Airport Ground Vehicle Alerting System

A Proposal to Reduce V/PD Runway Incursions

FAA Design Competition for Universities: 2009-2010
Runway Safety/Runway Incursions

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Executive Summary

This report details the design of a runway incursion mitigation technology as a response to the FAA Design Competition for Universities for the 2009-2010 Academic Year.

Our background research—on runway incursions and the current technologies in place to prevent them—and visit to General Edward Lawrence Logan International Airport revealed the need for a low-cost, in-vehicle alerting technology that provides airport surface vehicle drivers with real-time surface information without requiring their focused attention, directly and exclusively interacting with the drivers so as to not interfere with the greater airport operations environment.

We designed a simple alerting system with two levels of warning severity. The low-level (less dangerous) alert acts as a situational awareness tool for drivers, informing them of upcoming runway intersections and runway-end safety areas. The high-level (more dangerous) alert acts as an emergency warning system, using real-time sensor information about the location of other vehicles and aircraft to inform drivers of imminent danger situations.

We developed a low-fidelity prototype and tested it on an airport surface driving simulator. The results of our test indicated that if developed further, our design could help reduce the likelihood of vehicle/pedestrian deviations. Additionally, we assessed the potential benefits and risks associated with our proposed design and developed a cost estimate for its implementation. Our design targets many FAA runway safety goals with regard to incursion prevention technologies, particularly affordability and utility.

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1. Introduction and Problem Statement

This report describes the research and design process conducted by a team of undergraduate Engineering Psychology students at Tufts University in response to the Federal Aviation Administration's Design Competition for Universities for the 2009 – 2010 Academic Year. This project addresses the design focus of runway safety/runway incursions, particularly vehicle/pedestrian deviations.

Airports during flight operations present complex, busy work conditions that leave little room for error. There are over 60 million flight operations per year in the United States being handled by only 500 towered airports, which makes for a high-speed, hectic environment where even a small mistake can result in the death of hundreds of people. Although runway incursions are reported at only 14 incursions per million operations (FAA Runway Safety, 2009), any incursion poses a danger to travelers and airport personnel alike. Consequently, the Federal Aviation Administration (FAA) is constantly searching for ways to make air travel as safe as possible.

The current technologies in place to prevent runway incursions, which are generally designed for controllers and pilots, fail to account for a significant contributor of incursions: ground vehicles. A low-cost, easily implementable system that targets ground vehicle operators while not interfering with other airport operations would be a valuable addition to the FAA's runway safety arsenal.

To address this need, our team has undertaken the project of designing and evaluating a system that will improve runway safety. Through additional research on the airport environment and a visit to General Edward Lawrence Logan International Airport (Logan Airport), we developed system requirements that would guide our first iteration of design. The proposed design solution in this report targets airport ground vehicles to help reduce the likelihood of V/PDs. The design aims to improve the situational awareness of vehicle operators by alerting them in appropriate situations on the airport surface. Our design will also act as a real-time alert to vehicle operators about potential collisions and imminent-danger situations. We developed a low-fidelity prototype in order to test our design concepts in a usability test. The feedback we received from the testing revealed that our design has the potential to make a significant contribution in preventing runway incursions.

2. Background and Literature Review

2.1 Runway Incursions Defined

The FAA and International Civil Aviation Organization (ICAO) define a runway incursion 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 take-off of aircraft" (FAA Safety Plan, 2010, p. 37). Runway incursions are an important measure for assessing trends in airport safety and efficiency because they count and categorize incidents of danger on the airport surface. Between FY 2005 and FY2008, runway incursions have occurred at a rate of

14.3 incursions per million airport operations, though many incursions go unreported (FAA Runway Safety, 2009). Although this number seems small, and even though incursions almost never result in collisions, they can still be distractions to airport personnel, hindrances to airport efficiency, and, most importantly, threats to the lives of both airport personnel and travelers.

2.2 Runway Incursions by Severity

Runway incursions are classified by severity into four categories (Table 1). Categorization by severity depends on factors such as "the speed and performance characteristics of the aircraft involved, the proximity of one aircraft to another aircraft or a vehicle and the type and extent of any evasive action by those involved in the event" (FAA Safety Plan, 2010, p.7). The vast majority (97%) of incursions are Category C or D incursions, which are characterized as incursions not resulting in a significant potential for collision (see Figure 2-1). Category A and B incursions are collectively known as serious incursions; there were 25 serious incursions in FY2008, only nine of which involved commercial flights (FAA Runway Safety, 2009).

Table 1. Runway incursion severity classification (adapted from FAA Runway Safety, 2009)

Increasing Severity

Category A	A serious incident in which a collision was narrowly avoided.
Category B	An incident in which separation decreases and there is a significant potential for collision, which may result in a time critical corrective/evasive response to avoid collision.
Category C	An incident characterized by ample time and/or distance to avoid a collision.

Category D	An incident that meets the definition of runway incursion such as incorrect presence of a single vehicle/person/aircraft on the protected area of a surface designated for the landing and take-off of aircraft but with no immediate safety consequences.

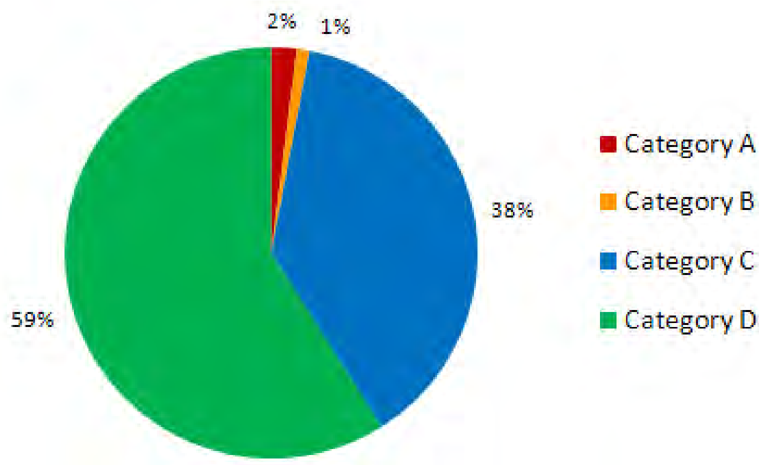

Figure 2-1. Runway incursion severity distribution FY2005-FY2008
(adapted from FAA Runway Safety, 2009)

2.3 Runway Incursions by Type

Each runway incursion is also categorized into one of three types: (1) pilot deviations (PDs); (2) operational error/deviations (OE/Ds); and (3) vehicle/pedestrian deviations (V/PDs). These incursion types are not necessarily indicative of the person responsible for the incursion; instead, the type refers to the "last event in a chain of pilot, air traffic controller and/or vehicle operator actions that led to the runway incursion" (FAA Safety Plan, 2010, p. 8). The definitions of each type of incursion can be found in Table 2 and the breakdown of runway incursions by type can be found in Figure 2-2.

Table 2: Definitions of Types of Runway Incursions (adapted from FAA Runway Safety, 2008)

Pilot Deviations
An action of a pilot that violates any FAA Regulation.
Operational Error/Deviations
Operational Error (OE): an action of an air traffic controller that results in: 1) Less than the required minimum separation between two or more aircraft, or between an aircraft and obstacles (e.g. vehicles, equipment, personnel on runways). 2) An aircraft landing or departing on a runway closed to aircraft. Operational Deviation (OD): an occurrence attributable to an element of the air traffic system in which applicable separation minima were maintained, but an aircraft, vehicle, equipment, or personnel encroached upon a landing area that was delegated to another position of operation without prior coordination and approval.
Vehicle/Pedestrian Deviations
Includes pedestrians, vehicles, or other objects interfering with aircraft operations by entertain or moving on the movement area without authorization from air traffic control.

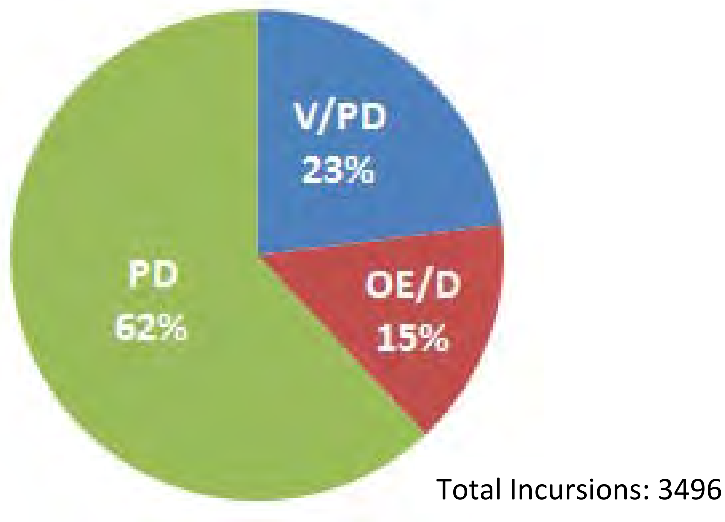

Figure 2-2. Breakdown of runway incursions types FY2005-FY2008
(data from FAA Runway Safety, 2009)

2.4 Focus of Study: Vehicle/Pedestrian Deviations

There are a number of safety tools and procedures designed to prevent runway incursions. Tools consist of signs, markings, etc. On the procedural side, radio communication between controllers and aircraft and vehicles are used to actively manage traffic flow; no one is allowed to cross a runway without requesting and receiving permission to do so from the ground controller. Even with these procedures, however, runway incursions are a significant threat to aviation safety. Recognizing the importance of this problem, in 2008, the FAA established the goal of reducing runway incursions by 10% by 2013 (FAA Flight Plan, 2009). This objective has resulted in a flood of new technological solutions to the problem of reducing runway incursions. Many of these technologies focus on increasing the situational awareness of the pilot or ground controllers by presenting complex information in the cockpit or control tower. However, these solutions are typically very costly to implement and fail to account for a major culprit of runway incursions: ground vehicles. V/PDs account for a significant percentage (23%) of all runway incursions (FAA Runway Safety, 2009).

The most recent *National Runway Safety Plan 2009-2011* (FAA, 2009) calls for many improvements in training and airport development, with the goal of reducing runway incursions, including those caused by V/PDs. Reviewing current procedures and protocols, accelerating the installation of improved airport signage and markings, and reemphasizing operator training are all important steps in reducing V/PDs under the safety plan. However, these steps do not take advantage of advanced sensing technologies in the way that many solutions for Pilot and Operational Deviations have.

2.5 Current Measures for Preventing Runway Incursions

Measures to prevent runway incursions of all types can be broken down into three categories: protocols, airport design strategies, and sensor/display technologies

2.5.1 Protocols

Airport protocols, or rules for operation, are the first line of defense against runway incursions. Protocols are designed to enable controllers to safely and efficiently direct air and ground traffic through and around the airport's movement areas. Although operational errors make up the lowest percentage (15%) of runway incursions, pilots and ground vehicle operators can also make protocol-related mistakes that result in runway incursions, such as disobeying a hold short instruction from the tower (FAA Runway Safety, 2009).

To reduce opportunities for V/PDs, operators of ground vehicles must always obtain permission from the controller to cross onto a taxiway or runway. Ground vehicle operators are also held to the same standard phraseology as pilots and controllers to support awareness through clear, consistent communication. The *Airport Ground Vehicle Operations* guide stresses that operators should always be sure that they understand the controller's instructions before proceeding (FAA Airport Ground, n.d.).

The *National Runway Safety Plan 2009-2011* (FAA, 2009) outlines several possible measures to enhance the safety of airport communications protocols. One proposal is to require that a separate runway-crossing clearance be given for each runway, eliminating "taxi to" instructions that allow operators or pilots to proceed through numerous en-route intersections and that imply the need to obtain clearance only for runway-crossing at the final hold-short line. Theoretically, this proposed change in communications protocols would prevent many runway incursions because all ground vehicle operators would know that specific clearance is required for every runway crossing along the route they are travelling.

2.5.2 Airport Design

Many design features of the airport, such as markings, lights, and runway/taxiway layout, purposefully strive to reduce the likelihood for runway incursions. While some of this infrastructure is standard at all airports, other components may only be implemented at airports that meet certain size requirements.

One example of infrastructure design intended to reduce incursions is a perimeter/end-around taxiway. These perimeter taxiways reduce the possibility of runway incursions by allowing planes to taxi to and from the runway without crossing additional runways. However, because of the additional space these taxiways require, they are often costly and can only be added at airports with sufficient surrounding land.

Other facets of airport design are standard to all airports. Runway and taxiway signage, markings on the surface itself, and the lights that outline runways and taxiways are uniform across all controlled airports. Hold-short lines indicate to pilots and vehicle drivers that a runway is ahead and serve as a reminder that clearance must be obtained from the tower before proceeding across an active runway. However, because these lines are always present regardless of whether a runway is active or not, they may frequently be ignored or go unnoticed, particularly in airports with multiple runway configurations.

2.5.3 Technologies

(1) Facility-Based Controller Notification technologies essentially require a central observer (ground controller) to perceive an imminent incursion through technology and then convey this situation to the appropriate vehicle, whether an airplane or a surface vehicle, via radio communication. If the controller can give instructions to the vehicle driver quickly enough, the incursion can be avoided. Of course, this style of incursion prevention is a last-resort system; only if the protocols are violated will this central-observer system be needed.

The limitations of this central-observer system are two-fold. First, the system relies on busy ground controllers noticing a potential incursion. From a human factors perspective, this task is difficult because the ground controllers already have a large cognitive load directing ground traffic. The additional vigilance required to notice potential incursions may be too much for ground controllers to be expected to handle. The second limitation is time: contacting the appropriate vehicle driver and giving instructions to avoid the incursion takes time. Furthermore, it will also take some time for the vehicle driver to change action accordingly. Together, the time it takes to alter vehicle actions in the central-observer system may be too long to prevent incursions if the ground controller notices the potential danger too late.

The primary facility-based controller notification equipment is Airport Surface Equipment, Model X (ASDE-X), which provides controllers with a radar map showing the position of aircraft and vehicles on the airport surface (FAA Runway Safety, 2007). ASDE-X is a useful technology, particularly in low-visibility conditions, because it provides controllers with information about the vehicles on the airport surface (such as the call sign of an aircraft) that may be difficult to ascertain in bad weather or at night. However, to reduce clutter on the screen, some areas of the airport are masked so that vehicles and structures in these areas do not show up on the screen. Generally, these masked areas are places on the airport surface that are between runways and taxiways or around the perimeter of the airport where construction vehicles would be. The drawback to this masking is that sometimes masked vehicles may suddenly appear on an active runway, making prompt notification very difficult; the controller would have no time to contact the driver to prevent the incursion. ASDE-X is also an expensive system to install; the current plan to install ASDE-X in 35 airports by 2011 was estimated to cost $549.8 million (FAA Need to improve, 2007), which is over $15 million per airport.

(2) The second classification of runway incursion prevention technologies is On-Board Flight Crew Notification Equipment. These technologies are installed directly in the cockpit of aircraft in order to enhance pilot situational awareness and provide alerts if another vehicle is about to encroach a runway. By integrating GPS, ground-based technologies, and specifically developed software, on-board notifications can provide both visual and aural alerts to pilots. On-board technologies are also advantageous because their warnings to pilots are not susceptible to adverse weather conditions.

On-board technologies are, however, susceptible to pilot inattention. With all the technology pilots have to attend to in the cockpit, cognitive load is high and as a result, some warnings may go unnoticed, particularly in tense situations.

Runway Incursion Prevention System (RIPS) is a notable on-board runway incursion prevention technology developed by the National Aeronautics and Space Administration (NASA Fact Sheet, 2000). It incorporates both head-down and head-up displays to give pilots information about air traffic, ground terrain, ground obstacles, airport configurations, and approach patterns.

(3) The third classification of runway incursion prevention technologies is Ground-Based Flight Crew Notification Equipment. These technologies are designed to be independent systems that alert pilots directly that a runway is active. If pilots are alerted in some way when they are

approaching an active runway, they can act to avoid the incursion and contact the tower for instruction. This type of system acts as a situational awareness tool for pilots. Its effectiveness relies not only on alerting pilots, but also on the pilots' understanding of the alert being sent and the action needed to be taken. Also, by cutting out the step of the controller noticing the potential incursion and then contacting the pilot, these direct-alert systems can prevent incursions that central-observer systems may be too slow to stop.

The primary limitation of direct-alert systems is that they generally are very aircraft-centric, being designed to alert only pilots and not other ground vehicle operators. The lack of technology designed specifically for ground vehicles is a significant concern because from FY 2005 to FY 2008, V/PDs accounted for 23% of all runway incursions (FAA Runway Safety Report, 2009).

Runway Status Lights (RWSL) is a direct-alerting system that will be installed at 20 airports by 2011 (FAA Runway Safety, 2009). RWSL consists of two sets of lights embedded into the runway that indicate either that the runway is unsafe for entry—Runway Entrance Lights (REL)—or that the runway is unsafe for takeoff—Takeoff Hold Lights (THL). This system is integrated with the airport's ASDE-X surveillance system to determine when a runway is active. When the lights are illuminated, pilots know that the runway is active and can react appropriately.

Other runway incursion prevention technologies are described in Appendix G.

2.6 Suggested Solutions and Future Technologies

While the FAA continues to make infrastructure improvements to the entire air traffic system, many contractors and organizations are developing component technologies to aid in improving the safety and efficiency of air transportation.

At the forefront of future air transportation technologies is the Next Generation Air Transportation System (NextGen), the ultimate goal of which is a GPS-based air traffic control system (FAA Fact Sheet, 2010). Because the current air transportation system is essentially at capacity in terms of traffic volume, the FAA is looking for a system that can increase airport efficiency to allow more flights without the cost of building more runways and/or taller control towers. The NextGen system utilizes GPS technology, which is not subject to the same weaknesses as radar, such as weather and inaccurate targets. The system uses ASDE-X and ADS-B to monitor aircraft both on the ground and in the air. With access to more accurate information, controllers will be better prepared to monitor and direct the vehicles and aircraft on the airport surface.

The FAA-sponsored design competition for universities has also spawned interesting solutions for runway incursion prevention. In 2009, the winning submission team from the University of Southern California proposed a Controller Intent Monitoring Interface (CIMI) (White et al., 2009). This proposed system analyzes the flight strips and their positioning in order to keep track of controller intent. By cross-checking the intended progress of the flights with the actual position of the planes, the system would be able to determine if controller actions are likely to result in an incursion. CIMI essentially acts as a third party keeping track of controller intent and aircraft positions to determine if incursions are imminent. Assuming the software and airport-wide surveillance system were seamlessly integrated, CIMI would probably act as an effective situational awareness tool and “second set of eyes” for controllers. This technology would be facility-based controller notification equipment. However, CIMI requires the airport to already have an airport-wide surveillance system (such as ASDE-X) that typically costs millions of dollars to implement and maintain.

In the 2008 design competition, a team from Embry-Riddle Aeronautical University proposed a GPS-based unit to be installed in airport surface vehicles that would act as a situational awareness tool for vehicle operators (Vleck et al., 2008). The system was a modified GPS unit that displayed a moving map of the airport surface. The design contained both audio and text alerts for the driver approaching an area of particular importance, such as hold-short lines and runway incursion hot spots. This solution technology would be a very powerful situational awareness enhancement tool for surface vehicle operators. However, because it does not integrate any real-time information about the location of other vehicles or aircraft on the airport surface, this solution cannot act as a real-time alerting system for potential incursions and collisions.

Based on our research of current and future technologies that aim to mitigate the problem of runway incursions, we feel there is a need for a low-cost, in-vehicle technology that provides drivers with smart, real-time surface information while still keeping their attention outside the vehicle. A technology that meets these needs and that could be installed in smaller-scale airports would be a valuable addition to the runway safety system because it satisfies many needs that the current technologies do not address.

3. Team Problem Solving Approach to the Design Challenge

Because runway incursions are often a result of human factors-related problems, our team of Engineering Psychology majors approached this design challenge from a human factors perspective, which we describe in this section of the proposal. Our initial research goal was to understand the airport environment from a systems perspective, both as a whole and as a sum of many parts, including human controllers and vehicle operators. We then reviewed relevant sensing systems and other proposed solutions for runway incursion prevention in order to identify existing technologies that could facilitate a design solution that was both functionally and economically feasible. After narrowing our scope to technologies for reducing potential V/PDs, we began to develop our requirements analysis based on available literature, as well as a site visit to Logan Airport. We then developed several design concepts and, after choosing the concept we felt best met our requirements, we began our more formal phase of prototyping an in-vehicle alerting system to reduce V/PDs. We ran a usability test on an early iteration of this design prototype to obtain feedback on our design and guide further iterations of design refinement.

3.1 Initial Research

To understand the complex environment for which we were designing, we first reviewed several FAA documents, such as the Runway Safety Reports (FAA, 2009; FAA, 2008; FAA 2007) and the Airport Ground Vehicle Operations Guide (FAA, n.d.), to understand how the FAA is approaching the problem of runway incursions and to identify areas in which we could meaningfully contribute within the scope of this single-semester project. Our analysis of current measures for preventing runway incursions revealed that a significant portion of runway incursions (V/PDs) could be targeted with a low-cost technology. The FAA is improving runway safety through advanced technologies and the development of a comprehensive NextGen system, but a low-cost technology that is simple to create and install would be a valuable addition to the FAA's runway incursion prevention arsenal.

Because airport operations are already complicated and intricate, we knew it was important to focus on a solution that would not interfere with current systems. Controllers already have a high cognitive workload and airport surfaces are generally designed for aircraft, not surface vehicles. These features of airport operations necessitate a system that will directly and exclusively interact with airport surface vehicle operators without changing the greater operational environment (for example, by requiring the incorporation of additional runway lighting or signage).

3.2 Requirements Analysis

The second major component of our approach was creating a comprehensive set of requirements to guide our design. Our requirements analysis was based on a combination of technical research, discussions with subject matter expects, and a visit to Logan Airport. Requirements analysis is a crucial step in the design process because it provides a clear vision of what the system needs to incorporate in order to be successful and effective.

However, literature can only take research so far; many of the most important system requirements are uncovered through interactions with subject matter experts and exploration of the environment. Our visit to the airport was an opportunity not only to speak directly with airport operations personnel but also to experience the airport environment first-hand. Discussions with the operations personnel helped us to establish several of the broader requirements for our proposed system. We explained the scope of our project and our high-level concepts in order to get first-iteration feedback from them. These subject matter experts agreed that the system must be a simple complement to air traffic safety and that it must not alert drivers unnecessarily. These requirements led to our focus on a solution that would be an individual driver alert system (simple and complementary to current airport operations) and would use some sort of real-time surveillance and logic to determine the appropriate times for alert. For a complete list of requirements and the corresponding sources and design impacts, see Appendix H.

By riding in a vehicle on the airport surface, our team was able to get a feel for the environment in which our solution must operate. Airport surfaces are designed for aircraft. The signs, lights, and markings are all designed for pilots. As a result, navigating the huge runways in a standard-sized SUV is difficult and intimidating. Our vehicle driver, airport operations manager Bob Lynch, commented that driving on the surface is particularly difficult in a snowstorm. In low-visibility conditions, the driver will have a hard time seeing the signs and markings on the surface. This piece of information told us our system needed to be effective in all weather. As a result, we decided to make our alert in-vehicle so that the driver could be effectively alerted in any weather. A more detailed description of the airport visit can be found in Appendix I.

Because of the wide range of vehicles that may be on the airport surface, particularly itinerant vehicles such as state trooper cars and construction vehicles, it is important for our system to be able to be easily installed in any vehicle.

3.3 Design

Our design process consisted of identifying and integrating two separate technologies to develop a low-cost system for alerting airport surface vehicle drivers about potential incursions on the airport surface. These technologies included (1) a large-scale sensor system with logic algorithms to survey the airport, monitor traffic, and send warning signals prior to V/PD events; and (2) an in-vehicle alerting technology to present these warning signals the appropriate vehicle operator. The emphasis of this project's design process was the in-vehicle alerting system and the human factors principles that need to be considered to maximize usability and utility. However, we have also paid considerable attention to the salient engineering challenges of the large-scale sensor and processing system

3.3.1 Sensor System

The behind-the-scenes technology in our solution is a sensor surveillance system that can determine where vehicles and aircraft are on the airport surface and make calculations to determine speed and predict collisions. The system must then send a signal to the appropriate vehicle so that the in-vehicle alert can warn the driver.

The in-vehicle alerting messages will be supported by OptaSense™, a fiber optic cable-based surveillance system developed by QinetiQ, our team's industry partner for this proposal effort. This technology uses fiber optic cables laid at a very shallow depth in the ground to sense vibration and monitor movements on the surface. The changes in light reflection patterns along the length of the fiber optic cable, caused by ground vibrations, allow the OptaSense™ system to determine the location and direction of entities on the surface. Classification algorithms are then used to automatically identify the type of entity that is being sensed (e.g., large or small aircraft, truck, light car, pedestrian, animal). The existing OptaSense™ system can differentiate between vehicles by detecting and evaluating the different frequencies of vibrations caused by different vehicles. OptaSense™ is already being used for perimeter surveillance and pipeline monitoring around the world, but has never been used in an airport environment. Because the OptaSense™ system has been specifically developed to be relatively inexpensive to install over long linear distances (e.g., borders that may be hundreds or thousands of miles long), the necessary cabling to provide surveillance for the entire movement surface of even a large, multi-runway airport is extremely low-cost. The OptaSense™ technology is described in more detail in Appendix J.

The second aspect of the behind-the-scenes technology, which is not inherent to OptaSense™, is the communication with specific airport vehicles. Once OptaSense™ has determined that an alert needs to be sent, there must be a way for the system to trigger the alert in the appropriate vehicle. One solution to this problem is to use a universal mobile telecommunications system (UMTS), a third-generation (3G) telecommunications technology that is often used to wirelessly transfer data. If each vehicle is given an alerting module before entering the grid that OptaSense™ covers, and each alerting module has a UMTS connection, the system could keep track of that particular vehicle and trigger the alert when appropriate.

3.3.2 In-Vehicle Alerting System

The sensor system would determine when an alert should be sounded and relay that information to our in-vehicle module. Conceptually, our in-vehicle design consists of two alerts for the driver. Each alert represents a particular level of warning.

The lower-level alert cautions drivers in situations with no significant potential for a collision, but with high potential for a category C or D incursion. This alert is intended as a situational awareness tool for vehicle operators. One example of this situation is a vehicle approaching a hold-short line or a runway intersection at a speed and location such that stopping smoothly before the hold-short line is unlikely. In this situation, the vehicle is supposed to have explicit clearance to cross the runway. The alert simply reminds the driver that he or she is approaching a hold-short line or runway. The alert would be triggered early enough for drivers to “remember” that they need to stop and then stop quickly. Another example of a trigger for this lower-level alert is the detection that a vehicle on a perimeter road is approaching the end of a runway. In these situations, drivers are not required to stop or get tower clearance, but are supposed to look both ways for aircraft. However, drivers may forget they are on an important roadway, and may consequently forget to check for planes. The lower-level alert is intended as a reminder to vehicle operators in these situations and will stop automatically after the vehicle has gone through the runway intersection or can be stopped manually after each activation by a switch (or button).

The higher-level alert (i.e. the more serious warning) warns drivers of an imminent collision. This alert is intended to inform drivers that if no action is made, the likelihood of a collision is high. In this situation, it is recommended that the driver immediately pull the vehicle over into the grass to ensure safety. In terms of runway incursion severity categories, this higher-level alert represents warnings for the A and B category incursions. One example of this situation is a vehicle driver being given clearance to cross a runway while an aircraft has been clearance to take off on that runway at the same time. The sensor system would be able to detect the high likelihood of a collision or imminent danger and then alert the vehicle driver. This alert will continue until the driver has moved the vehicle such that the danger is no longer predicted by the sensor logic (e.g., by dramatically slowing or changing direction of motion).

The physical design of these alerts consists of (1) a light with a specific hue and flash rate; and (2) a tone of a specific pitch and sounding pattern. Both alerts would be emitted from a single hardware module, which would be placed on the dashboard when the vehicle is being prepared for operation. The higher-level alert would be red, with a flash rate between 180 and 240 flashes per minute (fpm). The lower-level alert would be yellow with a flash rate between 60 and 180 fpm. The matching of light hues and flash rates to warning levels is based on research done by Chan and Ng (2008), who found that red was the hue that implied the most danger and that faster flash rates also implied more danger to the participants, and the in Military Standard 1472F Department of Defense Design Criteria Standard Human Engineering (Department of Defense, 1999), which assert flashing red be used to indicate emergency conditions which require immediate operator action. Additionally, the standards state that yellow light be used to indicate a situation in which caution is necessary. It was also found that a combination of visual and auditory alarms was more effective in conveying danger than either visual or auditory alone. The luminance of the lights should be at least 10% higher than the surrounding luminance. Similarly, for the audio alarm, there should be at least a 10 decibel difference between the signal (i.e. the alarm sound) and the noise (i.e. the environment noise). Figure 3-1 illustrates the physical module of our design.

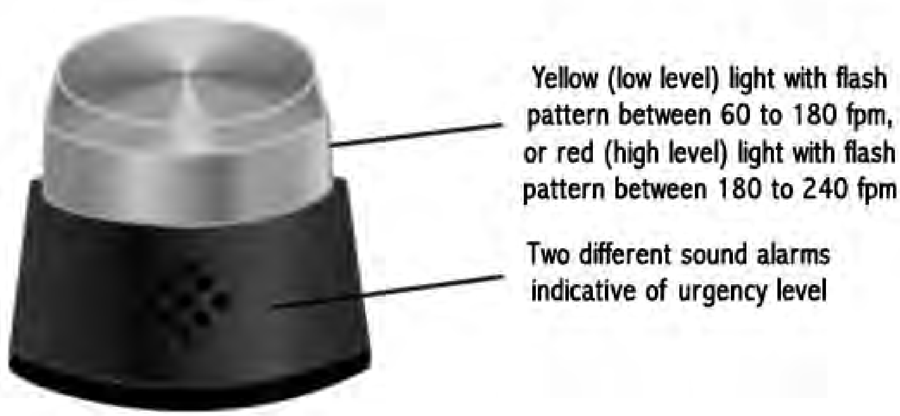

Figure 3-1. Illustration of alert module with beacon light and speaker

3.4 Prototyping

When creating a prototype of our design, our goal was to create something that would allow us to quickly evaluate our preliminary design concepts, namely the use of a variable light and audible alarm system to alert airport surface drivers of two different airport surface situations. To this end, we created a working model which had two modes corresponding to our design: a warning mode and an emergency mode. The warning mode consisted of two white 10mm light emitting diodes (LEDs) with a yellow filter and a corresponding warning tone. The emergency mode consisted of two red 10mm LEDs and a corresponding tone which was both louder and quicker in pace than the warning tone. All the components necessary to create the lighting system were purchased from a local Radio Shack; a complete parts list can be found in Appendix K.

The prototype was then installed in an airport driving simulator located at the John A. Volpe National Transportation Systems Center (Volpe Center), located in Cambridge, Mass. The Volpe Center is part of the U.S. Department of Transportation's Research and Innovative Technology Administration and is an innovative, fee-for-service, Federal organization integral in the improvement of transportation systems. More details on the simulator can be found in the Usability Testing section below and in Appendix L.

Due to time constraints and limited access to the Volpe simulator prior to testing, we employed the "Wizard-of-Oz" method of prototyping; both the lights and the alarms were triggered manually by testers at the onset of key, pre-scripted events, as opposed to being triggered automatically by the simulator. The lights were turned on using a two-way switch which could be held by a tester seated behind the driver. The alarms were played over speakers attached to a laptop computer, and they were set off simultaneously with the lights by a tester similarly located behind the scenes.

LEDs were chosen to simulate our proposed lighting system because they were sufficiently bright to attract the driver's attention within the simulator environment, generated little heat (which allowed for a light filter to be used), and were easily obtained. They were positioned on a bar in the simulator to the right of the steering wheel at dashboard level (84 cm from the ground), providing a viewing angle of approximately 30 degrees from the horizontal, which is within the field of view recommended in Military Standard for Human Engineering (Department of Defense, 1999). Figure 3-2 shows the position of the LEDs in relation to the driver and the simulator screen.

Figure 3-2. Picture of the visual alarm placement on simulator

The alarms we used were downloaded from an online alarm resource (Conklin, 2010), a website which contains numerous alarms in use by government vehicles, from police cruisers to submarines. The red alarm, a Power Plant Casualty alarm for a 616 Class Submarine, was chosen for its high fundamental frequency and multiple harmonics. The yellow alarm sound, a minor alarm called a Space Shuttle SM alert, was chosen for its low frequency and non-urgent yet alerting character.

Researchers have suggested that the urgency of an alarm should be associated with the level of urgency of the triggering event (Patterson, 1982; Momtahan, 1990; Edworthy, Loxley, & Dennis, 1991). If the urgency of a triggering situation is high, the alarm signal should convey high urgency through use of high frequency, high intensity, and fast repetition rate. If the urgency of a triggering situation is low, the alarm sound should have a lower frequency, lower intensity, and slower repetition rate (Patterson, 1982). Other studies investigating auditory alarms have shown that signals similar to sirens are perceived as the most urgent (Arrabito, Mondor, & Kent, 2004). These findings are further supported by Edworthy et al. (1991), who found that sounds with high fundamental frequency, multiple harmonics, and a quick offset led to higher ratings of perceived urgency. For these reasons, the emergency alarm utilized a sound with a siren-like quality containing high fundamental frequency and a quick offset. In contrast, the less urgent warning alarm sound had a lower frequency and less complex sound character.

The audio and visual components of our prototype are low-fidelity; they need to be triggered manually and they do not meet the exact audio and visual specifications (i.e. placement, brightness, volume) we recommended for the final design, but they serve as a reasonable approximation in our simulator environment. In conjunction with the driving simulator, this prototype allowed us to test our preliminary design concepts to gain valuable feedback from users regarding the feasibility and potential usefulness of the in-vehicle alerting system we are proposing.

3.5 Usability Testing

In order to determine the feasibility and potential usefulness of our proposed system, we used our prototype to conduct usability testing with participants who are experts in runway safety and have significant exposure to airport operations. Testing was conducted at the Volpe Center, which was an ideal location for our evaluation because it supplied us with both: (1) a driving simulator specially adapted for airport operations; and (2) a pool of knowledgeable personnel with extensive airport domain knowledge who were willing to participate in our tests.

3.5.1 The Simulator

The Airport Surface Low-Cost Driving Simulator at the Volpe Center was developed as a more affordable way to simulate driving at airports. It uses a specially adapted version of X-Plane flight simulation software (Laminar Research, n.d.), three 50-inch display screens, and a videogame steering wheel/foot pedal combination input device to produce a fairly high-fidelity driving experience (see Appendix L for more information about X-Plane). We modified the simulator with the addition of our prototype alarm system, using a “sidecar” display configuration which did not interfere with the existing simulator components. We also prerecorded a loop of a plane taking off to make our simulation of the emergency alert more realistic. Finally, we were given time to familiarize ourselves with the simulator environment, as well as the different traffic scenarios we would use to support the evaluation of our prototype alarm system.

3.5.2 The Participants

Four Volpe employees were recruited to be participants for our usability test. Of the four, one was a commercial pilot with experience in various aircraft and airports, and the other was a private pilot with 1000 hours in single-engine and light multi-engine planes. The other two were engineering psychologists who specialize in analyzing runway incursions. Although these participants have no experience driving airport ground vehicles, we felt their other airport experiences made them reasonably representative of potential users.

3.5.3 The Scenarios

Two different driving scenarios were created for our evaluation. Each scenario contained a specific route the participant was to drive at a simulated version of Logan Airport. Each scenario also contained an associated script which was used by one of the testers to simulate the tower granting the driver appropriate clearances. The routes were designed to place the drivers in situations where the alarm system would be necessary, and each scenario also included a near-collision in order to test the emergency mode of the prototype. Maps of the airport, with the driving routes used in our evaluation superimposed, and the scripts that were read to the drivers during each scenario can be found in Appendix M.

3.5.4 Testing

The same three-step procedure was followed for every participant:

1. When the participant first arrived, he or she was briefed on our project and the system we were testing. We explained that we were conducting this testing as part of an FAA design

competition and gave them some background information about the OptaSense™ technology we would be employing to support actual vehicle sensing and tracking. We then showed them the two different alert levels of our prototype, and explained that the low-level alert meant they were approaching a runway too quickly to stop smoothly and the high level alert indicated an imminent collision. We advised that if the high-level alert goes off, they should immediately exit the runway. Finally, we showed them the route they would be driving on a map of the airport and gave them a copy of the script for them to follow. Each participant only drove one scenario, due to time constraints, but the scenarios were alternated between participants.

2. After the introduction phase, participants were allowed to adjust the seat to a comfortable height and the driving task began. Our four-member team acted as testers for the test. One tester served as the controller, providing drivers with required clearances and directing the driver if necessary. Another tester sat behind the participant and triggered the light switch in conjunction with a third tester, who controlled the sound. A fourth tester observed each trial and took notes of participant actions and comments. Each driving sequence lasted approximately 20 minutes, and ended shortly after the narrowly avoided imminent collision event. Images of participants engaged in the driving task can be found in Appendix N.

3. After finishing the driving task, each participant was administered a questionnaire, which contained four questions designed to gather the participants' opinions of our proposed

solution and to collect any comments or suggestions they had. A copy of the questionnaire can be found in Appendix O.

3.5.6 Questionnaire Responses

There was a lot of overlap in the comments made by the participants. Three of the four test participants (TPs 1, 3, and 4) noted that the audible alarms alerted them more successfully than the lights. One of the participants (TP 3) stated that the yellow light seemed to be in acceptable position, but that the red light should be moved into the central field of view. Two participants (TPs 1 and 4) recommended that both the lights should be placed directly in their field of view instead of in the periphery.

Two test participants (TPs 1 and 3) commented that the alarm volume was acceptable for the lab environment, but that both alarms may need to be louder for an environment with a lot of radio chatter and ambient noise. All four participants said they could clearly distinguish between the two alert levels. One participant (TP 2) did note that while on a runway, his first instinct upon hearing an alarm (whether it was high- or low-level) was to swerve to get off of the runway. He recommended we change the high-level alert to a different medium; he suggested keeping the auditory alert but substitute a seat rumble for the yellow light as a potential warning-level indicator.

All four of the participants felt the system would be valuable for ground vehicle operators. They did note that it would be important for such a system to have a very low false alarm rate to ensure that it would be trusted by the drivers. It was also important to participants that the low-level warning alert should only go off if the driver is not already stopping, to avoid it becoming a nuisance to the drivers.

3.5.7 Evaluation Conclusions

The goal of our usability test was to put our prototype in front of airport domain experts, explain to them the logic behind our proposed system, and solicit their input and feedback regarding the feasibility, appropriateness, and potential efficacy of our design. We were able to achieve this goal quite successfully. The Subject Matter Experts (SMEs) were extremely helpful, and, for the most part, they supported our proposed design.

Most of the negative comments were in reference to the location/visibility of the lights and the volume of the alarms. These issues were the product of the limitations of the simulator as well as the restrictions of our prototype, due to a lack of time and money. Our actual system would have a bigger light, which would be located on top of the dashboard within the central field of view of the operator. The auditory alarms of our proposed system would also be louder than those used in the lab-based evaluation. The actual volume of the alarms would need to be at least 10% greater than the typical volume range of background noises on the airport surface, as recommended by the Military Design Standards for Human Engineering (Department of Defense, 1999). This range would be determined as part of the system implementation process.

Aside from the placement of the lights and the volume of the alarm, most of the comments were positive. The SMEs liked the idea of a very simple alerting system that (1) demanded minimal visual attention; and (2) had built-in logic that reduces the likelihood of false alarms, keeping the alert from becoming a nuisance.

3.6 Interaction with Industry Partners and Academia

In early February 2010, our student team met with Greg Duckworth, Director of Advanced Research and Development at industry partner QinetiQ, developer of the OptaSense™ technology, to discuss the potential applicability of this sensor system to an airport environment. Mr. Duckworth explained the technical details of the OptaSense™ technology, its capabilities, and its current uses. His review of the fiber optic cable technology helped us realize its potential utility for our design. Mr. Duckworth also confirmed that OptaSense™ can differentiate between different types of vehicles (such as airplane and trucks) and that the cables may be easily installed and repaired in an airport environment with minimal need for interfering with the existing runway surface. He also explained that rain does not interfere with the sensing technology because it can be filtered out as a constant noise.

Our team also coordinated with Professor Jason Rife, Assistant Professor in the Department of Mechanical Engineering at Tufts University, and one of his doctoral students, Okuary Osechas, from the mechanical engineering course *Advanced Engineering Controls*. Professor Rife and Mr. Osechas have helped answer many of our technical questions about the OptaSense™ technology from a signals processing perspective. We met with Mr. Osechas several times during the project to discuss technical aspects of our design. Through our discussions with our industry and academic partners, we were able to calculate rough costs estimates of installing the necessary lengths of sensing cables at Logan Airport, evaluate critical hardware and software development challenges, and better understand the technical capabilities of OptaSense™ in terms of spatial resolution and accuracy.

In late March 2010, accompanied by faculty advisor Dr. Ryan Kilgore and engineering psychologist Dr. Dan Hannon, our team visited Logan Airport to talk with Flavio Leo, Manager of Aviation Planning; Robert Lynch, Airport Operations Manager; and Vincent Cardillo, Deputy Director of Aviation Operations, about airport operations in general and our project more specifically. We were also driven around the airport surface, including runways and perimeter roads. The visit gave us valuable insight into several important aspects of the airport environment that would significantly influence our design. For example, we learned that vehicle operators on perimeter roads are not required to contact the tower but are trained to look for planes when crossing behind a runway (runway-end safety area). However, because drivers sometimes forget to check for planes, we decided to add perimeter roads to the coverage of our system to aid driver situational awareness (and thus reminding them to check for planes). A more detailed description of our visit to Logan Airport can be found in Appendix I.

Dr. Dan Hannon, engineering psychologist at the Volpe Center and chair of the Engineering Psychology program at Tufts University, acted as a SME on both airport- and human factors-related issues for this project. Dr. Hannon helped us coordinate several trips to the Volpe Center, where we conducted the usability test of our preliminary design prototype, as well as our visit to Logan Airport.

4. Technical Aspects Addressed Through Visual Aid

4.1 Intra-System Communication

The flowchart below (Figure 4-1) describes the nature of systems communication within our proposed alerting system. The OptaSense™ system gathers information in real time to assess the speed, location, and identity of any presence within a specific area. The sensitivity of OptaSense™ depends on the intensity of the vibration produced by that presence and its effect on light pulses emitted by OptaSense™ interrogator units, as discussed in Appendix I. An interrogator unit associated with the specific section of cable will then analyze the light disturbance to determine its pattern, intensity, and location. The interrogator unit will pass this event data to OptaSense™ processing units to evaluate and interpret the data. In our system, once the need for an alert is identified, the alarm module in the vehicle will be triggered through the use of a server system communication, such as UMTS.

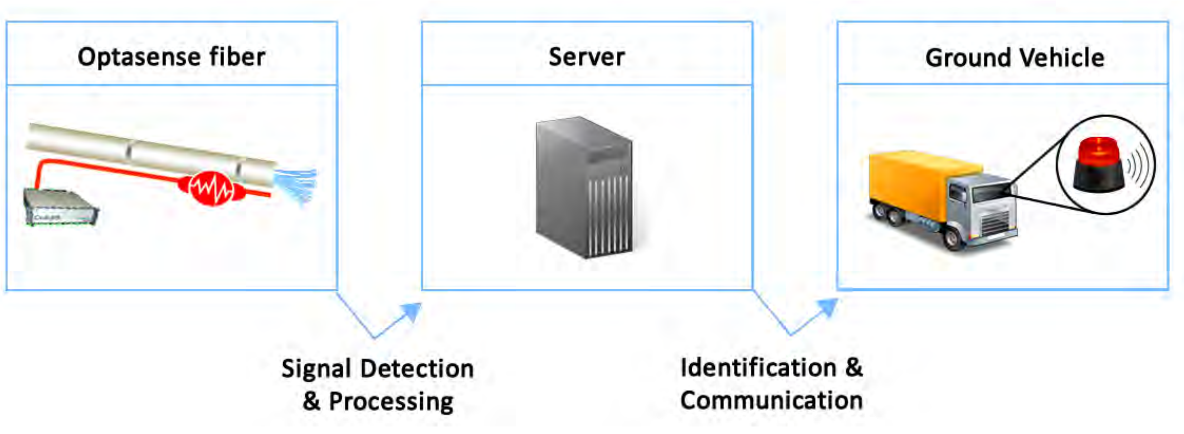

Figure 4-1. Flowchart representing intra-systems communication

4.2 In-Vehicle Alarm System

The complexity of communication between OptaSense™ and the alarm system is hidden to ground vehicle drivers, who are simply given the alarm light as informational output from a larger system of logic. The alarm light will be placed in the center of vehicle dashboard, within peripheral view for every driver, so that it will be conspicuous when turned on. Figure 4-2 illustrates a model of the alarm module mounted on the dashboard. The sound output of each alarm will also be emitted from this module.

Figure 4-2. Model dashboard with alert module

5. Safety / Risk Assessment

Because runway incursions almost always stem from human-factors issues, the human-factors perspective is critical for analyzing the potential safety impact and inherent risks of our design. Human factors analysis of runway incursions (i.e. the hazard) reveals that a decrease of situational awareness is almost always involved. Our proposed design solution (i.e. the treatment) acts to maintain situational awareness of surface vehicle operators in order to decrease the likelihood of a V/PD runway incursion (FAA Advisory Circular SMS, 2007).

To maintain vehicle driver situational awareness, our design alerts drivers in situations when the potential for incursion is high. These situations can be predicted using surface-wide surveillance and predictive algorithms based on the location, speed, and heading of vehicles on the surface. When a high potential for incursion is detected, the system will alert the appropriate vehicle operator as a reminder that he or she is approaching an area of importance. In the case of approaching a hold-short line or a runway intersection, our system will serve as a reminder to obtain clearance from the tower before proceeding. In the case of a runway-end safety area, when driving on a perimeter road without tower contact may cause a reduction in situational awareness, our system will serve as a reminder to check both directions before proceeding. By ensuring that driver situational awareness outside the vehicle does not decline, our system is decreasing the likelihood of a runway incursion.

Importantly, our system will also act as a real-time emergency alert for vehicle operators in situations where the potential for a collision (and not just incursion) is imminent. The sensor assessment and modeling of vehicle movement on the airport surface, as supported by the proposed OptaSense™ technology, is particularly valuable in bad weather and low-visibility conditions when situational awareness is also low. With the introduction of the system, drivers would be advised to immediately stop approaching (or exit) a runway if a high-level alert is triggered. This alert would decrease the likelihood of a more severe incident (i.e. collision).

Because our design does not involve interaction with any other system or personnel, it will not interfere with or increase the complexity of airport operations. Controllers and pilots, who are already operating with a high cognitive load, will not be distracted or otherwise negatively impacted by the alerts generated by this system. Similarly, because our system does not use any verbal interactions or indicators, it will minimize reliance on driver's limited cognitive resources for verbal processing, which is important as the driver may be holding as many as three radio conversations at one time, all while monitoring traffic chatter.

Additionally, the low-detail nature of our design does not require direct, focused visual attention from the driver. As a result, the driver can keep his or her eyes outside the vehicle and still receive and process information from the alert. By utilizing the driver's peripheral vision and the omnidirectional characteristic of audio alerts, our design can convey information to the driver without requiring the driver's vigilance or direct attention.

As with any alerting system, one of the human-factors risks is decreased sensitivity to the alert. If the vehicle operator is receiving an alert too often, it becomes an annoyance and eventually may be ignored altogether. To mitigate this risk, our system employs logic that only alerts the vehicle operator if it is determined that it is unlikely a vehicle can be gradually (i.e. not abruptly) stopped before the appropriate point.

Another potential risk of our system is the confusion of vehicle operators of what to do when the alert is triggered. The alert must be not only perceived, but also understood in order to be effective. It must be clear to the operators what vehicle action is the appropriate response to each alert. To mitigate this risk, our system takes advantage of natural human tendencies in implying danger from alerts. Based on previous research, it is clear that red, louder, faster alerts indicate more danger to people than do yellow, softer, and slower alerts (Chan & Ng, 2008). Yellow is generally regarded as a “proceed with caution” stimulus, while red is regarded as a “danger” stimulus (Department of Defense, 1999). This simplicity in our design reduces the cognitive load of deciphering what each alert means.

As new technologies continue to be introduced into the air traffic environment, it is becoming increasingly important to ensure an effective Safety Management System (SMS) is in place (FAA, 2004). In order to improve safety in the air transportation system, the SMS maintains a cooperative relationship between processes, policies, and procedures that manage risk. Our system will integrate easily and effectively with the SMS because it is a technology that will improve runway safety while mitigating the risks of its implementation.

6. Projected Impact of Design and Financial Analysis

6.1 Projected Impact

We expect our design to reduce runway incursions of all severities. Our high-level alert will help reduce the likelihood of a serious incursion (categories A and B), while our low-level alert will help improve vehicle operator situational awareness, which will reduce the likelihood of a non-serious incursion. This effect would contribute to the FAA goal of reducing the severity, number, and rate of runway incursions (FAA Runway Safety, 2007). Our design should contribute to improving the situational awareness of vehicle operators, which is a goal the FAA stresses in almost every document on runway safety (FAA National Runway Safety, 2009).

Our design specifically targets V/PDs, which represented 23% of incursions from FY2005 to FY2008 (FAA Runway Safety, 2009) yet have not received the attention of many proposed technological solutions for mitigating runway incursions. A future study of a prototype system actually implemented and evaluated at an airport is necessary to estimate the percentage of V/PDs our proposed system would prevents. If our system could prevent close to half of V/PDs, it would serve as a very useful tool in helping the FAA reach its 2008 goal of cutting 10% of runway incursions by 2013 (FAA Flight Plan, 2009).

Additionally, our design represents a technological solution that is low-cost, quickly implementable, and effective, characteristics of systems that the FAA is particularly interested in developing (FAA National Runway Safety, 2009). The following sections describe the work that needs to be done to bring our preliminary design to a comprehensive and functional state, as well as the steps and estimated costs associated with implementing our system at an airport.

6.2 Further Design Development

Before our design could be implemented at an airport, it would need to undergo refined design and usability testing stages. These iterations are vital to developing an effective system that meets FAA goals of reducing the likelihood of runway incursions. A high-fidelity prototype that actually utilizes OptaSense™ technology and smart sensor logic would need to be created and tested on real users (i.e. airport surface vehicle operators). The testing phases that emphasize human-factors issues are crucial to the process of system validation, which aims to ensure that the system has its intended impact on the users. In our case, these test and redesign iterations would seek to determine if the lower-level alert would improve driver situational awareness and if the higher-level alert would help avert imminent danger situations.

System verification is also necessary to the future development of the design. As several of our participants (who were engineering psychologists with an expertise in runway safety) commented, the false alarm rate for our alert would have to be very low, otherwise users would begin to ignore it. A low false alarm rate, therefore, is an important technical requirement of the system. To address this issue, testing would need to be performed on the OptaSense™ system complete with sensor logic as part of the verification that the system will operate effectively.

6.3 Implementation Plan

The implementation of our system at a particular airport can be outlined in three phases. The first phase is the installation of the cables into the airport surface. Depending on the layout and size of the runways and taxiways, the cables could be laid in the infield grass/dirt areas or trenched into the concrete or asphalt itself. This phase also requires setting up the hardware of the interrogator units and the control units that process the data. This phase will be supervised by a QinetiQ engineer. The second phase involves setting up the software to match the physical layout of the airport. This step includes the finalization of sensor logic and processing that will be used by the control unit to determine when to alert the vehicle drivers, as well as the implementation of the software that will send signals to the individual vehicles. The third step is the installation of the alarm units in the surface vehicles. All non-airplanes that will be on the runway surface would be equipped with our device, but whether the device is permanently installed in each vehicle or just put in a way similar to GPS navigation devices.

6.4 Financial Analysis

Optasense™ installation and integration is slated to cost orders of magnitude less than most monitoring and surveillance technologies currently used at airports.

The OptaSense standalone system, which includes one interrogator unit and the contract for a QinetiQ engineer to oversee the installation, integration, and calibration of the system, costs $250,000 (K. Stein, personal communication, April 15, 2010). Additional interrogator units, which would be needed for airports that require more than 40km of cable, cost approximately $200,000 each (K. Stein, personal communication, April 15, 2010). In addition to the interrogator units, a server is required to process the data, run the sensor logic algorithms, and trigger the signal to the vehicle. Mr. Osechas estimates server cost between $2,000 and $3,000 (personal communication, March 16, 2010). Software would also need to be developed for the servers, but this cost is inestimable at the current moment because further factors, such as the development environment, cost, quality, and scope, must be taken into consideration (Software Technology, 2009). These factors vary across professionals and specific installation environments.

The fiber optic cable must be purchased separately, but generally costs $1 per meter. Based on our upper-bound estimates of sufficient cable coverage (see Appendix P), Logan Airport would require approximately 64,000 meters of cable, which would cost $64,000 (G. Duckworth, personal communication, February 3, 2010). For sufficient coverage, however, the exact layout of the cable would be determined by QinetiQ engineers. We were told that the cost of trenching installation of the cable could not be estimated because the it is a function of length and terrain, which typically vary by location. Maintenance of the cable requires a fusion splicer, which can cost between $15,000 and $40,000 (VDV Works LLC, 2008).

An in-vehicle alert module would also need to be purchased for each vehicle. These modules are relatively inexpensive to create, with prices ranging from $100 to $300 per unit (Euchner-USA, Inc., 2007; North American Signal Company, 2005). To trigger the signal remotely, Global Services for Mobile (GSM) chips would need to be integrated into each alerting module. These chips cost approximately $70 per unit. For both of these purchases, bulk orders will decrease the unit cost.

Ultimately, using upper board estimates, the total of the costs that we were able to estimate is $657,000. Assuming reasonable costs for trenching installation, software development, maintenance, and power supply, we project that the cost of implementing our system at a large airport will be less than $1 million. Despite our rough estimates, it is clear that our proposed system will cost orders of magnitude less than most runway incursion prevention technologies. See Appendix Q for tables containing costs estimates and sources.

7. Conclusion

Our design is a low-cost, in-vehicle alerting system that is intended to reduce the likelihood of V/PDs. With the goal of reducing runway incursions, we researched current and future runway incursion technologies to determine what aspects of airport ground traffic operations still need to be addressed. The most obvious limitation for installing new technologies is cost. Airports that are too small generally cannot afford to install advanced, complex radar-based systems such as ASDE-X, which costs an average of over $15 million per airport (FAA Need to improve, 2007). As a result, only 22 towers have the system installed through 2009 and only 13 more are scheduled to have ASDE-X operational by 2011 (FAA Runway Safety, 2009). Because our proposed system is several orders of magnitude less expensive (hundreds of thousands compared to tens of millions), it could offer runway incursion prevention technology to hundreds of airports that have a tighter budget.

Our design is simple yet effective. In most cases, it acts as a situational awareness tool for drivers, providing them with smart reminders about their proximity to runway intersections and runway-end safety areas. Utilizing logical algorithms that use real-time speed and location information, our alert only cautions drivers when it predicts they might need a reminder. The high-level alert also uses real-time information about airport surface activity to warn drivers in imminent danger situations when immediate action is necessary. Our design takes advantage of human-factors principles such as implied meanings of certain colors, omnidirectional alerts, and low visual attention requirements to effectively convey information to surface vehicle operators without significantly increasing their cognitive load. Additionally, because our system automatically and directly alerts vehicle drivers, it does not add to the cognitive load of controls or increase the complexity of airport surface operations.

Ultimately, our system would need several iterations of refined design and usability testing before it could be implemented for a real-world test at an airport. However, from our preliminary testing, it seems that our system has the potential to be a valuable technological tool for improving runway safety by reducing the likelihood of runway incursions caused by VP/Ds.

Appendix A

Contact Information

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Appendix B

Description of University

Established in 1852, Tufts is a private research university with four campuses throughout Massachusetts and one located in Talloires, France. Tufts has two undergraduate schools: the School of Arts and Sciences and the School of Engineering, both located on the Medford, Mass. campus. There are approximately 5,000 undergraduate students with 80% enrolled in the School of Arts of Sciences and 20% enrolled in the School of Engineering.

The majority of courses are taught by full-time professors, most of whom hold a PhD and many of whom are practicing professionals in their fields. The university strives to foster personal relationships between students and faculty, encouraging individual attention in both the classroom and research settings.

Broadly recognized as one of the premier liberal arts colleges within a research university, the School of Arts and Sciences at Tufts University educates students for transformational leadership in communities around the world. Tufts' tradition of innovation dates to the School's founding in 1852. Today, a multi-disciplinary and experiential approach defines scholarship and teaching. Faculty and students use the curricular framework of the arts and sciences to address the great intellectual and social challenges of the 21st century.

The School has a distinctive style. Excellence in scholarship and teaching are the School's highest priorities; translating inquiry and research into action is a defining theme. The Faculty of Arts & Sciences, the largest of Tufts' seven schools, explores collaborative research opportunities across the University's professional schools and around the world. More than 5,000 students at the undergraduate and graduate levels represent the broad range of intellectual, creative and personal attributes. The creation of new knowledge in traditional and emerging disciplines; a dedication to globalism and active citizenship; a commitment to humanitarianism and diversity in its many forms; and a belief that intellectual discourse and discovery serve the common good are deeply held ideals.

Along with the School of Liberal Arts, the Tufts University School of Engineering is uniquely positioned to educate the technological leaders of tomorrow. We offer a rigorous engineering education in an environment characterized by the best blending of a liberal arts college atmosphere with the intellectual and technological resources of a world-class research university. Our goals are to educate engineers committed to the innovative and ethical application of technology in the solution of societal problems, and to be a leader among peer institutions in targeted areas of interdisciplinary research and education that impact the well-being and sustainability of society.

Another area that sets Tufts apart is its undergraduate Engineering Psychology major. Only a handful of other universities throughout the country offer this major and Tufts has developed an outstanding national (and international) reputation in this area. Each year, an increasing number of students graduate with a Bachelor of Science in Engineering Psychology. All four members of the design team will be graduating from this program in May 2010.

Compiled from the Tufts University Mission Statement and the Undergraduate Engineering Psychology: Guide to the Major.

Appendix C

Description of Non-university Partners

Dr. Gregory Duckworth
QinetiQ North America
Director of Advanced Research and Development
350 Second Ave.
Waltham, MA 02451
Phone: (781) 684-4000 ext. 4291

Dr. Duckworth briefed us on the OptaSense™ technology. He explained at a high level how the technology works, and informed us of the current uses of the technology. He also answered some of our questions about maintenance, sensitivity, and installation costs and requirements.

Dr. Daniel Hannon
Engineering Psychologist
Volpe National Transportation Systems Center
55 Broadway
Cambridge, MA 02142
Phone: (617) 494-2198
Email: daniel.hannon@dot.gov

Dr. Hannon was instrumental in coordinating both our visit to Logan Airport and our access to the driving simulator at Volpe. He served as our escort for the hours we spent at Volpe (once on a Sunday morning) and also helped us find airport experts to serve as participants in our usability test.

Robert J. Lynch, A.C.E
Airport Operations Manager/Airside
Operations Department
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East Boston, MA 02128-2909
Phone: (617) 561-1936
Email: rlynch@massport.com

Mr. Lynch was our point of contact for our visit to Logan Airport. We met with him, Mr. Flavio Leo (Manager of Aviation Planning), and Mr. Vincent Cardillo (Deputy Director of Aviation Operations) to learn about the driving environment and also to receive feedback on our initial design concepts. After our meeting, Mr. Lynch also gave us a tour of the airport surface, which included driving on taxiways, runways, and the perimeter road.

Appendix E

Evaluation of Educational Experience

Students

Hunter Kopald

The FAA Design Competition was a meaningful learning experience for me because it was an opportunity to work on a real-world human-factors design project. Through my schoolwork as an Engineering Psychology major at Tufts University, I have learned and practiced the process of human factors design, from literature review and requirements analysis to prototyping and usability testing. This project served as a consolidation exercise for everything I have learned. I was part of a team that carried out a design project from the initial proposal to the first iteration of design and usability testing.

The most difficult lesson I learned was how many things can slip through the cracks during a long project. With so many different aspects of the project developing at once, it was difficult for me and my team to keep track of everything and not fall behind on certain phases. Additionally, the project gave me experience working with industry partners as part of the design process. I have learned about the importance of setting up visits and meetings early in the design process and being prepared for them by reviewing literature and creating a list of goals and questions.

Interaction with QinetiQ and MassPort were crucial to our project. QinetiQ provided the foundation sensor technology for our design, and our visit to Logan Airport gave us important information we needed to make the best design possible.

Our process for the Design Competition was based on the human factors design approach of research, requirements analysis, design, prototyping, and usability testing. From both our research and our discussions with airport personnel, a representative from QinetiQ, and Dr. Hannon, we were able to narrow our scope to an in-vehicle alert and develop specific requirements. Dr. Hannon also coordinated our visits to the Volpe Center for our usability testing.

The first challenge we faced was related to the scope of our design. The OptaSense™ technology could theoretically provide data for ground-based controller notification equipment or for a smaller-scoped in-vehicle alert. Our discussion with airport operations personnel at Logan Airport pushed us onto the path of a controller-independent, in-vehicle alerting system. Another challenge we faced was in our prototyping (and, consequently, usability testing). It was difficult to create a prototype that we felt would suitably represent the design we were envisioning. Ultimately, we had to implement a design using the most available resources: Radio Shack and the internet. The Volpe driving simulator was very useful because we were able to set up a prototype that interacted with a high-fidelity virtual representation of Logan Airport. Additionally, Dr. Hannon helped us recruit some Volpe employees with extensive airport experience to test our design.

Overall, working on this project has certainly helped me sharpen my skills in human factors product design. The interdisciplinary and industry-partner elements of the project have given me experiences that I had been missing in my other engineering psychology coursework. Finally, having to prepare a report that meets FAA expectations is valuable practice for my future in writing real-world deliverables.

Kiran Lokhande

The FAA Design Competition provided me with an invaluable learning experience. I am grateful for the chance to have worked with and learned from so many professionals in the field from Logan Airport and the Volpe Center. This project gave me the chance to truly understand the complexity of airport systems and was an invaluable experience in working with a team of hard-working, dedicated individuals. In addition to this, the challenge of dealing with unforeseen circumstances in a real-world situation allowed me to sharpen my skills in problem-solving, teamwork, research, and communication. This is something that will certainly help me in my future endeavors.

While working on this project our team's most significant challenge was narrowing the scope of our project and also narrowing which elements of OptaSense™ we wanted to utilize in our solution. After careful consideration of multiple factors, such as the high workload of airport personnel, we were able to create a minimally invasive solution that imposed little to no extra workload upon controllers, drivers, and pilots. I believe the strength of our solution lies in its deceiving simplicity: while the physical alarm is a simple one, there is a highly intelligent system controlling it to make the user aware of potential incursions.

After narrowing the scope of our project to in-vehicle alarm systems, we had to simultaneously consider the applications of OptaSense™ that we would utilize and also choose the manner in which we would utilize them. Our alarm system was ultimately the result of a careful consideration of the workload of airport personnel through our visit to Logan Airport and existing literature.

Participation by industry was highly crucial to our project. Our visit to Logan Airport was extremely insightful and without the help of various people there, we could not have gained the insights we did into the high degree of workload and information processed by airport personnel. Also our usability tests would not have been possible without the help of Dr. Dan Hannon and Drew Kendra from the Volpe Center, and our participants who were professionals in the field.

Jay McNamara

Participating in this design competition was excellent experience for me, especially as a senior majoring in an engineering discipline. My earliest course work taught me the theories behind human factors engineering and some of my more advanced courses strove to bring our knowledge to bear on real-world problems, however school projects can only go so far. This was my first experience tackling a truly important problem, one that involved coordinating with other professionals and companies who could possibly see real returns from our work. This was refreshing, interesting, and taught me lessons I know I will take with me into the workplace.

We faced a number of challenges over the course of the project. Our first obstacle was narrowing our focus and developing a reasonable solution, but it was the more nuts and bolts problems that were new to me and taught me important lessons. I had to learn how to coordinate with professionals in industry and to get the most out of limited access to experts. The entire domain of simulator research presented a number of obstacles we had to overcome, from a lack of fidelity in the simulated environment to problems with interfaces to making reasonable scenarios that fit in our allotted time slot. My team and I were forced to think on our feet, to adapt, and to look at the problem from a different perspective to find feasible solutions.

Another challenge that I have not had to face before is the difficulty in getting accurate cost estimates. We would be quoted different numbers from different sources, and there always seemed to be a cost we had not anticipated originally. Finding reliable estimates required a surprising amount of work and diligence (and a lot of emails), but in the end we were able to overcome the various obstacles.

Our design process began with a lot of research about existing systems and discovering some of the problems associated with them. We realized that there had not been much focus on providing the operators of ground vehicles with alerting systems, and found this to be a potential area for improvement. We also discovered that most of the systems in place for monitoring ground traffic were fairly expensive, and the OptaSense™ technology provided a potentially low-cost alternative to radar-based systems. From there we met with industry experts and were told that such a system would be useful but we were warned to keep it simple. From there, we came up with a somewhat deceptively simple alarm, but one that seemed to work. We created a prototype to see what kind of response we would get from other experts in the field, and we found that they also liked the idea.

This close contact with professionals from industry was one of the things that set this project apart from others that I had worked on. Receiving input from experts at Logan Airport and the Volpe Center helped us to create something that we knew could work, not something that might be suitable. Connecting with QinetiQ allowed us to find an existing technology that could very likely improve safety at airports, again adding real-world experience that I had never been given access to before.

Finally, this project allowed me to gain a whole new insight into the fascinating world of aviation and airport design/safety. One of the things I really like about human factors engineering is the chance to learn about people and careers that I have never been exposed to before. On top of that, the experience I gained in solving a real-world problem from basic research all the way to usability testing will be invaluable as I move into the working world. I learned much about coordinating with professionals in industry, and I will definitely carry with me the lessons I learned from working with the simulator at the Volpe Center.

Luis Valencia

Participating in the FAA Design Competition was a unique hands-on experience to learn about the airport environment and its safety regulations. This opportunity helped make me aware of the highly structured guidelines the FAA enforces at airports that maintain their high level of security and safety.

Our first challenge was to narrow our scope. We had several ideas of how runway incursions could be addressed, but we needed to analyze the environment firsthand in order to focus our design approach. We faced our next challenge coordinating with Logan Airport to schedule our visit. As full-time students and full-time employees, coordination required organized planning to create some flexibility on both parts. Our visit proved very insightful and informative and, as a result, we were able to sharpen our design. In order to assess the effectiveness of our design, we conducted usability tests at the Volpe Center. Ideally, we wanted to test our prototype with actual ground crew members from our local airport to gather feedback from the group of users our design was primarily intended for. It was again challenging to coordinate with these full-time employees for interviews or usability testing. Instead, we recruited four employees from the Volpe Center, two pilots and two airport ground operations experts, to participate in our usability test. These participants served our purpose and provided insightful feedback.

Our group conducted initial research to understand the issues of runway safety and the causes of runway incursions. Once we identified the problem, we investigated the current technologies in place that serve to maintain runway safety to learn about their abilities and capacities. We became aware that the current technologies have high costs to install and maintain and that our solution would need to be cost-effective, among other things. We found a relatively low-cost technology in QinetiQ's OptaSense™ fiber-optic acoustic sensors to detect vehicles on the airport surface. Although the OptaSense™ technology has never been implemented to provide runway safety, our group saw its potential of complementing the current airport technologies without causing interference. Our proposal of the OptaSense™ technology compatibility with our alerting design received approval from the airport operations managers. At Logan Airport, we noted several important aspects of driving on the airport ground that were not as transparent in our research and proved critical for our design concept.

Our visit to Logan Airport and access to the simulator and employees at the Volpe Center provided important questions along with insightful information and suggestions for us to consider in the development of our design. Interacting with these members of the aviation industry granted us a firsthand experience that proved indispensible.

I acquired further experience working as a design team member and new knowledge about careers in the aviation industry. This opportunity helped me develop essential skills in the workforce such as research and development, design, project management, and team work.

Faculty

Dr. Ryan Kilgore

The four members of this project team completed the FAA Design Competition as part of a senior-level capstone design course in Tufts University's Engineering Psychology program. This course requires students to work in teams to address human-factors design issues in engineering problems set by industry partners. The course is intended to provide project teams the opportunity to integrate the many component skills they have developed across their undergraduate studies, while exposing them to the challenges – and rewards – of designing for complex, real-world systems.

The FAA Design Competition proved to be an excellent vehicle for motivating, structuring, and supporting the student team's activities within the context of this capstone design course. In particular, the Competition's requirement for interaction with airport operators and industry experts dovetailed extremely well with the pedagogical goals of the capstone design course. It was this direct interaction between the students and the potential developers, integrators, and users of their proposed alerting system that set this experience significantly apart from much of their undergraduate coursework. The Competition provided students a unique opportunity to participate within a larger design context, and in doing so challenged them to act as a bridge between industry partners with focused technical knowledge and domain experts with unique operational experience. Direct access to both of these groups allowed students to develop a deeper appreciation of the importance and intrinsic challenges of human factors-based design methods than is possible through more traditional course assignments where these relationships are absent.

As a team, the students faced significant challenges, particularly in executing a sufficiently broad and robust design effort (requirements analysis, design, prototyping, evaluation) within the time constraints of a single, thirteen-week semester project. At the outset of the project, most team members had very little knowledge of the aviation domain, and none had prior knowledge of the specific sensor technologies developed by the industry partner. The team overcame these challenges by working closely and frequently with airport operators and industry experts to apply the component knowledge elicitation and requirements analysis methods they had learned through their prior studies. I have no doubt that these first-hand experiences in efficiently eliciting, understanding, and leveraging this novel domain knowledge will serve the team members extremely well in their future endeavors as human factors practitioners.

I would definitely consider using the Competition as an educational vehicle in the future. The emphasis on real-world problem solving and safety considerations, coupled with direct interaction with airport operators and industry experts across an integrated analysis, design, and evaluation effort make this an excellent fit with the goals of Tufts' senior capstone design course. I recommend that the project sponsors consider a separate track for projects completed within the time constraints of a single-semester effort, although I appreciate that this would present other logistical challenges.

Appendix F

References

Arrabito, R.G., Mondor, T.A., & Kent, K.J. (2004). Judging the urgency of non-verbal auditory alarms: a case study. *Ergonomics*, 47(8), 821 – 840.

Baddeley, A. (2009). A Grounding in Surveillance. *Asian Military Review*. Bangkok, Thailand.

Chan, Alan H.S., Ng, Annie W.Y. (2008). Perceptions of implied hazard for visual and auditory alerting signals. *Safety Science*, 47, 346 – 352.

Conklin, E. (2010). Authentic Navy Alarm Sounds Page. Retrieved from <http://policeinterceptor.com>.

Department of Defense. (1999). *Design Criteria Standard*. MIL-STD-1472F. Retrieved from <http://safetycenter.navy.mil/instructions/osh/MILSTD1472F.pdf>.

Edworthy, J., Loxley, S., Dennis, I. (1991). Improving auditory warning design: Relationship between warning sound parameters and perceived urgency. *Human Factors*, 33, 205 – 231.

Euchner-USA, Inc. (2007). Overview Optical-Audible Signal Devices. Syracuse, NY.

Federal Aviation Administration. (2010). Fact Sheet: Next Generation Air Transportation System. Retrieved from <http://www.faa.gov/news/fact_sheet/news_story.cfm?newsId=10261>.

Federal Aviation Administration – Air Traffic Organization. (2009). *Annual Runway Safety Report*. Washington, DC: Government Printing Office.

Federal Aviation Administration. (2009). *FAA Flight Plan*. Washington, DC: Government Printing Office.

Federal Aviation Administration – Air Traffic Organization (2009). *National Runway Safety Plan 2009 – 2011* (AJS-129). Washington, DC: Government Printing Office.

Federal Aviation Administration. (2008). *Runway Safety Report*. Washington, DC: Government Printing Office.

Federal Aviation Administration. (2007). Advisory Circular: Change 11 to Airport Design (AC 150/5300-13). Washington, DC.

Federal Aviation Administration. (2007). Advisory Circular: Introduction to Safety Management Systems (SMS) for Airport Operations (AC 150/5200-37). Washington, DC.

Federal Aviation Administration. (2007). FAA needs to improve ASDE-X management controls to address cost growth, schedule delays, and safety risks (AV-2008-04). Washington, DC.

Federal Aviation Administration – Safety Services. (2007). *Runway Safety Report*. Washington, DC: Government Printing Office.

Federal Aviation Administration. (2004). *Safety Management System Manual*. Volume 1.1. Washington, DC.

Federal Aviation Administration – Office of Runway Safety. (2002). *Runway Safety Blueprint 2002 – 2004*. Washington, DC: Government Printing Office.

Federal Aviation Administration – Office of System Safety, ASY-300. *Airport Ground Vehicle Operations: an FAA Guide*. Washington, DC.

Laminar Research. (n.d.). Meet X-Plane. What is it? Retrieved <http://www.x-plane.com>.

NASA – Langley Research Center. (2000). Fact Sheet: RIPS (FS-2000-09-53-LaRC). Retrieved from <http://www.nasa.gov/centers/langley/news/factsheets/RIPS.html>.

North American Signal Company (2005). Audio-Visual Combo Devices. Wheeling, IL.

Patternson, R. (1982). Guidelines for auditory warning systems on civil aircraft. London: Civil Aviation Authority.

QinetiQ Ltd. (2009). OptaSense™ Frequently Asked Questions. Hampshire, United Kingdom.

QinetiQ Ltd. (2009). OptaSense™ System Overview. Hampshire, United Kingdom.

Software Technology Support Center (2009). Software Development Cost Estimating Guidebook. Hill Air Force Base, Utah.

VDV Works LLC. (2008). “Lennie Lightwave’s Guide to Fiber Optics.” Fallbrook, CA.

Vlek, J., Genge, R., & Wilhelm, A. (2008). *Applying GPS Technology to Mitigate V/PD Runway Incursions*. Daytona Beach, FL: Embry-Riddle Aeronautical University.

White, T., Turner, S., Seuino, L., & Hauburger, T. (2009). *Controller Intent Monitoring Interface (CIMI): A proposal for reducing high-speed runway incursions*. Los Angeles: University of Southern California.

Appendix G

Other Runway Incursion Prevention Technologies

Facility-Based Controller Notification Equipment

Airport Movement Area Safety System (AMASS) – This radar-based technology alerts controllers both visually and aurally when potentially dangerous situations on the airport surface occur. AMASS was developed as an enhancement of the ASDE-3 technology but is now considered an earlier iteration of ASDE-X. St. Louis (STL), Seattle (SEA), Atlanta-Hartsfield (ATL), and Washington-Dulles (IAD) have all recently replaced ASDE-3/AMASS systems with ASDE-X (FAA Runway Safety, 2007).

Low Cost Ground Surveillance (LCGS) Systems – For small and medium-sized airports that do not have surface surveillance technology, the FAA is evaluating the potential for inexpensive, commercially available radar systems (FAA Runway Safety, 2009).

On-Board Flight Crew Notification Equipment

Electronic Flight Bag (EFB) – A computerized replacement of paper flight charts, this technology integrates Airport Moving Map Display (AMMD) technology to show pilots their position on the airport surface in real-time. To determine EFB's impact on pilot situational awareness, the FAA is currently testing EFB and AMMD technology at twenty-one airports, including Los Angeles (LAX), Chicago O'Hare (ORB), Boston (BOS), and Atlanta-Hartsfield (ATL) (FAA Runway Safety, 2009).

Ground-Based Flight Crew Notification Equipment

Final Approach Runway Occupancy Signal (FAROS) – This technology is designed to alert pilots on final approach that the runway they are approaching is occupied. When the runway is occupied and hazardous, the system flashes Precision Approach Path Indicator (PAPI) lights to alert the pilot. Because this system does not require controller input, it does not add any cognitive demands to the controller, relying instead on the situational awareness of the pilot. FAROS is being tested at Long Beach-Daugherty Field Airport (LGB) and Dallas Fort-Worth (DFW) and the initial investment decision is scheduled to be made in 2010 (FAA Runway Safety 2009).

Appendix H

Table of System Requirements

Requirement	Source	Design Impact
System must be cost-effective	Research/Project Scope: It is important that any system we propose be a cost-effective solution to be feasible and worthwhile.	OptaSense™ technology allows us to create a real-time map of all vehicles on the movement area at a fraction of the cost of radar-based systems.
System must be simple.	Airport Visit: our domain experts informed us that, in their experience, low-cost surveillance systems such as the one we are proposing (OptaSense™) work best when kept simple. If they are too complex, effectiveness is reduced.	Our system uses the OptaSense™ technology to create a relatively low-cost surveillance system that covers the movement areas and perimeter road. By using a simple light/sound system to alert the driver we are able to maximize the advantages of the system without adding complications that could reduce effectiveness.
System must use both auditory and visual signals to alert the driver	Research/Human Factors Standards: multi-modal alarms are more effective in drawing attention than one source alone.	Our system has both a warning light and an audible alarm that work in conjunction to alert the driver.
System must not interfere with the monitoring of radio traffic or communications	Airport visit: our domain experts at Logan Airport noted that drivers can be monitoring up to 3 radio conversations at once	Our system contains a visual component to compensate for the loud environment. The auditory component of our alarm is also a tone (not a voice reading instructions) which serves to alert the driver but does not require constant monitoring.

System must not have unnecessary alerts	Airport visit and Usability Test: both our domain experts at Logan Airport and our usability test participants felt it was important that any alerting system only activate when it is necessary in order to avoid it becoming a nuisance (which means it ends up being ignored). It was also important that any system (especially one designed for an emergency situation) have a low false alarm rate so that operators will trust it.	For the low-level alert, our system uses the OptaSense™ technology to determine if the operator of the vehicle is stopping at the runway and only triggers an alert if they are traveling over a certain speed. For the high-level alert, the same technology keeps false alarms to a minimum.
If the system has two categories of alarm (a low-level alert and a high-level alert) they need to be easily differentiated.	Research/Human Factors Standards: if lights are used to alert the driver to different situations they must be different in color or brightness etc. and auditory alarms need to differ in volume or pitch etc.	The yellow and red colors of the visual alerts of our system are clearly different, and the audible alerts differ in pitch and sounding pattern.
System must also function in runway-end safety areas	Airport visit: our domain experts at Logan Airport felt that the runway-end safety areas could use additional safety measures especially as the drivers allowed on the perimeter road do not have the same license as those who drive on movement areas. We also observed these areas to be potentially dangerous in our driving tour of the airport surface.	Our system covers the perimeter road as well as the movement area and alerts the driver when they are approaching a runway-end safety area.
System must work equally well in poor-visibility conditions	Airport visit: during our driving tour of the airport Mr. Lynch mentioned that it can be very difficult to see the lights/markings of the airport under low-visibility conditions (i.e. snowstorms or heavy rain)	Our system is an in-vehicle alerting system

System must identify potential incursions and notify the driver in time to prevent them.	Airport visit as well as a research: there are already procedures in place to prevent incursions, but currently there is nothing in place with the sole task of monitoring the position of ground vehicles and notifying them before an incursion happens.	Our system alerts the driver directly (does not go through a controller). This allows us to alert the driver more quickly and does not add to the cognitive load of the controllers.

Appendix I

Detailed Description of Airport Visit

Our visit to Logan Airport consisted of two parts, a meeting with three domain experts and a driving tour of the airport movement area. We met with Flavio Leo, Manager of Aviation Planning; Robert Lynch, Airport Operations Manager; and Vincent Cardillo, Deputy Director of Aviation Operations, to learn about the challenges associated with airport driving and to get their input on our design concepts. We started by describing the Optasense technology, and informed them that we wanted to find a way to use it to create an alerting system for ground vehicle operators. The experts thought that the Optasense technology could be useful for airport operations in a number of ways, and provided us with some solid advice as we refined our design. They felt it would be worthwhile to develop a system that would alert drivers in the field, but one point that they particularly stressed was the need for the alarm system to not become a nuisance. They recommended that we only activate the alert when the driver is approaching an active runway at a speed that indicated they were not going to stop. They also stressed that we keep our design simple. Mr. Cardillo especially stated that in his experience low-cost surveillance systems work best when they do not try to do too much. He said that if too much is required they lose their effectiveness, and often become more expensive as a result.

After the meeting our group where driven around the airport grounds by Mr. Lynch in a modified SUV. We drove to the beginning of runway 15R and requested permission to drive all the way down the runway to the perimeter road. We were given permission to proceed down the runway and were cleared to cross runway 22R but told to hold short of runway 22L (runway 15R intersects with three runways: 22R/4L, 22L/4R, and 9/27). One of the major things we noticed while driving down the runway was how flat it was and how quickly we were confused. When we passed 22R (the runway we were cleared to cross) none of the team would have known if Mr. Lynch had not informed us. We then held short of 22L while a plane took off in front of us, and received clearance to continue. Once on the perimeter road we were no longer required to talk to the controller, but Mr. Lynch pointed out to us that the runway-end safety areas could still be dangerous and that drivers were told to look for planes before stopping. There were large red signs informing drivers of the danger, but for the most part we used them more as yield signs because we would not come to a complete stop. This observation prompted our design requirement that our system inform the driver when they approach a runway-end safety area.

Throughout our tour we were able to ask Mr. Lynch questions, and the information we gained was extremely enlightening. We learned that permission was needed to enter any open runway, and runways were considered open even if they were not being used at that moment. We also learned that there are different licenses at the airport, and a less stringent license was required to drive on the perimeter road than that which was required for driving on the movement area. We also observed the amount of radio chatter that Mr. Lynch needed to monitor while he was driving, both talking to the control tower as well as a car that was following behind us. He informed us that he could be monitoring as many as three different radios at once.

Appendix J

OptaSense™ System Details

OptaSense™ consists of fiber optic wires that employ Distributed Acoustic Sensing (DAS) to detect, locate, and assess animal or vehicle presence over a large area (QinetiQ Ltd, 2009). Pulses of light are emitted into the fibers by OptaSense™ interrogator units. Each unit sends and receives light pulses through the fiber to monitor disturbances and can handle up to 40 kilometers of fiber. The fibers through which light is passed are sensitive to movement above or near them, such as the vibrations caused by human or vehicle movement. These vibrations distort the light pulses emitted by interrogator units and the light pattern produced by vibrations allows the OptaSense™ system to detect and identify disturbances.

The interrogated information is then relayed to an OptaSense™ processing unit, which analyses acoustic data gathered over these channels of fiber to determine the presence, identity, and location of anything causing ground vibrations within. Light surface vehicles, such as SUVs, can be detected up to 50 meters away, while heavier vehicles, such as aircraft, can be detected up to 500 meters away. Processing units further relay this information into the desired form of output (visual user interfaces, audio outputs, etc.).

Figure J1 illustrates the accuracy density of two strips of OptaSense™ flanking a runway. The interrogator unit detects a different acoustic channel every 10 meters, which allows the system to pinpoint vehicle locations within 1 meter (O. Osechas, personal communication, March 17, 2010). Additionally, the OptaSense technology can detect low-flying aircraft (Baddeley, 2009), though tests still need to be done to accurately quantify the detection range (G. Duckworth, personal communication, February 3, 2010).

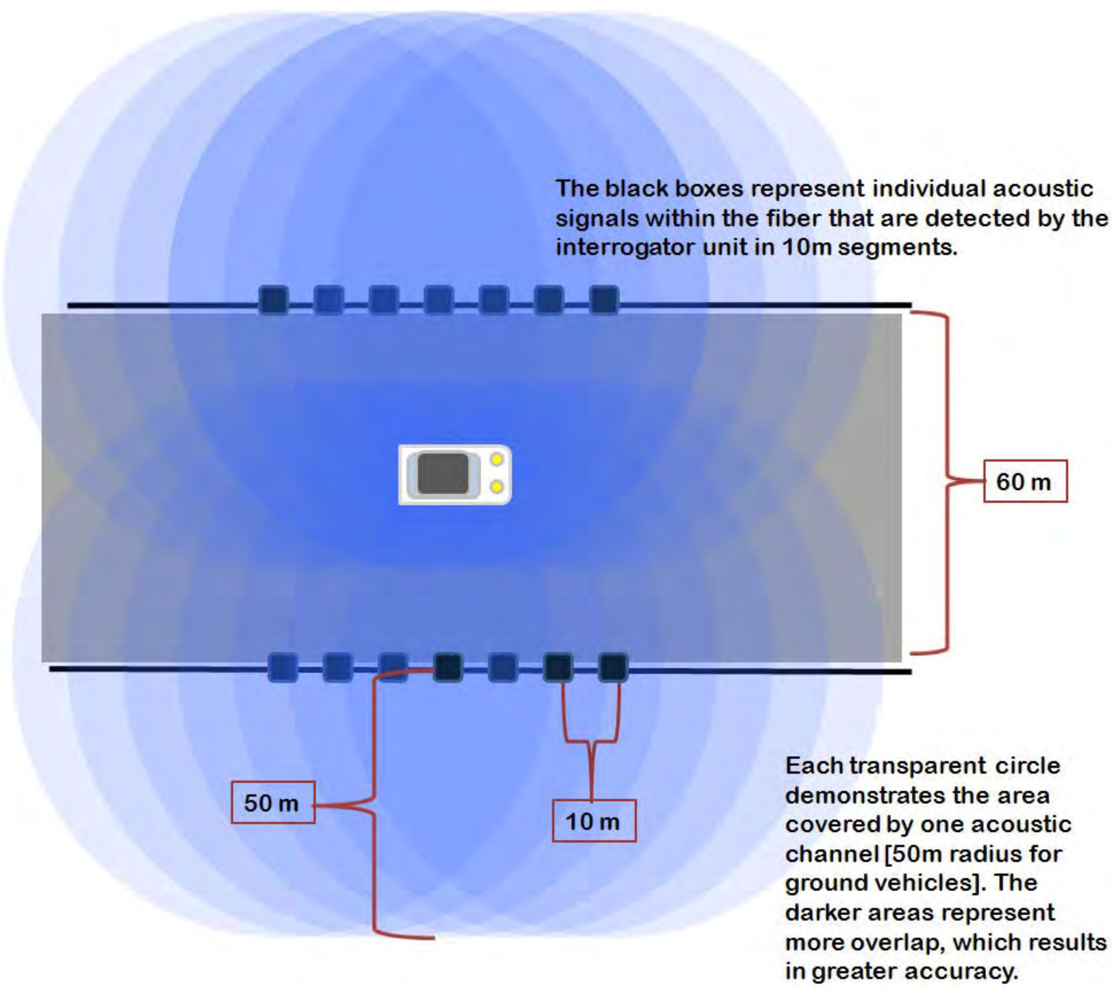


Figure J1. Diagram of OptaSense™ detection by acoustic channel

Appendix K

Table of Prototype Lighting System Parts List

Part Name	Part Number (Radio Shack)	Quantity
10mm White LED	2760005	2
10mm Red High Bright LED	2760015	2
Battery Holder (2-AA)	2700408	1
DPDT Toggle Switch	2751533	1
100’ #22 Wire	2781215	1
AA Batteries	N/A	2
Yellow Light Filter	N/A	1

Appendix L

X-Plane Simulator Information

X-Plane Desktop, created by Laminar Research (n.d.), is a flight simulation software that allows users to operate airplanes and ground vehicles in airports and other environments. The software is installable on any personal computer and there are several kinds of add-ons that allow users to create and implement any kind of virtual environment, and flight/ground vehicle within it.

For the purposes of our usability testing, the Boston International Airport downloaded and modified by employees at Volpe Systems was utilized. Participants drove around in a fuel vehicle and were given a standard video game steering wheel and braking system that allowed them to operate the vehicle.

One X-Plane plug-in utilized was XTraffic, a simulation software that allows users to record traffic into any environment and replay it while simultaneously operating an a vehicle in real-time. With this plug-in we were able to simulate airplane traffic on the runway while participants were driving their fuel vehicle. Airplane traffic was also utilized to simulate potential collisions that participants were saved from by our prototype’s red alarm alert.

Appendix M

Usability Test Driving Routes and Scripts

ROUTE #1

C53	“Logan Tower, Charlie five three terminal Echo.”
LATC	“Charlie five three, Logan Tower.”
C53	“Logan Tower, Charlie five three requesting to taxi to runway one five Right.”
LATC	“Charlie five three, Logan Tower proceed on taxiway Lima. Hold short of runway one five Right.”
	Once C53 has reached 15R
C53	“Logan Tower, Charlie five three holding short of runway one five Right”
LATC	“Charlie five three, Logan Tower proceed on runway one five Right. Hold short of runway two two Right.”
	Once C53 has reached intersection of 15R and 22R
C53	“Logan Tower, Charlie five three holding short of runway two two Right. Requesting to proceed on runway two two Right and go up taxiway Mike.”
LATC	“Charlie five three, Logan Tower proceed on runway one five Right to taxiway Mike.
	Once C53 has reached 22L
C53	“Logan Tower, Charlie five three holding short of runway two two Left. Requesting to proceed down runway two two Left.”
LATC	“Charlie five three, Logan Tower proceed down runway two two Left.
	Once C53 has reached intersection of 22L and 15R
C53	“Logan Tower, Charlie five three experienced a runway incursion on runway one five Right. Proceeding down runway two two Left.”
LATC	“Charlie five three, Logan Tower proceed down runway two two Left.
C53 experiences a near-collision, and is directed back to the terminal.*	

Figure M1. Route 1 Script

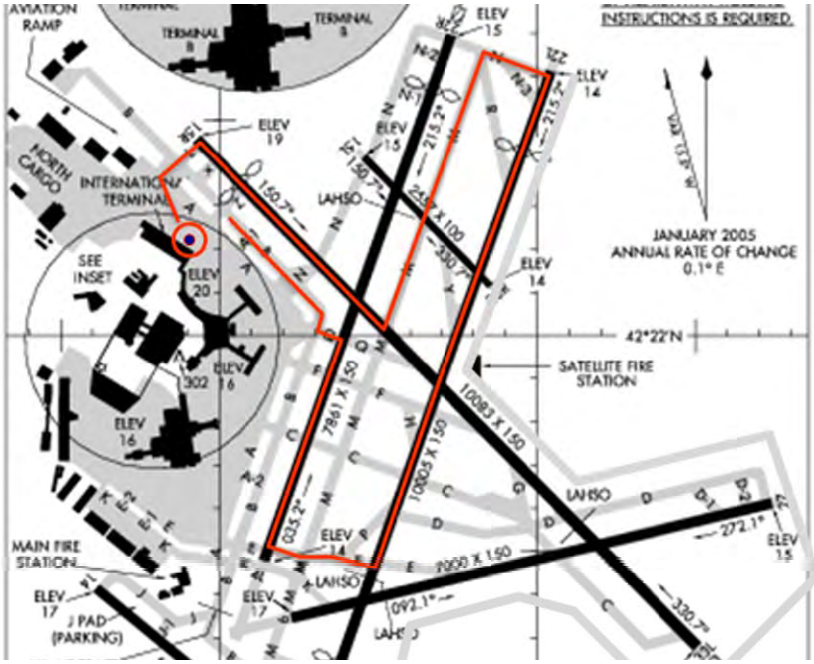


Figure M2. Route 1 Map

ROUTE #2

C53	"Logan Tower, Charlie five three terminal Echo."
LATC	"Charlie five three, Logan Tower."
C53	"Logan Tower, Charlie five three requesting to take taxiway Kilo to runway four Left. "
LATC	"Charlie five three, Logan Tower proceed on taxiway Kilo to runway four Left. Hold short of runway four Left."
	Once C53 has reached 4L
C53	"Logan Tower, Charlie five three holding short of runway four Left. Requesting to proceed onto runway four Left to taxiway Foxtrot."
LATC	"Charlie five three, Logan Tower proceed onto runway four Left to taxiway Foxtrot. Hold short of runway two two Left."
	Once C53 has reached 22L
C53	"Logan Tower, Charlie five three holding short of runway two two Left. Requesting to proceed onto runway two two Left."
LATC	"Charlie five three, Logan Tower turn left and proceed onto runway two two Left. Hold short of runway one five Right."
	Once C53 has reached intersection of 22L and 15R
C53	"Logan Tower, Charlie five three holding short of runway one five Right. Requesting to proceed up on runway one five Right to taxiway Mike."
LATC	"Charlie five three, Logan Tower proceed up on runway one five Right to taxiway Mike. Hold short of runway one five Left."
	Once C53 has reached15L

C53	"Logan Tower, Charlie five three holding short of runway one five Left. Requesting to proceed onto runway one five Left to runway two two Right."
LATC	"Charlie five three, Logan Tower proceed onto runway one five Left to runway two two Right."
	Once C53 has reached intersection of 15L and 22R
C53	"Logan Tower, Charlie five three requesting to proceed onto runway two two Right.
LATC	"Charlie five three, Logan Tower proceed down runway two two Right.
	While driving on 22R C53 experiences a near-collision and is directed back to the terminal.*

*The notes about a near collision did not appear on the scripts given to the participants.

Figure M3. Route 2 Script

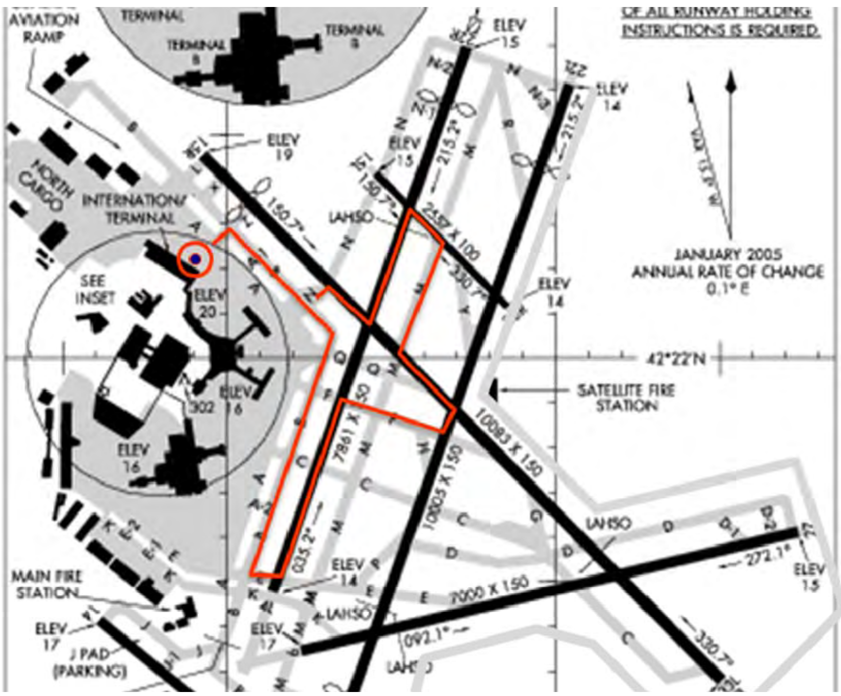


Figure M4. Route 2 Map

Appendix N

In-Progress Usability Test Photographs

Figure N1. Screenshot of simulator

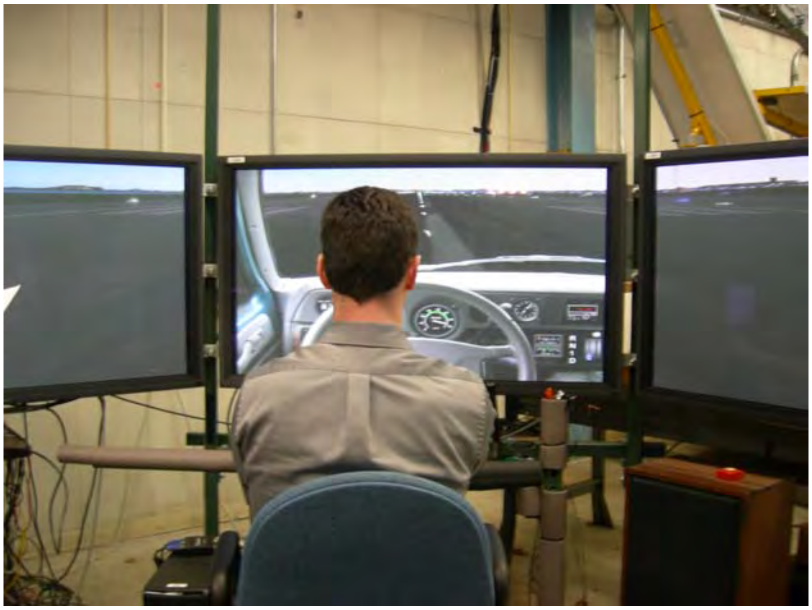


Figure N2. Image of a participant using the simulator during the usability test

Figure N3. Image of tester sitting behind participant to manually trigger alerts

Appendix O

Usability Test Questionnaire

Airport Ground Vehicle Alerting System Evaluation

Thank you for your help! We are designing a novel way to alert the ground vehicle operators at airports in the case of an emergency or a potential infraction (such as a runway incursion). One of the most important steps in this design process is getting feedback from users to help us make our system both effective and helpful, not a hindrance or an annoyance. We would now like to ask you to fill out this brief questionnaire about your opinions of the system; any input you can give us will be greatly appreciated.

1. What experience do you have (if any) with airport operations and/or driving on both movement and non-movement areas of an airport?

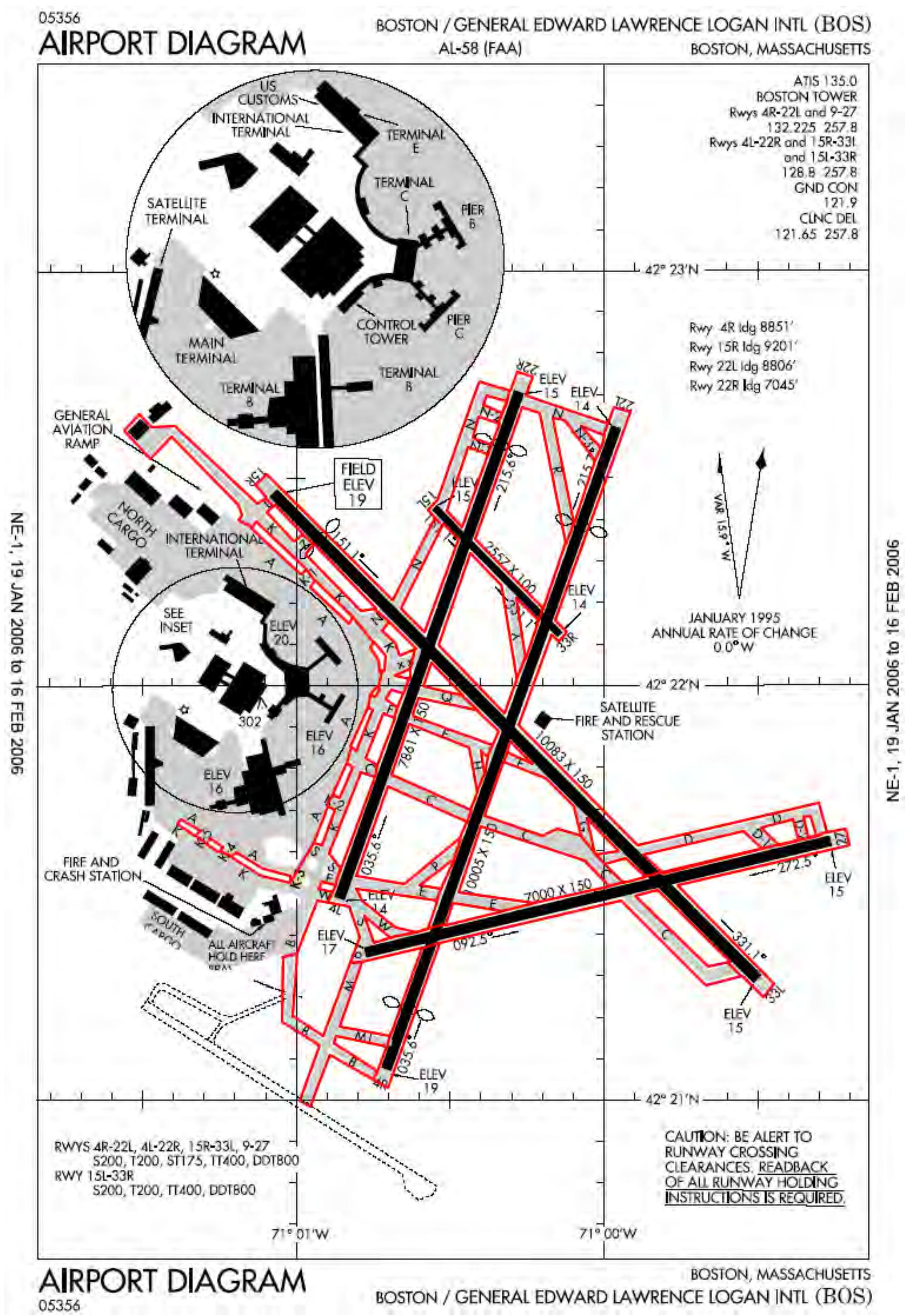
2. How effective was the system in catching your attention? Did you think the alarm was too loud or too quiet? Was the light in an appropriate place?

3. Could you clearly differentiate between the different kinds of alarms? If not, where were they too similar? Do the levels of alerts make sense? Did you understand the meaning of the alarm?

4. Do you think this system could potentially be helpful? If you were a ground vehicle operator and this system was installed in your vehicle, would you consider it a valuable safety precaution or an annoyance? Why? Would you trust such an alarm? What would you change to make it more useful?

Appendix P

Airport Diagram with Estimated Cable Installation Layout Overlay



Appendix Q

Tables for Cost Estimates in Financial Analysis

Table Q1. Cost estimates and sources.

Item	Cost	Source
Fiber Optic Cable	$1/m	Dr. Greg Duckworth, QinetiQ North America
Optasense Stand Alone System *	$250,000	Kevin Stein, QinetiQ North America
Additional Interrogator Units	~$200,000	Kevin Stein, QinetiQ North America
Server (to run Optasense software and trigger alerts in ground vehicles)	$2,000-$3,000	Mr. Okuary Osechas
Trenching/ Installation labor costs	Made on a case by case basis. The cost is a function of length and terrain characteristics (hilly vs. flat, dirt vs. concrete, etc.)	Celergy Networks Inc.
GSM Chip for signaling vehicle alert system	~$70 retail (larger orders will decrease per unit cost)	Okuary Osechas

In-vehicle alerting system (custom light/sound alarm)	$100 to < $300 per unit (larger orders will decrease per unit cost)	Euchner-USA, Inc., 2007; North American Signal Company, 2005
Cost of software development	Dependent on a variety of factors: development environment, cost, quality, scope	Software Technology, 2009
Maintenance: fusion splicers	$15,000 - $40,000	VDV Works LLC, 2008

Table Q2. Upper Bound Estimable Costs for Installation at Logan Airport

Item	Unit Cost	Number of Units	Subtotal
Fiber Optic Cable	$1/m	64,000	$64,000
Optasense Stand Alone System	$250,000	1	$250,000
Additional Interrogator Units	~$200,000	1	$200,000
Server	$2,000-$3,000	1	$3,000
Trenching/Installation labor costs	not estimable	-	-
GSM Chip for signaling vehicle alert system	$70 estimated retail	100	$70,000

In-vehicle alerting system (custom light/sound alarm)	$300 estimated retail	100	30,000
Cost of software development	not estimable	-	-
Maintenance: Fusion splicer	$40,000	1	$40,000
Total			**$657,000**