Preventing Runway Incursions:

A Vehicle Monitoring and Alert System Using RFID Technology

Team members:

Jessica Scolnic - Graduate Student, Mechanical Engineering

Astrid Veroy - Graduate Student, Human Factors Engineering

David Young - Graduate Student, Human Factors Engineering

Advisors:

Daniel Hannon, Professor of Human Factors Engineering

Maureen Mulcare, Principal Human Factors Engineer and Adjunct Professor

Ashley Russell, Principal Human Factors Engineer and Adjunct Professor

Tufts University

Executive Summary

Runway incursions pose a major safety risk to flights taking off or landing, as well as to ground vehicle operators on airport runways. In 2014, over 1,200 runway incursions occurred nationwide, causing major delays, extraordinarily dangerous situations, and costing airfields millions of dollars. A recent study done by the Federal Aviation Administration (FAA) found that nearly 80% of all reported runway incursions could have been prevented if the individuals involved had better awareness of their surroundings.

This report outlines the development of an in-vehicle alerting system designed with human factors principles in mind. This system was designed specifically to remind ground vehicle operators to pay attention at specific high-risk movement areas of the airfield. These in-vehicle devices are designed to be portable and transferable, so they could be utilized by transient vehicle operators who may be less familiar with the airfield. The alerting devices were tested with a group of users to determine the most effective visual and audial cues to aid participants in stopping at required hold lines. If commercialized, these alerting devices would be integrated with a system of Radio-Frequency Identification (RFID) transmitting/receiving beacons. The beacons, when placed at the lead up to high-risk movement areas, would trigger the in-vehicle alerting devices when vehicles drive past the beacons.

This system was designed for use in General Aviation airports with no surface-radar or GPS monitoring systems in place. Because the target market is the GA airport community, cost was a huge factor in designing this system. The cost to outfit the largest GA airport in New England was determined to be only $18,000, which is extremely inexpensive compared with other products on the market detailed in the report.

In addition to the team’s design process and motivation, this report details potential benefits this technology could provide to the industry. Also, the usability studies conducted are also described in detail, including positive results indicating participants who were aided by this device stopped for hold lines more frequently than those who did not use the device. Finally, conclusions about the work and future recommendations are made, including detailing the steps that would be required to bring this product to market.

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1. Problem Statement and Background on Design Challenge

a. The Competition and Design Challenge Area

The Airport Cooperative Research Program (ACRP) is sponsoring a national competition for universities to design solutions addressing issues encountered in airport operations and the National Airspace System. The issues fall into four broad categories: Airport Operation and Maintenance, Runway Safety/Runway Incursions/Runway Excursions, Airport Environmental Interactions and Airport Management and Planning. A team or individual should design a solution that addresses a specific issue in these broad areas. The competition aims to increase the involvement of the academic community and encourage students to provide innovative solutions to address issues faced by airports around the country.

The purpose of this project is to design a solution to address the issue of Runway Incursions. Specifically, this team chose to design a solution addressing runway incursions involving ground vehicles at General Aviation (GA) airfields.

b. Runway Incursions Background

Runway incursions pose a major safety risk to flights taking off or landing, as well as to ground vehicle operators on airport runways. An incursion occurs whenever something on the ground interferes with an airplane that is in the process of an Air Traffic Control (ATC) approved takeoff or landing. This could be a vehicle, person, object, or even another plane. With twenty incursions for every million runway operations, the situation may not seem dire. However, considering steadily increasing air traffic volume nationwide, frequent radio congestion, and sometimes outdated airport infrastructure, the rate of incursion is only likely to increase in coming years if attention is not paid to the issue.

Runway incursions are classified by type according to one of three categories: Operational Incidents, Pilot Deviations and Vehicle/Pedestrian Deviations. Operational Incidents are attributed to Air Traffic Controller (ATC) action or inaction. Pilot Deviations are actions of a pilot that violate any Federal Aviation Regulation. Vehicle/Pedestrian Deviations are defined as any entry or movement on the movement area or runway safety area (RSA) by a vehicle or pedestrian without authorization from the ATC. Movement areas of the airfield are the taxiway and the runway. The runway safety area is an area that surrounds the runway, measured from the runway ends and center line. It functions much like the shoulder on a highway, for use by aircraft in emergency situations.

A recent study done by the Federal Aviation Administration (FAA) found that nearly 80% of all reported runway incursions could have been prevented if the individuals involved had better awareness of their surroundings. Airport layouts can be complex, and visual impairments due to weather or obstructions makes the jobs of runway operators much more difficult. Operators must keep track of the positions of aircrafts and ground traffic, as well as routes of travel on runways, not to mention all their other responsibilities. Cognitive load increases to an unmanageable level, and accidents happen.

2. Summary of Literature

a. Literature Review Focus

Our main focus for conducting the literature review was researching existing solutions for the problem of runway incursions. We relied on personal interactions with industry experts and airport operators to gain background on communication chains and in-situ actions and reactions. Our literature review largely focused on elucidating the motivation for investing in this project, as well as current products available. Below are the results of our literature review.

b. Motivation

The FAA recently set goals aimed at reducing the severity, number, and rate of runway incursions. In order to do so, a number of different strategies have been considered, including technological and infrastructure improvements as well as procedural and training interventions. The FAA, along with thousands of independent companies, is working to understand and develop feasible, cost-effective technologies to help reduce incursions. Among the measures that have been implemented are 1) publication of guidance materials, 2) installation of improved signage and markings, 3) installation of improved lighting systems, and 4) availability of new tracking and monitoring software.

c. Existing products

One example of an improved lighting system that is currently operational in nine U.S. airports is called the “Runway Safety Lights (RWSL)” system. The system was designed to be compatible with existing procedures and makes use of current Runway Entrance Lights (RELs) and Takeoff Hold Lights (THLs). The system is intended to reduce the number and severity of runway incursions by automatically turning runway or taxiway lights red when other traffic creates an incursion hazard. Currently, 17 airports across the U.S. have, or have been designated to receive RWSL.

Figure 1: Runway Safety Lights.

Another improvement to airport lighting systems being promoted by the FAA is called

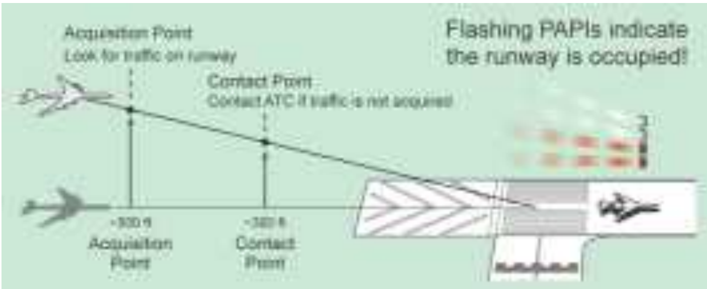


Figure 2: FAROS.

Final Approach Runway Occupancy Signal (FAROS). The FAROS system is comprised of a single row of 4 lights that turn red when it is unsafe for an approaching aircraft to land. FAROS ties into to the automatic signaling found in the RWSL.

Other solutions have been developed to aid with tracking ground movements. The series of Airport Surface Detection Equipment/Airport Movement Area Safety System Models (ASDE/AMASS) provide a variety of visual and audial aids to controllers. For example, ASDE-3/AMASS is radar-based, and tracks ground movements in order to detect potential collisions. The FAA has installed this system at the U.S.'s top 34 largest airports. However, this system only provides alerts to controllers. Another model in the same series, the ASDE-X provides more detailed surface detection information, sourced from a variety of different sensing technologies. This system not only provides accurate location information, but also identification information, so the controllers can know exactly what vehicles are involved in potential collisions. The ASDE-X system is currently in place at 34 U.S. airports.

Figure 3: ASDE.

One technology currently being investigated is titled the Electronic Flight Bag (EFB) with Moving Map Displays. This technology is specifically for pilots to increase their situational awareness. This technology has been funded via an agreement between the FAA and several U.S. airlines, to investigate the effectiveness of in-cockpit runway safety systems.

Figure 4: Electronic Flight Bag.

As for runway incursion warning systems, a company called Exelis has a product line called Symphony that is currently in use at Logan airport, part of the Massport system in Massachusetts. The Symphony V-MAT is a Universal Access Transceiver (UAT) Automatic Dependent Surveillance-Broadcast (ADS-B) vehicle tracking unit. It provides precise, real-time tracking of ground vehicles in the airport movement area. It is compatible with the FAA's Next Generation surveillance technology ADS-B. The V-MAT shares ground vehicle position, velocity and identity with other ground vehicles, aircraft and ground station equipment. It obtains this information from an internal aviation-certified GPS and compares the position with a stored configuration map provided by the FAA. If the V-MAT is within the movement area, it transmits its data once per second. Its components are fully compliant with FAA standards and each unit costs $8,000.

Figure 5: V-MAT unit.

All vehicles that use the V-MAT automatically get their movement data integrated into the accompanying products, the Symphony MobileVue and OpsVue. The MobileVue allows operators and operations management personnel to see aircraft and vehicle surveillance data on a portable device.


Figure 6: Symphony MobileVue

Other companies and government organizations, including NASA, have even tried to come up with solutions to the problem of runway incursions. NASA proposed a very complex system that utilized some existing technology already found on aircraft, but also included new systems that would be expensive and time consuming.

3. Team's Problem Solving Approach to The Design Challenge

a. Problem Solving Approach

Figure 7: The team's design process.

Our team took an interdisciplinary approach to solving the problem of runway incursions. Having both human factors engineers and a mechanical engineer on our team meant we had expertise in hardware design, user interface design, and human factors. We were able to use our varied strengths during each phase of the process. Our design process consisted of the following activities: 1) obtain user needs, 2) develop product concepts, 3) develop an initial prototype, 4) obtain feedback regarding the prototype, 5) refine prototype 6) develop and conduct usability studies, and 7) develop a final product proposal. Specific actions taken at each step to inform our design, including the expert feedback process, are detailed below.

b. Individual Responsibilities

The members of the project team have the following responsibilities and perform the following roles:

Name	**Astrid Veroy**
Job Title	Project Manager
Qualifications	Astrid has over 7 years of project management experience in software development. As a Human Factors Engineering graduate student, she is well-versed with operator issues such as situational awareness,

	complacency and safety.
Role	The Project Manager has overall responsibility for project execution. The Project Manager monitors progress and is the primary communicator for the project. Astrid brings to the role of Project Manager her exceptional organizational and communication skills, as well as attention to detail. She likewise adds a human factors perspective to the task of addressing airport operations and safety issues.

Name	**Jessica Scolnic**
Job Title	Hardware Design Lead
Qualifications	Jessica is a Mechanical Engineering graduate student and has studied hardware design and modeling extensively. Her thesis involves design and production of an educational robotics platform.
Role	The Hardware Design Lead is responsible for all hardware-related technical aspects of the project, and ensuring that the project is implemented in a technically sound manner. The Hardware Design Lead is responsible for all hardware-related designs, overseeing the implementation of the designs and preparing relevant documentation. This role requires close communication with the Project Manager. As the Lead Hardware Designer, Jessica brings her Mechanical Engineering design skills to the project. Her knowledge of electronics will be helpful in the design of the in-vehicle alert device.

Name	**David Young**
Job Title	User Interface Design Lead
Qualifications	David has a degree in Graphic Design and has over 11 years of experience in designing user interfaces for websites and for visualizing complex data. Recently, David has been working with scientists and engineers in the field of aviation as part of his work at Charles River Analytics.
Role	The User Interface Design Lead is responsible for all user interface - related technical aspects of the project. The UI Design Lead is responsible for all UI designs, overseeing the implementation of the designs and preparing relevant documentation. This role requires close communication with the Project Manager. David brings his extensive user interface design skills to his role in the project. His knowledge and familiarity with aviation ensures a deeper understanding of runway safety issues.

c. Project Organization

Figure 8 shows how the project team is organized, as well as the flow of information to and from the parties involved in the project.

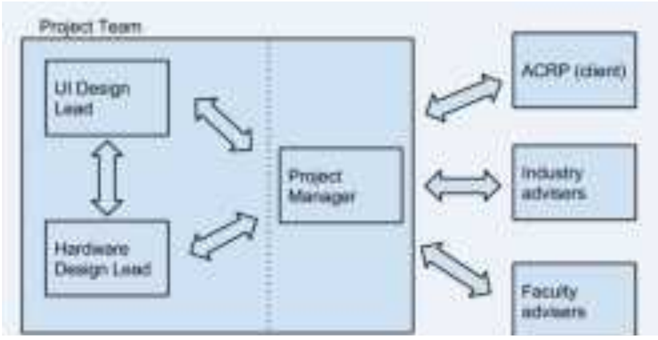


Figure 8: Team Organization and Information Flow

All team members can communicate directly with another member of the team internally. On the other hand, communication with external parties is handled exclusively by the Project Manager.

d. Obtaining User Needs

The team employed a number of methods to obtain user needs for this project. Our first step was to consult industry advisors provided on the competition site, as well as to contact the Virginia Space Grant Consortium (VSGC) to ask for assistance. We determined the advisors whose field of expertise was runway safety or incursions, and were able to select three names from the list. We proceeded to contact them by email and present our first concept for addressing runway incursions. The idea was in its initial stages, and was mainly used as a starting point for conversation. We found we received better responses by reaching out with a proposed idea, rather than asking for general communication. One of the advisors we contacted, Alex Gertsen, was able to share a lot of information about the issue. Through several emails and conference calls, Alex pointed us in the right direction and guided us to further research on the technologies that are currently being used for runway incursion warning systems. Alex also put us in touch with Massport officials in Logan airport and Hanscom Field. The Logan

Figure 9: The VSGC was contacted.

officials shared information regarding the state-of-the-art technology they currently use. They also suggested a direction of our focus to General Aviation (GA) or smaller commercial service airport facilities that do not have surface movement radar. We also discussed switching the function of our product from emergency alerting to boundary proximity alerting.

We then met with Keith Leonhardt, the Massport Operations and Maintenance Manager at Hanscom Field, the second largest airport in New England, that is used mainly for GA. The discussion confirmed our decision to focus our efforts on a GA airport and on boundary proximity alerting. It also brought to light other issues such as vehicles that may be on other parts of the airfield such as lawns and grassy areas bounded by the movement areas. Details of all interactions with industry experts can be found later in this report.

e. Assessing User Needs

Assessing user needs for our project was tricky, and depended largely on our limited number of visits with industry experts. We have relied heavily on discussions with airport administrators, inside looks into runway monitoring systems, and an observation session conducted with Keith as he drove on Hanscom airfield. We also drew heavily on our literature review and assessing the solutions currently on the market. After meeting with Keith at Hanscom, we chose to narrow the focus of our project to GA airports such as Hanscom. We chose to use Hanscom airfield as an illustrative example for the system we developed. With these constraints in mind, the user needed identified and assessed throughout the project are:

Figure 10: In-situ observation: driving on a runway at Hanscom Airfield with Keith Leonhardt.

1. Users need to be reminded when they are approaching an important junction or barrier (such as a runway/taxiway intersection, or a grass/pavement barrier.)
2. Any alerts must be heard over the noisy atmosphere on the runway.
3. Any locating system must be updating and alerting quickly enough to be relevant when a ground operator is driving at 60 mph down the runway.
4. The system must identify different vehicles with different purposes. For example, the mower's alert system will behave differently than that of a snow remover.
5. Users cannot be alerted when engaging in "ordinary behaviors" that are approved by ATC, unless they are in danger.
6. Normal operations of users must be enhanced, not interrupted. For example, communications with ATC should not be interrupted.
7. Users need to be able to see where they are going and read all possible signage, including road markings.

f. Concept Development

From the information we obtained from the ACRP competition website, independent research and our conversations with airport operators and industry experts, we were able to develop a number of concepts. Through many brainstorming and creativity sessions, we narrowed the focus of our product and zoomed in on the most important functions of our potential product. These concepts are discussed later in this report. The final concept selected involves portable, in-vehicle alerting devices to ensure ground vehicle operators are paying attention at areas of high risk of incursion, such as hold lines. These alerting devices will have both visual and audial cues determined by human factors research and tested in usability testing sessions.

g. Prototyping

After deciding on our concept, we developed two low resolution, low fidelity prototypes. These two prototypes were brought to our meetings at Logan and Hanscom in the hopes of sparking conversation and obtaining “gut reactions” to one particular concept. These prototypes are described in more detail below. These prototypes served as the basis for the development of the next level of prototypes, which were used in the usability testing.

h. Usability Testing

In order to determine the specifics of the visual and audial alerting device, usability testing was required. The motivation for usability testing was three-fold:

1. Determine viable visual alerting cues
2. Evaluate the effectiveness of audial cues, and
3. Receive subjective feedback from potential users

The participants we recruited for the study were at least 18 years of age and had a driver’s license. The setup for the study involved the use of a driving simulator (X-Plane 10), driving controls (a steering wheel and foot pedals), and a simulator for the in-vehicle warning device (iPhone 6). Refer to the figures below for reference.

Figure 11: Usability Testing Setup

The setup was designed to mimic an actual ground vehicle driving scenario. X-Plane 10 is a low-cost flight simulator and it was selected for its facility to be customized according to our requirements. The software was modified to simulate a ground vehicle as opposed to an aircraft. This was achieved by building a custom vehicle dash and modifying cockpit dials to show a ground vehicle. Additionally, the physics of the vehicle motion was hacked to more accurately represent the motion of a ground vehicle as opposed to a plane. Moreover, the scenery was customized to show the Hanscom Airfield environment. Appropriate environmental objects such as signage and markings were created. Lastly, the steering wheel and pedals were configured to function correctly with the simulator. The following figure shows the path that the participants drove during the usability test.

Figure 12: Driving path for participants during the usability study.

The various components comprising the alerts that were tested for the in-vehicle device were selected after careful deliberation. First, the number of appropriate warning stages was determined. The system could be a cautionary (2-stage) or imminent (1-stage) type. Cautionary warnings are made in advance of imminent warnings. Each has its own set of considerations for use. A single stage avoids driver confusion with a 2-stage alarm and has fewer nuisance alarms. On the other hand, a 2-stage alarm may help drivers develop a better mental model of the system and may reduce startling effects due to a single stage. We decided to implement the alerts in 2 stages.

Visual alerts are effective at conveying non-urgent information and spatial information. However, they are not good for conveying urgent information. The type of visual display that has the best rating for both cautionary and imminent warnings incorporates a symbol/icon strategy. These are simple graphic signs that convey information. For the symbolic icons selected for use in usability testing, reference Figure 12 below.

The discrete type of display has good ratings for cautionary warnings but no data exists for imminent warnings. Discrete displays are simple LEDs that lack symbolic content. For the discrete displays used in usability testing, reference Figure 13 below.

Audial alerts are useful for getting the attention of a driver who is distracted or has looked away from a visual alert. They are also good for urgent or time-critical messages. Precisely because they are effective in catching the attention of a distracted driver, they are obtrusive and are not advisable for frequent warning messages as they can be an annoyance. The types of auditory alerts that have good ratings for imminent warnings are the simple tone and the auditory icon. A simple tone is defined as a “single or grouped frequencies presented simultaneously”, for example, a square wave. An auditory icon is characterized as familiar sounds that transmit the information about the thing they represent.

Figure 13 shows the visual alerts and representation of audial alerts that were used in the usability study.

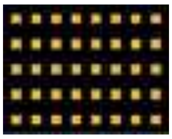
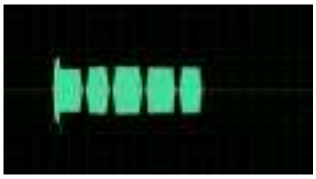
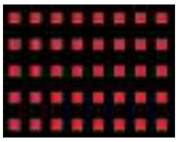
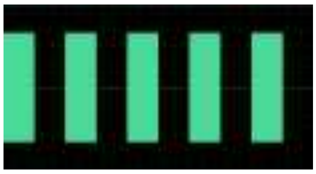
	Visual Alerts - Type 1	Visual Alerts - Type 2	Audial Alerts
	Discrete	Symbolic	Sounds
Warning			
Imminent			

Figure 13: Visual and audial alerts used in usability testing.

The usability study was done in 2 phases. The first phase sought to determine which of the visual alerts (Symbolic or Discrete) was more effective in making participants stop before the hold line. That type of alert would go on to the second phase where it would be tested again, this time alongside no alert.

An abbreviated roadside training session and quiz was conducted to prepare subjects. Participants were also given an opportunity to practice driving to acclimate to the physics of the simulator. Participants then completed the two driving tests. Lastly, subjective feedback was obtained from the participants in the form of a post-interview.

Results from the usability testing were extremely positive. Phase 1 results showed that the symbolic type was more effective than the discrete in getting the participants to stop before the runway hold line. Phase 2 testing showed the effectiveness of the Symbolic visual alert over no alert. Some limitations to our usability testing exist, such as using laypeople rather than airfield vehicle operators. Also, some bias was introduced to participants due to the roadside signage preparation immediately prior to the usability testing. However, these positive results indicate that moving forward with this concept to future stages is warrented.

4. Interactions with Airport Operators and Industry Experts

The runway and airport situation has many players involved in a complex and rich communication network. There are a lot of groups of stakeholders who are involved with runway operations at different levels of immediacy and importance. We found it necessary to discuss with people in as many different groups as possible, as well as industry experts who are no longer directly involved with runway operations but have perspective that can only be gained from a distance.

a. Interaction 1: Conference Call with Alex Gersten

Alex helped fill in a lot of the motivation for our project. He explained that while the number of nationwide incursions per year (~1200) seems low to non-industry personnel, the FAA and field experts still view incursions as a big problem. Even reducing a small percentage of those incursions, such as the ~200 caused by ground vehicles, would be a big accomplishment. The FAA and other industry financing agencies pour millions of dollars each year into investigating ways to reduce incursions. Alex also gave us background on the communication chain on the runway: he explained that for air traffic controllers (ATC), decision making is difficult and time consuming. Adding in reaction time by pilots or ground vehicle operators makes the whole process of communicating hazards and incursion avoidance directives much too slow. He suggested that direct communication or alerting to vehicle operators would be helpful to them, in the event that they are not paying attention, or the ATC cannot communicate information in a timely fashion. He also expressed thoughts that vehicle operators have a lot of noise and distractions around them, so we should think carefully and do a lot of research about the types of alerts we provide, should we go that route. He suggested having visual and audial cues to ensure emergency messages are heard. Alex also put us in touch with administrators at Logan Airport and Hanscom Airfield so we could proceed with the next stage of our user analysis.

b. Interaction 2: Visit to Logan Airport, group interview in administration room with Flavio Leo (Deputy Director of Aviation Planning and Strategy of Massport), Vincent Cardillo (Deputy Director of Operations), and Robert Lynch (Airport Operations Manager)

Flavio, Vincent and Robert were very helpful in demonstrating the administrative level of operations at Logan Airport, which is the largest airport in New England, and the 18th busiest airport in the country. 31.6 million passengers traveled through Logan in 2014, and operations are taken extremely seriously. Our conversation covered many topics, such as the roles each of the men play in runway operations, the current tracking system the administration uses, and some of our initial concept ideas. Vincent first detailed his role as Deputy Director of Operations--he has a team that works 24/7/365 on making sure the runway operations are safe and efficient. His team consists of shift managers who are in charge of safety (Robert Lynch is the head of this team of managers), supervisors who take care of customer service, and a communication and dispatch center making sure that planes and ground vehicles are moving appropriately.

The technologies used to track and manage runway vehicles are sophisticated and expensive. The operations administration has invested in mobile and computer versions of Symphony, the tracking and management software described above. They use a customized setup with specific colors for Massport ground vehicles, arrivals and departures--the vehicles all move around on three extremely large monitors in the control room of the airport administration offices. The team also said the software is customizable in many other ways, and can give alerts for taxi time, diversions, and other abnormalities in runway movement. Logan has all different surface sensing and ground tracking technology, utilizing everything from ASDX to ADSB to ASD. These different systems (described in more detail above) provide information at varying response times and to various groups of people, with ASD being the slowest but providing information to everyone.

Our conversation continued as we brought out our low fidelity, low resolution prototypes to spark discussion of some of our preliminary ideas. One of the most interesting moments happened as the three men began to argue about what color some of the runway lights were, suggesting that this could be a space where improvement is needed. Flavio also informed us that the space where a lot of companies are investigating is the question: “How do you determine if there is a serious risk or a normal situation?” He said that this is the “million dollar area” right now--companies are investing huge amounts of money to build software and sensing technology into all of the existing, sophisticated systems already in place to meet this need.

Our meeting with the Logan officials was extremely helpful in narrowing the focus of our problem. Seeing the amount of time and money Logan has already invested in current systems made us realize if we were to create a product for them, it would have to integrate seamlessly. We became curious about seeing a smaller airfield, and hearing from officials there, to begin to understand the differences in the situations.

c. Interaction 3: Meeting and Observation with Keith Leonhardt (Operations and Maintenance Manager, Massport Hanscom Field)

Our meeting at Hanscom airfield with Keith was very productive in allowing us to understand smaller general aviation airports. Hanscom is the second largest airport in New England, with over 134,000 air operations last year (and Keith assured us this number is low.) Keith is in charge of all ground operations, including 34 vehicles performing snow removal, landscaping, pavement repair, light and signage maintenance and more. Keith has an in-depth knowledge of runway operations, especially at Hanscom. He told us they have no ground tracking program (like Symphony) because they have no need--they can see everything on the airfield. They also have an extensive training program for all ground vehicle operators. To facilitate knowledge transfer, all ground vehicles communicate on two radio frequency channels. One channel is solely for vehicles, including planes, to keep track of placement and timing of vehicles using the runway. The other channel is for ground vehicles to obtain clearance to enter movement areas such as runways or taxiways. Keith emphasized that although they have working systems in place, accidents definitely do happen. He stressed that ground vehicle operators can just forget to ask for clearance, and enter restricted areas unannounced. Other times, vehicles are cleared to do an inspection on a runway, and a plane is cleared for take-off right behind. Timing is precise, and in situations with multiple vehicles, it can get messy.

We then inquired about transient vehicles on the airfield, because we had gotten the impression that transient vehicles on the runway could be unfamiliar with the airfield and therefore more likely to make errors. Keith confirmed this, and informed us that 90% of transient vehicles that come to Hanscom are escorted around by local vehicles. However, that last 10% could be administrators from other Massport airports, such as Flavio from Logan, or state troopers. These visitors check in, but do not need to be escorted around. They are completely legally able to drive around, but since they only visit periodically, they may be unfamiliar with the runway area, and therefore more likely to cause an incursion.

After our conversation, we joined Keith for a drive around the runway and taxiways to observe him in action. Keith got approval for certain routes from ATC, and then we drove around the taxiways and parking areas a bit. Keith pointed out an area that changes from taxiway to runway at a strange angle, and told us that sometimes private planes end up on the runway at this junction without clearance and by accident. After this, Keith drove about 60 mph down the middle of the runway, after he got clearance from ATC. We observed signage and ground markings as we drove.

Keith explained to us that as operations manager, he has sort of a blanket pass to go wherever he wants on the airfield--the ATC will give generally always him clearance as long as he alerts them. However, other more specialized vehicles do not have this privilege. They may have specified routes laid out, or only have clearance to be in one particular area. Hanscom has recently invested in a system for their iPads that will allow ground vehicles to put in work orders from the runway field more instantaneously.

Keith expressed some thoughts on potential focus areas for any system. First, he expressed concern for vehicles not on taxiways, but on grassy areas in between the pavement, such as mowers. These vehicles have a designated area, and often times have a hard time seeing when they are nearing the boundary between grass and pavement. Secondly, Keith expressed curiosity about a silencing feature for whatever alerting system we create--for instance, if vehicle operators are being notified too frequently, or do not need the system. Keith also reminded us that sometimes he has to stop on the runway to pick something up or take measurements, so whatever system designed would have to understand when this is acceptable and when it is not.

5. Technical Aspects of the Design Challenge

a. Different Design Concepts Generated

One idea was to incorporate an intricate lighting system that would tie directly into existing runway and taxiway lights. We initially thought that utilizing existing lighting systems would help reduce cost and lower operating expenses. However, after looking into the complexities of doing this we discovered that 1) The current housings used would not support additional hardware and 2) There was no real cost savings in doing such a thing. This concept also incorporated a method by which a vehicle could communicate with the airport lighting system. The communication device that we originally imagined was a custom application that incorporated the Global Positioning System (GPS). We knew that GPS was already being used on-board aircraft and the technology has matured enough to be accurate enough for our needs. Our reason for not pursuing GPS beyond this design concept was that integrating with the existing GPS system is already being undertaken by companies who have invested huge amounts of money into it. It would not make sense to compete with them at this level.

Another communication option considered was using the new “iBeacon” system. iBeacon uses Bluetooth low energy proximity sending and has three ranges:

1) Immediate: within a centimeter
2) Near: Within meters
3) Far: Greater than 10 meters and up to 450 meters (1,350 ft)

iBeacon has the ability to approximate when a user has entered, exited, or lingered in a region for a period of time. Using iBeacon technology could be very cost efficient due to a recent push by major mobile device manufacturers to put the technology in their devices. This means that a vehicle operator could place his/her mobile device in a standard window-mounted holder and receive information using iBeacon. One unique feature about iBeacon is that the beacons themselves do not push notifications to devices other than the beacons identity. Software on the

Figure 14: iBeacon concept.

operator's mobile device uses the signal received from the iBeacon to trigger push notifications. Push notification would allow for new content (alerts) to be sent to the operator's mobile device without any need to interact with the device itself. To complete the system, a network of iBeacons would need to be placed in strategic location around the airport. These iBeacons will allow vehicle operators to see their proximity from controlled locations. The mobile device will have an active application that will present to the operator information such as their current location on a taxiway or runway, or how far away they are from key locations such as hold points. It could even send alert messages.

The main reason the iBeacon system was discarded was information provided by Keith at Hanscom airfield. Keith informed us that regulations mean whenever an iPad, iPhone, or other mobile device with a screen is in use in a ground vehicle, a second employee must ride as a passenger in the vehicle to interact with the device. This meant the iBeacon system would be inefficient and not actually do anything to alert the driver to high-risk areas.

b. Selected Concept

The concept we ended up choosing involves an in-vehicle alerting system equipped with Radio-Frequency Identification (RFID) tags along with a network of two-way radio

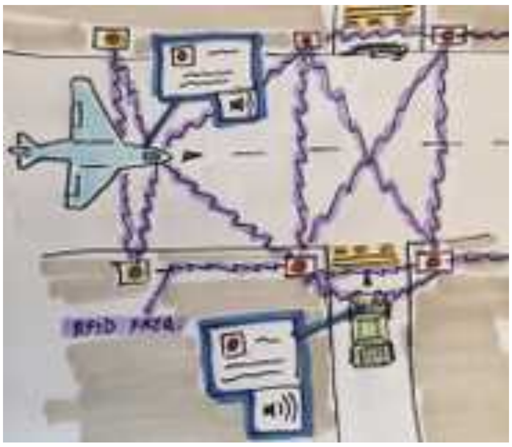


Figure 15: Initial RFID system concept.

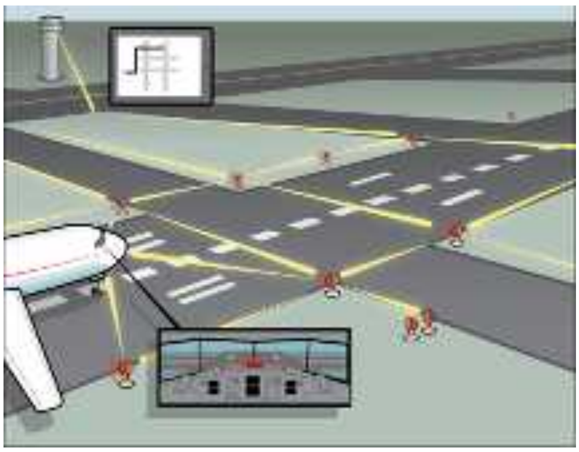


Figure 16: Final RFID system sketch.

transmitter-receivers known as interrogators or readers. These transmitter-receivers send a signal to RFID tags within proximity and they read the responses sent back from the tags.

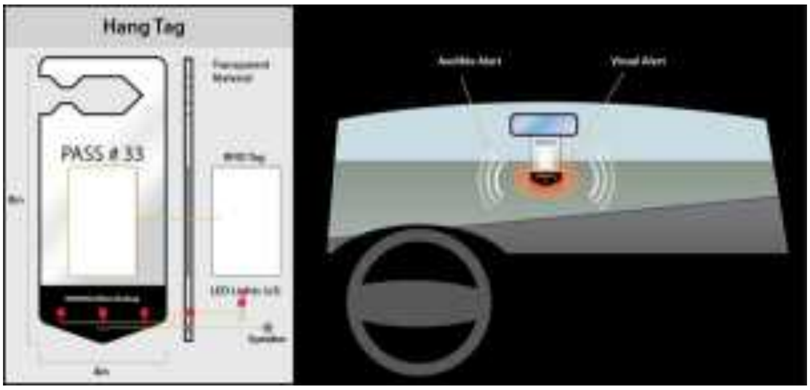


Figure 17: Preliminary hangtag design and in-vehicle view.

The RFID tags can be active, passive, or even battery-assisted passive. Active means the tag is internally powered and sends periodic identification signal, while passive requires the power sent by the transmitter-receiver to activate the tag and respond back. The battery-assisted version only activates when in it is within range of a reader. The actual tag type we would use had not been determined at this point as all three were viable options. Whichever tag used would be contained in a custom housing. The housings that we explored are rearview mirror mounted and dash-mounted. The rearview mirror housing acts as a hangtag and contains a speaker, integrated circuit, lighting/visual alerting system and the RFID tag. The dash-mounted display incorporates the same hardware as the hangtag, but is intended to sit on a flat surface inside a vehicle. Both models are portable, so they can be picked up and dropped off as needed by transient vehicle operators.

c. Final Product Concept

Figure 18: Preliminary design for dashboard mounted device.

We propose using a system that would incorporate active radio-frequency identification (RFID) tags and a driver notification system to help reduce vehicle incursion rates. The system will be powered locally. Transient vehicles on the airport grounds can pick up one of our portable devices upon entry to the airfield. Each device contains an RFID tag and notification system. Once a vehicle enters into an important safety zone, or movement area of high risk of incursion, there will be a network of two-way radio transmitter-receivers that send a signal to the RFID tags and activate the visual and audial alert system. The in-vehicle notification system will alert the relevant driver with symbolic visual cues and sound. Since this system will operate independently of all other communication methods, it eliminates human-caused lag (eg: the control tower operator recognizing the problem and taking a moment to decide who to call, and then making the call) and alerts the vehicle operators to sensitive situations requiring their attention immediately.

The visual and audial alerting cues to be used in the vehicle were determined through the usability testing outlined above. The symbolic visual cues were found to be most effective at alerting users to the necessary action of stopping, and so they were selected for use in the final product. The hangtag model is illustrated below. If clients desired, an additional dashboard model, adapted from the initial design presented above, would be designed. However, that would require additional user testing, since only the hangtag model was tested in this study. Additionally, the distances at which each symbol would appear could be customized based on prefer ences of individual client airports.

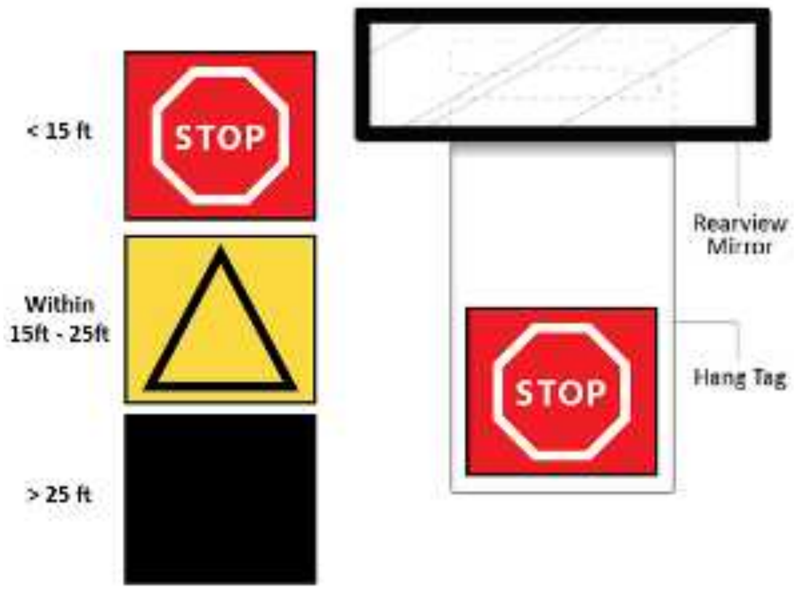


Figure 18: Final design for hangtag symbolic alerting device.

6. Safety Risk Assessment

In line with the guidelines outlined in the Introduction to Safety Management Systems for Airport Operators (FAA Advisory Circular 150/5200-37), the safety risks for introducing an in-vehicle warning device were assessed. The 5 Phase assessment system recommended in the above circular was used to assess the safety risks in the runway incursion situation. Below is the process used to complete the 5 Phase assessment.

Phase 1: Describe the System

- Runway environment at GA airports without surface movement radar
- Existing driver training programs
- The use of escorting drivers for transient vehicles
- Air Traffic Control (ATC) Tower
- Signs, markings, and lighting of taxiways and runways
- Ground vehicle operators
- Runway operations personnel

Phase 2: Identify the Hazards

- Ground vehicles crossing the primary runway
- Ground vehicle drivers who may be distracted by the multitude of stimuli in the vehicle and runway environment

Phase 3: Determine the Risk

- Major: Aircraft hitting the ground vehicle on the primary runway
- Secondary: Near accidents, including vehicles driving on the runway without clearance

Phase 4: Assess and Analyze the Risk

Using the Predictive Risk Matrix, there is a remote chance that a ground vehicle would deviate from prescribed guidelines and cross the primary runway without an escort or clearance from the ATC. The likelihood of a transient vehicle crossing the runway and causing an incursion is therefore *remote* or *extremely improbable*, but the severity of such an event would be *catastrophic*.

The current practice of relying solely on the vehicle operator to hold short of runways must be mitigated.

Phase 5: Treat the Risk

The risk may be *controlled* by using an in-vehicle warning system. This would help transient ground vehicle operators be more aware of approaching a runway if they are distracted or unfamiliar with airport signage and rules. This would also apply during low-visibility instances such as inclement weather.

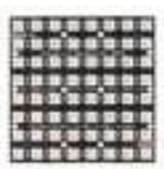
7. Projected Impact

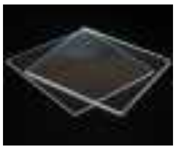
a. How the Design Meets FAA Goals

According to the 2009-2013 Flight Plan, the first goal of the FAA is to increase safety: "to achieve the lowest possible accident rate and constantly improve safety." The third objective under this goal is to reduce the risk of runway incursions. The FAA intends to achieve this objective by implementing key runway incursion reduction technologies, among them Low Cost Ground Surveillance (LCGS) systems. Our design solution focuses on meeting this goal and specific objective by providing a comparatively low-cost option to aid ground vehicle operators' awareness of the approach to a runway hold line. With more awareness, the ground vehicle is more likely to recognize the need to hold short of the runway, thus decreasing the risk of a possible vehicle/pedestrian deviation. With further testing and research to develop this solution, the FAA can achieve increased safety goals.

b. Cost Analysis

Our proposed solution was created with cost as an important factor. Small, movable devices are important to ensure that all airport personnel (even transient help, like snowplows) have access to the boundary proximity notification system. The cost of one possible low-cost implementation of the system is outlined in the figure below:

RFID Reader, Physical Hang Tag & RFID Tag				
Reader (Qty 1)				
Item	Image	Description	Quantity	Cost
ThingMagic M6e Reader		UHF RFID	1	795.00
Weatherproof Reader Enclosure		Clear	1	9.95
			TOTAL	$805.00
Vehicle Hang Tag (Qty 1)				
Item	Image	Description	Quantity	Cost
Micro controller		84 MHz Arduino DUE	1	39.10
Speaker Module		Arduino Piezo	1	3.49
Light board		Adafruit NeoMatrix 8x8 64 RGB LED	1	34.95

Acrylic sheet (hang tag)		Acrylite Resist 65 Clear 6” x 10”	1	3.08
Housing		Duino Case-A	1	29.95
DC Power Adapter		HQRP Car Charger 12V DC	1	6.91
			TOTAL	$117.48
RFID Tag (Qty 1)				
Item	Image	Description	Quantity	Cost
RFID Tags		Nox TI-2	1	.99
			TOTAL	$.99

Total System Cost Estimate (Qty 1)	$913.47

Figure 19: Cost analysis for RFID system.

Using the above costs as estimates, each beacon setup would cost approximately $900.00. In an airfield like Hanscom, which is the largest GA airfield in New England, there are approximately 10 intersections between runways and taxiways that should be outfitted with our system. Each intersection would need two beacons (one for the warning notice and one for the imminent notice), bringing the total cost to outfit Hanscom to around $18,000. This is significantly less than many other runway-incursion prevention solutions, which range from $100,000 to upwards of $500,000. This cost is also significantly less than the cost to repair or replace a typical GA aircraft that could be involved in an incursion ($25,000-$200,000).

It should be noted that this is not the only possible product implementation for the system proposed, but only one of many this team investigated. RFID technology is always becoming more advanced and less expensive, so these costs are expected to drop even further.

c. Potential Impact of the Proposed Solution

The potential impact of this solution is huge. While runway incursions can never be fully eliminated due to the nature of human error, any reduction in runway incursion occurrences improves safety in dramatic ways. Safety is, of course, the first priority in aviation, however we expect our solution to have positive effects on airfield efficiency as well as financially. Runway incursions are not only risky and dangerous situations, but costly and time consuming as well. Reducing the likelihood of incursions by helping vehicle operators maintain awareness of hold lines will improve the overall operation of the airfield.

There is also natural commercial potential here. The technology involved is not complex, and RFID technology is only improving as it gains popularity. The vision for outfitting airports is simple. First, relevant personnel at an interested airfield would have a consultation with a commercial expert. Together, these parties determine how many beacon setups are needed (for example: every taxiway/runway intersection) as well as estimate how many in-vehicle alerting devices should be ordered The commercial expert fulfills the order, and the company sends an installation team to install the beacons. This should be done during the least busy hours of the airfield, however since all work happens off the runways and taxiways (on grassy areas, for example) the airfield should not have to close for installation.

The company should also provide regular maintenance for the beacons, to ensure proper functionality. The airfields would pay for initial installation, as well as a nominal fee for continued support.

8. Conclusions and Future Work

This report outlined the creation of an in-vehicle alerting system to prevent runway incursions by ground vehicles. The in-vehicle alerting system consists of visual and audial cues to remind ground vehicle operators of important safety areas, such as hold lines. Usability testing was performed in order to determine the most user-friendly and safe visual cues, and to determine the efficacy of audial cues. During this testing, it was determined that an alerting device with a set of symbolic visual cues combined with audial alerts, was more effective at encouraging vehicle operators to stop at hold lines than having no alerting system.

In order to bring the design to a product/implementation state, the following steps need to be taken:

1. Usability testing of visual/audial alerts with actual ground operators.
2. Piloting of RFID beacon system.
3. HIgh fidelity, high resolution prototyping of the in-vehicle warning device, including RFID tag and screen system.
4. Integrated field testing of entire RFID system.
5. Consultations with Air Traffic Controllers and ground vehicle operators to ensure the needs of all stakeholders are being met.
6. Consultations with interested airports and crucial FAA personnel to ensure all standards are being met, and demand can be met adequately.

We expect that any future investigations of this technology will only yield more insights into the complicated issue of runway incursions. Generally, more work concerning the improvement of situational awareness of ground vehicle operators should continue, as well as efforts to investigate low-cost methods of training and alerting operators to danger.

Appendix A: Contact Information for Advisors and Team Members

Faculty Advisors:

Daniel Hannon (dan.hannon@tufts.edu)
Maureen Mulcare (Maureen.mulcare@tufts.edu)
Ashley Russell (Ashley.r.russell@gmail.com)

Team Members:

Jessica Scolnic
j.scolnic@gmail.com

Astrid Joanna Veroy
astrid.veroy@tufts.edu

David Young
ogflanker@gmail.com

Appendix B: Description of Tufts University

Tufts University, located on three Massachusetts campuses in Boston, Medford/Somerville, and Grafton, and in Talloires, France, is recognized among the premier research universities in the United States. Tufts enjoys a global reputation for academic excellence and for the preparation of students as leaders in a wide range of professions. A growing number of innovative teaching and research initiatives span all Tufts campuses, and collaboration among the faculty and students in the undergraduate, graduate and professional programs across the university's schools is widely encouraged.

Fast facts:

- **Established:** 1852
- **Total students:** 10,819
- **Undergraduates:** 5,131
- **Graduate and professional:** 5,284
- **International:** 1,246
- **Total faculty:** 1,456
- **Total staff:** 3,070
- **Total volumes, all libraries:** 1,236,421
- **Total libraries:** 6
- **Campuses:** 4 (Medford/Somerville; Boston; Grafton; Talloires, France)
- **Motto:** Pax et Lux
- **Colors:** Brown and blue
- **Mascot:** Jumbo (elephant)
- **Affiliations:** NESCAC

Appendix C. Description of Non-University Partners Involved in the Project

Advisor	**Title**
Alex Gertsen	Runway Safety Expert; President of Aviation Fury, LLC
Prof. Jose Ruiz	Professor, Aviation Management and Flight at So. Illinois University
Flavio Leo	Deputy Dir. Aviation Planning and Strategy, Massport (Logan airport)
Vincent Cardillo	Deputy Dir. Aviation Operations, Massport
Robert Lynch	Airport Operations Manager/Airside, Massport
Keith Leonhardt	Operations and Maintenance Manager, Hanscom Airfield

Appendix E: Evaluation of the educational experience provided by the project

<u>Students</u>

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

Yes, the ACRP Design Competition provided a meaningful learning experience for us. We completed our entry over the span of 1 semester, through a "Human Factors Product Design" course at Tufts University. We gained access to legitimate user groups (FAA and Massport employees) and experienced a true design cycle. It was amazing to interview airfield employees, and learn an understanding for the real challenges faced by the field of aviation today.

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

It was challenging to make the most of our limited opportunities with experts in the field. We quickly decided to bring rough prototypes with us to meetings, as well as lists of interview questions to begin conversation. It was interesting meeting with experts throughout our design process, so the experts had the opportunity to give us feedback, and really shape the product we were creating. We made sure to let all the industry advisors know where we were in our process so they could understand how to best give feedback.

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

Our initial hypothesis, of improving situational awareness of ground operators in efforts to reduce runway incursions, stemmed mostly from research we did when trying to choose which competition prompt to respond to. After doing some reading, we realized how serious an issue runway incursions are, and made a connection in our minds to the problem of car accidents, and the current cutting edge technologies being used to help prevent car accidents (like the rear-view camera on new cars, and even radar-based auto-stopping features.) We extrapolated a bit to come up with our end product of the hold-line alerting device triggered by RFID technology.

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

Yes-- we had an exceptional group of people helping us, and the experts we spoke to were always respectful and ready to help. Alex Gertsen's phone call in the beginning of our process was invaluable at providing basic information, and assisting us with choosing a design path. Our visit to Logan with Flavio Leo and his coworkers showed us the complex system that is Logan airport, and all of the technology that major airports employ to keep everyone safe. At Hanscom, Keith Leonhardt was very responsive in person and via email in follow ups to help us refine our concept. Our observation of Keith in action as he performed runway tasks was invaluable and provided us with true insights into the field.

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

I feel as a graduate student team, we were prepared to take on such an open-ended, real industry problem. This project definitely helped with giving us each more experience in the early phases of the design process, like user analysis and concept generation, as well as the final stages, such as usability testing.

Faculty

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

This competition provided the students an opportunity to directly apply their understanding of the methods taught in the Human Factors in Product Design class to a real world application. They experienced actual challenges and limitations that are more representative of what they should expect when addressing the types of problems in actuality and should position them to transition into a professional career with this improved understanding. Not only did this project help improve their critical thinking and domain expertise, it provided them a valuable opportunity to engage with professionals in the field and to work as team to solve an open-ended problem. The graduate students were more accustomed to functioning as a team and making progress to the timeline, though practicing these practical skills is extremely useful.

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

Yes, though the graduate students competing did have an observable advantage due to the additional skills many had acquired in the workforce prior to this course in addition to access to more prototyping resources. Conversely, it was interesting to see that many of these students tended to "jump ahead" and apply their work experience to the problem state, not necessarily focused on Human Factors. They were able to adjust accordingly with this feedback over time.

3. What challenges did the students face and overcome?

The primary challenge for the students centralized around handling a more nebulous problem than they are traditionally exposed to in their course work. The students were required to go beyond their comfort zone and actively engage with sponsors and actual end users to help them formulate their thoughts and tackle each activity in the design process.

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

Absolutely. It provided motivation for the students that is difficult to achieve in academia alone as it promotes recognition in industry.

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

The website had some missing links to necessary information. The intent of the competition itself is great and provided the students an option for the type of design problem they wanted to tackle.

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