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Development of an Airport Ground Vehicle Runway Incursion Warning System

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16. Abstract

The Federal Aviation Administration continues to assess ways to prevent runway incursions and other airport operational incursions, especially during ground vehicle operations at airports. The minimum operational performance specifications described in this report identify a stand-alone incursion warning system for a ground vehicle driver. A global positioning system (GPS) was used to provide vehicle location information for this warning system.

The objectives of this research were to evaluate current navigation devices for use in airport ground vehicles to prevent airport incursions, provide recommendation criteria for the design and operation of a system defining both minimum performance and optimal features, and provide cost estimates for the procurement of equipment.

The two types of devices that were evaluated could be modified and used as an airport ground vehicle runway incursion warning system to prevent runway incursions. The first device demonstrated a preconfigured system that functions without additional modifications for all airports. The second device was a custom system with software and hardware components that can be modified to the airport user's needs.

Based on this report, minimum performance criteria for an airport ground vehicle incursion warning system were established. Minimum performance criteria included the vehicle location accuracy equal to a wide area augmentation system GPS accuracy of <3 meters 95% of the time, location receiver placement on a vehicle, proximity warnings, alert areas, audible and visual signals to the driver, system updates, and compliance. An airport ground vehicle runway incursion warning system should not give directions for navigating on an airport, and must not take the place of airport familiarization and air traffic control instructions. The system should be used as a situational awareness tool. Optional features that were not critical to preventing a runway incursion but would provide additional benefits to airport users are discussed in this report.

Cost estimates for the preconfigured system ranged from $1500 to $2000. The cost for the custom system depended on the requirements specified by the airport user. A single, independently operated device ranged from $2000 to $4000. If an airport user requested a network infrastructure to take full advantage of the custom system's capabilities, the cost reached upwards of $100,000.

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LIST OF ACRONYMS

AC	Advisory circular
ACY	Atlantic City International Airport
ADS-B	Automatic Dependent Surveillance-Broadcast
AFD	Airport Facility Directory
AOA	Airport Operations Area
ASDE-X	Airport Surface Detection Equipment, Model X
ATC	Air traffic control
DEVS	Driver's Enhanced Vision System
FAA	Federal Aviation Administration
FOD	Foreign object debris
GPS	Global Positioning System
ILS	Instrument landing system
LED	Light-emitting diode
PC	Personal computer
RF	Radio frequency
RFID	Radio frequency identification
RSA	Runway safety area
USB	Universal serial bus
VGTeam	Visual Guidance Team
WAAS	Wide Area Augmentation System

EXECUTIVE SUMMARY

The Federal Aviation Administration continues to assess ways to prevent runway incursions and other airport operational incursions, especially during ground vehicle operations at airports. The minimum operational performance specifications described in this report identify a stand-alone incursion warning system for a ground vehicle driver. A global positioning system (GPS) was used to provide vehicle location information for this warning system.

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1. INTRODUCTION.

The use of vehicle navigation devices has become common to the average consumer requiring navigational assistance. Devices that use a global position system (GPS) are now extremely accurate, and the technologies used to manufacture these devices are becoming less expensive. GPS technology is used in aircraft, boats, automobiles, computers, cell phones, and other personal hand-held devices.

The Federal Aviation Administration (FAA) continues to assess ways to prevent runway incursions and other airport operational incursions, especially during ground vehicle operations. The minimum operational performance specifications described in this report identify a stand-alone incursion warning system for a ground vehicle driver. GPS is used to provide the vehicle location information for this warning system; however, other methods or technology, such as radar, transponders, or radio frequency identification (RFID), may be used if it can demonstrate the same reliability and accuracy.

An airport ground vehicle runway incursion warning system should provide warnings, alerts, or signals to vehicle drivers. The system should not give directions for navigating on an airport, and must not take the place of airport familiarization and air traffic control (ATC) instructions. The system should be used as a situational awareness tool to help reduce runway incursions.

1.1 PURPOSE.

The purpose of this research was to evaluate current navigation devices and recommend performance criteria that could prevent runway incursions of airport ground vehicles.

1.2 OBJECTIVES.

The objectives of this research were to

- evaluate navigation devices and their technology for use in airport vehicles to prevent airport incursions.

- provide recommendations for criteria for the design and operation of a system defining both minimum and optimal features.

- provide cost estimates for the procurement of the equipment.

2. DISCUSSION.

2.1 IDENTIFYING TECHNOLOGIES.

The Airport Technology Research and Development Visual Guidance Team (VGTeam) identified two technologies that, potentially, could be used for an airport ground vehicle runway incursion warning system. Meetings were held with two companies with different approaches using current technology that could be used to prevent runway incursions. The VGTeam then identified each device's performance capabilities to develop the minimum operational performance requirements needed for an airport ground vehicle runway incursion warning system. Devices from two companies, I.D. Systems (ID) and Team Eagle Ltd. (Eagle), were used to define both the minimum and optimal operational features.

2.1.1 Device 1.

Device 1 used a mobile GPS device similar to what a consumer would use for navigation in their personal automobile. The device consists of a small, compact portable unit with a built-in GPS receiver, small display, and speaker that are powered by an internal battery or by connecting to a power source. The display shows a color moving map, vehicle location, turn-by-turn directions, voice directions (the ability to give voice directions was not considered for this evaluation), and other functions and features. Figure 1 shows this device mounted on the inside windshield of a truck. ID partnered with a GPS device manufacturer to develop and run prototype airport navigation software in an automobile GPS device. Navigation software and hardware were used to create an airport map display and other features. Device 1 shows basic airport layouts with limited functions that are preconfigured and programmed by the manufacturer. Device 1 demonstrates the capability to perform as an airport ground vehicle runway incursion warning system.

Figure 1. Automobile GPS

2.1.2 Device 2.

Device 2 combines computer software, which can be installed on any personal computer (PC) running Microsoft® Windows®, with a GPS receiver for vehicle location information. An aerial photograph/map of a user's specific airport is uploaded to the program, which allows the vehicle driver to view its location on the PC. In addition to viewing vehicle location, the interface and settings can be customized to create zones, warnings, alerts, or signals to notify a vehicle driver or airport operations management. Device 2 also has the capability to function in a network infrastructure linking several individual PC systems together for two-way communications. Eagle, who developed the software, has two types of navigation and tracking systems and software that are already used by airports in the United States and Canada—a Driver's Enhanced Vision System (DEVS) [1] used to reduce response times for aircraft rescue and firefighting vehicles responding to emergencies in low-visibility situations and a tracking and incursion management system. Device 2's tracking and incursion management system, PC, and GPS receiver demonstrated the capability to perform as an airport ground vehicle runway incursion warning system.

2.2 PERFORMANCE DISCUSSION.

The VGTeam relied on its experience, knowledge, and research, as well as input from each company, to determine the minimum performance functions needed to prevent a ground vehicle incursion inside the airport operations area (AOA). These functions are discussed in the following sections.

2.2.1 Incursions.

The FAA and the International Civil Aviation Organization defines a runway incursion as any unauthorized intrusion onto a runway, regardless of whether or not an aircraft presents a potential conflict. Runway incursions are further classified into four categories (A through D) depending on the severity if the incursion (also referred to as incidents) [2].

- Category A is a serious incident in which a collision was narrowly avoided.
- Category B is 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 is an incident characterized by ample time and/or distance to avoid a collision.
- Category D is 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.

Other types of incursions that do not directly involve the runway are often called surface incidents, which are just as significant as runway incursions. To satisfy the second objective of this research effort, i.e., provide recommendations for criteria for the design and operation of an airport ground vehicle runway incursion warning system, an understanding of airport layouts, signage, markings, lighting, and airport communications is needed. An incursion or surface incident can happen when there is a breakdown in one or more of these areas at any given time for any reason, such as complacency, poor communications, loss of situational awareness, disorientation, and poor visibility.

2.2.2 Identifiable Features to Prevent Incursions.

2.2.2.1 Holding Position Markings.

Areas that could potentially result in an incursion or surface incident on an airport involve areas controlled by ATC within the AOA. These areas are, in effect, boundaries that are controlled points in which an aircraft or vehicle must get permission from ATC before crossing them. These boundaries are typically supplemented with paint markings, signage, and airport lighting so that aircraft and vehicles are aware of their location. These boundary areas are

- Runway Holding Position Markings on Runways
- Runway Holding Position Markings on Taxiways
- Taxiways Located in Runway Approach Areas
- Instrument Landing System (ILS)/Microwave Landing System (MLS) Holding Position Markings
- Precision Obstacle Free Zone Holding Position Markings
- Intermediate Hold Position Markings for Taxiway/Taxiway Intersections
- Nonmovement Area Boundary Markings or any markings bordering the AOA that may cause an incursion or surface incident.

Detailed information of these boundary areas can be found in Advisory Circular (AC) 150/5340-1 [3], AC 150/5210-20 [4], and additional information in the Aeronautical Information Manual [5].

2.2.2.2 Runway Safety Areas.

The runway safety area (RSA) is another location that could result in an incursion or surface incident. The RSA is a defined surface surrounding the runway prepared or suitable for reducing the risk of damage to aircraft in the event of an undershoot, overshoot, or excursion from the runway [6]. This area is monitored by the ATC, and all vehicles should be aware that they are approaching or are within the RSA. The RSA's width and length beyond the runway end varies, depending on airplane design group and aircraft approach category. The RSA width ranges from 120 to 500 ft (36 to 150 m). The RSA length beyond the runway end ranges from 240 to 1000 ft (72 to 300 m). The dimensions of the RSA are determined by AC 150/5300-13 [6].

2.2.3 Signals.

A vehicle driver should be made aware that he/she is approaching a potential incursion area. The common methods used to signal a vehicle driver is by sound and sight. These two methods singularly or in combination should elicit a response from the vehicle driver in most environments. In addition to informing the vehicle driver that he/she is approaching a marking or RSA, a visual signal should alert the vehicle driver that he/she is still within this critical area. This is important because a vehicle may be within the RSA for an extended period of time, depending on the vehicle or assignment.

2.2.4 Obtaining Vehicle Location.

To provide any type of signal to a vehicle driver, location information must be reliable and received in all weather. The reliability and availability of current GPS receivers are accurate. Both devices evaluated in this report used GPS receivers for vehicle location information.

A standard GPS signal is only accurate up to 15 meters. The addition of land-based equipment, differential GPS, has improved accuracy 3 to 5 meters. The FAA and industry have developed an even more accurate GPS signal, <3 m 95% of the time, by incorporating the Wide Area Augmentation System (WAAS) [7]. WAAS corrects the standard GPS signal errors using ground reference stations across the United States that monitor the GPS data. WAAS was created to meet precise aviation navigation requirements for accuracy, availability, continuity, and integrity to enable pilots to rely on the GPS for all phases of flight.

2.2.5 Airport Information Updates and Changes.

The FAA publishes and distributes an Airport Facility Directory (AFD) every 56 days with updated airport information, communications data, navigational facilities, and certain special notices and procedures. An airport ground vehicle runway incursion warning system should be updated within the same 56-day cycle to coincide with the AFD updates. Airport updates and changes provide assurance that the information on the system is the most recent and up to date.

3. TECHNICAL OVERVIEW.

Devices 1 and 2 represent devices that were evaluated to help determine minimum operational performance criteria for an airport ground vehicle runway incursion warning system. Each device provided a different approach, equipment, and technology that helped define the minimum performance needed to prevent an incursion and optional features that should be considered.

3.1 EQUIPMENT.

Equipment for Devices 1 and 2 are described in this section.

3.1.1 Device 1 Equipment.

The VGTeam evaluated two prototype devices of similar equipment. The devices were characterized as Device 1A and Device 1B because of the differences between the two prototype devices.

3.1.1.1 Device 1A.

ID established a partnership with a portable GPS manufacturer and modified an automobile GPS device, its software, and the manufacturer interface to incorporate airport diagrams and airport information while still having all the basic automobile GSP capabilities. Device 1A, a prototype device, was used to demonstrate the capabilities of the modified GPS device in an airport environment. Device 1A, shown in figure 2, was designed to be an outdoor, rugged, and waterproof GPS navigation device. The basic specifications for this device are a color touch screen, 3.5-inch display, rechargeable internal battery, waterproof, preloaded maps, GPS receiver with WAAS, turn-by-turn directions, speed indicator, and speaker.

Figure 2. Device 1A

The prototype airport software and interface for Device 1A had only basic functionality, showing vehicle location and a moving map of airports with runway text labels across the top of the screen. Because this device is preloaded with all the U.S. airport maps and features, it was ready to use immediately for any airport. Other simple visual and audio signals or functions were engaged when the vehicle navigated onto a runway.

3.1.1.2 Device 1B.

Throughout the criteria development, the VGTeam worked with and informed ID of their progress and preliminary findings. ID provided a newer prototype device, Device 1B shown in figure 3. The basic specifications for the device are the same as Device 1A, except it has a 4.3-inch display and new software. The new software incorporated new features such as runway/taxiway labeling, holding position markings, and audible beep, and visual color bar that changes and grows as the vehicle approaches a runway.

Figure 3. Device 1B

3.1.2 Device 2 Equipment.

Device 2 is a tracking and incursion management system developed by Eagle that represents a fundamentally different method compared to Device 1. Device 2 is a customizable GPS/geographic information system with airport-specific vehicle tracking and incursion management program that is operated on a PC inside a vehicle. The basic system is comprised of a computer, software program, and GPS receiver. Device 2 is a modular system that can be operated independently, separately, combined, networked, or added in phases, depending on the hardware and airport user's objectives for tracking a vehicle(s) and providing warnings for incursions. The following airports currently use this system:

- Ted Stevens Anchorage International Airport
- El Paso International Airport
- Cincinnati/Northern Kentucky International Airport
- Calgary International Airport
- Montreal International Airport
- Vancouver International Airport

3.1.2.1 Device 2 Software.

The core of Device 2 is a software program that includes an aerial photograph/map of the user's airport. Within the software, the user can create zones that can be overlaid on the aerial map, such as incursion zones, construction zones, information zones, warnings zones, and others, depending on the user's preferences. This is called a geofence, a virtual perimeter for a real-world geographic area. The software has selectable options that trigger an action(s) when a GPS-tracked vehicle approaches, travels into, or exits a zone(s). These actions can be in the form of warnings or signals to the vehicle driver or operations center. Some of these actions include an audible beep, voice message, textual information, flashing screen, blinking lights, notification of speed, loss of power, system malfunction, movement into/out of zones, and historical tracking. Other options include inputting text on the map for labeling, adding various colors/shades to the map, display documents, send messages, and acknowledge information.

Device 2's software also has the capability to integrate into other airport systems already in use and approved by the FAA, such as foreign object debris (FOD) detection equipment, Airport Surface Detection Equipment, Model X (ASDE-X), DEVS, and airfield maintenance and inspection programs.

3.1.2.2 Device 2 Hardware.

Device 2 has the flexibility to use a variety of devices or computers to run the software. Airport vehicles or the airport operations center may require different PCs, such as a desktop, laptop, tablet, ultra portable laptop, or hand-held device, all of which have to meet the Device 2 software performance specifications. Figure 4 shows an example of a portable PC mounted inside a vehicle with a moving map displayed. Appendix A shows other types of PCs that can run the Device 2 software. These PC devices can be permanently mounted or be portable, depending on the airport user's requirements and objectives. A GPS receiver is required to obtain a vehicle's location. Some PCs have built-in GPS receivers and others have the capability to add a peripheral GPS receiver, typically through a universal serial bus (USB) port on the PC (figure 5).

Figure 4. Portable PC Inside a Vehicle

Figure 5. A USB GPS Receiver

Eagle designed another piece of hardware that can be used with Device 2, referred to as the brick. The brick, shown in figure 6, is a portable hardware device containing a built-in GPS receiver, speaker, light-emitting diode (LED) lights, and peripheral attachments for power and an external radio frequency (RF) antenna. The brick works like a scaled down, simplified PC, providing audible and visual signals to a vehicle driver. For the brick to provide signals, it has to be operated on a network infrastructure with a command PC workstation running the Device 2 software. The PC command workstation monitors, tracks, and communicates with all the bricks on the network. The brick can be temporarily or permanently placed in the vehicle. If the vehicle travels into an incursion zone, the brick can provide an audible or visual signal (LED light) to the vehicle driver. The settings for each brick can be individually customized at the command workstation.

Figure 6. The Brick

Due to advances in technology and lower-cost PC devices, the brick is being phased out for more favored and capable PCs with displays. However, the bricks did demonstrate how these systems can work within a network infrastructure.

3.1.2.3 Device 2 Networking.

Eagle has demonstrated that their system can function on a license-free cellular 900-MHz network and a wireless local area network or WiFi. When Device 2 is configured for a network, more options are available to the user for vehicle tracking, management, viewing other vehicles, and information exchange. Updates, messages, zone changes, actions, warnings, etc., can all be changed wirelessly and almost instantaneously to all other PCs operating on Device 2. The only additional hardware needed is an external RF antenna or wireless network card built into each PC device. Note: Prior approval by the FAA Spectrum Analysis Office and the Federal Communications Commission is required before any communications or data can be transmitted in an airport environment.

3.2 FEATURE DEVELOPMENT AND EVALUATION.

Because there are no current standards to evaluate devices for an airport ground vehicle runway incursion warning system, the VGTeam was required to use the systems in an airport environment to observe how the systems work and how their capabilities provide some type of warning, alert, or signal to a vehicle driver of a potential incursion. Significant time was spent using and evaluating Devices 1 and 2 at the FAA William J. Hughes Technical Center's aircraft apron and the Atlantic City International Airport (ACY). During these evaluations and testing sessions, Devices 1 and 2 were used simultaneously so the VGTeam could understand the perspectives of both systems.

After using both systems, the VGTeam realized that, in order to warn a vehicle driver traveling on an airport at different rates of speed, a proximity warning would be needed to warn the driver of an approaching incursion situation. The proximity warning would have to be established on a speed, distance, and time relationship for determining a safe minimum performance. The faster a vehicle travels, the farther the vehicle travels in a second; therefore, more time would be needed to warn the vehicle driver of a potential incursion. Two important questions were identified.

- Will an airport ground vehicle runway incursion warning system alert the driver to initiate braking?
- Can the vehicle stop before the incursion?

During the evaluations, Device 2's capabilities to customize preferences and performance options for testing different warning methods, different signals, and experiment with different speed, distance, and time parameters were ideal for this research effort. In addition, Eagle provided software program changes at a reasonable turnaround time as evaluations and test sessions evolved. ID was unable to provide similar software program changes due to budgeting and turnaround time. However, ID was briefed and consulted as the evaluations and test sessions progressed.

3.2.1 Proximity Warning Zones.

The initial evaluation involved creating a proximity warning zone around every holding position marking on an airport, which would alert a vehicle driver he/she is approaching a holding position marking. Next, the size of the warning zone and how they are arranged on various airports layouts had to be determined. Google Earth™ was an important tool in creating and viewing the arranged warning zones. The first evaluated warning zone was a circle with a 150-ft radius extending out from intersecting holding position markings and taxiway centerlines to match enhanced taxiway centerline markings on airports. The enhanced taxiway centerline's purpose is to warn a pilot that they are approaching a holding position marking and should be prepared to stop until the ATC clears them to cross.

After viewing these zones arranged on several airports (such as Hartsfield-Jackson Atlanta International Airport, Seattle-Tacoma International Airport, Los Angeles International Airport, John F. Kennedy International Airport), it became evident that this kind of zone would not work.

These zones would not work because (1) the 150-ft warning would only apply to vehicles traveling on the taxiway centerlines; (2) some holding position markings are stretched out over several hundred feet with no taxiway centerline, thereby creating gaps where a vehicle could cross a holding position marking without crossing the warning zone; and (3) variations in taxiway angles and merges created some warning zones that were not 150 ft prior to the holding position marking. Figures 7 and 8 show some of these examples.

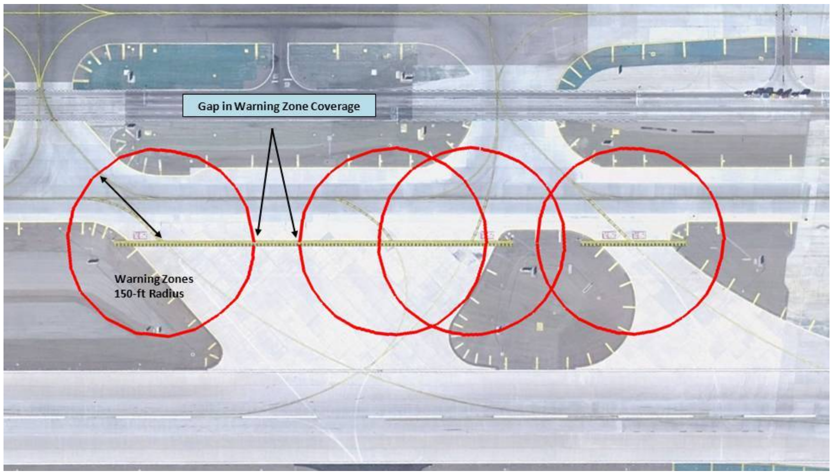

Figure 7. Warning Zone Gaps

Figure 8. Warning Zone is Less Than 150 ft to Holding Position Marking

To address this problem, the VGTeam created a 150-ft radius zone around all the holding position markings to eliminate the gaps between the circle warning zones on the taxiway centerlines. The VGTeam also evaluated 100- and 200-ft warning zones, and after viewing these warning zones at several airports, it became evident that there would be too many warning zones scattered across some airports due to complex layouts and converging taxiways. It was apparent that this would create repeated and constant warnings, and in some cases, a vehicle would always be in a warning zone because of overlapping zones. Figure 9 shows some of these examples.

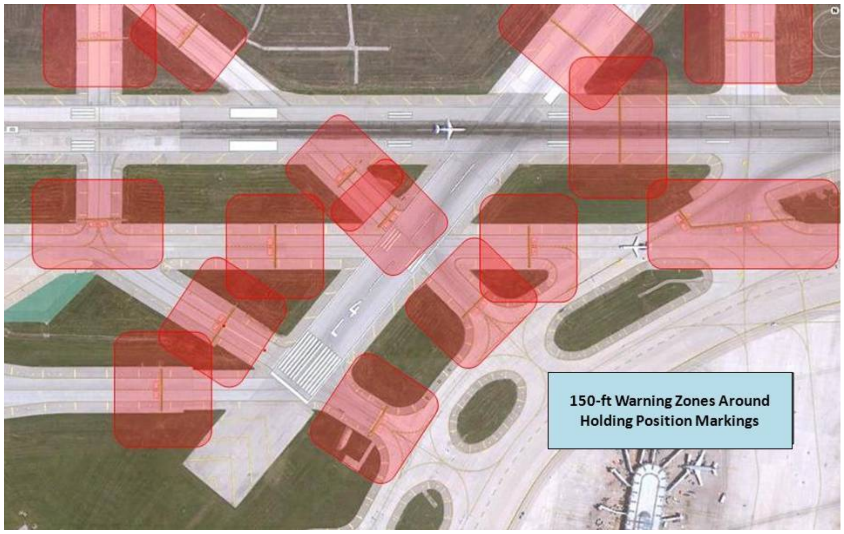

Figure 9. The 150-ft Warning Zone Around Holding Position Markings

3.2.2 Vehicle Proximity Warnings.

3.2.2.1 Proximity Warning Bubble.

The VGTeam took a different approach by creating a proximity warning around a vehicle (or bubble) so the warning would travel with the vehicle's GPS location, as shown in figure 10. For example, when a vehicle's bubble came in contact with a holding position marking, it would trigger a proximity warning in advance of the holding position marking, signaling the vehicle driver. This would eliminate the need for large and overlapping warning zones all over an airport map. The concept was shared with Eagle, and the researchers asked if this feature could be programmed into Device 2's software so the VGTeam could evaluate this method.

Figure 10. Proximity Warning Bubble

Eagle was able to add this feature to Device 2 so that when a vehicle's proximity warning bubble came in contact with warning zones or holding position markings, the system would trigger a proximity warning to the vehicle driver. In addition, the software enabled the radius of the bubble to be changed to evaluate different-sized bubbles. After testing the new proximity warning bubble at ACY, it was clear that this was an effective method.

However, a problem arose while testing the proximity warning bubble. The VGTeam experimented with different-sized radii to compensate for different speeds and distances, larger proximity warning bubbles often triggered proximity signals 90 degrees to the left or right of the vehicle as the vehicle traveled forward. This was a problem because the proximity warning bubble needed to be far enough in advance of the vehicle to trigger a signal, but not so far to the left or right to trigger unnecessary warnings. Figure 11 shows this problem while traveling straight on taxiways with intersections.

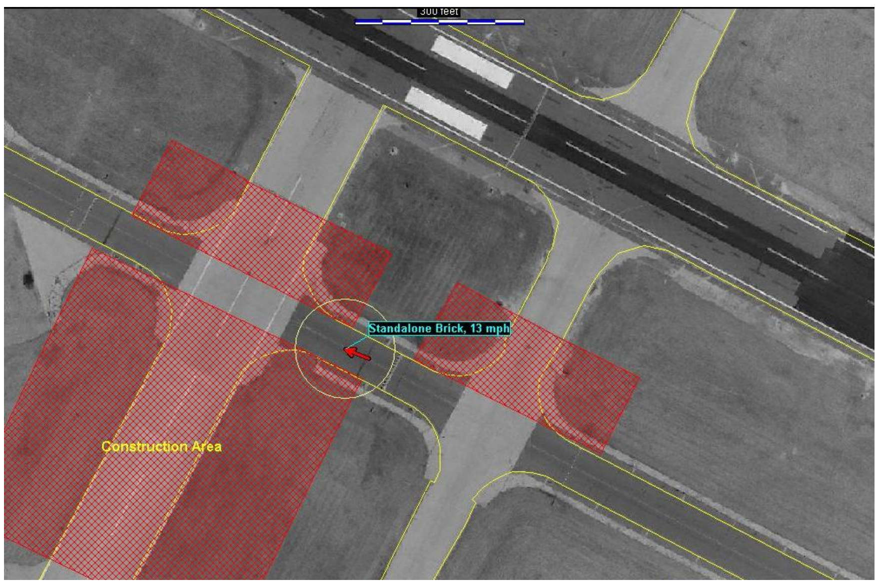

Figure 11. Proximity Warning Bubble Triggering Side Warnings

3.2.2.2 Proximity Warning Pie Wedge.

The VGTeam concluded that a proximity warning bubble would not be necessary since GPS location is directional, based on movement, and it moves regardless of forward or reverse direction. Eagle was asked if they would reprogram Device 2's software to create a proximity warning in the shape of a pie wedge in advance of a vehicle's movement, and to add a feature to change the radius distance and angle parameters of the proximity warning pie wedge. This would eliminate triggering warnings to the extreme left or right and even behind the vehicle. The capability to select the radius distance and angle parameters allowed the proximity warning distances in advance of the vehicle's movement and to its sides to be evaluated. This modification is shown in figure 12.

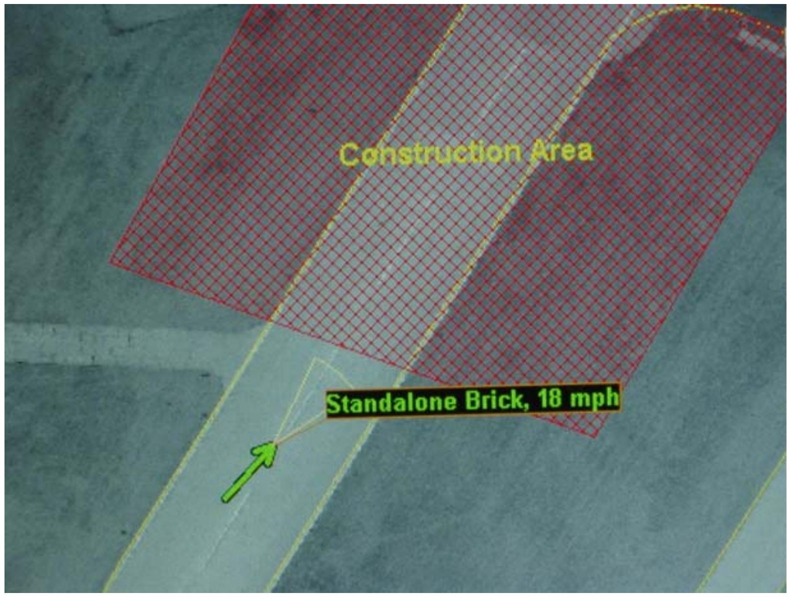

Figure 12. Proximity Warning Pie Wedge

After testing the proximity warning pie wedge, improvements were observed, but it also caused some additional problems.

The width of the proximity warning pie wedge was dependent on the radius distance and angle chosen. It was challenging to test the pie wedge radius distance and widths because of the relationships shown in figure 13 and table 1. The VGTeam was unable to test different radius distances while keeping a desired width between the arc of the pie wedge. When the angle was small, the pie wedge failed to warn a vehicle driver who was parallel and in close proximity to a holding position marking. However, if the angle chosen was large, the pie wedge performed similar to the proximity warning bubble.

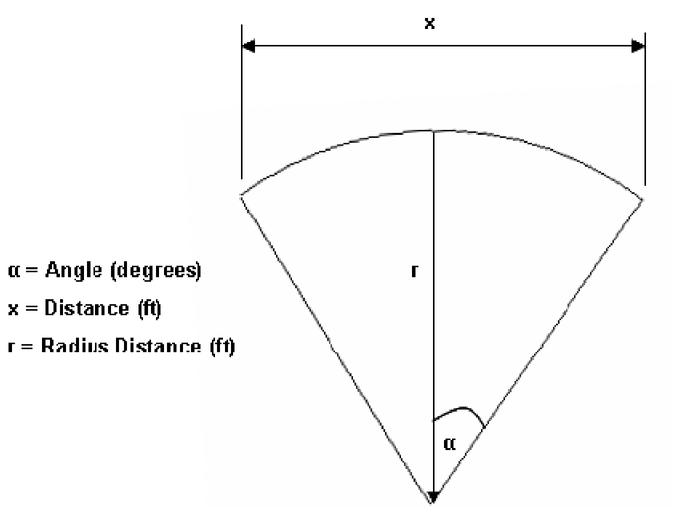

Figure 13. Widths of Pie Wedge

Table 1. Widths Between Arcs of Pie Wedge

		α—Angle (degrees)										
		10	15	20	25	30	35	40	45	50	55	60
r—Radius Distance (ft)	25	8.7	12.9	17.1	21.1	25.0	28.7	32.1	35.4	38.3	41.0	43.3
	50	17.4	25.9	34.2	42.3	50.0	57.4	64.3	70.7	76.6	81.9	86.6
	75	26.0	38.8	51.3	63.4	75.0	86.0	96.4	106.1	114.9	122.8	129.9
	100	34.7	51.8	68.4	84.5	100.0	114.7	128.5	141.4	153.2	163.8	173.2
	125	43.4	64.7	85.5	105.7	125.0	143.4	160.7	176.8	191.5	204.8	216.5
	150	52.1	77.6	102.6	126.8	150.0	172.1	192.8	212.1	229.8	245.7	259.8
	175	60.8	90.6	119.7	147.9	175.0	200.8	224.9	247.5	268.1	286.7	303.1
	200	69.4	103.5	136.8	169.0	200.0	229.4	257.0	282.8	306.4	327.6	346.4
	225	78.1	116.5	153.9	190.2	225.0	258.1	289.2	318.2	344.7	368.6	389.7
	250	86.8	129.4	171.0	211.3	250.0	286.8	321.3	353.5	383.0	409.50	433.0
		x—Distance Between Arcs (ft)										

3.2.2.3 Proximity Warning Rectangle.

After evaluating several scenarios using the proximity warning pie wedge, the VGTeam recognized that it worked well in some scenarios and not as well in others. Based on the tests, the VGTeam determined that some type of proximity warning was needed to signal the vehicle driver when they are within close proximity to a holding position marking, especially when a vehicle is traveling parallel to the marking.

The VGTeam changed the proximity warning shape to a rectangle, shown in figure 14. It was decided that the rectangle was the best way to evaluate proximity warning distance, ahead of and to the sides of a vehicle, needed to signal the driver of a potential incursion when in proximity of a holding position marking.

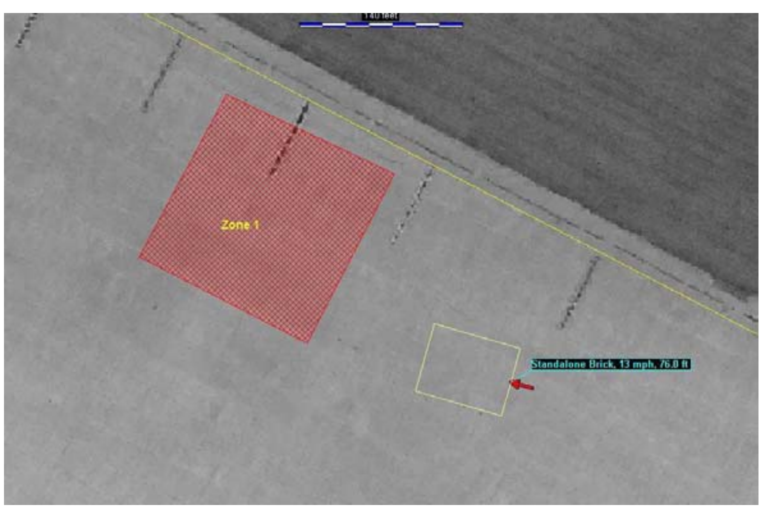

Figure 14. Proximity Warning Rectangle

Eagle reprogrammed Device 2 to produce a proximity warning rectangle with a 35.5-ft warning to either side of the vehicle and in advance of the vehicle's movement that increased and decreased based on speed. The 35.5 ft to either side (75 ft total width of the proximity warning rectangle) was selected because it is the most common width of airport taxiways. Based on previous experience, a fixed distance in advance of a vehicle would not be adequate for all situations. For example, a long, fixed distance in advance of a vehicle traveling at slow speeds would trigger a proximity warning too far in advance of the vehicle's position, and a short, fixed distance at fast speeds would not trigger a proximity warning early enough for the vehicle to stop before crossing a holding position marking. Eagle would be able to reprogram Device 2 and include a scalable proximity warning, but needed additional parameters.

3.2.3 Speed, Distance, and Time.

Based on previous proximity warnings, settings, and evaluations, the VGTeam considered rates of speed, distance traveled, and time to determine a scalable proximity warning parameter. Table 2 shows speed compared to distance traveled in 1 second. As speed increased, the distance traveled in 1-second increased.

Table 2. Speed Compared to Distance Traveled in 1 Second

Speed (mph)	Distance per Second (fps)
1	1.46
10	14.6
20	29.3
30	44
40	58.6
50	73.3
60	88

3.2.4 Braking Tests.

Field tests were performed to determine if a vehicle could be stopped in an aggressive braking scenario without activating the vehicle's antilock braking system within the distances shown in table 2. The development of an airport ground vehicle runway incursion warning system had to consider the range of speeds at which airport vehicles operate and normal vehicle operations on an airport.

Several tests were set up with parking cones on the FAA William J. Hughes Technical Center's aircraft apron and ACY's Taxiway Alpha representing a holding position marking (figure 15). Cones were then placed in a line away from the holding position marking cones (shown in figure 16) at the distances shown in table 2. For these tests, a VGTeam project pick-up truck, commonly used by airport operations, was used. It became evident, as the vehicle's speed increased beyond 20 mph, that it was impossible to stop within the distances shown in table 2. Several factors affect this type of braking test:

- Vehicle braking performance
- Vehicle weight
- Tire interaction with the surface
- Weather conditions

Figure 15. Setting Up Parking Cones on the Aircraft Apron for Braking Test

The weather conditions during this test were clear and dry. A standard empty, heavy-duty pickup truck traveling at 60 mph requires over 150 ft to stop, according to most vehicle manufacturer specifications. High-performance cars require approximately 100 ft in similar conditions.

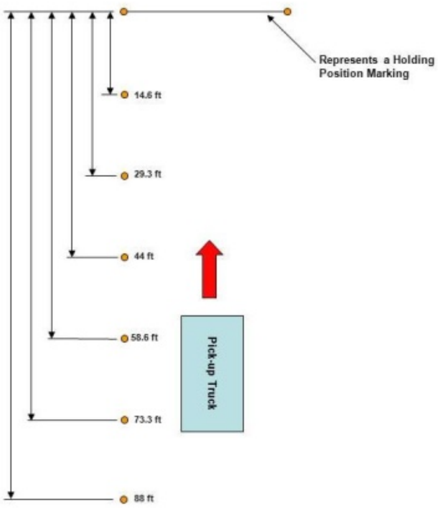

Figure 16. Parking Cone Placement

Based on the results of this test, the VGTeam doubled the distances in table 2, recognizing that while a vehicle is braking and decelerating, the distance traveled per second decreases. The proximity warning distance would also decrease in the same manner. The previous test procedures were performed again with the distances doubled. (Note: the 2.92-ft distance was rounded to 3 ft for simplicity.) The test showed that the truck could stop within the allotted distances and speeds.

The VGTeam also sought to provide a minimum proximity warning distance in advance of a vehicle's movement. This was important because the proximity warnings are triggered based on where the GPS receiver is physically located on a vehicle. A minimum warning distance compensates for short warning distances at speeds less than 10 mph, GPS inaccuracies, and GPS receiver location on a vehicle. Since GPS receivers are typically placed on vehicle roofs or on windshields, the minimum warning distance also compensates for the distance from the front bumper of a vehicle to the GPS receiver. The VGTeam established a minimum warning distance of 30 ft in advance of a vehicle's movement traveling 0-10 mph. Thirty feet was chosen based on the braking test and an assessment of the vehicle driver's forward viewing angle so that a holding position marking was visible without the hood of the vehicle obstructing the marking. Several vehicles such as cars, pick-up trucks, and box trucks were taken into consideration for determining the minimum warning distance. Therefore, for every 1 mph greater than 10 mph, the warning distance would increase or decrease by 3 ft, with a minimum of 30 ft, as shown in table 3.

Table 3. Test Parameters

Speed (mph)	Warning Distance (ft)
0-10	30
11	33
12	36
20	60
30	90
40	120
50	150
60	180

After additional software programming of Device 2 to allow a scalable proximity warning rectangle (using the parameters in table 3), field tests were conducted to determine if the scalable proximity warning and signals were adequate for a vehicle driver to initiate braking and have the vehicle stop before crossing a holding position marking.

Two interesting facts arose from the field tests. First, a vehicle could stop within the distances and speeds shown in table 3 if braking was initiated at the exact warning distance given in table 3. Second, Device 2's proximity warnings (audible and visual signals) did not trigger until approximately halfway through the desired warning distance, resulting in a delay in the vehicle driver's braking. In most cases, the vehicle could not be stopped within the allotted distance due to the delayed proximity warning. For example, at 30 mph, the proximity warning would trigger at approximately 45 ft instead of the desired 90 ft.

The VGTeam concluded that the delays resulted from a combination of GPS location updates being received by the system, the system processing time to trigger a proximity warning, and the vehicle driver's reaction time to initiate braking. Therefore, the proximity warning distances in table 3 were not sufficient. The proximity warning was doubled again to 6 ft per 1 mph, with a minimum of 60 ft. The process of speed, distance, and time of a vehicle traveling; GPS coordinate updates; system process time to trigger proximity warning; reaction time of the vehicle driver to initiate braking; and vehicle performance were reconsidered, see table 4.

Table 4. New Test Parameters

Speed (mph)	Warning Distance (ft)
0-10	60
11	66
12	72
20	120
30	180
40	240
50	300
60	360

In addition to discussions on this topic, GPS coordinate update delays were researched with ID and Eagle. ID and Eagle and their GPS specialists substantiated that it takes approximately 1 second for a GPS receiver to update location coordinates from the orbiting GPS satellites. While field testing with Device 2, it took 1 to 2 seconds for the system's computer/software to update the GPS information to trigger a proximity warning. Device 1 experienced a delay as well, but it was timed to be no more than 1 second. A standard reaction time of 1.5 seconds is commonly used by accident reconstructionists for a vehicle driver to react to initiate braking. Therefore, all the variables would have to be factored into a proximity warning. To better understand how the variables affect warning distance, tables B-1 through B-4 in appendix B show mathematically calculated distances traveled at speed, and how different delays in time of these variables affect speed, distance, and time relationships.

After the software reprogramming of Device 2's warning distances were complete, the field tests were repeated. These tests determined if the programming was adequate for the vehicle to stop within the new distance and if the system was capable of warning the driver before crossing a holding position marking. The change provided greater warning distances for the vehicle compared to the warning distances in table 3. However, during the field tests, two results were observed: (1) the vehicle could stop within the distances shown in table 4 without aggressive braking, if initiated at the warning distance, and (2) Device 2 still had a problem with delayed proximity warnings affecting the vehicle driver's ability to stop within the allotted distance. The VGTeam and Eagle agreed that the software would need to be refined to get a faster response. The additional software reprogramming was not initiated due to time constraints. However, the VGTeam was confident that with faster hardware and/or software, Device 2 could perform to a final minimum proximity warning performance standard.

3.2.5 Side Proximity Warnings.

During the braking tests with the proximity warning rectangle, the VGTeam also evaluated the side proximity warnings. A 75-ft wide (35.5 ft on either side of the GPS receiver) proximity warning rectangle was chosen because the average taxiway width at most airports is 75 ft. To evaluate the side proximity warnings, multiple warning zones around holding position markings and miscellaneous test zones were created on Device 2's map of ACY. After several test drives at ACY, the VGTeam found that the proximity warning of 35.5 ft on either side of the vehicle was too wide, and it would unintentionally trigger proximity warnings or surrounding warning zones. This situation was experienced when the vehicle passed a warning zone perpendicular to the direction of travel without turning. Since the proximity warning is always in advance of a vehicle's movement, the GPS location information would track any changes in direction and would trigger a signal to the vehicle driver; therefore, the 35.5-ft side proximity warning could be reduced. After several additional test drives were performed, the side proximity warning distance was reduced to 20 ft on either side of the GPS receiver location, as shown in figure 17, which gave the vehicle driver ample warning of the approaching warning zone or holding position marking.

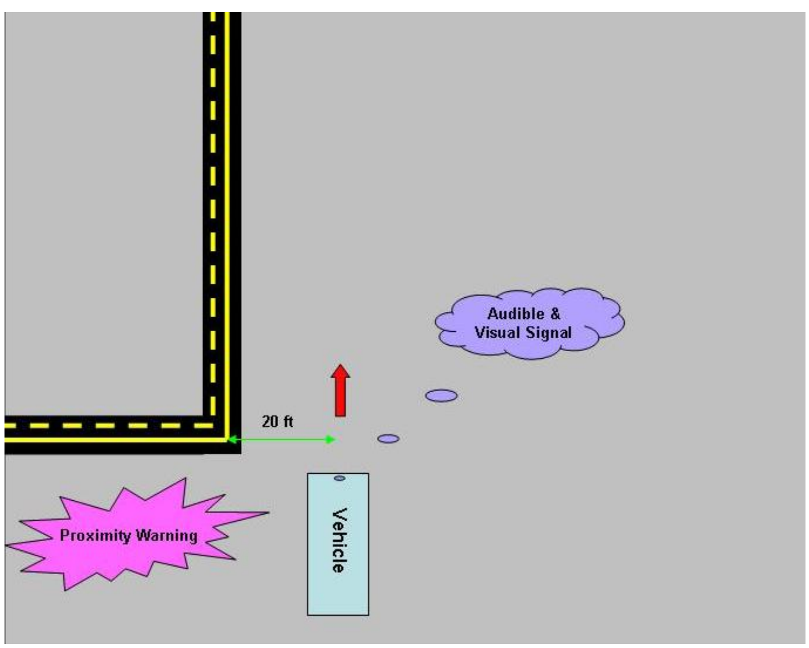

Figure 17. Side Proximity Warning Tests

3.2.6 Holding Position Marking Alert Area.

During the evaluation of warning zones, proximity warnings, and audible and visual signals, the VGTeam determined that there should be a final alert when a vehicle is within close proximity of a holding position marking. Because holding position markings identify an invisible boundary area, an additional alert should be triggered to notify the vehicle driver that they are within a certain distance of the marking. This alert area would also provide additional situational awareness of the marking to the vehicle driver.

The VGTeam found that a 30-ft alert area in all directions around all holding position markings and the driver's ability to view the marking while within a vehicle was acceptable. It was suggested that a unique audio and visual signal (different from the standard proximity warning signal) should be used when the vehicle's GPS location enters this area. Alert areas should also trigger the proximity warnings, instead of the marking itself, creating an additional 30-ft distance before a vehicle crosses the marking. Having the alert area trigger proximity warnings allows for small errors in the system programming, GPS inaccuracy, late vehicle braking, weather conditions, etc. Figure 18 shows an example of a holding position marking alert area.

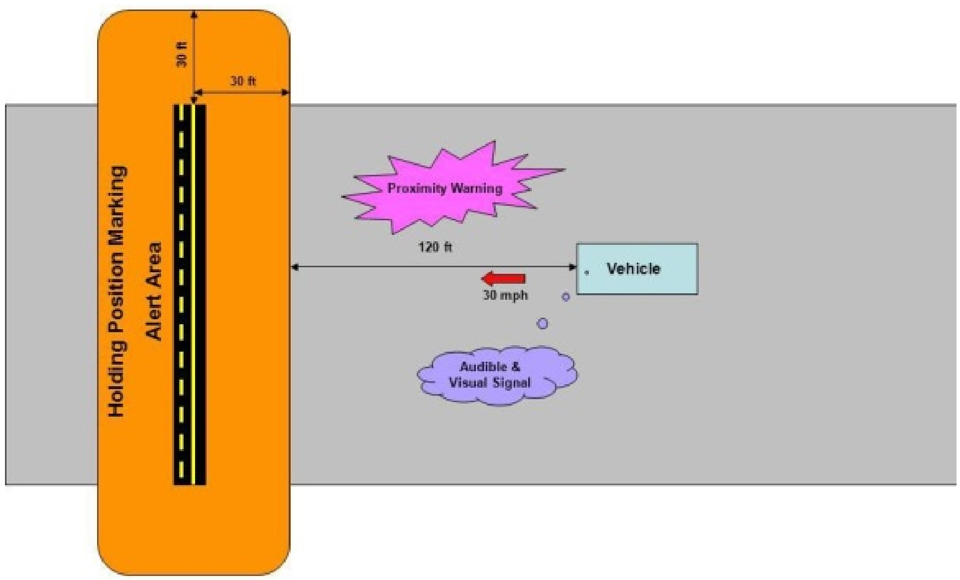

Figure 18. Example of a Holding Position Marking Alert Area

3.2.7 Runway Safety Area Alert Area.

Some vehicles may travel off a taxiway and into areas surrounding a runway for various reasons, such as airfield maintenance, grass cutting, yielding to an aircraft, and may not know where the RSA is located. In addition to a holding position marking alert area, the VGTeam recommends that an alert area be established for the RSA. The RSA alert area should be determined by the criteria contained in AC 150/5300-13 [6]. The RSA alert area should also be the trigger of a proximity warning to give an advanced warning that the vehicle is approaching this area. A specific visual-only signal should be activated when the vehicle enters this area, based on GPS location. The visual-only signal should be continuously active while the vehicle is in the RSA alert area and deactivated when the vehicle leaves the area. Figure 19 shows an example of an RSA alert area.

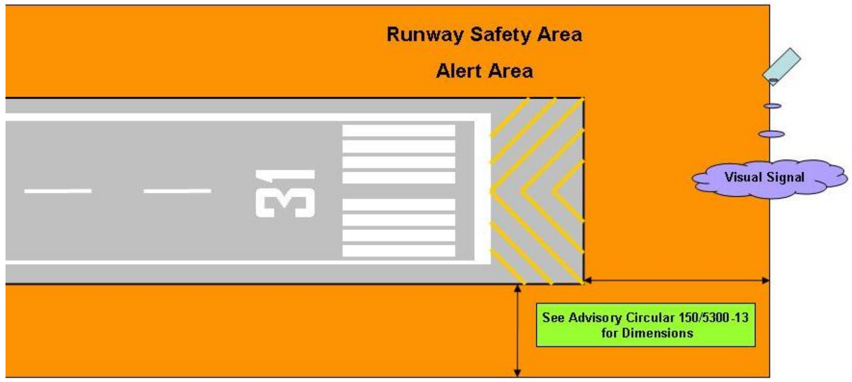

Figure 19. Example of an RSA Alert Area

The visual-only signal was chosen because (1) a continuously active audible warning would be distracting to a vehicle driver who may spend considerable time in the RSA alert area (for maintenance or grass cutting, for example) and (2) a vehicle driver should be monitoring all radio communications with ATC or other Unicom frequencies and a constant audible alert would be distracting.

3.2.8 Audible Signal.

Several different types of audible signals were tested that could notify a vehicle driver of a proximity warning or alert area. Audible signals, such as beeps, tones, and voice messages, were selected and tested throughout the evaluations. Since airports across the U.S. do not all operate or function the same way, an airport ground vehicle runway incursion warning system should provide options for audible signals so each airport can select one that meets their operational needs. The only signals that should be mandatory are the specific voice message signals that are activated when a vehicle enters a Holding Position Marking Alert Area stating which ground marking is being entered, for example, "runway hold line," "taxiway hold line," or "instrument landing system (ILS) critical area."

3.2.9 Visual Signal.

Several different types of visual signals were tested that could notify a vehicle driver of a proximity warning or alert area. Visual signals such as LED lights, flashing screens, different colors, textual messages, graphics, or combinations thereof were tested throughout the evaluations. Again, since airports across the U.S. do not all operate or function the same way, an airport vehicle runway incursion warning system should provide options for visual signals so each airport can select which one meets their operation needs. The signals that should be mandatory are the visual signals used to differentiate between a proximity warning, a Holding Position Marking Alert Area, and an RSA Alert Area.

4. SUMMARY.

The following sections discuss the two devices that have been identified as a possible airport ground vehicle warning system, the minimum design and operational criteria needed to perform as an airport ground vehicle warning system, and the cost estimates for the two devices.

4.1 SYSTEM TECHNOLOGY.

Two technologies have been identified using GPS that work on different devices that could be modified and used as an airport ground vehicle warning system to prevent runway incursions. Device 1 is a preconfigured system that functions for all airports without additional modifications (similar to a personal automobile GPS device that shows a moving map with some interface and setting preferences the airport user can choose); however, these preferences are limited by the manufacturer's software. Device 2 is a custom system that works on a PC using specific airport's aerial photograph/map and software to function as a GPS device. The software has numerous settings and interface options for the airport user to choose how they want to manage their specific and customizable system. The airport user can also specify what PC hardware would work best for their operations, and can be operated independently, separately, combined, networked, or phased in depending on the airport user's objectives providing warnings for incursions and tracking. Devices 1 and 2 have both shown potential to meet the design and operation criteria for minimum performance stated in section 4.2.

4.2 DESIGN AND OPERATION CRITERIA.

Any airport ground vehicle runway incursion warning system should not give directions for navigating on an airport and must not take the place of airport familiarization or ATC instructions, but instead should be used as a situational awareness tool.

4.2.1 Minimum Operational Performance.

Based on this report, the following minimum performance specifications for an airport ground vehicle incursion warning system were established.

- Vehicle Location. Location accuracy is critical for operating and navigating on an airport. When using the GPS for vehicle location, a GPS WAAS-capable receiver is currently the most accurate. The accuracy of the vehicle location should be <3 meters 95% of the time, which is the industry standard when incorporating WAAS. Other vehicle location methods such as radar, transponders, or RFID may be used if it demonstrates the same reliability and accuracy.

- Location Receiver Placement. How a vehicle receives its position on an airport is dependent on its location receiver's placement. The location received must be centered on/in the vehicle as far forward as possible without obstructing the signal.

- Proximity Warnings. Proximity warnings should consist of an audible and visual signal to the vehicle driver making them aware that the vehicle is approaching an alert area and potential incursion. A vehicle traveling 0-10 mph should trigger a proximity warning

20 ft on either side of a vehicle's location receiver and a minimum distance of 60 ft in advance of the vehicle's movement direction. The proximity warning should increase 6 ft in advance of the movement direction for every 1-mph increase in speed. The proximity warning should decrease in the same manner to a minimum of 60 ft. Table 5 shows speed and proximity warning distances, using the 6-ft per 1-mph formula.

- Holding Position Marking Alert Areas. A holding position marking alert area is the final indication to the vehicle driver that they are in close proximity to a holding position marking. The holding position marking alert area should consist of a 30-ft area in all directions around the holding position marking. When a vehicle's receiver position enters this alert area, an audible and visual signal (different from a proximity warning signal) should be triggered. The audible signal should be a voice message signal stating which surface marking is within the alert area. For example, "runway hold line" or "ILS critical area."

- Runway Safety Area Alert Area. The size of the RSA alert area is determined by the criteria in AC 150/5300-13 [6]. When a vehicle enters this alert area, a visual signal that is different from a proximity warning and holding position marking alert area should be triggered. The visual signal should be continuously active while the vehicle is in the RSA alert area and discontinued when the vehicle leaves the alert area.

- Audible Signal. An audible signal can consist of beeps, tones, voice messages, or melodies. A preconfigured or custom airport ground vehicle runway incursion warning system should provide options from which the airport user can select the audible signals that meet their operational requirements. A custom system should have the ability to add additional or custom audible signals as the airport user requires. Specific voice message audible signals should be triggered when a vehicle enters different holding position marking alert areas, stating and identifying what the holding position marking is, for example, "runway hold line" or "ILS critical area."

- Visual Signal. A visual signal can consist of different styles of lights, flashing screens, different colors, textual messages, graphics, or combinations thereof. A preconfigured or custom airport ground vehicle runway incursion warning system should provide several options from which the airport user can select the visual signals that meet their operational requirements. A custom system should have the ability to add additional or custom visual signals as the airport user requires. Different visual signals should be used for proximity warnings, holding position marking alert areas, and RSA alert areas. The visual signal for the RSA alert area should be continuously active while the vehicle is in the RSA alert area and discontinued when the vehicle leaves the alert area.

- System Updates and Compliance. The ground vehicle runway incursion warning system should be updated at least every 56 days to coincide with AFD updates. Airport updates/changes provide assurance that the information on the device is the most recent and up to date. (Compliance with the system updates could be performed by FAA inspectors.)

Table 5. Speed and Proximity Warning Distance

Speed (mph)	Proximity Alert Distance (ft)
0-10	60
11	66
12	72
13	78
20	120
30	180
40	240
50	300
60	360

4.2.2 Optional Features.

The following optional performance features for an airport ground vehicle runway incursion warning system were considered. These options are not critical to preventing runway incursions, but provide additional benefits to airport users and, in some cases, were included in the devices evaluated. The optional features should be taken under consideration and should be specified by the airport user with a justification for their operational requirements.

- Moving Map. Both devices evaluated used moving map displays. A moving map display is not essential to provide proximity warnings, alerts, or signals to a vehicle driver to prevent an incursion. However, the moving map display does provide more valuable situational awareness to the vehicle driver by confirming their location using the map and seeing their direction of travel. If a moving map display is used, the vehicle's location should be centered on the map for complete 360° situational awareness around the vehicle. A color or aerial photograph/map of the airport could be specified by the airport user that meets their operational requirements. In addition, a moving map display should show all an airport's runways, taxiways, aircraft aprons, and other areas where a vehicle can travel within the AOA. The specific size of the display should be a minimum of 4.5 inches diagonal, based on the displays evaluated. However, the airport user should specify the size of the display to meet their operational requirements. The moving map display should also have the ability to visually show a minimum of 200 ft around the vehicle for added situational awareness.

- Vehicle Speed Indicator/Warning. A vehicle's speed can be shown on a display. In addition, a vehicle speed warning can be triggered if a vehicle exceeds an airport user's speed limit preferences.

- Historical Tracking and Vehicle Trails. Historical information of where a vehicle has been can be stored within a device, and the vehicle's trail can be shown graphically on a display.

- System Integration. Device integration should be considered with other airport systems already in use and approved by the FAA, such as FOD detection equipment, ADS-B, ASDE-X, DEVS, and airfield maintenance and inspection programs.

- Zone Creation. The airport user can create other type of zones to provide additional warning, information, and tracking, such as construction zones, speed zones, traffic zones, and temporary zones.

- Display Dimming. The user should be able to dim the display's backlighting so the vehicle driver is not distracted by the display or can adjust for night vision during night airport operations.

- Network Capability and Infrastructure. A network-capable device can be operated and monitored over a wireless communication network. By operating over a network infrastructure, each individual device can function as one integrated system to provide airport operations monitoring, individual devices can see other individual devices on their map display, information can be distributed between individual devices without interfering with radio communications, changes to the software program can be done instantly and collectively at one time, real-time weather information can be displayed, current airport operating information can be displayed, etc. For a device to function on a network, the infrastructure must be in place. This can be accomplished by using airport WiFi infrastructure or a license-free cellular 900-MHz infrastructure.

- Multiple-Vehicle Tracking. Multiple-vehicle tracking can be accomplished using a device capable of operating on a network.

- Document Display. A device can store documents, such as airport operating procedures; regulations; guidelines; directions; and NOTAMS, etc., within a system, that can be retrieved by the vehicle driver for review.

- Weather Conditions. The airport user should specify if the device needs to be operated in an outdoor environment or in any unusual weather conditions.

- Power Requirements. There are several options for powering a device or system in vehicles, such as direct hardwire power connections, 12V quick plug-ins, battery, battery backup, or combinations thereof. The airport should specify what they require for a power source(s) to meet their operational requirements.

4.3 COST ESTIMATES.

The VGTeam spoke with ID and Eagle, which sell the two devices evaluated in this research, concerning general procurement cost estimates of their devices. Device 1, the preconfigured system developed by ID, was still in a prototype development phase. However, they are awaiting final design and operational criteria for minimum performance by the FAA for software development. Early cost estimates for the preconfigured device range from $1500 to $2000 (The level of software development will influence the overall cost).

Procurement costs for Device 2, the custom device developed by Eagle, is extremely dependent on airport-specified requirements. A single, independently operated device could range from $2000 to $4000, depending on the hardware specified. The cost estimate will increase if a central workstation is required. However, if several devices were requested in a system, a discount would be provided. If the airport user requests a network infrastructure to take full advantage of the system's capabilities, the cost could reach upwards of $100,000 or more for the infrastructure plus the cost of the system and devices. It is strongly emphasized that these costs are extremely variable, depending on the airport user's specifications, current infrastructure, vehicle installations, or if the airport already has hardware available.

5. REFERENCES.

1. Federal Aviation Administration, "Driver's Enhanced Vision System (DEVS)," Advisory Circular 150/5210-19, June 2009.

2. http://www.faa.gov/airports/runway_safety/news/runway_incursions/ (last visited September 29, 2009).

3. FAA, "Standards for Airport Markings," Advisory Circular 150/5340-1K, September 2009.

4. FAA, "Ground Vehicle Operations on Airports," Advisory Circular 150/5210-20, June 2002.

5. FAA Aeronautical Information Manual (AIM), "Official Guide to Basic Flight Information and ATC Procedures," February 11, 2010.

6. FAA, "Airport Design," Chapter 3, Advisory Circular 150/5300-13, September 1989.

7. http://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/techops/navservices/gnss/waas/ (last visited September 29, 2011).

APPENDIX A—OTHER PERSONAL COMPUTER OPTIONS FOR DEVICE 2

Figure A-1. Laptop

Figure A-2. Ultra Mobile Personal Computer

A-3. Personal Computer Installed Under the Driver's Seat With the Monitor on the Vehicle Dashboard

A-4. Tablet Personal Computer

APPENDIX B—HOW DISTANCE BEFORE AN ALERT AREA IS AFFECTED BY SPEED, DISTANCE, AND TIME

Table B-1. A 3-Second Delay

	1-mph Increase or Decrease = 6-ft Increase or Decrease Distance of Proximity Warning	GPS Location Update	Visual and/or Audible Signal Activation	Vehicle Driver Reaction Time		Total Time Delay
Time Delay		1 Second	1 Second	1 Second		3 Second
Speed (mph)	Distance to Alert Area (ft)	Distance Traveled (ft)	Distance Traveled (ft)	Distance Traveled (ft)		Distance Left Before Alert Area (ft)
0-10	60	-14.6	-14.6	-14.6	=	16.2
20	120	-29.3	-29.3	-29.3	=	32.1
30	180	-44.0	-44.0	-44.0	=	48.0
40	240	-58.6	-58.6	-58.6	=	64.2
50	300	-73.3	-73.3	-73.3	=	80.1
60	360	-88.0	-88.0	-88.0	=	96.0

Table B-2. A 3.5-Second Delay

	1-mph Increase or Decrease = 6-ft Increase or Decrease Distance of Proximity Warning	GPS Location Update	Visual and/or Audible Signal Activation	Vehicle Driver Reaction Time		Total Time Delay
Time Delay		1 Second	1 Second	1.5 Seconds		3.5 Seconds
Speed (mph)	Distance to Warning Zone (ft)	Distance Traveled (ft)	Distance Traveled (ft)	Distance Traveled (ft)		Distance Left Before Alert Area (ft)
0-10	60	-14.6	-14.6	-21.9	=	8.9
20	120	-29.3	-29.3	-44.0	=	17.5
30	180	-44.0	-44.0	-66.0	=	26.0
40	240	-58.6	-58.6	-87.9	=	34.9
50	300	-73.3	-73.3	-110.0	=	43.5
60	360	-88.0	-88.0	-132.0	=	52.0

Table B-3. A 4-Second Delay

	1-mph Increase or Decrease = 6-ft Increase or Decrease Distance of Proximity Warning	GPS Location Update	Visual and/or Audible Signal Activation	Vehicle Driver Reaction Time		Total Time Delay
Time Delay		1 Second	1.5 Seconds	1.5 Seconds		4 Seconds
Speed (mph)	Distance to Warning Zone (ft)	Distance Traveled (ft)	Distance Traveled (ft)	Distance Traveled (ft)		Distance Left Before Alert Area (ft)
0-10	60	-14.6	-21.9	-21.9	=	1.6
20	120	-29.3	-44.0	-44.0	=	2.8
30	180	-44.0	-66.0	-66.0	=	4.0
40	240	-58.6	-87.9	-87.9	=	5.6
50	300	-73.3	-110.0	-110.0	=	6.8
60	360	-88.0	-132.0	-132.0	=	8.0

Table B-4. A 4.5-Second Delay

	1-mph Increase or Decrease = 6-ft Increase or Decrease Distance of Proximity Warning	GPS Location Update	Visual and/or Audible Signal Activation	Vehicle Driver Reaction Time		Total Time Delay
Time Delay		1 Second	2 Seconds	1.5 Seconds		4.5 Seconds
Speed (mph)	Distance to Warning Zone (ft)	Distance Traveled (ft)	Distance Traveled (ft)	Distance Traveled (ft)		Distance Left Before Alert Area (ft)
0-10	60	-14.6	-29.2	-21.9	=	-5.7
20	120	-29.3	-58.6	-44.0	=	-11.9
30	180	-44.0	-88.0	-66.0	=	-18.0
40	240	-58.6	-117.2	-87.9	=	-23.7
50	300	-73.3	-146.6	-110.0	=	-29.9
60	360	-88.0	-176.0	-132.0	=	-36.0