed to recognize the potential for these challenges to become problems and they seemed to actively and jointly work on keeping them under control. In particular, the team seemed proud of the friendly relationships they maintained throughout, the way they had scoped their solution to a manageable size and complexity, and the democratic style of teamwork they had adopted.

One challenge the team found frustrating was identifying a solution. In retrospect, the team seemed frustrated that so much time had been spent on understanding the problem space and identifying a feasible solution, leaving relatively little time for them to evaluate and develop the design concept and write a report about the work. They learned from this the importance of interacting with stakeholders early and often—an activity they found useful and seemed to wish they had begun earlier in their work. From this challenge, the team also seemed to learn about the tradeoff that is made by spending time on understanding the problem and design possibilities before choosing a solution versus choosing a solution early and accepting a higher risk of the solution subsequently being found to be redundant with other efforts, unacceptable to key stakeholders, or inadequate.

Participation in this competition was a valuable experience for the students in my class and for me. We all learned more about aviation, runway incursions, teamwork in engineering projects, and everyone learned about each other's areas of experience and expertise. We also got to know a number of very generous and helpful aviation experts and consultants through the project work. I will be asking the students in my 2010 Systems Concepts course to participate in the competition. I hope they will benefit from the 'lessons learned' that the Air PALS team wrote down for them and expect they will identify new lessons to pass down to the next groups of students.

E-2 Maria Appel

Participating in the FAA design competition was a wonderful experience. This project, although quite intimidating at times, was a great learning experience. I came into this design competition in my first semester of graduate school with a B.S. in psychology and no systems engineering experience. The FAA design competition really helped me understand key concepts involved in the early stages of the "systems engineering" process. I believe that this project helped facilitate my learning and understanding of all the different components that are involved with systems engineering more than any other thing we did in the class.

Prior to the FAA design competition, I never worked on a project that involved so much teamwork. I enjoyed this aspect of the project because I really felt like everyone really made an impact on our design. In addition, working with a group of people with such diverse backgrounds was a beneficial experience because everyone brought something unique to the table.

Overall, I think that the FAA design competition was an incredible experience that I will look back at as a turning point in my academic career. I am glad that I got the chance to participate in this design competition because it opened my eyes to systems engineering and it is now something that I will seriously consider pursuing as a career.

E-3 Joseph Crimi

The biggest lesson I learned during the course of this project is teamwork. I was never required to work in large team and this project demonstrated the importance of coordination and team reliability. Working in a team of eight, each person had a specific part to complete for the project. Dividing up tasks and placing your full dependence on another person to complete their part is what makes a team strong. This project simulated a real life situation where different people are going to have to work together towards a common goal. Since this team was comprised of graduate students, I had much more faith in other members to complete their tasks to the best of their ability. Not only did I have the opportunity to learn more about aviation safety and the operation of aircraft on the runway, but this project was a good example of what projects will be like in a career.

With the eight of us coming from different backgrounds, it was interesting to see the impact each of us had on the project. In our group meetings, other members were suggesting things I wouldn't have thought of. With the diverse backgrounds each of us has, we were each able to contribute a significant part to the success of the project.

E-4 Stephen Dorton

Working on this project has given me a great experience and allowed me to grow as a person and a scholar. Being that this is my first semester of graduate work, it seemed at first to be quite a daunting task. Aside from an internship paper I have never worked on anything with such a scale and need for high performance in my life. As the project progressed it seemed much easier of a task to accomplish as we kept dividing and conquering the workload. Of course this came full circle where in the end, when all of the intricacies and what-if questions built up; I realized that designing even a small, simple system for the FAA is in fact a remarkable feat. So much research and application must go into each small change to the NAS. This project helped me realize that with a solid team almost anything can be accomplished. Completing this project has also given me invaluable experience in teamwork. All of my previous undergrad work had me working with people of the same major and similar backgrounds and knowledge bases. This was a great experience to work with people with backgrounds in aviation, human factors, software engineering, psychology, and see how safety (my background) interact and come together to produce a deliverable we can all take pride in. The project work has had a tremendous impact on my work ethic as well as my interpersonal skills with people of various backgrounds. I also learned a tremendous amount about writing papers, conducting research, and built on several other skills that will surely help me in my graduate work.

E-5 Hilary Greenfield

There were eight graduate students, including myself, working on this report. I have never worked with that many other peers on one project before and thought it would be difficult to work in cohesion, but I was mistaken. Each person was open to ideas and brought a different attribute to the project design. We had people with backgrounds in flying, safety, and software engineering, to name a few. We worked well together, and I believe this report demonstrates the type of strength that can be gained with a diverse work group.

Working on this project not only focused the group to work as a team, but also helped us to define goals and keep schedules. Because this report needed to be developed in one semester, we were forced to be strict with time management. Each week we discussed what we had accomplished and what the next step should be, yet we were always encouraged to change the ideas, if needed. Keeping an iterative process helped mold the lighting system into what we have presented. I believe we have an innovative safety design that can be easily implemented in any airport to increase safety.

E-6 Il Hwan Lee

Coming from a software engineering background, I was used to teamwork and familiar with its associated nuances. From this perspective, teamwork usually consisted of a designated leader setting up the goal and schedule while the rest of the group followed orders. However, the FAA Design Competition has shown me that every team doesn’t always have to be this hierarchical. The project was a valuable experience because I was able to work with people who are came from different expertise and experiences. I was able to gain new insights – especially in system engineering – and different approaches to solving and designing a system and system of systems. Furthermore, I have also learned that software isn’t everything – different systems and subsystems consist of more than just codes and modules. Humans are an integral part of the system design and the developers often forget that.

I have also learned a valuable lesson from the team dynamics and integration of parts. It was remarkable to function without having a designated “leader” who just tells his or her team what to do. Under this structure, individuals in the team were empowered to participate and contribute his or her expertise and his or her views to develop and refine new ideas. I have strongly felt that we, as a team, completed the project not for a grade but because we were motivated and shared a common goal. Working towards a common vision and finally achieving that goal was more than satisfying, and I am sure everyone else in the team felt the same way.

The last lesson I learned is that given the lives at stake within an aviation system such as this, a lot of research and work must be done to ensure a simple mistake or overlooked fact does not become a system risk. In comparison to the software designs I’m more familiar with, greater care and attention to detail were required for the project as, more often than not, humans are at risk in the system of aviation.

E-7 Robert Maloney

Thanks to this project, I have a greater understanding of how the system development process works. Our system incorporated a software development process for the project. It was interesting to see how successful it was to apply a software development process to a hardware system.

I was tasked with determining the stakeholders of our system and creating a stakeholder analysis. Most of the documents that I used for references pertained to software development, but with a few modifications I was able to cater it to our lighting system. I also learned how many different stakeholders are involved in some way with the creation of a new system, especially involving a government organization.

This project was also helpful because it opened my eyes to how serious the aviation industry is regarding improving safety. We had to research current systems and devices that are in place to reduce the rate of runway incursions at airports. After this research, I am very confident that this lighting system, in conjunction with the NextGen system technologies, can help to reduce the incursion rate.

I really enjoyed my involvement with this project because it taught me the fundamentals of the system development process. This was an applied project that could possibly have a serious impact on the aviation industry. It was great working with such an amazing group. Each member brought unique skills and knowledge that proved to be an asset to our project.

E-8 Allison Popola

Before this FAA project, I was unaware of current safety systems in place at airports. With no air traffic control or pilot background, the systems were unfamiliar to me, but I found it easy to learn and work with the team to try and come up with a new device. The new system that we are proposing is something that will greatly improve situation awareness and from the subject matter experts that we have talked to, that is a very important thing. Situation awareness is what can lead to preventing or causing an accident on the runway. The subject matter experts were very helpful because they gave us insight as to what problems they face at airports and in the industry of runway incursions and safety.

E-9 Brian Potter

Working on this project has given me great insight into the importance of teamwork and requirements in the early stages of product design. As this team worked through conceptualizing and designing Air PALS it was clear that our diverse interests and backgrounds helped to formulate both a practical and workable runway incursion mitigation solution to a relatively underappreciated sector of aviation – operations at smaller airports. In the field of Human Factors, one underlying premise is that any new system or technology must be designed with a user-centered mentality to be successful. Despite the fact that only two members of this group had flight experience, the perspectives of the non-pilots proved to be an invaluable check-and-balance in terms of design practicality, flexibility, and functionality. In the end, this design has significant potential to make aircraft operating at nontowered airports more safe and situationally engaged.

My belief is that the simplicity and cost-effective nature of this idea is its biggest strength. As the team completed several analyses of our design, the requirement for these two tenets became increasingly apparent given the operational nature of small airports and the uphill budget battles they face in their communities. The opportunity alone to work with several highly enthusiastic airport operators and industry experts over the course of the design process was well worth the effort.

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