Ground Vehicle Runway Incursion Prevention Alerting System Literature Review

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16. Abstract

The Federal Aviation Administration Airport Technology Research and Development Branch conducted a literature review of technology and technological solutions that could be used to prevent runway incursions and surface accidents involving vehicles with authorized access to the aircraft movement area. The objective was to identify a technology that would be optimal for this purpose and would warrant further evaluation.

The optimal technology was defined as a complete system that provides an alert to ground vehicle operators when approaching a sensitive or restricted area, while having minimal equipment installation requirements that could impact the airport infrastructure.

The components needed for an alerting system are (1) reliable ground vehicle position information as to where it is on an airport, (2) a device is needed to provide the visible and audible alerts to the vehicle operator, and (3) the most critical, the logic necessary to take and send the alert directly to the device in the ground vehicle. A literature search was conducted to identify technologies and systems that have the potential to provide a visible and audible alert to ground vehicle operators when approaching a restricted area, such as runways, runway safety areas, etc.

A number of technologies have components that could be used in an alerting system; however, only three were identified that constituted a complete system. They were (1) the Incursion Collision Avoidance System (ICAS), (2) The Runway Incursion Monitoring Detection Alerting System (RIMDAS), and (3) The Asset Tracking and Incursion Management System (ATIMS).

The analysis of the literature search showed that the RIMDAS did not provide an alert when approaching a sensitive or restricted area. The lack of this feature is a disadvantage compared to the ICAS and ATIMS systems, which provide this capability. Both the ICAS and RIMDAS systems required equipment to be installed on the airport in addition to the equipment needed in the ground vehicle. For these reasons, the ICAS and RIMDAS were not recommended for further evaluation.

The analysis of the literature search showed that the ATIMS met the optimal criteria, and a version of the ATIMS is already being used on airports. The only equipment needed is in the ground vehicle. Because of these advantages, the ATIMS is recommended for further evaluation.

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LIST OF ACRONYMS

ADS-B	Automatic Dependent Surveillance-Broadcast
AMA	Airport movement area
ASDE-3	Airport Surface Detection Equipment
ASDE-X	Airport Surface Detection Equipment, Model X
ATC	Air traffic control
ATIMS	Asset Tracking and Incursion Management System
eFAROS	Enhanced version of Final Approach Runway Occupancy Signal
ES	Extended squitter
FAA	Federal Aviation Administration
FAROS	Final Approach Runway Occupancy Signal
FY	Fiscal year
GA	General Aviation
GAO	Government Accountability Office
GPS	Global Positioning System
ICAS	Incursion Collision Avoidance System
NAS	National Airspace System
NAVSTAR	Navigation Satellite Timing And Ranging
nm	Nautical mile
NTSB	National Transportation Safety Board
RFID	Radio frequency identification
RIMDAS	Runway Incursion Monitoring Detection Alerting System
RWSL	Runway status light
UAT	Universal Access Transceiver
U.S.	United States

EXECUTIVE SUMMARY

The office of the Federal Aviation Administration (FAA) Airport Safety and Standards requested that the FAA Airport Technology Research and Development Branch conduct a review of technology and technological solutions that could be used to prevent runway incursions and surface accidents involving vehicles with authorized access to the airport movement area on an airfield. The focus of this literature review was to identify technologies that have the potential to provide an alert to a vehicle operator when approaching an area where a runway incursion could occur.

An alerting system consists of three components: (1) the system needs have accurate vehicle position information, (2) a device is needed to provide the visible and audible alerts to the vehicle operator, and (3) the most critical, is the logic, or decision-making algorithms, to use the position information and send the visual and audio alerts to the device in the ground vehicle, which provide timely alerts to the ground vehicle operator.

A literature search was conducted to identify technologies and systems that have the potential to provide a visible and audible alert to ground vehicle operators when approaching a restricted area, such as runways, runway safety areas, etc. Furthermore, this report identifies and describes optimal technologies that have the potential for mitigating runway incursions caused by ground vehicles operating on an airfield and would benefit from further evaluation.

The optimal technology was defined as a complete system that provides an alert to ground vehicle operators when approaching a sensitive or restricted area, while having minimal equipment installation requirements that could impact the airport infrastructure.

A number of technologies have components that could be used in an alerting system; however, only three systems were identified that could be used to send a visible and audible alert to the ground vehicle operator: (1) the Incursion Collision Avoidance System (ICAS (2) the Runway Incursion Monitoring Detection Alerting System (RIMDAS), and (3) the Asset Tracking and Incursion Management System (ATIMS). The ATIMS can use global positioning systems or other positioning technologies to collect and process information. The ATIMS then sends a visible and audible alert to a device in the ground vehicle when it approaches a sensitive or restricted area.

The literature search analysis showed that the RIMDAS did not provide an alert when it approached a sensitive or restricted area. The lack of this feature is a disadvantage compared to the ICAS and ATIMS systems, which provide this capability. Both the ICAS and RIMDAS systems require equipment to be installed on the airport in addition to the equipment needed in the ground vehicle. For these reasons, the ICAS and RIMDAS systems were not recommended for further evaluation.

The literature search analysis showed that the ATIMS met the optimal criteria, and a version of the ATIMS is already being used on airports. The only equipment needed is in the ground vehicle. Because of these advantages, the ATIMS was recommended for further evaluation.

INTRODUCTION

PURPOSE.

The number of aircraft operations performed within the National Airspace System (NAS) of the United States (U.S.) continues to rise. The National Transportation Safety Board (NTSB) has expressed concern that due to this expected increase in air traffic, there will be a corresponding increase in aircraft accidents and incidents, including runway incursions. Federal Aviation Administration (FAA) data indicate the number of runway incursions reported to the FAA has increased from 900 to nearly 3000 between 1990 and 2010.

The office of the FAA Airport Safety and Standards (AAS-1) requested that the FAA Airport Technology Research and Development Branch conduct a review of technological solutions that could be used to prevent runway incursions and surface accidents involving vehicles with authorized access to the airport movement area (AMA) on an airfield. This report identifies technologies that have the potential to provide an alert to a vehicle operator when approaching a sensitive or restricted area. Furthermore, this report identifies and describes optimal technologies that have the potential for mitigating runway incursions caused by ground vehicles operating on an airfield and would benefit from further evaluation.

The optimal technology is a complete system that alerts ground vehicle operators when approaching a sensitive or restricted area, while having minimal equipment installation requirements that could impact the airport infrastructure.

BACKGROUND.

On October 1, 2007, the FAA adopted the International Civil Aviation Organization's more restrictive definition of a runway incursion, which is "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." The FAA previously considered a runway incursion to be: "Any occurrence in the airport runway environment involving an aircraft, vehicle, person, or object on the ground that creates a collision hazard or results in a loss of required separation with an aircraft taking off, intending to take off, landing, or intending to land." [1]

The FAA seeks to reduce both the number and the severity of runway incursions that occur within the NAS. The runway incursion severity is classified by the risk of collision and is divided into five categories. The categories vary from a narrowly avoided collision to an incident that technically meets the definition of a runway incursion but presents no immediate safety consequences. The current definition for runway incursion classes are as follows [2]:

- 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 a 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 takeoff of aircraft, but with no immediate safety consequences.

- Category E: Insufficient information, inconclusive, or conflicting evidence precludes severity assessment.

Because of the life-threatening nature of the most severe runway incursions, reducing their occurrence has been on the NTSB's top ten "most wanted" list of safety improvements since 1990. The Government Accountability Office (GAO) has produced several publications recommending the FAA determine if technological solutions are needed for airports not scheduled to receive any new technology [3]. It lists the primary causes of runway incursions as human factors issues, including problems with communication, situational awareness, and performance or judgment errors on part of pilots and air traffic controllers [4].

According to the GAO [4], runway incursions peaked in fiscal year (FY)2001, declined, then remained approximately constant in FY2001-2006, then increased in FY2006-2007. The GAO recommends nonpunitive Air Traffic Control (ATC) safety reporting programs, as well as NTSB/expert-recommended technology deployment to pilots. The GAO notes the FAA only counts runway incursions that occur at controlled airports, and the real (total) rate of occurrence at all airports is probably higher. Furthermore, an FAA audit of 2006 runway incursion data questioned the accuracy of the reported severity of runway incursions.

CAUSES OF RUNWAY INCURSIONS.

Runway incursions can occur when there is a breakdown in communications or situational awareness at an airport. They can be caused by pilots, air traffic controllers, vehicle operators, or people working on an airfield, regardless of their level of training or experience. A general lack of situational awareness of their surroundings or confusion about their own position on an airfield seems to be the most prevalent cause of vehicle runway incursions. This can be due to a lack of training; misunderstanding of, or inattention to, airport layouts; changes to an airport layout due to construction; or even simple complacency. Miscommunication is also a common cause for runway incursions, whether it is due to poor radio etiquette, nonstandard phraseology, or a squelched message.

HUMAN FACTORS ISSUES

HUMAN FACTORS OVERVIEW.

Several studies and papers have been written about the human factors element of causing and preventing runway incursions. While most of these documents were written primarily from a pilots' perspective, the principles behind the studies were relevant to this research and can be directly applied or extended to the operator of a vehicle on an airport. There is significant overlap between the feedback given to researchers by both pilots and by ground vehicle operators. During interviews, pilots and vehicle operators expressed concerns with the high demand for their attention during airport movement operations. The consumption of their attentive capacity by different responsibilities could lead to both inadvertent runway incursions and the possibility that they would miss an alert, unless the alert was presented in such a way as to be brought to the forefront of their attention. With so many concerns present, i.e., workload concerns, checklists, attention to radio traffic, attention to vehicle position, etc., there is high competition for the attention of the vehicle operators by each concern.

Major Mark Adams, USAF, discussed the challenges presented during landing/taxi/takeoff procedures; these basic difficulties presented affect ground vehicle operators as well [5]. Adams reviewed various workload challenges and noted that difficulties with radio operation, eye physiology in periods of low light or at dusk, effects of glare, and confusion about airport layout all contribute to difficulty in navigating the airfield. Adams further stated that up to 20% of pilot incursions involve aircrew being reluctant to seek assistance and end up continuing with a potentially hazardous course of action. It is easy to see that this attitude can sometimes be present with vehicle operators as well. This essentially contributes confusion about the vehicle position (i.e., lack of situational awareness), to being a contributing factor to runway incursions [5]. This notion can be directly extended to vehicle traffic, especially where the vehicle operator is conducting movements in busy areas or is preoccupied with occupational priorities.

WHO SHOULD GET THE ALERT.

GAO-interviewed experts recommend presenting pertinent traffic information and alerts directly to users [4]. The research indicates the time needed to notify the pilot or vehicle operator of the warning through ATC and verbal communication channels greatly reduces or negates the alert by reducing the time available to take corrective action. Currently, Airport Surface Detection Equipment (ASDE)-3/ASDE-X/AMASS detection systems only alert ATC. ASDE-X systems, which could directly alert the pilot or vehicle operator, are still being developed.

HOW THE ALERT SHOULD BE PRESENTED.

Young and Jones [6] investigated runway incursion detection and display technology, and found that automatic detection and alerts could give pilots an additional 6 seconds to take corrective action. In another article, Jones, et al [7], tested simulations in which two different runway incursion detection algorithms were used across various scenarios. One was a generic detection algorithm, and the other looked for over 40 specific scenarios. A group consisting of 16 general aviation (GA) pilots was tested in the simulations. The group represented characteristics present across sections of the Part 91 pilot population, i.e., both low- and high-time (400 hr) visual flight rules and instrument flight rules (<1000 and >2000 hr) certified pilots. The pilots were presented with a display that included a moving map similar to the Global Positioning System (GPS) units available for automotive navigation. The situations with a moving map display that showed both airport traffic and their own aircraft position were perceived to be better and have a higher added safety value. The pilots expressed that the addition of graphical presentations of alerts overlaid on the surface maps were necessary, and that audible alerts would bring the runway incursion to their attention sooner than only visible alerts; therefore, that combination is desired. Providing both cautionary and warning alerts gave pilots additional time and comfort over single-alert systems. Pilots expressed a desire for automated collision avoidance maneuvering guidance. This combination of visible and audible alerts also would be appropriate for warning vehicle operators of the potential for causing a runway incursion. Instead of simply detecting an incursion, the focus of this research is to use a combination of visible and audible alerts to avoid a situation that could become an incursion.

Squire, et. al [8], conducted a human factors analysis showing that a pilot's visual attention was occupied more than their auditory attention during takeoff. As a result of pilot interviews and other human factors studies, the authors concluded that audible alerts would be the best way to warn the pilot. The authors proposed that the optimum alert would provide a brief form of verbal conflict resolution as well as gain the pilot's attention. Applying this situation to vehicle operators, it can be expected that he or she likely would be focusing their attention outside their vehicle, rather than on a visual reference within the vehicle. Therefore, audible and visual cues would also benefit vehicle operators.

GROUND VEHICLE ALERT.

In reference 9, it was determined that an airport ground vehicle runway incursion warning (alert) system should not give directions for navigating on an airport. The alert must not replace personal airport familiarization and ATC instructions; instead, it should be used as a situational awareness tool. Minimum performance criteria (receiver location placement, proximity warnings, alert areas, audible and visible signals, system updates, and compliance) were recommended for this ground vehicle alerting system. Optional features that were not critical to preventing runway incursion but provided additional benefits to airport users included moving maps, vehicle speed indicator/warning, historical tracking and vehicle trails, system integration, zone creation, display dimming, network capability and infrastructure, multiple vehicle tracking, document display, and weather conditions.

ALERTING SYSTEM COMPONENTS

An alerting system consists of three components: (1) accurate vehicle-positioning information, (2) a device to provide the visible and audible alerts to the vehicle operator, and (3) the most critical, is the logic, or decision-making algorithms, that uses the positioning information to send the visible and audio alerts to the operator at the appropriate time via the device in the ground vehicle.

The following three sections briefly describe the currently available technologies, while not complete systems, which could provide components for an alerting system.

POSITION INFORMATION.

RADAR.

Primary Radar Systems. Radar provides primary surveillance for determining the location of aircraft and vehicles within the NAS. A radio transmitter broadcasts a signal and processes the return signature (or echo) to track the objects returning the signal. One such radar, ASDE-3, is a Ku-band primary radar that provides AMA surveillance. This radar tracks aircraft or vehicles independent of the aircraft or vehicle. However, it only gives ATC a limited amount of information and is susceptible to complications due to multipath reflections; signal processing errors; artifacts due to weather, such as presenting a snow bank as an aircraft reflection; and other issues.

Secondary Radar Systems. Since primary radar only gives the radar operator a limited view of the radar return echo and does not provide any identifying information, secondary surveillance radar is broadcast concurrently with the primary radar signal. When this signal is intercepted by an aircraft, a transponder onboard the aircraft responds with an informational reply that the secondary radar system uses to display identification information to the radar operator. This type of radar relies on the response of the aircraft and the cooperation of the transponder to send the proper reply.

The ASDE-3 and ASDE-X Radar. The GAO reports that the FAA has installed ASDE-3 radar and ASDE-X. ASDE-X incorporates ground surveillance radar, such as ASDE-3, with other ground and terminal radars and incorporates the information with self-reported location data from aircraft transponders [4]. To give ATC a better or more informative picture, a secondary surveillance radar system is used that applies a radar signal to interrogate a transponder on the aircraft. The transponder then replies with information about the aircraft, such as aircraft identifier, altitude, heading, etc., depending on the type of transponder. ASDE-X-equipped airports have experienced problems with false alerts and false targets. The false targets mainly come from erroneous sensor data, and the false alerts tend to come from a specific combination of detection logic and surveillance data fidelity.

MULTILATERATION OPERATIONS. Multilateration is a mathematical operation similar to triangulation, but in three dimensions [10]. Three or more sensors on the ground are used to provide information for the triangulation. Each sensor sends a signal to the object being tracked, which bounces back from the object to the sensor. Since the signal properties are known, measuring the difference in the timing in which each sensor receives the signal provides an estimation of the distance to the signal source. Combining the knowledge of these distances, and the known geometry of the sensors, the position of the signal source can then be computed. A similar concept is used onboard aircraft to estimate bearing in relation to beacons and other radio sources, as well as to provide GPS positioning.

GLOBAL POSITIONING SYSTEM. The GPS consists of geosynchronous satellites that broadcast a time-dependent signal that can be used to triangulate the position of the signal receiver. Due to atmospheric and other interferences, there is a limited resolution in the use of the basic ground signal. However, there are ground-based transmitters that broadcast a differential signal that can be used to make the proper corrections to the satellite-based signals. These increase the fidelity of the calculated signal to the point where the system can be used for flight under instrument flight rules within the NAS. GPS data are used to provide the position information of various systems discussed here, but proper discussion of this system is beyond the scope of this research.

<u>INDUCTIVE LOOP SENSORS</u>. Some systems, such as the Final Approach Runway Occupancy Signal (FAROS), propose the use of inductive loops to detect aircraft and ground vehicles. Inductive loop sensors are essentially large loops of wire that a current is passed through. The monitoring equipment looks for a voltage pulse that comes from the change in inductance indicated by the presence of magnetic or ferrous (iron-containing) metals. This approach would likely detect vehicles, but it would be less likely to reliably detect aircraft due to their construction. This would mean the installation of a ground vehicle detection system based on inductive loops would be unable to provide any additional utility in the form of detecting the presence of aircraft. It should be noted that the control signal produced by inductive loops could possibly be used as a control trigger to turn on other tracking systems, signage, alert systems, etc. The added complexity of tying separate systems together for aircraft and ground vehicle tracking (or the added cost of having two independent systems installed concurrently) would have to be factored into any decision to use the technology.

To further illustrate the deficiency of inductive loop sensors, one would only have to look to the development of the enhanced version of FAROS (eFAROS) that incorporates ASDE-X surveillance data. If the inductive loop sensors were adequate, eFAROS would not have been developed. Furthermore, using inductive loop sensors alone does not provide a complete vehicle-accounting system. A vehicle that enters a runway at a taxiway intersection, but leaves mid-field would still leave the system identifying the runway as occupied. The lack of vehicle position fidelity gives evidence of the need for an alternative sensor.

Having separate systems in place to detect the movement of aircraft and ground vehicles might be necessary in some cases. However, if a single system (or even a small set of systems) can reliably detect both aircraft and ground vehicles using unified system architecture, it might reduce system complexity or cost enough to become a viable option when cost-benefit analysis prevents deployment of other detection systems.

<u>AUTOMATIC DEPENDENT SURVEILLANCE-BROADCAST</u>.

<u>Automatic Dependent Surveillance-Broadcast Overview</u>. Automatic Dependent Surveillance-Broadcast (ADS-B) is transponder-based technology that provides broadcasts of aircraft or vehicle information. The location information that is broadcast is based primarily on GPS data. Though the primary purpose is to maintain shorter separation between aircraft on approach and during operation on runways, the system can provide safety and runway incursion benefits by announcing aircraft and vehicle position on the AMA [11]. The system uses transponders to electronically announce the transponder's position, heading, and speed. The

FAA has announced a ruling that would require equipage of ADS-B transponders by 2020 for aircraft operating in Class A, B, C, and certain Class E airspaces, and where otherwise specified. The widespread deployment of this technology would mean that the system hardware would be present at a number of airports, and if vehicles could be integrated into the system, it would negate the need for a specialized system for just tracking ground vehicles.

The ADS-B Data Link Concerns. In the U.S., the ADS-B transponders can operate at one of two frequencies, either 978 or 1090 MHz [12]. The 978-MHz frequency is used for the Universal Access Transceiver (UAT) link and is meant for GA aircraft that are currently not Mode S transponder equipped. The 1090-MHz link is used for both the Mode S transponders and the 1090 extended squitter (ES) links. The 1090 ES link is expected to provide a 40-nautical mile (nm) air-to-air range in high-density or high-interference environments and 90-nm range in low-density/interference environments. The FAA prefers that ground vehicle ADS-B systems use the 978-MHz/UAT link due to radio congestion on the 1090 ES link [13]. Pagano, et. al ([12], performed tests, which report that multiple transceivers can share an antenna, provided that certain radio and electronic requirements are met. This would reduce cost by not requiring an individual antenna for each transponder, i.e., equipment sharing. The mandate requiring the adoption of ADS-B transceivers would mean that with increasing economies of scale that come with widespread deployment, there would be a decreased and shared cost across the NAS.

The ADS-B Multilateration. The FAA [13] indicates that ADS-B transponder broadcasts provide a signal so multilateration calculations can be performed. This provides a secondary mechanism to determine vehicle position and provides a measure of error detection. Furthermore, the FAA states that the transmitter would only be active inside the designated squitter transmit area, and on only one link at a time. The on/off control would be performed within the unit. The FAA would authorize up to 200 transmitters per airport to prevent degradation of performance on other equipment operating at 1090 MHz. Therefore, the vehicle-based transmitters would only be allowed to operate within coverage of an ASDE-X/ADS-B multilateration system.

How ADS-B can Prevent Runway Incursions. The existing requirements dictating the positional operation of ADS-B transmitters for ground vehicles means that vehicle transponders have to maintain awareness of their own position on the AMA. This positional knowledge not only can be used to maintain on/off operation of transponder transmission, but also could be used to drive moving map displays. Having the display alone could prevent runway incursions simply by reminding the vehicle operator of their own position on the AMA and prevent position confusion. Furthermore, the unit could have added functionality, such as pointing out surface hazards and Foreign Object Debris reports [14].

IMAGE RECOGNITION AND COMPUTER VISION. There are numerous camera-based computer vision systems available, most primarily in the security surveillance market. Such systems use images from digital cameras to feed information to computers that perform digital signal processing on the data and can determine when an image changes. These changes are marked as targets for further processing. With proper programming, the systems can identify targets with a finite degree of certainty, regardless of target aspect with respect to the camera.

There are systems available that can automatically survey an area, identify and report targets of interest, and track them. When the data are fed to the cameras' pan-tilt-zoom functions, active target tracking is possible.

One major aspect of attempting surveillance through computer vision is the degradation of surveillance data in inclement weather. This can be mitigated to a certain degree by the deployment of relatively mature technology, such as camera housings that are heated and cooled, include snow removal techniques, and windshield wipers. To increase surveillance reliability, a dual camera system would be able to switch between visible and infrared imagers. FLIR Commercial Vision Systems illustrates that, through the use of mid- and long-wave infrared imaging, a camera system can be set up to effectively see through rain, snow, and fog [15]. Furthermore, due to the nature of the operation of such cameras, they "see heat" and can detect the hot engines and exhausts of both aircraft and ground vehicles. The use of infrared imaging to detect and track targets (even through fog, dust, and sandstorms) has already been proven in military operations.

RADIO FREQUENCY IDENTIFICATION.

Radio Frequency Identification Overview. Radio Frequency Identification (RFID) describes active radio equipment that is commonly used to identify a known object, which can be used for asset tracking and inventory management. The components are known as RFID tags and RFID readers. The majority of RFID systems use an active reader that sends out a radio signal to nearby RFID tags. The radio signal powers up the RFID tag, and an integrated circuit on the tag responds with a modulated response determined by the circuitry onboard the tag. The tags' reception depends on the characteristics of the tag type used and the particular situational characteristics presented.

How RFID can Prevent Runway Incursions. A vehicle's location can be determined by using a RFID interrogator system installed on a vehicle and a system of RFID tags positioned within the airport environment. This system would essentially treat the embedded RFID tags as grid location markers on an airport map. It requires a system of RFID tags be installed within the AMA, i.e., taxiways, runways, ramps, and gates.

A communication device would be installed on each vehicle and is the primary communication tool between the driver, the vehicle, and airport management. Each device could be capable of interacting with, or be tailored to, a specific vehicle(s), so airport management has the ability manage vehicle operations.

LOW-COST SURFACE SURVEILLANCE. Gallagher and Bassey [16] evaluated surveillance systems that track ground vehicle movement on the Airport Operations Area (AOA). A technology-based system was sought to supplement visual surveillance and increase surveillance and tracking performance in poor-weather or low-visibility conditions compared to radar and naked-eye scanning. As a low-cost system, it would provide coverage to airports that did not meet cost-benefit criteria for existing technologies, and it could supplement airport installations with existing radar systems. It was determined that the system would consist of identification providing transponders that would supplement nonidentifying technologies. Such a system would increase airport efficiency and utilization in addition to providing increased safety through additional situational awareness. The sensor data would be able to be combined to give an integrated central display. At a minimum, a self-reporting system based on ADS-B Mode S transponders and multilateration techniques can provide the needed information.

DISPLAY AND ALERT TECHNOLOGY.

It is believed that by adapting portable satellite-based navigation equipment with moving map technology to the airfield environment would greatly increase the situational awareness and possibly reduce vehicle runway incursions. The moving map displays are similar in concept to the GPS navigation units used in automotive navigation. The technology developed for this research is based on GPS, specifically Navigation Satellite Timing And Ranging (NAVSTAR) GPS, which is operated by the U.S. Department of Defense.

Subbotin [9] indicates FAA-imposed minimum device performance recommendations and iterates that runway incursion prevention devices should exist only to augment driver situational awareness. GPS is used in this instance, but other sensors and systems could be used. Vehicle operators should be alerted when they are within the runway safety area, as well as when they are in the proximity of a sensitive area.

As the result of an FAA university competition, a student group at Embry-Riddle Aeronautical University [14] proposed using a moving map display with a GPS-based geographic information system display, but notes that driver distraction could be a concern. Audible alerts would have to compete with other devices for driver attention. Note that this effort was concerned with AMA driver operational concerns, whereas other groups concentrated on pilot or ATC concerns.

DECISION TECHNOLOGY.

The algorithms behind the decision-making systems presented here are complex enough to warrant a discussion of their own. It should be noted that development and deployment of detection algorithms can occur independently of detection equipment. Therefore, an updated control system could be put in place with existing sensor systems and can be updated independently. Once the underlying sensors are in place, ground-based centralized control systems could be updated without having to change the sensors in the ground vehicles. If the control logic is based from the vehicle, the updated logic would either have to be downloaded to the vehicle manually or through some other communications link not discussed here.

Reference 17 states that Runway Status Light (RWSL) systems (which are currently operating at Dallas/Fort Worth and other airports) act to directly notify taxiing pilots and vehicle operators that the runway ahead of them is unsafe to enter. Driven by surveillance data and incursion detection logic, the system then alerts the pilots and vehicle operators with lights embedded in the pavement surface. RWSL only alerts one pilot or vehicle operator in each runway incursion situation, but the concept of alerting the incoming aircraft with flashing approach lights is under study. An estimated false operation error rate of 1 in 2000 operations was deemed acceptable.

Pilots surveyed during the program rated the system as effective (92%) and should be installed at other airports (88%). Responses by vehicle operators indicated a lower percentage of recommendation. Kuffner [18] suggests that system performance could be optimized for compatibility with high-density airport operations. With this optimization, it may be possible to obtain additional support from ground vehicle operators. Kuffner also indicates the remaining human factors challenges include making sure personnel understand that the system only represents a hazard and never implies a clearance, as well as determining the appropriate light properties (timing, spacing, array shape, location, etc.), and integration into other related systems. The acceptance of RWSL by pilots may mean that the system will see more widespread installation, and acceptance by vehicle operators could follow once they gain more experience with system operations. It should be noted that RWSL presents a visual alert, which some vehicle operators [14] said was preferable to an audible alert. The logic developed for this system is an example of the logic needed to provide an alert-to-ground vehicle operation.

PREPACKAGED ALERTING SYSTEMS

The following section describes the systems identified during the literature search that claim to provide the three components necessary for a ground vehicle alerting system.

INCURSION COLLISION AVOIDANCE SYSTEM.

According to the manufacturer, A.S.S.E.T., LLC, the Incursion Collision Avoidance System (ICAS) is "a reliable, flexible, and cost-effective solution to the prevention of vehicle runway incursions" [3]. The manufacturer also claims that this system has been designed, engineered, and operated using radio frequency technology.

Within the system (as shown in figures 1 and 2), an underground antenna cable is installed that emits a low-power radio signal. When an ICAS-equipped vehicle approaches the antenna, the vehicle operator is alerted via a visible alarm and audible warning that they are approaching a sensitive area and should be aware. (The audible warning can be tailored by the airport operator.) The manufacturer states that the alerts provide the vehicle operator with adequate time to react. The system allows for different configurations, ranging from permanent installations, temporary taxiway configurations, and runway closures.

Note that this system would not indicate the state of the immediate AMA or alert the operator to the presence of other vehicles or aircraft. The system simply provides a warning that the vehicle operators are about to enter a sensitive area. It would then be up to the vehicle operator to take appropriate action to prevent runway incursions. This system only provides an alert when approaching a sensitive area, not when an incursion is probable. One concern about any alerting scheme is the constant presence of alerts—the vehicle operator can become accustomed to the alert, and it may lose its effectiveness.

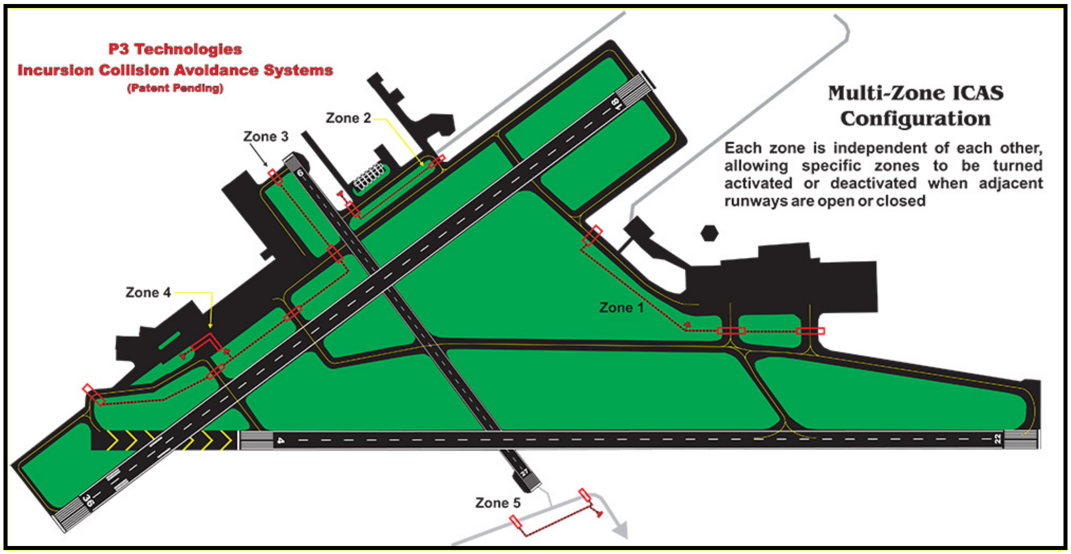

Figure 1. The ICAS System Layout–A.S.S.E.T., LLC

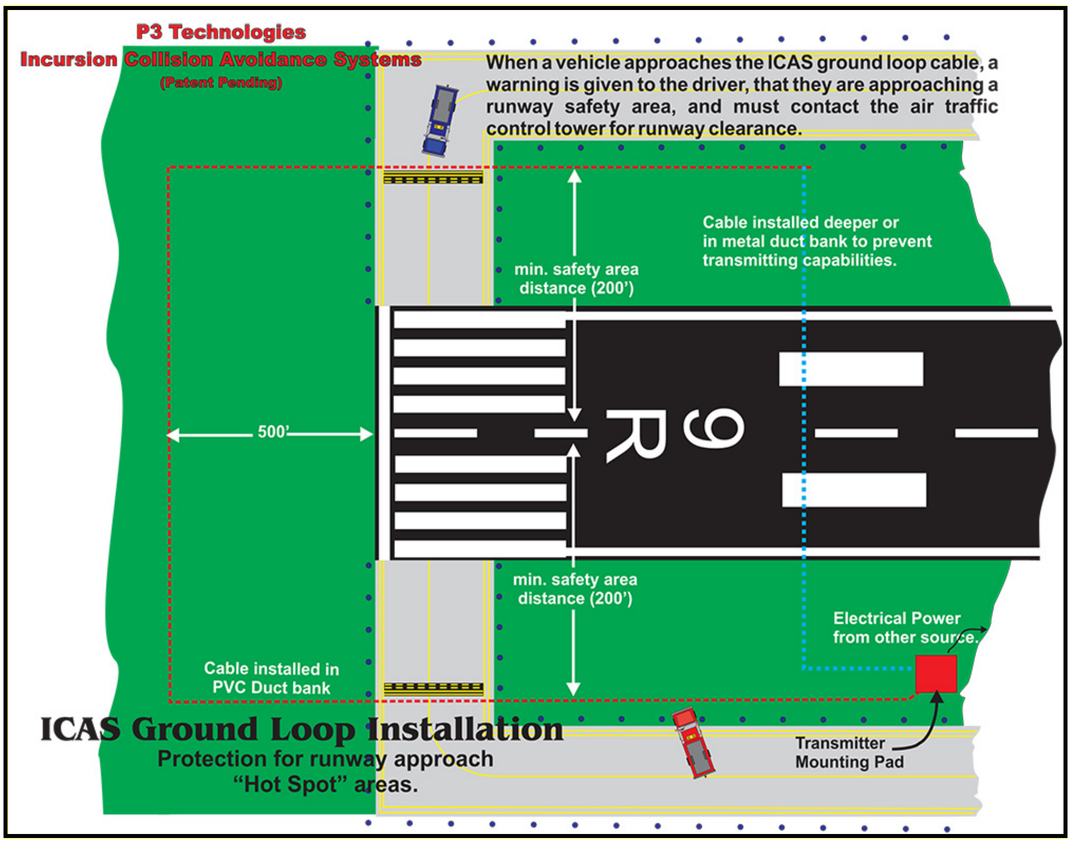

Figure 2. Diagram of Loop Sensor Layout–A.S.S.E.T., LLC

RUNWAY INCURSION MONITORING DETECTION ALERTING SYSTEM.

Another potential, low-cost system is the Runway Incursion Monitoring Detection Alerting System (RIMDAS) [8]. According to the manufacturer, this system is able to track all aircraft and ground vehicles operating at an airport by a centralized computer, based on the known positions of sensors installed throughout the airport environment.

Based on the position, speed, and direction of tracked aircraft and vehicles, the system can calculate the possibility of a potential conflict, as shown in figure 3. Once recognized, the system would send an alert to the appropriate aircraft and/or ground vehicle. At the same time, an alert can also be sent to the ATC tower to ensure that controllers are aware of the potential conflict. This system's logic is designed to provide an alert if an incursion potential exists, but it does not provide alerts when approaching a sensitive or restricted area.

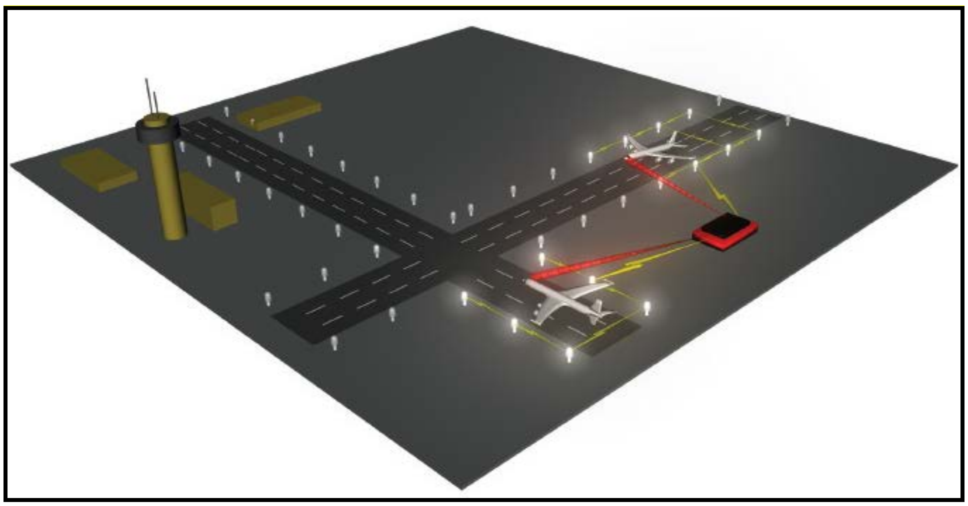

Figure 3. The RIMDAS Graphical Layout–Source: Ergonomics in Design, Spring 2010

ASSET TRACKING AND INCURSION MANAGEMENT SYSTEM.

The Asset Tracking and Incursion Management System (ATIMS) allows airport management to view an airfield's vehicle activity. This system has a central computer, which is typically located in the airport management's office. This computer contains the logic necessary to send and receive data from a device installed in the ground vehicle. Each vehicle operating on the airfield is tagged for easy identification, and the attributes of the vehicle's operations, such as vehicle speed and route traveled, can be collected and stored.

When using an orthographic image of the airfield, airport management can monitor ATIMS-equipped vehicles on a screen. They can see where the vehicles are, what they are doing, where they have been, and what they have done, as shown in figures 4 and 5. The system also has the ability to set up "geo-fences" at any location on the airfield. By using these geo-fences, vehicle operators can be warned through audible and visible alerts that their ATIMS-equipped vehicle is in or near a sensitive or restricted area, but it does not warn that there is the potential for a runway incursion.

Figure 4. Airfield Activity Using ATIMS

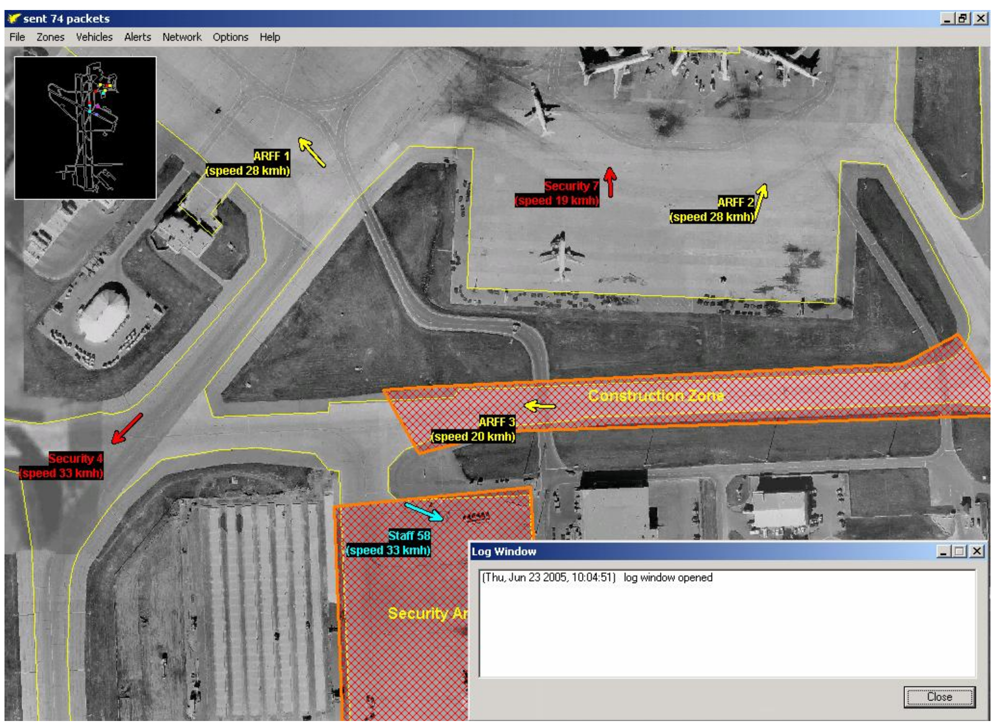

Figure 5. Airfield Layout in ATIMS

THE ADS-B OUT.

Currently within the FAA, ADS-B Out technology is being implemented for aircraft and being considered for ground vehicles. This would be a solution for major airports that have the required infrastructure. A brief description is provided below.

Collins [19] presents a discussion on ADS-B mandates, and how "ADS-B Out" will shift some surveillance data from ground-based radar to networked communications. Airspace that requires a transponder will now require ADS-B equipage, and ADS-B coverage is as good as the current radar. This information can then be sent to an ADS-B Out-compatible device in ground vehicles. Runway incursion alerting standards would need to be determined.

However, the technology used would have to be made available at a low-enough cost to be accessible to the GA community. It might be possible to have a homogenous equipage across both the commercial and GA communities if NAS-wide cost sharing can be agreed to by both communities.

Due to the widespread, global adoption of ADS-B technology, and the FAA requirement that equipped ground vehicles would need to be aware of location, the optimum solution would probably consist of an ADS-B unit that provides a moving map of the airport as well as local air and ground traffic. For airports that do not meet the cost criteria for advanced radar-based equipment, a multilateration- and transponder-based system might be able to provide both local traffic information and runway incursion warnings. A study would have to be performed to determine the minimum hardware and radio communication robustness requirements for a transmitter/multilateration-only system.

It might be possible to have a dual-use ADS-B system, whereby the system operates normally when airborne, and switches to an alert mode when within range of transmitters at an airport. The airport would then have the option of equipping ground vehicles with either ground-based ADS-B transmitters or any other low-cost, high-fidelity tracking system that could be transmitted to aircraft ADS-B units by the airport's ground-based ADS-B control transmitter.

SUMMARY

A literature review identified a number of technologies that have the ability to determine ground vehicle position. However, only three had the components necessary to provide a "complete system" that is able to alert a ground vehicle operator when approaching a restricted area. These systems have the functionality to allow incremental implementations, with each function providing an increased level of safety with respect to reducing runway incursions. When considering the implementation of these systems, a progressive approach is recommended because the systems or technologies already on the market are at various stages of development.

A solution to provide ground vehicle position may consist of an ADS-B unit that provides a moving map of the airport as well as local air and ground traffic.

For airports that may not have the infrastructure necessary for ADS-B, three systems—ICAS, RIMDAS, and ATIMS— were identified that have the potential to be an alternative to ADS-B-equipped vehicles.

The ICAS, which uses radio frequency technology, consists of an underground antenna cable that sends a low-power radio signal to a device in the ground vehicle. The disadvantage of this system is the cost of installing the infrastructure on the airport and installing a device in the ground vehicle. Because of the additional equipment needed, this system is not considered optimal and is not recommended for further evaluation.

The RIMDAS requires sensors to be installed throughout the airport to predict the possibility of a conflict with another aircraft or vehicle and send an alert to the ground vehicle. This system does not provide an alert when approaching a sensitive or restricted area and requires additional equipment on the airport and in the ground vehicle. This type of system would need very detailed algorithms to provide the necessary logic, such as in the RWSL system, which would increase cost. For these reasons, this system is not considered optimal and is not recommended for further evaluation.

The ATIMS has a central computer that contains the logic necessary to send and receive data from a device installed in the ground vehicle. The system has the ability to set up geo-fences at any location on the airfield. By using these geo-fences, vehicle operators can be warned through audible and visible alerts that the ATIMS-equipped vehicle is in or near a sensitive or restricted area. This feature could be useful at airports that need to change the areas where vehicles need to be restricted, such as in construction areas. This system can also receive and use ADS-B information in lieu of straight GPS signals, if desired, and it can be upgraded as necessary. This system is currently being used for vehicle tracking on airports. It has demonstrated the capability to provide the required alerts and does not require additional equipment to be installed on airports.

The RIMDAS does not provide an alert when approaching a sensitive or restricted area. The ICAS and RIMDAS both require equipment to be installed on the airport in addition to the equipment needed in the ground vehicle. For these reasons, these systems are not considered as optimal and are not recommended.

The analysis of the literature search showed that the ATIMS met the optimal criteria, and aversion of the ATIMS is already being used on airports. The only equipment needed is in the ground vehicle. Because of these advantages, the ATIMS is recommended for further evaluation.

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