

US-VISIT Increment 2C RFID Feasibility Study Final Report *January 21, 2005*

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EXECUTIVE SUMMARY

The mission¹ of the United States (U.S.) Visitor and Immigrant Status Indicator Technology (US-VISIT) Program, within the Department of Homeland Security (DHS), is to enhance the security of U.S. citizens and travelers, to facilitate legitimate trade and travel, to ensure the integrity of the U.S. immigration system, and to protect the privacy of travelers.

The Increment 2C Proof of Concept (POC) effort builds upon the framework that was developed in Increment 2B. Expanding upon Increment 2B capabilities, the Increment 2C POC Concept of Operations (CONOPS) introduces the issuance of a unique automatic identifier (a-ID) that is capable of being read automatically, passively,² and remotely.

Increment 2C POC introduces new technology and business processes that will be deployed in such a manner that will not impede cross border movement of commerce and persons.

Increment 2C POC capabilities are broken down into four components:

1. A-ID Issuance and Verification

The first time an in-scope traveler crosses at a land Port of Entry (POE) under the Increment 2C POC, the in-scope traveler will be referred to Secondary to determine admissibility per current standard operating procedures. Biographic and/or biometric (unless exempt) information collected on the in-scope traveler under the Increment 2B process will be verified. If no data exists, biographic and biometric (unless exempt) data will be collected. In-scope travelers meeting admissibility requirements will be issued an a-ID that is associated with the photo, biographic and biometric information on record for the in-scope traveler.

2. Pedestrian Entry

Upon subsequent entry of the in-scope traveler, the system will automatically read and record the in-scope traveler's a-ID, execute real-time biographic watch list checks and display to the Customs and Border Protection (CBP) Primary Officer the in-scope traveler's name, photograph, biographic watch list results, biometric watch list status and a-ID status (e.g., lost or stolen).

3. Vehicle Entry

Upon subsequent entry of the in-scope traveler in a vehicle, the system will automatically read and record the a-ID as an entry event.

4. Pedestrian and Vehicle Exit

As in-scope travelers depart the U.S. on foot or by vehicle, the system will automatically read and record the a-ID as an exit event.

¹ Executive Summary, Mission Needs Statement v3.0, November 2003.

² "Passive" means that the a-ID will be read by the Increment 2C system without requiring the traveler to take any active or concerted effort to enable the read.



The Increment 2C POC schedule is comprised of three stages. These stages are:

- **Radio Frequency (RF) Feasibility Study:** The study will provide direction for 2C technical requirements concerning RF technology (e.g., configuration, connectivity, security, etc.).
- **Establishment of a Mock POE:** The Mock POE will replicate the current land border environment. The Mock POE will be designed to test a variety of RF Identification (RFID) products and will simulate integration with existing land border POE processes and technology.
- **POC Implementation (Phase 1):** Phase 1 implementation will encompass seven business processes; a-ID issuance, pedestrian entry, vehicle entry, a-ID verification, pedestrian exit, vehicle exit and reporting.

This document records the results of the RF Feasibility Study as it was conducted in a simulated environment (Mock POE). This, and the establishment of a Mock POE, must be successful prior to Phase 1, POC implementation at POEs. Based upon successful completion of the phase 1 Increment 2C POC, full operating capability will be implemented in Phase 2. Upon completion of Phase 2, a thorough evaluation will be conducted. Based upon the results of that evaluation, further deployment will be determined.

Before the execution of the RFID Feasibility Study, considerable effort was expended analyzing the operational and technical alternatives that could support the Increment 2C business requirements. The results of that analysis are outlined in the Operational Alternatives Assessment document. The Operational Alternatives Assessment focused on those technologies that could automatically, remotely and passively identify a traveler. Technologies identified included various biometrics, Global Positioning System (GPS) based, active and passive RFID, kiosks, and outbound processing. After full analysis of the alternatives, passive RFID technology was identified as best able to support the Increment 2C business requirements.

DHS, like other government agencies such as the Department of Defense (DoD), has significant experience implementing RFID technology. Previous studies, and existing RFID systems, have shown that a-ID capture in pedestrian and vehicle entry scenarios can be performed successfully. For example, the DHS Secure Electronic Network for Travelers Rapid Inspection (SENTRI), NEXUS, and the Free and Secure Trade (FAST) systems have successfully demonstrated that RFID technology can be used to automatically and remotely identify travelers as they enter the U.S in a vehicle.

However, one of the most technically challenging operational scenarios in Increment 2C is the capture of a traveler's a-ID when they exit the U.S. in a moving vehicle. The RFID Feasibility Study was conducted to demonstrate that RFID technology could reasonably support the automatic, passive, and remote capture of a traveler's a-ID in a moving vehicle. This document records the results of that study.

The RFID Feasibility Study included extensive testing of the readability of passive RFID tags located within moving vehicles. The testing was conducted at a facility in Falls



Church, Virginia. Two vehicle lanes, along with an overhead gantry and other structures, were constructed to imitate an environment similar to the vehicle exit lanes of a typical U.S. land POE.

In order to test the ability to read a traveler's a-ID automatically, passively, and remotely, the tests consisted of a number of real-world situations such as the placement of RFID tags in multiple locations within a vehicle, and the handling of tags by travelers in various ways. Different types of vehicles, including cars, buses, and trucks, were run at different speeds. Testing also evaluated various combinations of RFID readers, antennas, antenna placements, tag types, and reader power levels. Testing was performed on the equipment from two RFID vendor teams, (b)(4); (b)(5) and the (b)(4); (b)(5) who were down selected after applying a number of criteria.

A number of recommendations and observations have been drawn from the statistical analysis performed on the data collected in the study. The key recommendations resulting from this study are as follows:

- (b)(4); (b)(5) **equipment should be considered for use in Increment 2C POC.** Although cost and interoperability with existing systems need to be taken into account, the study found that the RFID vendor, (b)(4); (b)(5) had statistically significant better performance in reading tags across all test permutations.
- **Traveler action should be taken into consideration as part of the Increment 2C vehicle exit solution.** To best capture the a-ID of travelers exiting the U.S. in a vehicle, occupants should hold their RFID tag and raise it toward a window, or place their tags securely on the dash, back shelf, or placed into a suitable holder on one of the car's windows. These four options yielded the best results, and there was no statistically significant difference between them. If travelers do not take one of these actions, the expected read performance will be poor.
- **Antennas for vehicle exit should be configured in the 'side fire' position, and be powered according to FCC Part 90 regulations (higher power).** Side fire antennas should be installed for all POEs where islands between exit lanes already exist. Overhead antenna configurations are a viable option, but should only be used where facility constraints preclude the use of side fire systems, and then only if the operational impacts of dealing with missed traveler exits are acceptable.

Along with these recommendations, the testing provided a number of observations including:

- **Speeds up to 50 miles per hour (MPH) did not affect the ability to read the RFID tags at higher reader power.** For both vendors, there was no reduction in read rates at the various speeds tested using readers operated at the high power. Based on empirical evidence, and the experience of the RFID vendors and RF engineers involved in the testing, a speed would eventually be reached where tag performance would be hindered, but the speed at which performance would drop was not found in the testing.
- **Tag types did not significantly affect read rates.** Two basic tag types were tested, a standard plastic card, and a RFID tag that could be placed within an I-94 form. For



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(b)(4); (b)(5) side fire there was no statistical difference between the performance of each tag type, and (b)(4); (b)(5) I-94 tag was only slightly better performing than their card.

- **Interference between antenna RF fields may occur.** There was evidence that interference due to overlap between RF fields could occur. The RFID equipment placement for the Increment 2C POC POEs will need to consider potential interference.

Given these recommendations and observations, a number of next steps should be considered:

- Additional RF antenna configurations and tag placements should be tested to improve the capture of exit events before Increment 2C POC rollout. It was evident that additional refinements, which were not possible during the RF Feasibility Study, could further improve performance.
- Additional operational details need to be explored to determine how RFID tags can be secured onto a window, dashboard, or back deck within a moving vehicle.
- The specific tag type used for Increment 2C needs to be determined.
- Because the construction of islands between exit lanes may not be feasible within the Increment 2C timeframe, overhead antenna configurations may need to be installed. Therefore, additional overhead antenna configurations should be tested to improve overhead antenna performance.
- It was not practical to test the effects of weather. Further evaluation of the effects of weather on the ability to read RFID tags should be considered during the Increment 2C POC.



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are withheld in their entirety under
Exemptions 4 and 5, FOIA,
5 U.S.C. §552(b)(4) and §552(b)(5).**



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REVISION HISTORY

Version No.	Date	Brief Description of Change	A=Add M=Modify D=Delete	Source
V1.0	1/21/2005	Final Release	A	SBA Inc 2C SEIT Team
V0.7	1/12/2005	Draft Release	A	SBA Inc 2C SEIT Team
V0.6	1/5/07/2005	Peer Review Copy For Draft Release	A	SBA Inc 2C SEIT Team
V0.5	12/22/2004	Interim Review document created – Executive Summary and Section 7 added	A	SBA Inc 2C SEIT Team
V0.4	12/7/2004	Interim Review document created – Section 5, 6 and Attachment D added	A	SBA Inc 2C SEIT Team
V0.3	11/24/2004	Interim Review document created – Section 4	A	SBA Inc 2C SEIT Team
V0.2	11/17/2004	Interim review document created – Section 2 and 3	A	SBA Inc 2C SEIT Team



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US-VISIT Program Approvals				
Organization	Name	Comment	Approve	Date
Director	Jim Williams			
Deputy Director	Bob Mocny			
Implementation Management	Shonnie Lyon			
Office of Facilities and Engineering	Manny Rodriguez			
Acquisition & Program Management	Dana Schmitt			
Office of the Chief Strategist	Patty Cogswell			
Mission Operations Management	P.T. Wright			
Outreach Management	Anna Hinken			
Budget & Financial Management	Keith Roemeling			
Information Technology Management	Scott Hastings			
Administration and Training	JaNelle East			

Approved _____
Director, US-VISIT

Date

Comments:



1.0 INTRODUCTION

The mission³ of the US-VISIT Program, within the DHS, is to enhance the security of U.S. citizens and travelers, to facilitate legitimate trade and travel, to ensure the integrity of the U.S. immigration system, and to protect the privacy of travelers.

The Increment 2C POC effort builds upon the framework that was developed in Increment 2B. Expanding upon Increment 2B capabilities, the Increment 2C POC CONOPS introduces the issuance of a unique a-ID that is capable of being read automatically, passively,⁴ and remotely.

1.1 PURPOSE

The Increment 2C POC CONOPS schedule identifies four stages in the development cycle. The first stage includes execution of the RFID Feasibility Study. This document records the results of that study.

This report documents the evaluation of two selected RFID vendors. The study involved creating an environment that simulated the land POE exit situation and designing and executing a comprehensive set of tests to measure the performance of the selected vendors. This document provides the results of these activities along with recommendations concerning the Increment 2C POC implementation and operational capabilities.

1.2 SCOPE

This document presents the results of the RFID Feasibility Study conducted by the Smart Border Alliance (SBA) for the US-VISIT Program. This study was tasked to examine options for the implementation of the a-ID capability, select from among those options the most feasible for implementation, identify vendors of the selected technology, test the systems available from those vendors and document the results of those tests, making recommendations on the resulting deployment. This a-ID capability will be used at vehicle and pedestrian entry and exit for all in-scope travelers at the selected Increment 2C POC sites.

1.3 US-VISIT BACKGROUND

The US-VISIT Program was chartered within the DHS to enhance national security and the integrity of the immigration system, facilitate legitimate travel and trade, and safeguard in-scope travelers' personal privacy. Through a dynamic and interoperable program, US-VISIT will collect, maintain, and share information including biometrics and photographs on individuals who:

- Should be prohibited from entering the U.S.
- Extend or adjust their immigrations status

³ Executive Summary, Mission Needs Statement v3.0, November 2003.

⁴ "Passive" means that the a-ID will be read by the Increment 2C system without requiring the traveler to take any active or concerted effort to enable the read.



- Have overstayed or otherwise violated the terms of their admission
- Should be apprehended or detained for law enforcement purposes
- Need special protection/attention

Figure 1-1 provides a high-level summary of the initial Increments in the US-VISIT program.

Increment	Process Scope	Schedule	Functionality
1A	Entry at Air and Sea Ports	January 5, 2004	Delivered the initial operating capability of using biometrics for identity verification to 115 air and 15 sea ports
1B	Exit Pilot at Air and Sea Ports	August – December 2004	Evaluates the exit pilot alternatives at air and sea ports
2A	Entry at Air/Land/Sea Ports	October 26, 2005*	Delivers the initial operating capability to read biometrically enabled travel documents at all POEs
2B	Entry at 50 busiest land Ports	December 31, 2004*	Electronically captures arrival and biometric data in the Passport Control Area and automates the Form I-94 issuance process
2C	Entry and exit at land POEs	July 31, 2005 (POC), December 31, 2007 (Busiest 50 POEs)	Automates recording of in-scope traveler entry and exit
3	Remaining land POEs	December 31, 2005*	Provides Increment 2B capability at remaining land POEs

* Indicates a legislative mandate

Figure 1-1 US-VISIT Program Increments

The first increment of US-VISIT was launched on January 5, 2004 with the deployment of biometric capture capabilities at 115 airports and 15 seaports (Increment 1A). An evaluation of exit pilot alternatives at air and seaports is ongoing (Increment 1B). On December 31, 2004, US-VISIT introduced the collection of biometrics into the issuance of Form I-94 and Form I-94W in the Passport Control area and automated the Form I-94 issuance process at the 50 busiest land POEs (Increment 2B).

On July 31, 2005, US-VISIT will automate the recording of in-scope traveler entry and record exit events through the issuance of a unique identifier (Increment 2C). By October 26, 2005, US-VISIT will deliver the capability to read biometrically enabled travel documents at all POEs (Increment 2A). By December 31, 2005, US-VISIT will introduce the collection of biometrics into the issuance of Form I-94 and Form I-94W in the secondary area of the remaining land POEs (Increment 3).



1.4 INCREMENT 2C LEADERSHIP

Key personnel involved with the Increment 2C initiative include, but are not limited to, the individuals identified in Figure 1-2.

US-VISIT Increment 2C Leadership			
Organization	Title	Name	Role
DHS	Secretary	Tom Ridge	Business Sponsor
BTS	Undersecretary	Asa Hutchinson	Business Sponsor
CBP	Commissioner	Robert Bonner	Business Owner
CBP	Assistant Commissioner	Jason Ahern	Deputy Business Owner
US-VISIT	Director	Jim Williams	Approving Authority
US-VISIT	Deputy Director	Bob Mocny	Approving Authority
DOS	Department Representative	John Cook	IPT member
DOT	Department Representative	Jim Zok	IPT member
ICE	Agency Representative	Kevin Merkel	IPT member
TSA	Agency Representative	Tom Freed	IPT member
CBP	Agency Representative	Elizabeth Tritt	IPT member
US-VISIT	Information Systems Security Manager (ISSM)	Bill Morgan	Certifying Official
US-VISIT	Information Systems Security Officer (ISSO)	Barry Nash	Maintain system security
US-VISIT	Implementation Management	Shonnie Lyon	Approving Director
US-VISIT	Implementation Management	Colleen Manaher	Project Manager
US-VISIT	Office of Facilities Management	Manny Rodriguez	Approving Director
US-VISIT	Office of Chief Strategist	Patty Cogswell	Approving Director
US-VISIT	Mission Operations Management	P.T. Wright	Approving Director
US-VISIT	Outreach Management	Anna Hinken	Approving Director
US-VISIT	Budget & Financial Management	Keith Roemeling	Approving Director
US-VISIT	Information Technology Management	Scott Hastings	Approving Director
US-VISIT	Information Technology Management	Michael Westray	Project Manager
US-VISIT	Acquisition & Program Management	Dana Schmitt	Approving Director
US-VISIT	Administration and Training	JaNelle East	Approving Director
SBA	Increment 2C	Kimberly Deshong	Project Manager



Figure 1-2 Increment 2C Key Personnel

1.5 APPROACH

SBA established a team to conduct the feasibility study with guidance on study objectives from the US-VISIT Program office. The team established a list of vendors to be evaluated. From this set, a test environment was designed and constructed, test parameters established and reviewed with the vendors, and test procedures created. The tests were then executed, data collected and analyzed and the final report prepared including recommendations.

1.6 DOCUMENT REFERENCES

- *Department of Homeland Security (DHS) Management Directive (MD) 4300, DHS Information Technology Security Program*
- *DHS Sensitive Systems Policy Publication 4300A Version 2.1, dated July 26, 2004*
- *DHS Sensitive Systems Handbook Version 2.1, dated July 26, 2004*
- *Smart Border Alliance (SBA) Security Requirements Traceability Matrix (RTM) Version 3, dated November 2, 2004.*
- *Increment 2C Phase I Proof of Concept Functional Requirements Document, USVISIT-APMO-CONTHSSCHQ04D0096T006-REQ0500010-D, January 12, 2005*
- *US-VISIT Increment 2C Concept of Operations - Proof of Concept Version 0.1, USVISIT-APMO-CONTHSSCHQ04D0096T0006-PLN040030-D, November 24, 2004*
- *US-VISIT Increment 2C Operational Alternatives Assessment, December 14, 2004.*



2.0 RFID FEASIBILITY STUDY OBJECTIVES

Increment 2C seeks to enhance the initial operating capabilities provided at land POEs, through the issuance of an a-ID device that is capable of being read automatically, passively, and remotely during subsequent exit and reentry by the travelers. A successful read of the a-ID device will start information retrieval processes for each individual as they approach the border crossing point. As each traveler arrives at the U.S. CBP Officer's station for admission to the U.S. or as they approach the border on exit from the U.S. the associated biographic and biometric information will be retrieved. In this way, information needed to aid the CBP Officer with an admissions decision will be available to the Officer with little delay.

Due to the fact that the exit scenario described above is a new application of this technology, this feasibility study was commissioned with the concurrence of the US-VISIT Program with the following objectives:

1. Test and evaluate, using a simulated POE environment, the ability of commercially available candidate RFID devices (tags, antennas and tag readers) to coordinate the flow of travelers on entry and exit.
2. Recommend an RFID vendor for an Increment 2C POC deployment based upon the evaluation of the test results.
3. Provide recommendations concerning the equipment configuration in the POC environment to achieve best RFID tag reading results.
4. Provide an initial Security and Privacy Study that assesses potential issues, and recommends methods for addressing security and privacy concerns.
5. Provide recommendations on how tags must be presented in the read field to achieve acceptable RFID reading performance.

This report presents the results of the investigation into the feasibility of using RFID technology for this application, and in particular, to evaluate the relative merits of the specific implementations provided by two vendors. Attachment D, RFID Technology Overview, provides information that is useful to understanding the technology, how it is applied today, and the applicable standards that exist. Because the case of a traveler exiting in a vehicle is the most difficult for RFID systems to address, SBA conducted thorough testing of the RFID technology in the vehicle exit scenario. This report documents the test methods and results. The evaluation provides the basis for recommendations for the preferred vendor, equipment, and configuration for deployment of POC systems at selected land POEs.

The design of the tests focused primarily but not exclusively on situations where there was a reasonable expectation that a tag could be read. This was necessary because of the limited time available for the testing and because of the need to acquire enough data to make a statistically meaningful statement about the results. SBA experience, results from the (b)(4), (b)(5) Study conducted earlier for SBA (described below) and the experience of the vendors who were evaluated in these tests indicated that under certain conditions RFID tag reading performance can be expected to be poor. SBA performed limited testing for those situations known to produce poor RFID tag reading results, such as



holding two or more tags together, or completely shielding tags from the reader by the travelers body (e.g., in a wallet) to confirm that tag read rates were unacceptably low.

2.1 a-ID ALTERNATIVES SELECTION

The following sections discuss the selection of the technology to be used for a-ID implementation.

2.1.1 SELECTION CRITERIA

The basic US-VISIT requirement for the Increment 2C capability is to provide an automated, passive and remote means of coordinating the flow of travelers when crossing the borders on entry and exit. The methods used should be automated so that DHS officers and information systems can efficiently incorporate the acquired traveler management information into the DHS systems to improve border operations. The method should be passive in the sense that direct action or cooperation on the part of the traveler is not required. Finally, the method should operate remotely so that the system can manage traveler crossings from some distance. The need to detect traveler departures while minimally impacting the unmanaged or unconstrained traffic flow drives the requirement for remote detection.

In addition to these criteria, the other discriminators in selecting the technology to implement a-ID include:

- Characteristics influencing the deployment – The deployment of a-ID systems should be feasible and within the constraints of the POE facilities.
- Existing industry, national and/or international standards – The technology should adhere to standards to insure interoperability with other equipment.
- Impacts to privacy – The use of the technology should not impose threats to personal privacy.
- Commercial availability – The chosen a-ID technology should not require development for deployment other than site-specific implementation modifications.

2.1.2 a-ID ALTERNATIVES AND SELECTION

US-VISIT conducted an assessment of alternatives for the implementation of Increment 2C requirements for a-ID. The document “US-VISIT Increment 2C Operational Alternatives Assessment” summarizes this assessment. Several alternatives were considered in this study, including biometric based technologies (facial, voice, retinal, iris, finger scan, hand geometry), active RFID, passive RFID, GPS –based devices and self-service kiosk. These were considered in regard to both entry and exit scenarios. Finally, an option for automatic referral to secondary on entry and outbound primary options were also considered.

These technologies were evaluated against the criteria that the alternative should:

- Support remote and passive operations
- Result in no increase in wait time
- Result in no degradation of service
- Cause no significant degradation of traffic patterns
- Be commercially available
- Be convenient to the traveler.



The assessment determined that none of the biometric alternatives would be sufficiently passive to be satisfactory on entry or exit. Self-service kiosks on entry or exit are not passive and automatic. Neither referral to secondary (on entry) nor outbound primary (on exit) are passive and/or remote. Of the remaining options, active and passive RFID, and GPS-based devices all are satisfactory from the point of view of degradation of wait time, service level and traffic patterns. Because of the form factor and for other related reasons, neither the active RFID nor the GPS device would be convenient to the traveler.

As a result of this evaluation, US-VISIT selected the passive RFID technology for this feasibility study.

2.2 STUDY SCOPE

The RFID Feasibility Study provides an assessment of examples of commercially available RFID technology applied to the US-VISIT land border POE vehicle exit scenario. This is the most technically challenging scenario to satisfy of the four modes of border crossing in Increment 2C. These four modes include:

- Vehicle entry – A vehicle (passenger, truck or bus) approaches the POE where the passengers carrying RFID enabled documents seek admission to the country. The RFID technology is used to locate information that will assist the CBP Officers in making their admission decisions.
- Vehicle exit – A vehicle exits through the POE. The RFID enabled documents carried by the passengers are detected during exit, providing a record of the exit of the document.
- Pedestrian entry – Pedestrian travelers carrying RFID enabled documents approach the POE, seeking admission to the country. The RFID technology is used to locate information that will assist the CBP officers in making admission decisions.
- Pedestrian exit – Pedestrian travelers carrying RFID enabled documents exit the country. RFID detecting devices located at the POE pedestrian exit lanes provide a record of the exit of the document.

Of these four modes of border crossing, the most technically challenging is the vehicle exit. At vehicle entry, the vehicle is stopped and under the control of the CBP Officer, so that one or more suitably presented RFID enabled documents can be read. The RFID enabled NEXUS and SENTRI systems have successfully demonstrated this capability. In early 2004, SBA contracted (b)(4); (b)(5) to perform an independent study (“the (b)(4); (b)(5) Study”) to evaluate RFID performance (see Attachment C of this document). The (b)(4); (b)(5) Study determined that pedestrians carrying an RFID tag could be detected 100% of the time with the proper vendor equipment and under conditions that can be easily achieved for pedestrian entry and exit. However, the (b)(4); (b)(5) Study determined that rates of detection were low in the vehicle exit case, where vehicles may be traveling at speeds up to 60 MPH and carrying several passengers.

An objective of this study is to test the ability of a suitably equipped POE to identify an RFID enabled document traveling exiting a POE at speeds up to 50 MPH, and to collect data that allows reasonable conclusions to be drawn about performance while monitoring vehicle exits at higher speeds. The following sections describe in more detail the method of testing in this evaluation.



SBA identified the adherence to industry, national or international standards as additional criteria for use in the evaluation of vendors. The RFID marketplace is moving toward the acceptance of standards for RFID interfaces. This will enable the interoperability of equipment from a combination of vendors, allowing the user community to configure equipment that is most suitable to their needs. Attachment D, Section 1.9 contains additional material on RFID standards. The (b)(4); (b)(5) readers and tags adhere to the EPCglobal Class 0 standard and the emerging EPCglobal Ultra-High Frequency (UHF) Generation 2 (Gen2) standard. The (b)(4); (b)(5) equipment is compatible with the International Organization for Standardization (ISO) 18000 standards and the EPCglobal Gen2 standard. However, the system from (b)(4); (b)(5) does not conform to accepted standards, and as a result was excluded from the short list for further evaluation.

As a result of this evaluation, (b)(4); (b)(5) and (b)(4); (b)(5) were selected for further vendor evaluation in the acquisition process. The decision was made that the study should include FCC Part 90 (high power) rules as well to consider performance at lower power levels. (b)(4); (b)(5) provides systems operating at high power levels. (b)(4); (b)(5) does not, and teamed with (b)(4); (b)(5) who does provide high power systems. Figure 2-2 summarizes the selection of (b)(4); (b)(5) and (b)(4); (b)(5) and (b)(4); (b)(5) hereafter referred to as (b)(4); (b)(5) for evaluation during this study.

Vendor	Criteria		
	(b)(4); (b)(5)	Reuse Opportunity	Standards
(b)(4); (b)(5)	Tags read at up to 55 MPH	No	EPCglobal Class 0, provisionally EPCglobal Gen2
(b)(4); (b)(5)	Not readable at 35 MPH and above	Yes	ISO 18000, provisionally EPCglobal Gen2
(b)(4); (b)(5)	N/A	Yes	ISO 18000, provisionally EPCglobal Gen2
(b)(4);	Not readable at 35 MPH and above	No	EPCglobal Class 1, provisionally EPCglobal Gen2
(b)(4); (b)(5)	N/A	No	No
(b)(4); (b)(5)	Poor performance even at walking speeds	No	EPCglobal Class 0 and Class 1,

* (b)(4); (b)(5) Study performed under low power rules only

Figure 2-2 Vendor Selection Process

2.4 STUDY APPROACH

SBA completed the following steps in the execution of this study:



1. Selected vendors to be evaluated during the study as described in Section 2.3 above.
2. Designed and constructed a test lane that supports the requirements of the test. Vendor recommendations on equipment orientation and positioning were incorporated into test lane construction.
3. Procured vendor RFID equipment, designed and constructed weatherized enclosures, and fabricated support structures.
4. Obtained the required FCC licenses permitting higher power operation.
5. Designed, developed, and tested software to interface with the RFID controller equipment, receive the output data stream, and store the data for further analysis. This software was only for use in the test environment. SBA also prepared tools to analyze and display the resulting data.
6. Defined a set of test cases to evaluate the vendor RFID equipment. These test cases were to determine the suitability of the equipment in an environment similar to that found at POE vehicle exit lanes. The test variables considered during the test included:
 - Vendor RFID tag types – cards and labels
 - Antenna positioning - overhead and side fire
 - Variations in Speed – 20, 30, 40, 50 MPH
 - High and low power levels (30 Watts (W) Effective Radiated Power (ERP) and 4 W ERP, respectively)
 - Number of passengers / tags per vehicles – from 2 to 36
 - Number of Vehicles – one or two
 - Vehicle types– sedan, truck and bus
 - Orientation of the tag – front, side, oblique, 90 degree turn
 - Mishandling of the tag – finger overlap
 - Passive handling of the tag – on car seat, shirt pocket, in glove compartment, window, dash, back deck
 - Window Tinting

Section 3.3 includes a matrix defining the test conditions.

7. Prepared detailed test procedures (included in Attachment F) to implement these test cases. The test procedures define the sequence of events to be executed during each test run.
8. Executed the tests in accordance with the test procedures.
9. Analyzed the test results.
10. Prepared recommendations and documented the results of the tests.

2.5 PRIVACY AND SECURITY

The RFID Security and Privacy Study was conducted in concert with the Feasibility Study. Further details of that study are outlined in Attachment E. Analysis indicates that several mitigation strategies are available to alleviate privacy and security concerns. Security mitigation strategies include the use of encryption, implementation of anti-collision algorithms to ensure reader availability and data integrity, the use of



filters and audit trails to permit detection of counterfeit tags or replay attacks, and education of tag holders about the use of physical shielding.

A number of privacy concerns related to the use of RFID-enabled documents are already being addressed within the Increment 2C design removing personal data from the tag and into a secure database. Additional privacy protection strategies include the implementation of Fair Information Practices, including educating the public about RFID technology and subsequent placement of tags in travel documents, assignment of a new a-ID number whenever a new or replacement a-ID is issued, and educating tag holders about the use of physical shielding that can prevent their tags from being read.

These strategies should be further evaluated during the design and development phase of Increment 2C in order to determine their effect on operational capabilities and to perform a business risk analysis before implementation.



3.0 RFID FEASIBILITY TEST METHODS

The following sections describe the environment and high-level procedures that were used during the RFID tests.

3.1 RFID TEST OVERVIEW

As described in Section 2, the RFID feasibility tests focused on the simulated exit of vehicles carrying RFID tags from a POE. A two-lane test site was constructed for this purpose at the Raytheon facility at Falls Church, Virginia. A gantry and other support structures were constructed to support RFID readers and antennas. Antennas were placed at different positions and orientations relative to the vehicle to evaluate read performance. The reader systems were interfaced with computers to automatically collect data from the tests. Test vehicles of different types and carrying varying numbers of passengers were driven down the test site at different speeds. The RFID antenna/readers collected data that was analyzed as described in Section 4 and Attachment I of this document. The results of these tests are presented in Section 4. The following sections describe the conditions for the tests in more detail.

It is important to note that SBA performed testing primarily, but not exclusively, on those situations with a reasonable expectation of acceptable RFID tag reading results. SBA team experience, the results of the (b)(4); (b)(5) Study and the experience of the vendors evaluated in this study agree that very poor RFID tag reading results should be expected in certain circumstances. The basic physics behind these limitations is well understood. For example, there is a high probability of obtaining poor tag reads when holding a stack of tags together, completely shielding tags from the reader by the travelers body (e.g., in a wallet in the pants pocket) or by substantial amounts of other shielding material such as metal or water. Both vendors involved concurred with this expectation. However, SBA did perform limited testing of this type to confirm that tag read rates were very low. This data is available for evaluation. SBA devoted the majority of the limited test time on test cases that would provide insight into the application of RFID technology to the Increment 2C task.

3.2 TEST LANE CONFIGURATION

The RFID test lane was constructed at the northern-most edge of the parking lot behind the Raytheon facility at 7700 Arlington Blvd, Falls Church, Virginia. The test site is approximately 1000 feet from one end to the other, and runs in an approximately east-west direction. The track has two lanes to accommodate two vehicles driving side by side for the length of the track, each lane being 14 feet wide, with an approximately 4 foot median between lanes. The test lane area is separated from the parking lot on the south side and the edge of the parking lot on the north side by concrete jersey barriers for the full length of the track with openings for cars to enter and leave at each end. These barriers were added for the safety of the personnel working in the test site area, including drivers. Figures 3-1 and 3-2 are photographs of the test site area from near the entrance of the track on the east, and from the exit from the track near the west end, respectively.

The tag detection area, depicted in Figure 3-3, is bounded on each end by infrared (IR) motion detectors. These were used to signal the entry and exit of vehicles from this area.



This area is approximately 360 feet from the start of the track. In the tag detection area, the median area is separated from the traffic lanes by concrete wheel stops. A concrete filled steel bollard is located at the beginning of the median in the tag detection area.

A steel construction sign bridge, or gantry, is located approximately 100 feet from each IR sensor at the start and finish of the tag detection area. Figure 3-4 depicts the elevation view of the gantry. The gantry supported antenna and reader equipment were oriented to look down on vehicles passing underneath the bridge. The gantry also carried the power and data cables to these antennas/readers as well as for other antennas/readers that were located in the median area farther down the track. The gantry has approximately 19 feet of ground clearance over the test site with 17 feet of ground clearance at the edges as indicated in the figure. The gantry included a steel walk way overhead to access the antennas/readers. The gantry walkway is accessed by a stairway on the south side of the track. Figures 3-5 and 3-6 are photographs of the tag detection area from the east end looking west, and from the west end looking east, respectively. Figure 3-7 is a view from the gantry as a truck and a sedan enters the tag detection area. Figure 3-8 is a view from the gantry as a passenger bus passes by the side fire antennas and leaves the tag detection area.



Figure 3-1 RFID Feasibility Test Site: View from Near Track Entrance Looking West



Note: Caption on next page



Figure 3-2 RFID Feasibility Test Site: View from Near Track Exit Looking East

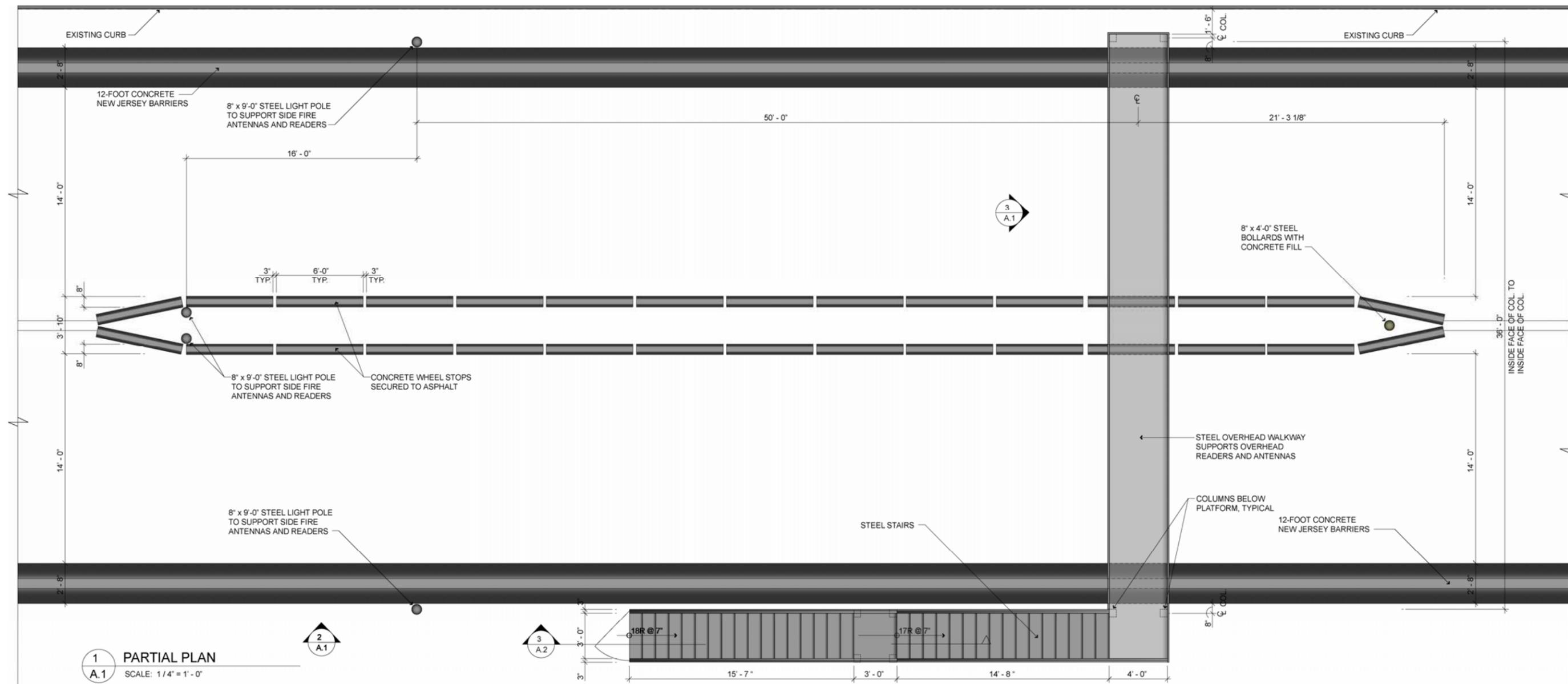


Figure 3-3 Test Site Tag Detection Area -Plan View

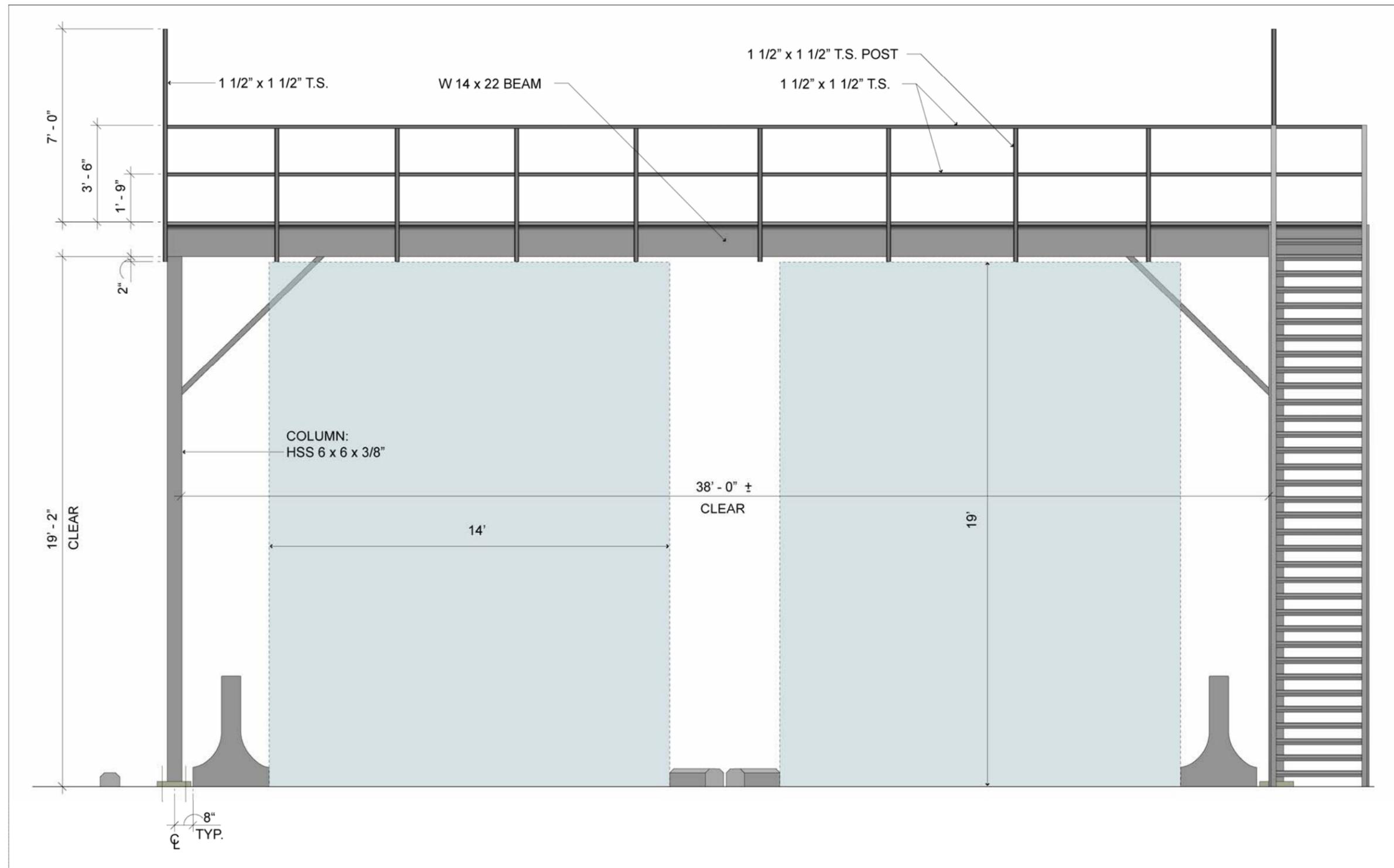


Figure 3-4 Detail of Overhead Gantry- Elevation View



Figure 3-5 RFID Feasibility Test Site: Tag Detection Area, Viewing from East to West



Figure 3-6 RFID Feasibility Test Site: Tag Detection Area, Viewing from West to East



Figure 3-7 View from the Gantry - Truck and a Sedan Enter the Tag Detection Area



Figure 3-8 View from the Gantry - Passenger Bus Leaves the Tag Detection Area



Two steel light poles are fixed approximately 150 feet from the start of the tag detection area (50 feet after the gantry), one on each outside edge of the test lanes. Two additional steel light poles are located in the median area approximately 16 feet beyond the first two poles. These four light poles support antennas/readers that were directed toward the test vehicles and offset from each other. These antennas directed inward toward the vehicles are in what is referred to as the 'side fire' position.

Speed detection devices and displays, one on the outside edge of each lane, are located near the start of the tag detection region. These are used to display to the drivers their current speed, aiding them in maintaining a correct and constant speed when entering the tag detection area.

A construction-type trailer is located near the gantry. This trailer contains the computers used to collect, save and analyze the data. The director for the test operations is located in the trailer and can observe test operations from that position through windows in the trailer. The test director is in radio communication with all drivers during the tests. Video cameras and monitors are also provided to monitor activities

A return lane is marked by painted lines and barriers in the parking lot on the south side of the test area between the test lane and the general parking lot. This allows the vehicles to return to the start point from the lane exit.

At the conclusion of testing on the test lanes, the RFID antennas, readers, and related equipment were removed from the test area and stored for possible future use. All other test lane equipment, including the gantry, are available for future testing should that be required.

3.3 TEST PARAMETERS DESCRIPTION

Figure 3-9, part A and B, is the test configuration matrix that describes each of the core test cases. Each test configuration in the matrix defines a different set of test parameters. The full set of tests described by this matrix was run with both the (b)(4); (b)(5) and the (b)(4); (b)(5) RFID equipment. Each test was repeated at least five times for each configuration. Ten repetitions were made for test configurations at 30, 40 and 50 MPH at two tag orientations: front and side. The results of these core tests were part of the body of information used to make the recommendations in Section 5 on the equipment to be deployed as part of the POC.

In addition to the core tests, other vendor-unique tests were conducted using other types of equipment from these vendors or used in different configurations. These vendor unique tests are listed in the test configuration matrices for (b)(4); (b)(5) and (b)(4); (b)(5) show in Figures 3-10 and 3-11, respectively. These tests were for information gathering purposes only. The informational tests were not scored for the purpose of making selection recommendations. In summary:

- (b)(4); (b)(5) Unique Tests – (b)(4); (b)(5) had completed development of a (b)(4); (b)(5) and (b)(4); (b)(5) just prior to the beginning of the tests. (b)(4); (b)(5) felt that SBA would want to evaluate the performance of the new



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equipment. A subset of 12 test configurations from the core test set was executed using the new (b)(4); (b)(5) equipment.

- (b)(4); (b)(5) Unique Tests- These tests involved repeating some of the test scenarios using the side fire system with the overhead system turned off.



Configuration	Number of Runs	Power		Tag Type			Speeds				Orientations				Location		Passive Use	Handling Finger Overlap	Passengers		No of Vehicles		Vehicle Type			Comment	
		Part 90	Side Part 15	Card	Label	New	20	30	40	50	Front	Side	Oblique	90 deg	Dash & Back	Window			2	5	1	2	Sedan	Truck	Bus		
		50	46	55	41	0	16	12	56	4	27	31	4	4	4	8	8	8	16	76	16	80	88	8	4	← Count of occurrences (not including TBDs)	
1	5	X		X			X				X								X	X		X					
2	5	X		X			X				X								X	X		X					
3	5	X		X					X		X								X	X		X					
4	5	X		X					X		X								X	X		X					
5	5	X		X			X				X								X		X	X					
6	5	X		X			X				X	X							X		X	X					
7	10	X		X				X			X								X		X	X					
8	10	X		X				X			X								X		X	X					
9	10	X		X					X		X								X		X	X					
10	10	X		X					X		X								X		X	X					
11	10	X		X						X	X								X		X	X					
12	10	X		X						X	X								X		X	X					
13	5	X		X				35			X							X		X			X			Maximum safe speed for truck	
14	5	X		X				35			X							X		X			X			Maximum safe speed for truck	
15	5	X		X				35			X							X		X	X	X				One Sedan and one truck. Maximum safe speed for truck	
16	5	X		X				35			X							X		X	X	X				One Sedan and one truck. Maximum safe speed for truck	
17	5	X		X					X			X							X		X	X					
18	5	X		X					X		BEST	BEST		X					X		X	X				Best of Front of Side, but axis of tag rotated 90 degrees	
19	5	X		X					X					X					X		X	X					
20	5	X		X					X						X				X		X	X				Windshield top left, top center, top right, bottom right, bottom left	
21	5	X		X					X						X				X		X	X				Rear window top left, top center, top right, bottom right, bottom left	
22	5	X		X					X		X							X		X	X	X					
23	5	X		X					X		X							X		X	X	X					
24	5	X		X			X										X		X		X	X				Passive use, Driver pocket, front seat, glovebox, two rear seat	
25	5	X		X					X								X		X		X	X				Passive use, Driver pocket, front seat, glovebox, two rear seat	
26	5	X		X					X		BEST	BEST						X		X	X					One Sedan and one Sedan with metallic tinted windows, closed	
27	5	X		X					X		BEST	BEST						X		X	X					One Sedan and one Sedan with metallic tinted windows, ajar	
28	5	X		X			X				X									X			X			35 to 50 passengers (tags)	
29	5	X		X				X			X								X		X	X				35 to 50 passengers (tags), Top speed on track TBD	
30	5	X			X		X				X									X			X			35 to 50 passengers (tags)	
31	5	X			X			X			X									X			X			35 to 50 passengers (tags), Top speed on track TBD	
32	5	X			X		X				X								X		X	X					
33	5	X			X		X				X								X		X	X					
34	10	X			X			X			X								X		X	X					
35	10	X			X			X			X								X		X	X					
36	10	X			X			X			X								X		X	X					
37	10	X			X			X			X								X		X	X					
38	10	X			X				X		X								X		X	X					
39	10	X			X				X		X								X		X	X					
40	5	X			X				X		X								X	X		X					
41	5	X			X				X		X								X	X		X					
42																											Not used
43	5	X			X				X			X							X		X	X					
44	5	X			X				X		BEST	BEST		X					X		X	X				Best of Front of Side, but axis of tag rotated 90 degrees	
45	5	X			X				X					X					X		X	X					
46	5	X			X				X						X				X		X	X				Windshield top left, top center, top right, bottom right, bottom left	
47	5	X			X				X						X				X		X	X				Rear window top left, top center, top right, bottom right, bottom left	
48	5	X			X				X		X							X		X	X	X					
49	5	X			X				X		X							X		X	X	X					
50	5	X			X		X										X		X		X	X				Passive use, Driver pocket, front seat, glovebox, two rear seat	
51	5	X			X				X								X		X		X	X				Passive use, Driver pocket, front seat, glovebox, two rear seat	
52	4	X			X				X		BEST	BEST						X		X	X					Extended runs to test tag to tag variability within tag type	
53	4	X			X				X		BEST	BEST						X		X	X					Extended runs to test tag to tag variability within tag type	
54	5	X			X				X		BEST	BEST						X		X	X					One Sedan and one Sedan with metallic tinted windows, closed	
55	5	X			X				X		BEST	BEST						X		X	X					One Sedan and one Sedan with metallic tinted windows, ajar	

Figure 3-9 (Part A) Test Configuration Matrix



Config uration	Number of Runs	Power		Tag Type			Speeds				Orientations				Location			Handling	Passengers		No of Vehicles		Vehicle Type			Comment	
		Part 90	Side Part 15	Card	Label	New	20	30	40	50	Front	Side	Oblique	90 deg	Dash & Back	Window	Passive Use	Finger Overlap	2	5	1	2	Sedan	Truck	Bus		
		0	46	29	17	0	8	6	28	0	14	14	2	2	2	4	4	4	12	34	8	38	44	4	0	↔ Count of occurrences (not including TBDs)	
Part 15 Changeover and Setup																											
56	5		X	X				35			X								X		X			X			Maximum safe speed for truck
57	5		X	X				35			X								X		X			X			Maximum safe speed for truck
58	5		X	X				35			X								X			X	X	X			One Sedan and one truck. Maximum safe speed for truck
59	5		X	X				35			X								X			X	X	X			One Sedan and one truck. Maximum safe speed for truck
60	5		X	X			X				X								X		X		X				
61	5		X	X			X				X								X		X		X				
62	5		X	X				X			X								X		X		X				
63	5		X	X				X			X								X		X		X				
64	5		X	X					X		X								X		X		X				
65	5		X	X					X		X								X		X		X				
66	5		X	X					X		X								X			X	X				
67	5		X	X					X		X								X			X	X				
68	5		X	X			X				X									X		X	X				
69	5		X	X			X				X									X		X	X				
70	5		X	X				X			X									X		X	X				
71	5		X	X				X			X									X		X	X				
72	5		X	X					X		X									X		X	X				
73	5		X	X					X		X									X		X	X				
74	5		X	X					X											X		X	X				
75	5		X	X					X						X					X		X	X				
76	5		X	X					X					X						X		X	X				
77	5		X	X					X						X					X		X	X				Windshield top left, top center, top right, bottom right, bottom left
78	5		X	X					X						X					X		X	X				Rear window top left, top center, top right, bottom right, bottom left
79	5		X	X					X		X								X		X	X	X				
80	5		X	X					X		X									X		X	X				
81	5		X	X			X												X		X	X	X				Passive use, Driver pocket, front seat, glovebox, two rear seat
82	5		X	X				X											X		X	X	X				Passive use, Driver pocket, front seat, glovebox, two rear seat
83	5		X	X				X			BEST	BEST								X		X	X				One Sedan and one Sedan with metallic tinted windows, closed
84	5		X	X				X			BEST	BEST								X		X	X				One Sedan and one Sedan with metallic tinted windows, ajar
85	5		X		X			X			BEST	BEST								X		X	X				One Sedan and one Sedan with metallic tinted windows, closed
86	5		X		X			X			BEST	BEST								X		X	X				One Sedan and one Sedan with metallic tinted windows, ajar
87	5		X	X			X				X									X		X	X				
88	5		X	X			X				X									X		X	X				
89	5		X	X				X			X									X		X	X				
90	5		X	X				X			X									X		X	X				
91	5		X	X					X		X									X		X	X				
92	5		X	X					X		X									X		X	X				
93	5		X	X					X				X							X		X	X				
94	5		X	X					X											X		X	X				
95	5		X	X					X						X					X		X	X				
96	5		X	X					X											X		X	X				Windshield top left, top center, top right, bottom right, bottom left
97	5		X	X					X											X		X	X				Rear window top left, top center, top right, bottom right, bottom left
98	5		X	X					X		X									X		X	X				
99	5		X	X					X		X									X		X	X				
100	5		X	X			X													X		X	X				Passive use, Driver pocket, front seat, glovebox, two rear seat
101	5		X	X				X												X		X	X				Passive use, Driver pocket, front seat, glovebox, two rear seat

Note: Cells marked BEST in the 'Orientations' columns mean a selection was made to choose the highest performance approach for these test runs. In all cases the orientation used was Side.

Figure 3-9 (Part B) Test Configuration Matrix



Config-uration	Number of Runs	Power		Tag Type			Speeds				Orientations				Location		Handling		Passengers		No of Vehicles		Vehicle Type			Comment
		Part 90	Side Part 15	Card	Label	New	20	30	40	50	Front	Side	Oblique	90 deg	Dash & Back	Window	Passive Use	Finger Overlap	2	5	1	2	Sedan	Truck	Bus	
		9	1	2	2	6	1	1	1	6	1	5	1	0	2	0	0	0	0	10	0	10	10	0	0	← Count of occurrences (not including TBDs)
100	5	X				X		X			X								X		X	X			No tags read	
101	10	X				X		X			X								X		X	X				
102	0	X				X			X		X								X		X	X			Not run because of poor performance in this orientation	
103	10	X				X			X		X								X		X	X				
104	0	X				X				X	X								X		X	X			Not run because of poor performance in this orientation	
105	10	X				X				X	X								X		X	X				
106																									Not used	
107	5	X				X					X								X		X	X				
108	5	X				X		X						X					X		X	X				
109	5	X				X			X					X					X		X	X				
110	5	X				X			X				X						X		X	X				
111																									Not used	
112																									Not used	
113																									Not used	
114	2		X		X		X												X		X	X				
115																										
116	10	X		X					X		X								X		X	X			Side fire system OFF	
117	5	X		X					X		X								X		X	X			Overhead System OFF	
118	5	X			X				X		X								X		X	X			Tags held higher in side window	

Figure 3-10 Test Configuration Ma (b)(4), (b)(5)

Config-uration	Number of Runs	Power		Tag Type			Speeds				Orientations				Location		Handling		Passengers		No of Vehicles		Vehicle Type			Comment
		Part 90	Side Part 15	Card	Label	New	20	30	40	50	Front	Side	Oblique	90 deg	Dash & Back	Window	Passive Use	Finger Overlap	2	5	1	2	Sedan	Truck	Bus	
		14	0	1	13	0	2	2	8	2	1	7	1	0	1	0	2	1	4	10	4	10	10	0	4	← Count of occurrences (not including TBDs)
201	5	X		X				35			X								X		X	X			Overhead system off and side fire system adjusted	
202	5	X		X				35			X								X		X	X			Overhead system off and side fire system adjusted	
203	5	X		X					X					X					X		X	X			Windshield, Overhead system off	
204	5	X		X					X					X					X		X	X			Rear window, Overhead system off	
205	5	X		X					X							X			X		X	X			Overhead system off and side fire system adjusted	
206	5	X			X		X				X							X		X			X		Overhead system off and side fire system adjusted	
207	5	X			X			X			X							X		X			X		Overhead system off and side fire system adjusted	
208	5	X			X				X		X								X		X	X			Overhead system off and side fire system adjusted	
209	5	X			X				X	X									X		X	X			Overhead system off and side fire system adjusted	
210	5	X			X				X				X						X		X	X			Overhead system off and side fire system adjusted	
211	5	X			X				X					X					X		X	X			Overhead system off and side fire system adjusted	
212	5	X			X				X									X		X	X	X			Overhead system off and side fire system adjusted	
213	5	X			X				X							X			X		X	X			Overhead system off and side fire system adjusted	
214	5	X			X				X		X								X		X	X			One Sedan and one Sedan with metallic tinted windows, closed	
215	5	X			X				X		X								X		X	X			One Sedan and one Sedan with metallic tinted windows, ajar	
216	5	X			X		X				X							X		X			X		Side fire system off and side fire system adjusted	
217	5	X			X			X			X							X		X			X		Side fire system off and side fire system adjusted	
218	5	X			X			X											X		X	X			Side fire system off and side fire system adjusted	
219	5	X			X				X	X									X		X	X			Side fire system off and side fire system adjusted	
220	5	X			X				X		X								X		X	X			Side fire system off and side fire system adjusted	

Figure 3-11 Test Configuration Ma



Note: No data on this page



The test parameters evaluated for both the core and vendor unique tests were:

1. Power – In terms of power output, two types of RFID systems were evaluated during these tests. RFID systems from (b)(4), (b)(5) and I (b)(4), (b)(5) that operate at low power levels, less than 4 Watts ERP, were evaluated. Additionally, RFID system from (b)(4), (b)(5) and (b)(4), (b)(5) that operate at high power levels, 30 Watts ERP, were also evaluated. In each case, the tests were run at the maximum power levels allowed under the applicable FCC rules.
2. Tag Type – At least two tag types were evaluated for each vendor. The two tag types are an ID card format and an adhesive label type tag format. The label was affixed to an I-94 document and the I-94 with the attached tag was inserted in a small notepad that simulates a passport. The (b)(4), (b)(5) ID Card type tag and the label type tag attached to an I-94 and inserted in a simulated passport are shown in Figure 3-12. The (b)(4), (b)(5) ID card type tag and the label type tag attached to an I-94 and inserted in a simulated passport are shown in Figure 3-13.
3. Speeds – Sedans were run at four tests speeds: 20, 30, 40, or 50 MPH. Vehicles accelerated from the start point, reached the indicated speed, held that speed until clear of the tag detection area and then slowed and exited the test site. For the truck tests, the maximum speed that could be safely used was 35 MPH. For the bus tests, the speeds were 20 and 30 MPH.
4. Orientations – Describes the orientation at which a tag is held. The ability to read a tag is more sensitive to the orientation of the tag for some tags than for others. The intent of this test variable was to discover if there was sensitivity to orientation for a particular vendor tag and the degree of that sensitivity. The tests evaluated the tags in four orientations when the tag was hand-held. In the ‘front’ orientation, the flat surface of the tag faced the windshield. In the side orientation, the flat surface of the tag faced the side window of the vehicle. In the oblique orientation, the tag was turned midway between the side and front positions and top tilted forward. The fourth orientation was to rotate the tag 90 degrees relative to its primary (best orientation). See Figures 3-14, 3-15, 3-16 and 3-17 for examples of these orientations using the (b)(4), (b)(5) tag, and see Figures 3-18, 3-19, 3-20 and 3-21 for examples of orientations using the (b)(4), (b)(5) tag.
5. Location – Describes where a tag is located when a passenger does not hold the tag. In addition to the hand held orientations, the RFID tags were placed in the vehicle at different locations as a simulation of more passive methods for making tags visible to the readers. Three configurations were evaluated. In one configuration, five tags were affixed to the windshield. The tags were placed in plastic sleeves that were taped to the window so that the sleeve hung away from the window. See Figure 3-22. The tags were placed at the top center, top right, bottom left, bottom center and bottom right positions. See Figure 3-23. In the second configuration, the tags were placed on the rear window in the same pattern as was used for the windshield. In the third configuration, two tags were placed on the front dash and two were placed on the rear ledge behind the passenger seat. See Figures 3-24 and 3-25.
6. Handling – Tag reading performance is expected to be better when a tag is held in a particular way, and the best tag holding technique is different for each vendor’s tags. SBA understood this fact prior to these tests from previous experience with RFID, from the (b)(4), (b)(5) Study and from informal input from the vendors. In most of



the tests where the tag was hand-held, the tag was held in the best way for tag reading as determined by the vendor.



Figure 3-12 (b)(4); (b)(5) Label Tag Attached to an I-94 and ID Card Type Tag



Figure 3-13 (b)(4); (b)(5) Label Tag Attached to an I-94 and ID Card Type Tag



Figure 3-14 (b)(4); (b)(5) 'Front' Orientation Tag

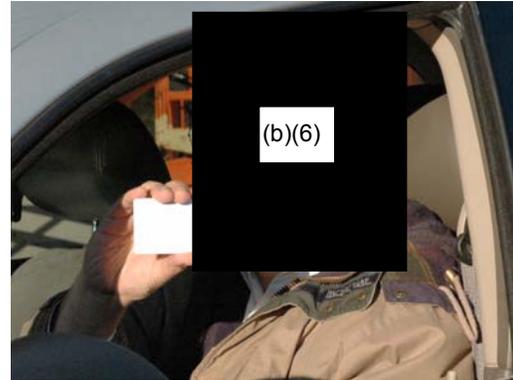


Figure 3-15 (b)(4); (b)(5) 'Side' Orientation Tag



Figure 3-16 (b)(4); (b)(5) 'Oblique' Orientation Tag



Figure 3-17 (b)(4); (b)(5) '90 Degree' Orientation Tag



Figure 3-18 (b)(4); (b)(5) 'Front' Orientation Tag

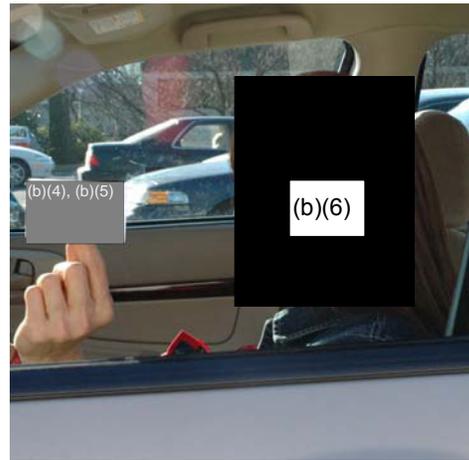


Figure 3-19 (b)(4); (b)(5) 'Side' Orientation Tag

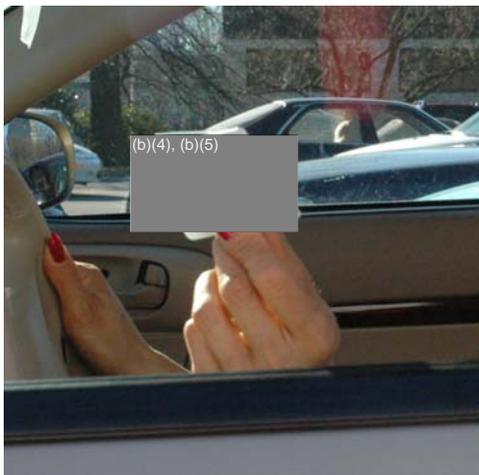


Figure 3-20 (b)(4); (b)(5) 'Oblique' Orientation Tag



Figure 3-21 (b)(4); (b)(5) '90 Degree' Orientation Tag



Figure 3-22 Window Attached Tag



Figure 3-23 Seat (Tag) Numbering in Vehicle



Figure 3-24 I-94 in Simulated Passport on
Dashboard



Figure 3-25 I-94 in Simulated Passport on
Rear Window Ledge



Figure 3-26 (b)(4); (b)(5) Normal ID-Card Holding



Figure 3-27 (b)(4); (b)(5) Normal I-94 Holding



Figure 3-28 (b)(4); (b)(5) Finger Overlap ID-Card Holding



Figure 3-29 (b)(4); (b)(5) Finger Overlap I-94 Holding



As recommended by (b)(4); (b)(5) Figures 3-26 and 3-27 indicate the best tag holding technique for the (b)(4); (b)(5) ID card and RFID label attached to the I-94, respectively. The 'Finger Overlap' tag holding technique, shown in Figures 3-28 and 3-29 for the (b)(4); (b)(5) ID card and RFID label attached to the I-94, respectively, was expected to degrade performance. Tests that used the finger overlap handling technique are indicated with an 'X' in this column of the test matrix. Figures 3-30 and 3-31 indicate the normal tag holding technique for the (b)(4); (b)(5) ID Card and RFID label on I-94. Figures 3-32 and 3-33 show the finger overlap handling for these same tag types, respectively.

7. Passive – This test was intended to evaluate certain types of passive tag use behavior. In this configuration, five tags were located in the car: one in the driver's shirt pocket, one in the glove compartment, one on the front passenger seat, and two on the rear passenger seat. Figures 3-34 through 3-37 illustrates these passive presentation methods. The shirt pocket and glove compartment methods were expected to produce poor results based upon prior experience with RF devices. The tests were included to explore the degree to which the RFID systems were sensitive to these conditions.
8. Passengers – Describes the number of passengers per vehicle. Each test using a passenger car or truck was run using either two or five passengers per vehicle. When a bus was used, at least 18 people were on the bus, each presenting two tags to simulate twice as many passengers.
9. Number of Vehicles – Either one or two vehicles were used in each test. When two vehicles were used, both vehicles entered the tag detection area side by side to the best ability of the drivers. If the vehicles were not sufficiently adjacent, the test run was cancelled and re-run.
10. Vehicle Type – Sedan-type passenger cars were used in most cases. A tour bus was used when the test required a bus. The truck used was a 26-foot box truck. These vehicles can be seen in Figures 3-7 and 3-8.
11. Other Parameters – Test configurations to examine the effects of tinted window and variations in tag-to-tag performance are also included in the test matrix. These items are designed in the Comments column.



Figure 3-30 (b)(4); (b)(5) Normal ID-Card Holding



Figure 3-31 (b)(4); Normal I-94 Holding

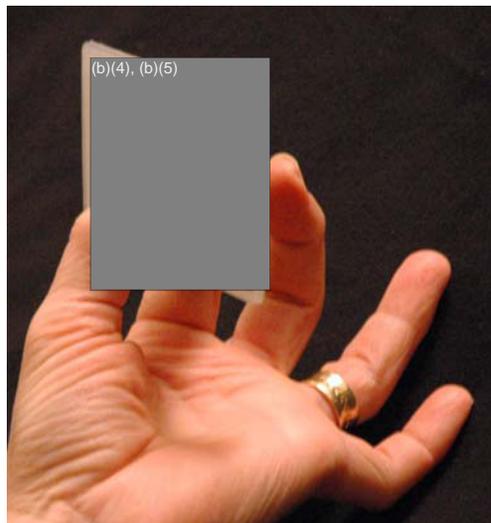


Figure 3-32 (b)(4); (b)(5) Finger Overlap ID-Card Holding



Figure 3- 33 (b)(4); (b)(5) Finger Overlap I-94 Holding



Figure 3-34 Illustration of Passive Use – Shirt Pocket



Figure 3-35 Illustration of Passive Use – Positioned on Rear Passenger Seat



Figure 3-36 Illustration of Passive Use – Positioned on Front Passenger Seat



Figure 3-37 Illustration of Passive Use – Glove Compartment



3.3.1 DATA COLLECTION METHODS

The description of the RFID system provided in this document so far has been from the external point of view: the tag is scanned and returns an identification code. However, the operation of the RFID system is more complex. The RFID reader illuminates the read field many times per second – from on the order of 100 times per second to 1000 times per second - and the RFID tag that is in the read field responds to the interrogation with a response message. In operation, the reader and/or the computer system that interfaces with the reader process the received signals and make the identification determination. In conventional operations of RFID systems, the reader “turns off” the tags when successfully read so that the reader may focus read and processing time on those tags that may only be marginally readable. After the initial read, the tags are silent.

SBA initially intended to run the test in an alternative mode. In this mode, the reader does not turn off a tag after reading. Each tag in the read field responds to every read attempt. In this mode, the reader devotes more time to reading tags that have already been read and so may not read all tags present. The advantage to the alternative mode is that the reader would return many messages for each test run, perhaps several thousand. This would improve the measurement statistics so that a more accurate estimate could be made of the systems ability to identify tags in vehicles exiting a POE at 60 MPH. SBA intended to run tests in the alternative mode using only one or two tags per vehicle to avoid the degradation in performance mentioned above.

However, very late in the definition of the tests the determination was made that neither vendor could support this alternative test approach without significant additional effort. As a result, the tests were run in the conventional mode of operations. In this case, data was collected for each tag that was read. The data returned by the reader indicated the tag ID, the reader ID, and a timestamp of the last time that the tag was read. No measure was returned indicating how often the tag was read. As a result, the number of test measurements that were made was small relative to the numbers that might have been obtained using the alternative method. However, the conventional mode of operation does most closely reflect how the tags and readers would be used in operations at a POE.

It is noted that though the supportable data collection regime provided less detailed data, the use of multiple tags and multiple runs provides a reasonable means of differentiating the various test configurations. In particular, the large majority of the test configuration included 10 tags that were presented a minimum of five times (two vehicles, each with five tags). The sample population thereby numbered 50, which was sufficient to draw statistically significant conclusions about the differences between vendors and configurations in nearly all cases. Twelve of the configurations use ten repetitions, giving a sample population of 100. Testing with buses raised that population to 360 tags. Situations that did not yield statistically significant conclusions resulted when the mean read scores were separated by less than about five percentage points. Though performing more repetition would have resulted in somewhat more



precise results, the level selected was judged to be adequate to accurately fulfill the objectives of this evaluation. In particular, the wide breadth of the parameters examined was only supportable using the number of repetitions selected within the time available.

Test configurations 52 and 53 for high power used a set of ten tags for a single test run, and then was changed to another set of ten tags and run again. This continued for four repetitions, collecting data on 40 tags of a given type. The objective of this test configuration was to determine the amount of variability within a set of 40 tags.

Several test configurations (26 and 27, 54 and 55, 82-85) involved the use of a vehicle with metallic window tinting. From very fundamental principles of physics, there is a sharp reduction of RF signal strength within a conductor. In a vehicle with windows tinted, successfully reading an RFID tag is difficult. The objective of these tests were to determine if any reads were possible, and the extent to which opening the window a few inches helped.

3.4 RFID ANTENNA AND READER CONFIGURATION

This section describes the RFID equipment from each vendor that was used during the tests. The positioning and orientation of the equipment is also discussed.

3.4.1 (b)(4); (b)(5) (b)(4); (b)(5)

The (b)(4); (b)(5) reader and the (b)(4); (b)(5) Antenna were used at all read points. Figure 3-38 shows the (b)(4); (b)(5) reader inside a weatherized container. Figure 3-39 shows two of the (b)(4); (b)(5) Antenna sets mounted to a side fire support pole with the weatherized container mounted to the pole below the antennas. Two reader configurations were used for these tests. A single reader controlled two side fire antennas, and one reader controlled four overhead antennas. The (b)(4); (b)(5) readers were enclosed in weatherized containers built by SBA/Raytheon for these tests. Figure 3-40 depicts the overall arrangement of readers and antennas for the (b)(4); (b)(5) test configuration.

Ten transmit/read antenna pairs were configured on the test lane. For each lane, four antenna sets were positioned on the gantry, one forward looking set for each lane before the gantry and one forward looking set for each lane behind the gantry. The view provided in Figure 3-41 of the (b)(4); (b)(5) antenna orientation on the gantry indicates how the antennas are pointed inward and down toward the vehicles. Figure 3-42 provides an elevation view of the gantry area as viewed from in back of the gantry. Extension poles were used to support the antennas away from the gantry. The side fire antenna sets were installed further down the test lane.

As indicated in Figure 3-43 for the side fire configuration, there were two antenna sets pointing inward toward the vehicles from the outer support poles, illuminating the vehicle from the side and just slightly behind. There were two sets of antennas on the median area support poles; one set illuminating the departing vehicle in each lane. At each of the two outside side fire read points, a single (b)(4); (b)(5) (b)(4); (b)(5) reader



controlled the antenna (b)(4); (b)(5) at that location. Each reader was internally multiplexed to the two antennas connected to it as well as (b)(4); (b)(5). This meant that each (b)(4); (b)(5) on the outer poles received the full power but operated for as little as one-quarter of the time. This operational dwell varied, depending upon whether unread tags were detected in the vicinity of a particular pole. (b)(4); (b)(5). The effect of this approach was to maximize reader performance while ensuring that the two readers, operating on the same frequency, did not interfere with each other.

The center median side fire antennas were controlled by a single (b)(4); (b)(5) reader which was operated at a different frequency than the readers on the outer poles. The two sets of antennas were internally multiplexed from the single reader, meaning that each received the full output power but operated only half of the time.

At the sign bridge, one (b)(4); (b)(5) reader controlled all four antenna sets. This single reader was internally time multiplexed to the (b)(4); (b)(5). This means that each antenna had full power applied, but was in operation only one-quarter of the time.

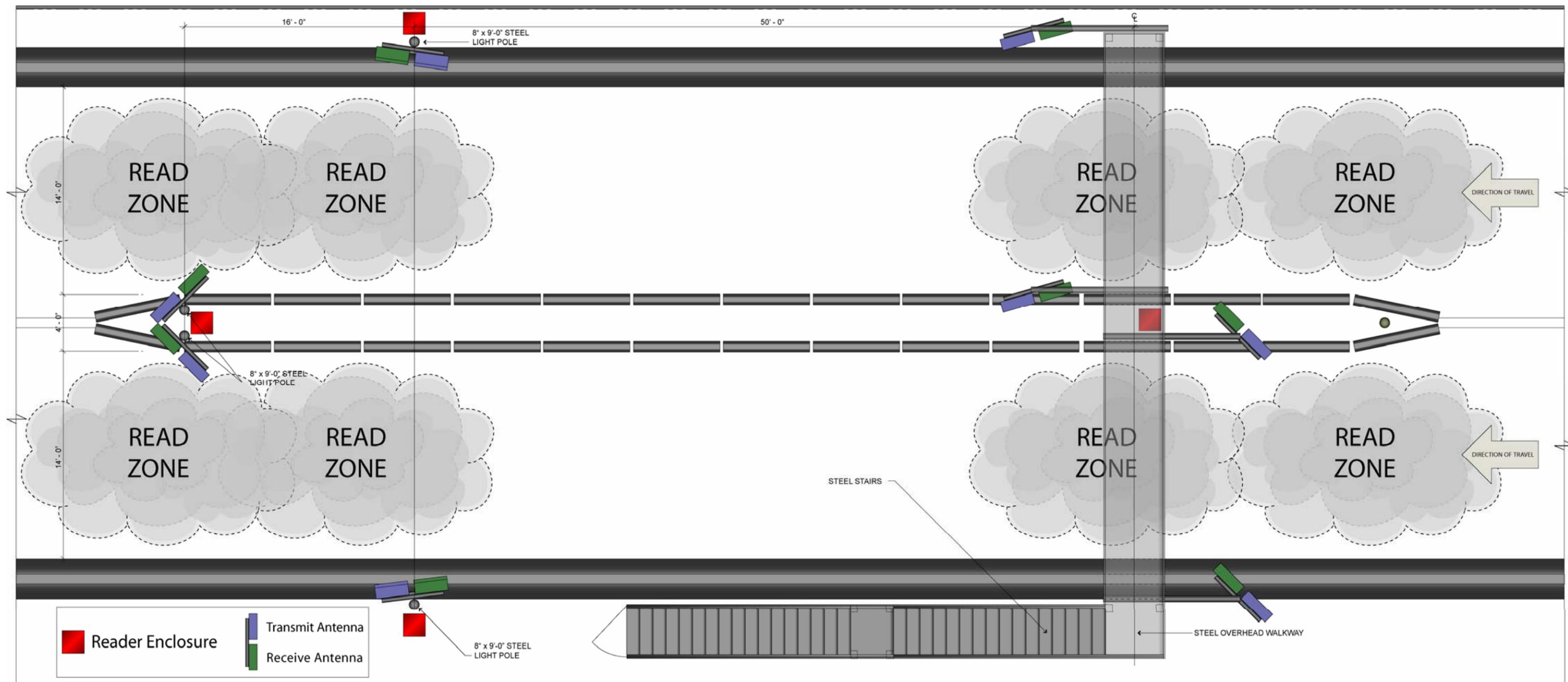
All readers were in turn connected to the test control computer, which was supplied by SBA. Note that both the side fire and the overhead oriented antennas and readers were operating at the same time, so that data was collected from both orientations with each drive-through event.



Figure 3-38 (b)(4), (b)(5) **Reader in Weatherized Container**



Figure 3-39 (b)(4); (b)(5) **Antennas and (b)(4); (b)(5) Reader in Weatherized Container**

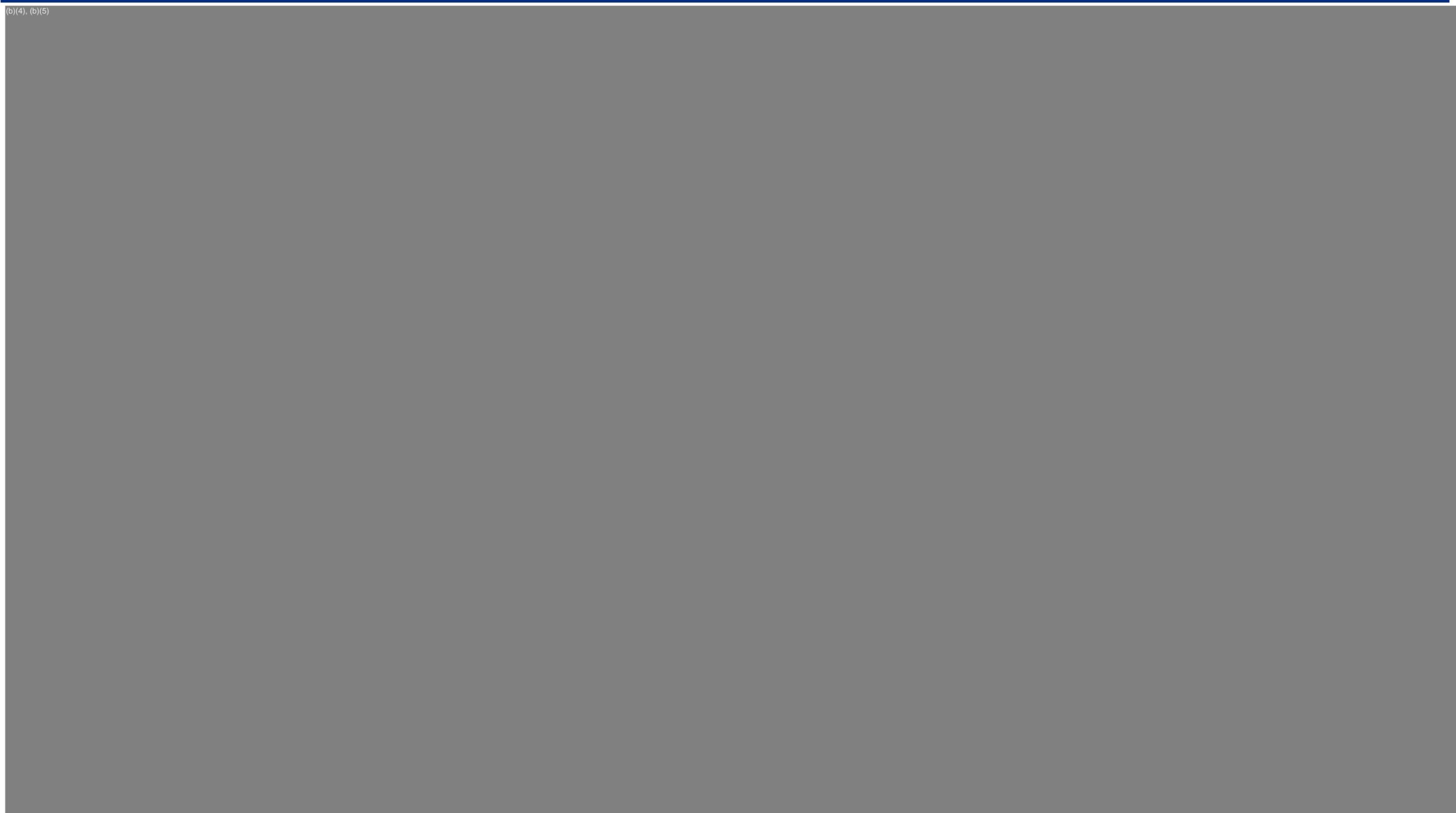


(b)(4), (b)(5)

cting Both Antenna Configurations



(b)(4), (b)(5)



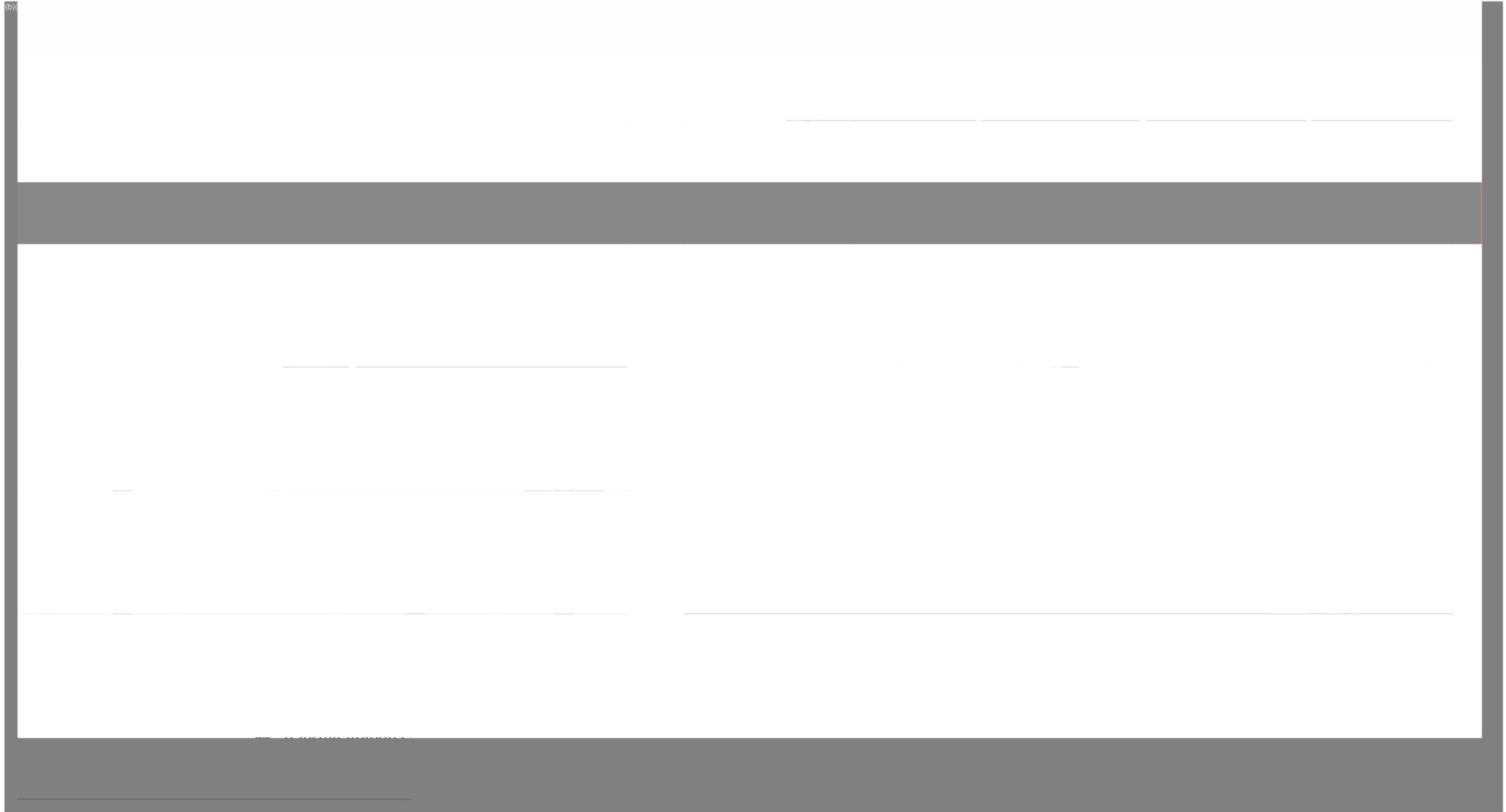


(b) (7) (F)





(b)





The test lanes were operated in two modes based upon power levels. In one mode, the side fire antennas were operated at low power, only. In the second mode, high power levels were used for both the overhead and the side fire antennas, simultaneously.

Two (b)(4); (b)(5) tag types were used. These were a 2"x2" read only tag laminated in Polyvinyl Chloride (PVC) and a 2"x2" ID Card tag, both shown above in Figure 3-13.

3.4.2 (b)(4); (b)(5)

Two types of readers were used for the (b)(4); (b)(5) configuration. The (b)(4); (b)(5) Brein Antenna and (b)(4); (b)(5) reader located below and behind the antenna, shown in Figure 3-44, were used for the low power tests. Although SBA offered to construct weatherized enclosures for (b)(4); (b)(5) equipment, (b)(4); (b)(5) declined.

(b)(4); (b)(5)

(b)(4); (b)(5) Reader (the white object mounted on the gantry above the antennas) and (b)(4); (b)(5) shown in Figure 3-45, were used in the high power tests. Figure 3-46 presents the plan view of the test lane using the (b)(4); (b)(5) equipment. The antennas on the gantry were mounted out from the gantry, pointed downward and perpendicular to the direction of traffic. The antennas were mounted in a staggered fashion so that there was 16 feet of separation between the beams pointed at a lane of traffic. Figure 3-47 provides the elevation view of the overhead placement of the (b)(4); (b)(5) antennas and readers. The same mounting poles were used in all tests.

The configuration used for the (b)(4); (b)(5) side fire antennas is shown in Figure 3-48. The (b)(4); (b)(5) antennas were pointed slightly toward the oncoming vehicles and downward from the mount point. The configuration used for the (b)(4); (b)(5) side fire antennas, (b)(4); (b)(5) is shown in Figure 3-49. As with the (b)(4); (b)(5) high power equipment, both the side fire and the overhead oriented antennas and high power readers were operating at the same time, so that data could be collected from both positions with each drive through event. All readers were in turn connected to the SBA supplied test control computer.

The test lanes were operated in two modes based upon power levels. In one mode, the antennas and readers were provided by (b)(4); (b)(5) and were operated in the side fire low power configuration, only. In the second mode, all reader and antenna equipment were provided by (b)(4); (b)(5) and were operated in the overhead, high power and side fire, high power configurations, simultaneously.

(b)(4); (b)(5)

(b)(4); (b)(5) this equipment was also evaluated. A set of test configurations identical to the core tests was used when evaluating these devices. The antenna used with these readers was the (b)(4); (b)(5) Antenna shown in Figure 3-45. The reader used for these tests is shown in Figure 3-50. The tags had the same appearance as the (b)(4); (b)(5) label type tag.



Two (b)(4); (b)(5) tag types were used. These were the (b)(4); (b)(5) (b)(4); (b)(5) both shown above in Figure 3-12.

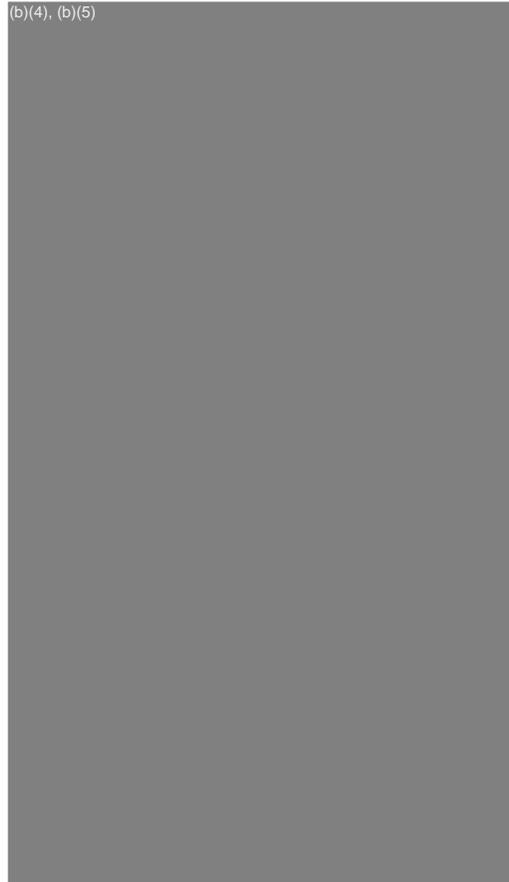
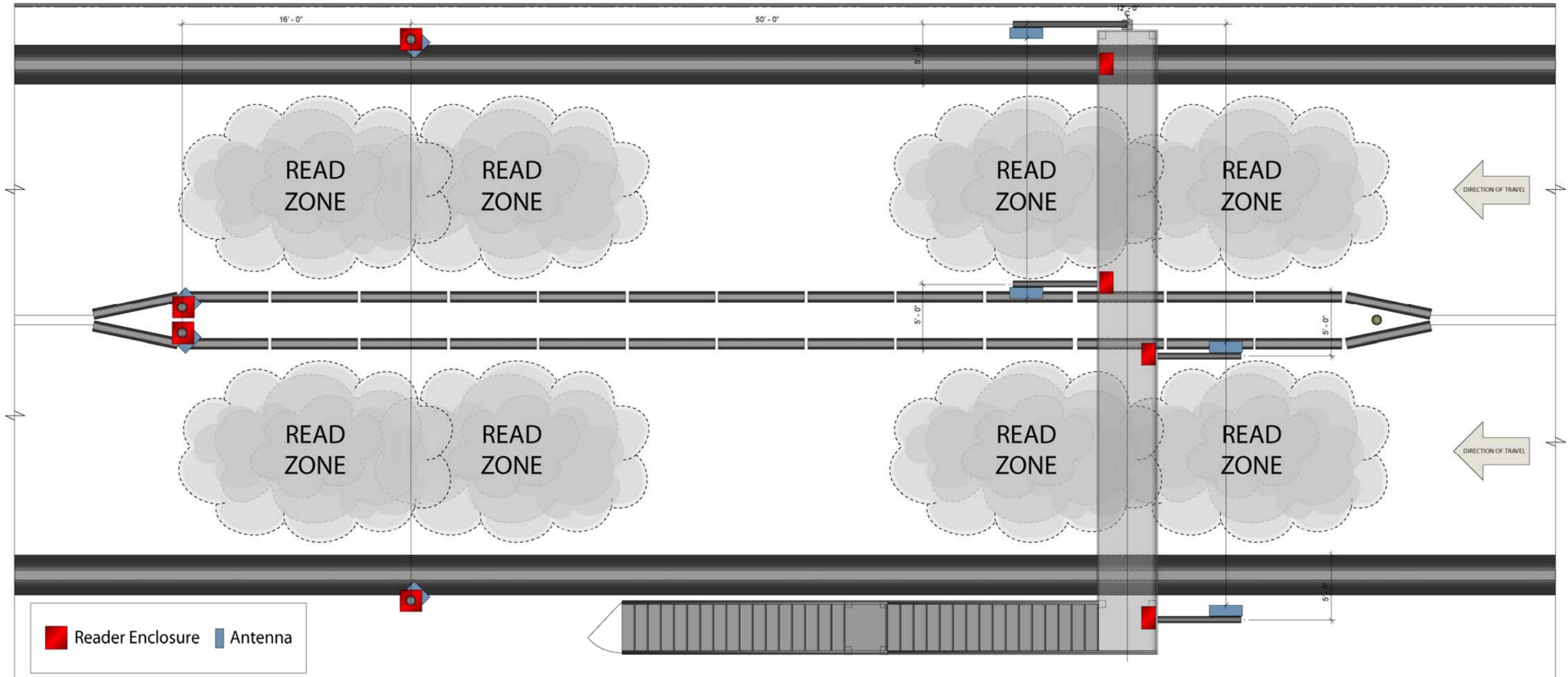


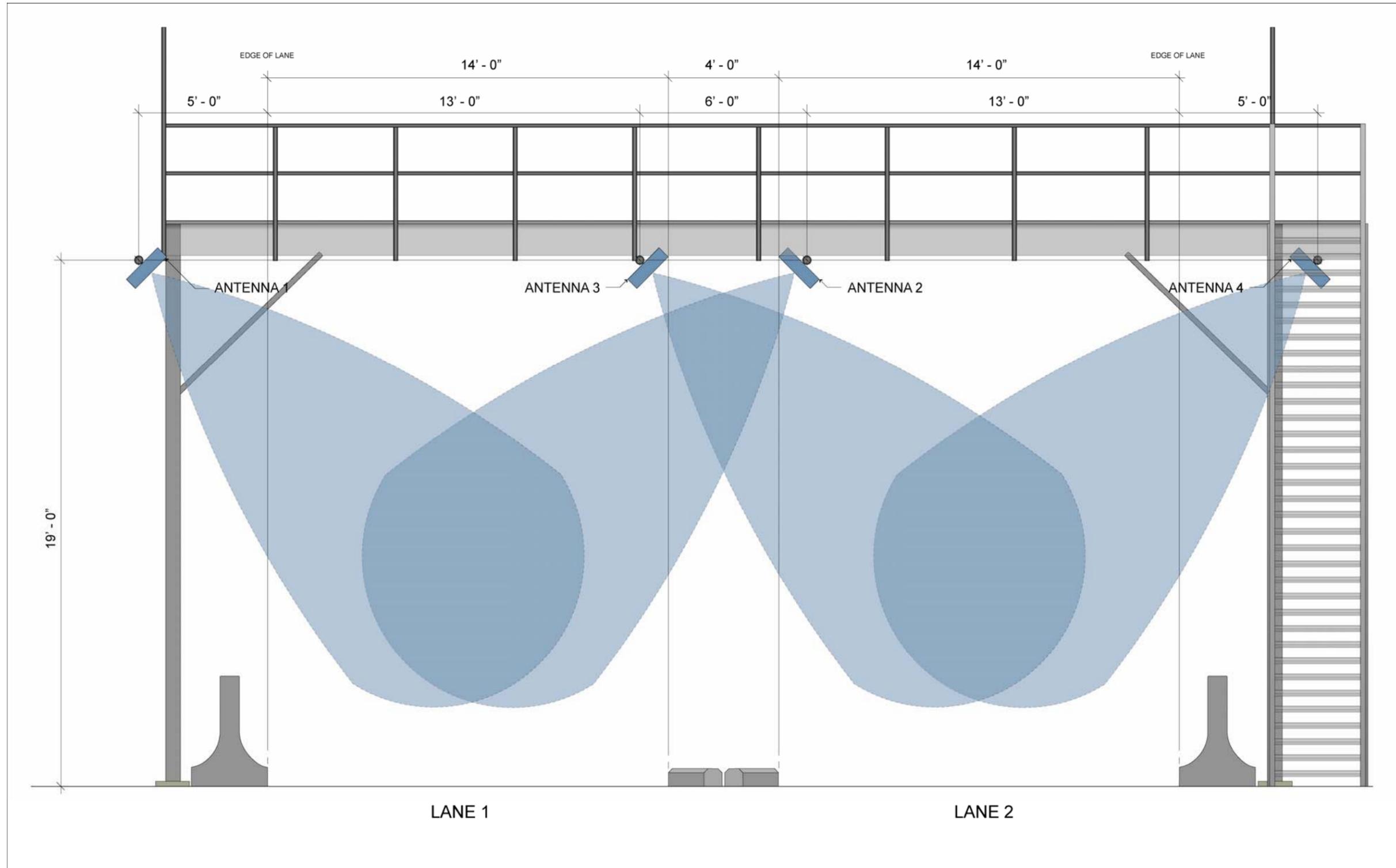
Figure 3-44 (b)(4); (b)(5) **Reader and** (b)(4); (b)(5) **Antenna**



Figure 3-45 (b)(4); (b)(5) **Reader and** (b)(4); (b)(5) **Antenna**

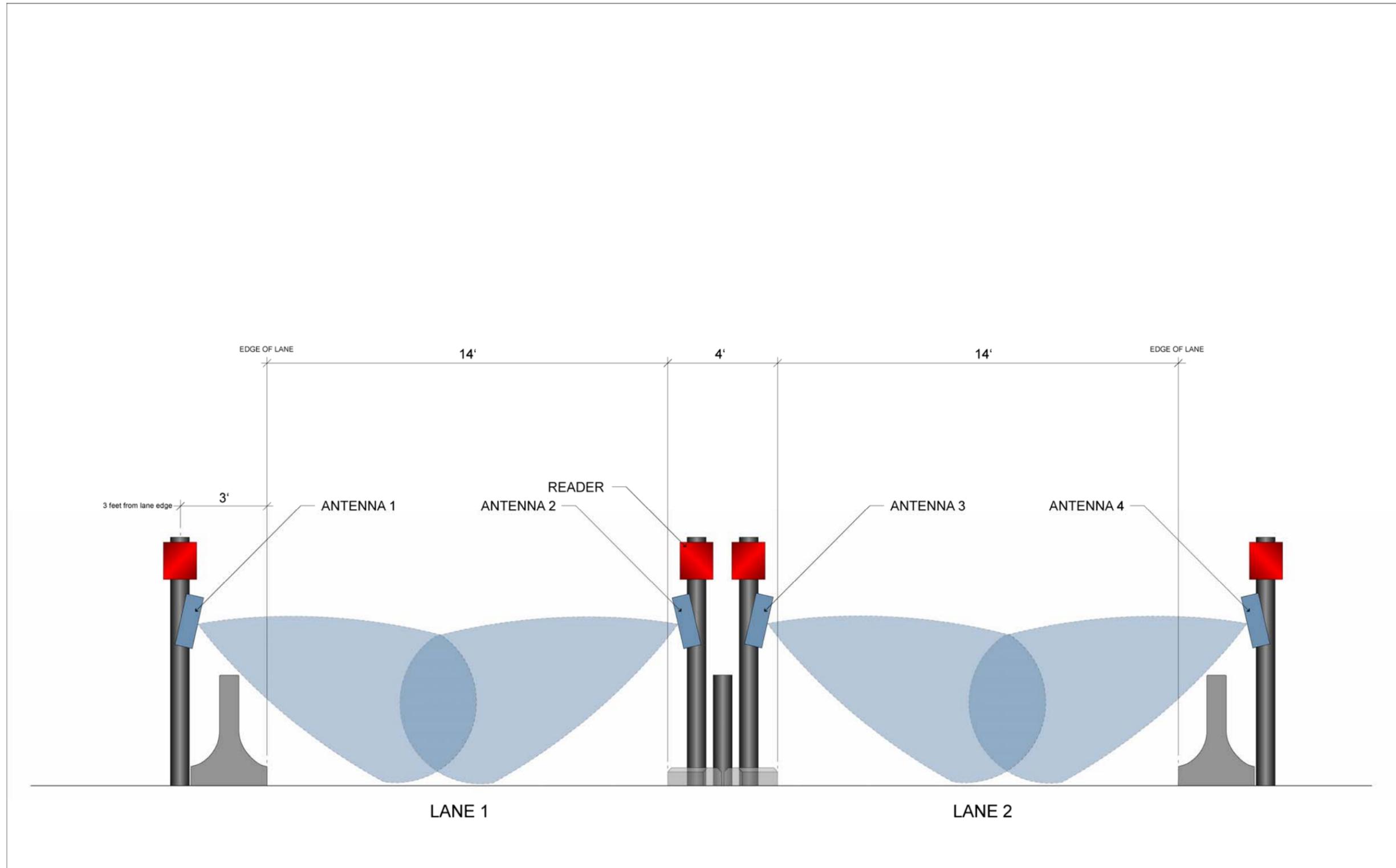


(b)(4), (b)(5)



(b)(4), (b)(5)

cting Overhead Antenna Configurations



(b)(4), (b)(5)

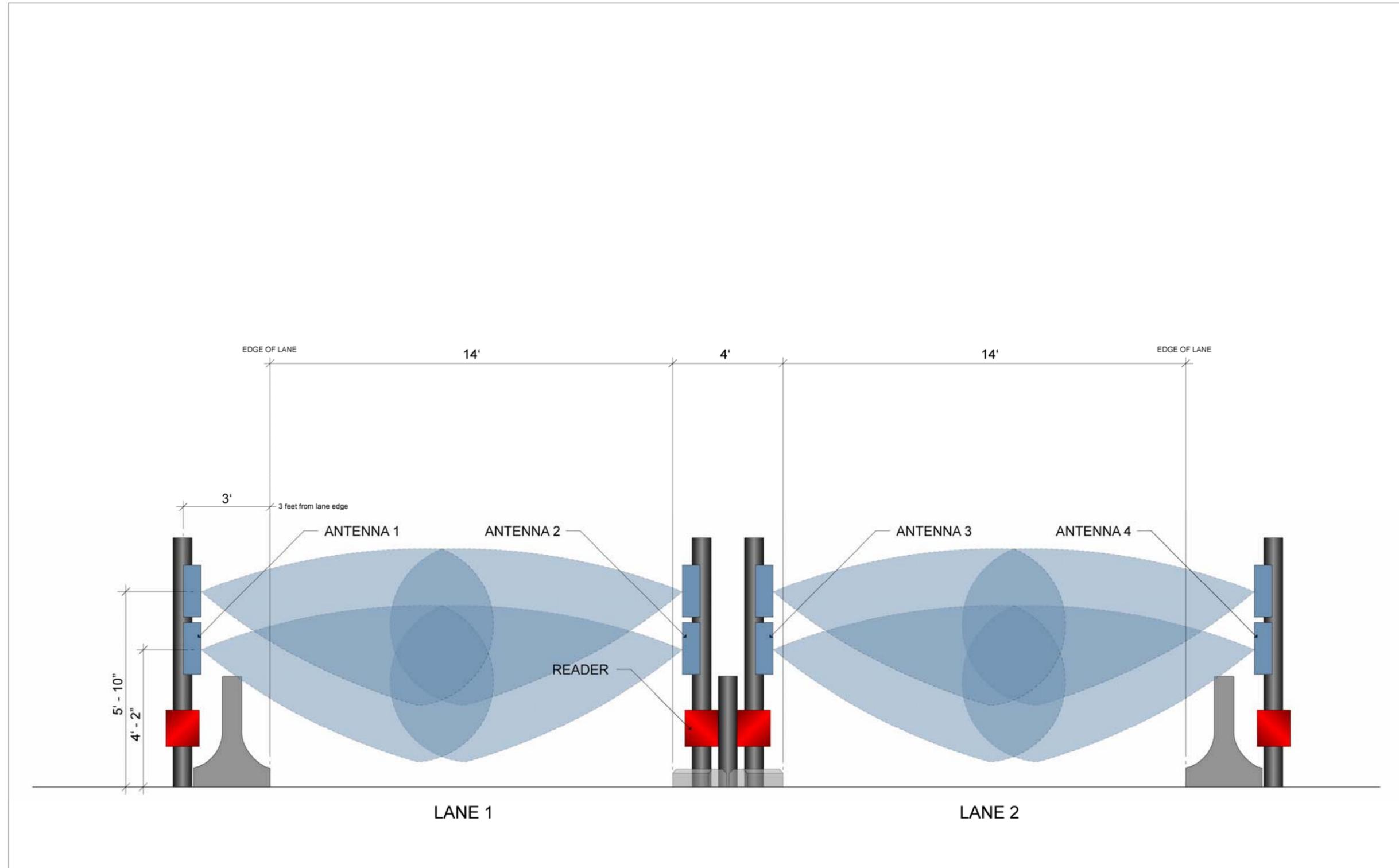


Figure 3-49 | Elevation View Depicting Side Viewing Antenna Configurations

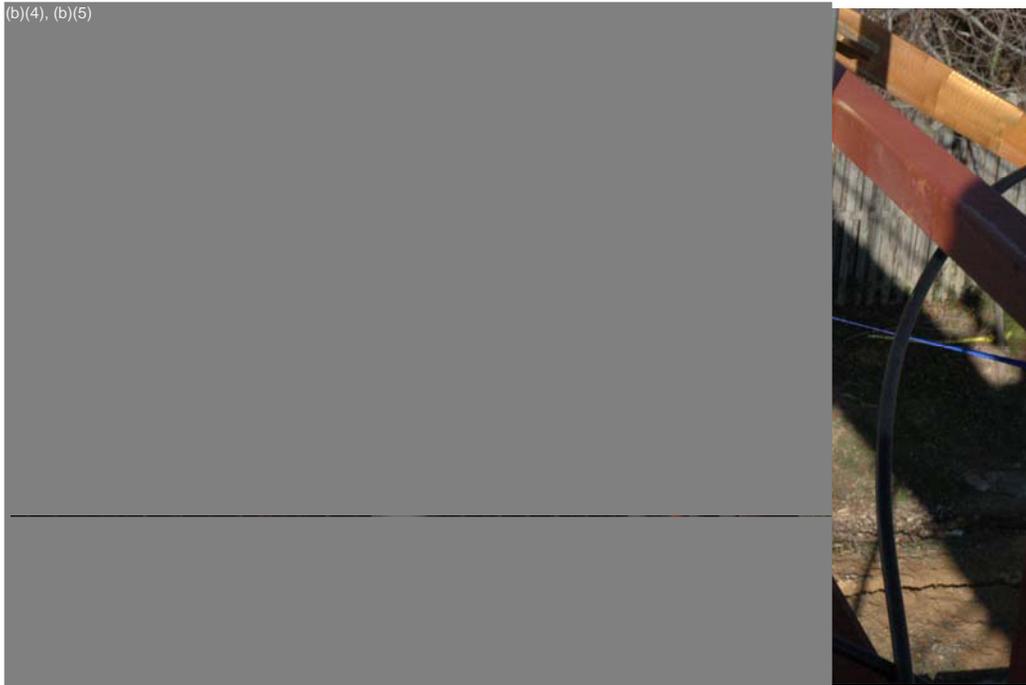


Figure 3-50 (b)(4); (b)(5) Reader

3.5 RFID TEST CONTROL, DATA CAPTURE AND PROCESSING SYSTEM

SBA provided computers, networks and associated software to control the test equipment, aid the execution of the test procedures, and collect and store the data from the readers. The software that was developed was not intended for operational use but to support testing activities. The software was also developed to minimize any potential human errors into the data. The data was collected and retained using a database management system. After the tests concluded, queries were used to extract data into spreadsheet format for offline analysis and display.

The following are the high level requirements defining the development of this system.

1. The test director and data collection (TDDC) system was to include a suitable data structure for storing (a) test configuration data and, (b) test data
2. The TDDC included capabilities for the initial loading of the database with test configuration data of the pre-defined test runs
3. The TDDC provided capabilities for enrolling tags to be used in the tests. Separate vendor specific RFID enrollment stations were procured to enroll the tags. The TDDC interfaced with the RFID vendor software to read the tags. The TDDC provided a GUI interface to initiate reading of the tags, captured the tag data from the tag enrollment reader and saved the data in the database.
4. The TDDC provided capabilities for browsing and editing the test configuration data in the database. The test configuration data included the vehicles used in the test, tags present in each vehicle used in the test, travel lane of the vehicle, and other test parameters.



5. The TDDC provided capabilities for collecting data from the RFID readers and saving them to the database for later analysis. The TDDC interfaced with the RFID vendor software to, (a) start and stop data collection by the readers (b) capture the data from the readers and save the data to the database for later analysis.

One laptop computer running Microsoft Windows XP was provided to host the TDDC. One was required to perform the test. The others were used as backup, for development and development testing. These systems included Microsoft SQL Server for data management purposes. Applications were written in Java, C# and .NET to interface with the RFID readers and receive the data. The data was then stored to the database for later retrieval and processing. Figure 3-51 presents the data model for the data that was captured.

SBA analyzed the data resulting from the tests to produce the results contained in Section 4.

3.6 RFID TEST PROCEDURE DESCRIPTION

This section provides a high level description of the procedures used during testing. The detailed procedures used are included in Attachment F.

Plans were made for the tests including the test scope and resources required. Schedules were prepared that defined the test period in detail. Discussions were held with the vendors selected for evaluation to inform them of the plans and collect their comments. Plans for the test site were made, including designs for the gantry structure and tag detection area. All equipment required for the test including test site elements, RFID system equipment, and instrumentation required for the test were procured or developed, installed and tested.

A period of approximately ten working days was required for the evaluation of each vendor's equipment on-site - approximately five days were required for the installation and check, and five days for testing. Installation included the mechanical, electrical and software interface integration. During the checkout period, after establishing the correct integration of components, preliminary tests were run to verify correct operation of systems and procedures but no formal test data was acquired. Vendor personnel were on-site and given the opportunity to recommend adjustments in equipment placement and operating procedures within confines of the test plan and schedule.

Before all tests, an RF power spectrum was collected to document the ambient RF radiation in the vicinity of the tests. A copy of the spectral analysis was given to the vendors prior to running the tests.

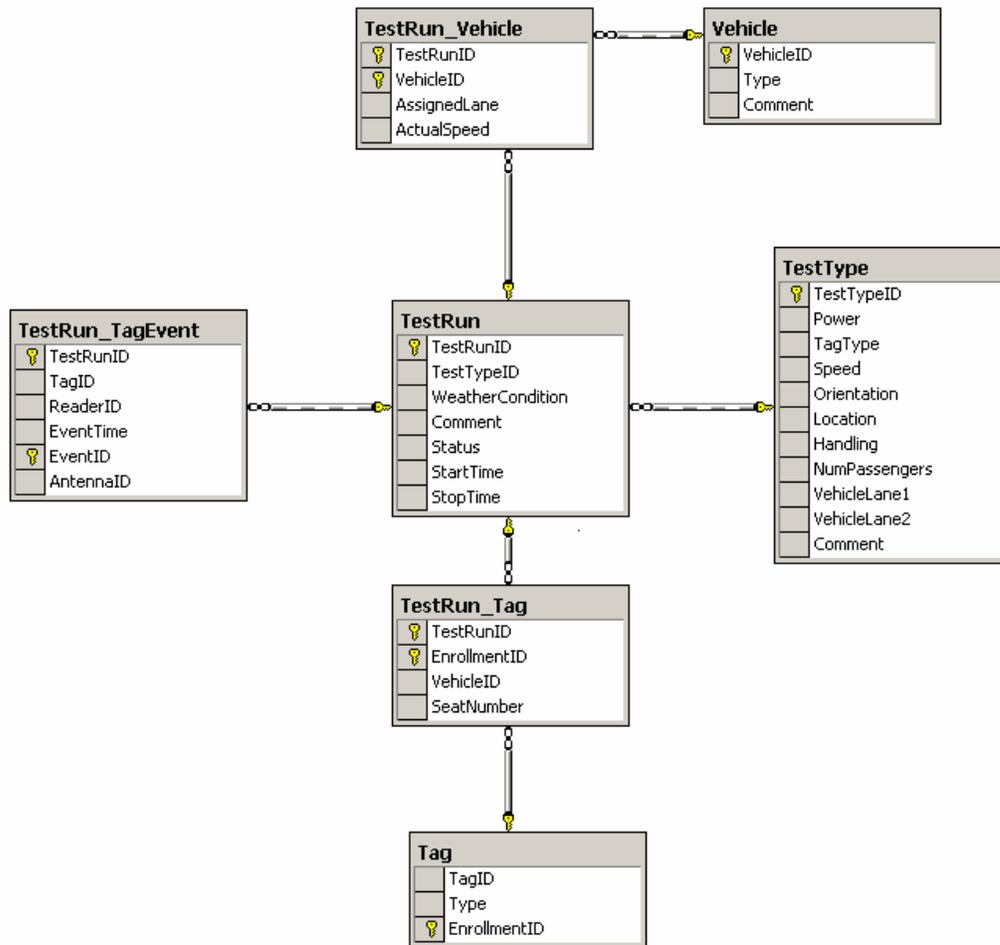


Figure 3-51 Test Director and Data Collection Data Model

Tests were run over the course of five 12-hour working days. A sixth day of testing was reserved in the schedule for problem solving or additional, low priority tests. However, this additional test time was not required for either vendor. The plan specified that 120 test runs were to be made each day for a total of approximately 600 tests, with fewer test runs conducted per day when a bus test was involved. The number of test runs conducted was consistent with the plan. As noted above, a core set of tests were planned and conducted by each vendor. Additional testing time was planned and used to conduct informational tests after core tests were complete. Although work was planned to continue during bad weather, halting tests only if the Raytheon plant closed, no delays in testing resulted from such conditions.

At the beginning of each test day, the test equipment was inspected, powered on, and checked out. The test director reviewed the sequence of tests to be conducted for that day with the test personnel (drivers, passengers, TDDC operators). The test site and other test related equipment was inspected.



For each individual test, the test director announced the test ID number and reviewed the key features of the test. When all personnel confirmed that everything was ready for the run, the test director started the test run by changing an indicator light from red to green.

The driver(s) proceeded down the track, reached the intended speed, as indicated by the speed detection device displays, and held that speed while in the tag detection area. When two vehicles were used in testing, both vehicles were required to enter the tag detection area at approximately the same time or the run was invalidated and repeated.

At the point at which the first car tripped the vehicle sensor, data collection began. Each tag read reported by all reader devices was recorded by the TDDC system. This and other information was used to compute the performance statistics described in Section 4.

After the vehicles exited the tag detection area, the vehicles slowed and exited the track area, drove down the return lane to the track staging area to either repeat the same test conditions or to be configured with new evaluation conditions for the next test. In general, five repetitions of a given set of evaluation conditions were run to better define the associated system performance.

Periodically during the day and at the end of the day, all data collected for the day were copied to backup storage.

Data resulting from the tests are presented in Attachment J.



4.0 RFID FEASIBILITY STUDY TEST RESULTS

This section provides results and observations for the series of tests run for (b)(4), (b)(5) and (b)(4), (b)(5) RFID systems. For purposes of this document, the main metric used to compare the systems is read score. This is a value indicating whether a tag has been read or not. Effectively, this measures whether a tag is seen - at all - across all read attempts. An average read score was calculated in the tests conducted. Read Score is defined as the number of tags read divided by the total number of tags in the test. For example, if a test run had 50 tags, and 36 were read, the average read score for that run was 72% ($36/50=0.72$).

Note that in the majority of tests, a minimum of 10 tags were presented for each of five repetitions of the same test (two vehicles, each with five tags). Thus, the sample population used in calculating the statistics presented here is 50. In addition, for twelve of the test configurations used to determine the read score verses speed dependency for the high power systems, 10 repetitions were run. Therefore, the test population for these tests contained 100 samples.

Refer to Attachment I for a more detailed discussion on the data analysis methodology used during this analysis.

4.1 POWER LEVELS

A side fire high power system yielded significant performance gains compared to a side fire low power system. For both (b)(4), (b)(5) and (b)(4), (b)(5), a relative improvement of 50% was observed in the tests (from 61% to 93% and 45% to 70%, respectively). The absolute difference between the high power and low power read scores for (b)(4), (b)(5) was $33\% \pm 4\%$, and the absolute difference for (b)(4), (b)(5) was $25\% \pm 4\%$.

4.2 TRAVELER PARTICIPATION

The need for active traveler participation and the level of such participation was investigated through the measurement of three operational parameters: alternative locations for RFID tags within a vehicle if not held by the traveler, orientation of the RFID tag when presented by a traveler, and the manner in which the traveler held the tag. These results are presented here for the high power overhead and side fire system configurations for both vendors' offerings. As discussed earlier, because of the relatively low performance provided by either vendor, low power results are not included here.

4.2.1 LOCATION

The potential for limiting or eliminating the active participation of a traveler while exiting the U.S. in a vehicle was examined by placing tags in various locations within the sedans used in the testing. Figure 4-1 summarizes these results for the high power systems for both vendors.

Experts from both vendors agree that antenna performance is significantly impaired by contact with the human body or when enclosed in a metal structure. To validate these assumptions, one tag was placed in the driver's shirt pocket in each vehicle as part of the Passive Use testing. During testing, these assumptions proved to be true. As evident in Figure 4-1, the tag located in a shirt pocket was read under 27 % of the time by the



(b)(4); (b)(5) side fire system. The successful reads may have been due to the placement of the tags outside the driver's jacket as shown in Figure 3-34. This was not according to the test procedures. The (b)(4); (b)(5) overhead and (b)(4); (b)(5) system tests followed the correct procedure where the tag was placed inside a shirt pocket. Those tests failed to read a tag in a driver's pocket.

Therefore, some level of active participation by the traveler may be required. To reduce the level of participation, a number of other locations for placing unattended tags were tested. Locations included placing tags on empty car seats, the padded dashboard, the deck below the rear window, and hanging from various locations on the windshield and back windows. These latter locations proved to be viable candidates in almost all cases.

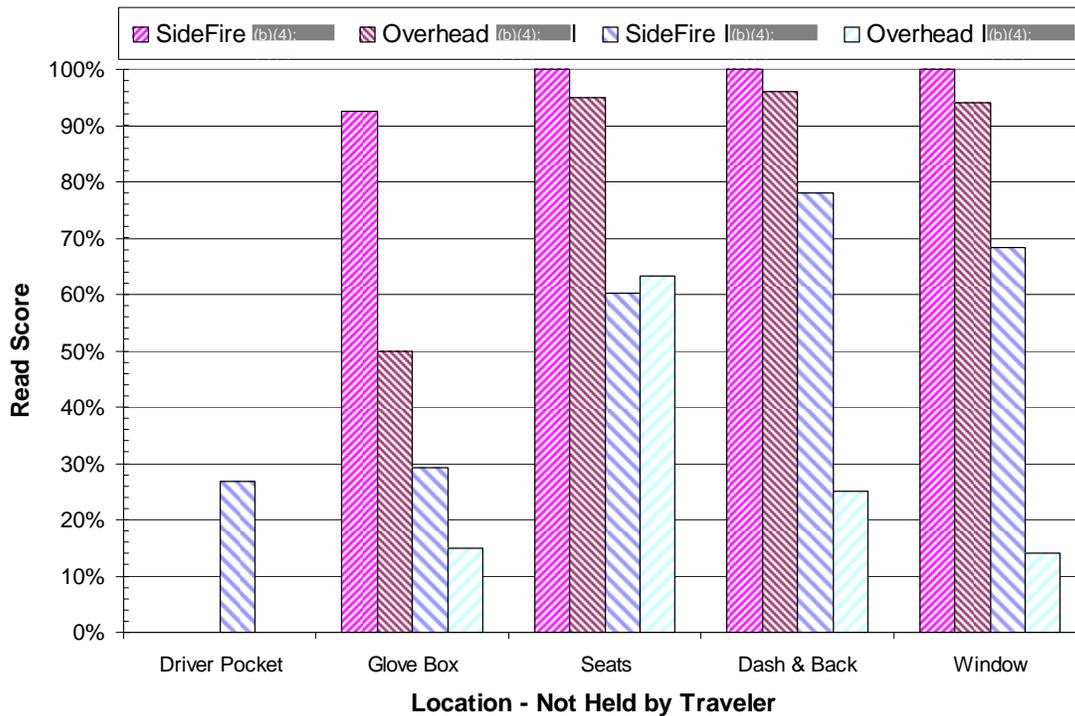


Figure 4-1 Read Score for Various Locations for High Power Systems



4.2.2 ORIENTATION

The performance of an RFID tag can be dependent on its orientation relative to its surroundings, and the antenna(s) used to read it. To minimize the level of active participation required of the traveler, while still achieving a high rate of tag reads, the tag and reader system must be substantially insensitive to tag orientation. The effect of presenting the tags in each of four specific orientations was evaluated to help quantify each vendor's offering in this regard. The results of this evaluation are summarized in Figure 4-2.

One of the most significant conclusion drawn from the orientation data is that Symbol offerings, both overhead and side fire systems, are substantially unaffected by the orientation of the tag. The total variation between the tested orientations is barely five percentage points for the (b)(4); (b)(5) side fire system and rises only to a 20 % variation for the overhead system. The read score for the (b)(4); (b)(5) overhead system is significant, ranging from a high of 50% for tags oriented toward the side of the vehicle, to a low of just a few percent for tag is orientated toward the front of the vehicle. The (b)(4); (b)(5) overhead system clearly suffers from a sensitivity to tag orientation. The (b)(4); (b)(5) side fire system exhibits a wide variation of 55 % from best to worst case situations (side to rotated 90 degrees).

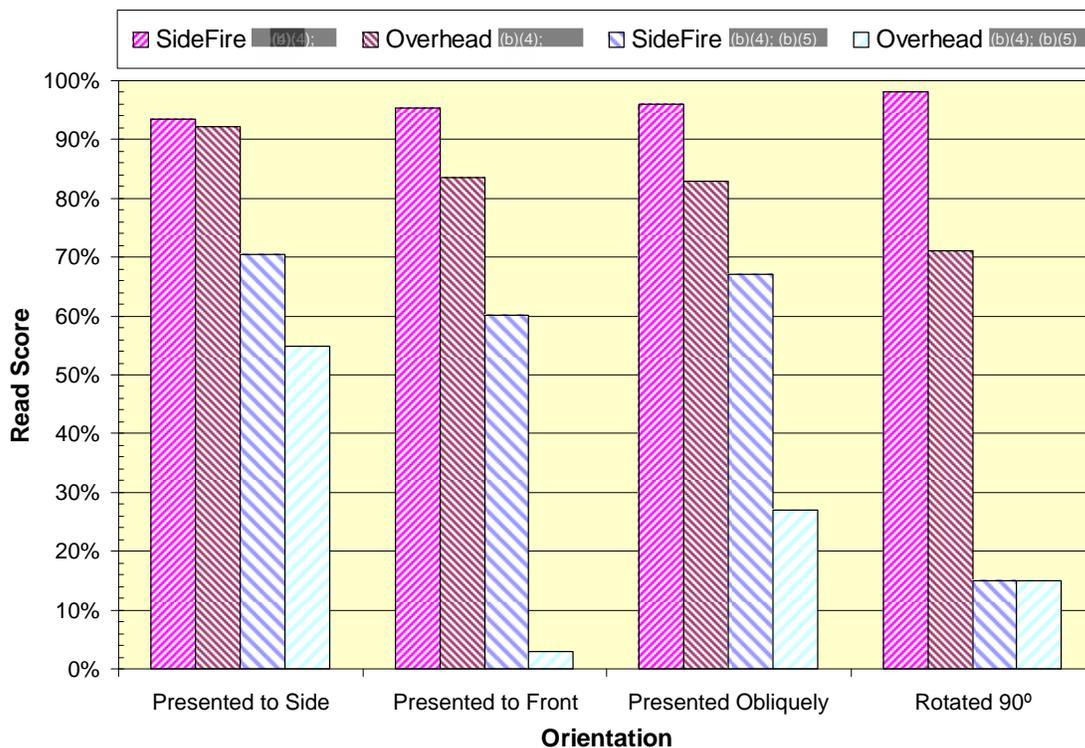


Figure 4-2 Read Scores for Four Orientations at High Power



4.2.3 HANDLING

As noted earlier, when a RFID tag contacts the human body, it decreases its performance. Because Increment 2C will require travelers to hold RFID tags when they enter or exit the country as a pedestrian, it is natural the travelers will have to learn to present their RFID tags while holding them. Thus, testing that had a traveler hold an RFID tag was performed. Generally, tags intended for this purpose are designed to tolerate, or even benefit slightly from certain particular handling techniques, as noted in Figures 3-26, 3-27, 3-30, and 3-31. One particular attempt to evaluate the impact of handling the tags in a manner not proscribed by its manufacturer was to have the participants holding tags place their finger and thumb overlapping a significant portion of the center of each tag type tested during an otherwise appropriate presentation of the tag. This gave the result provided below in Figure 4-3.

While noting no noticeable degradation of the tag performance due to this behavior for the tags provided by (b)(4); (b)(5) and read with their test systems, the performance for the (b)(4); (b)(5) tags degraded to an unacceptably low level.

The performance of the (b)(4); (b)(5) systems and tags was unexpected. It appears the (b)(4); (b)(5) tag was designed to be held. Although not demonstrated, discussions with the (b)(4); (b)(5) experts confirmed the suspicion that it is possible to position the fingers on the tag in a way that will seriously degrade their performance.

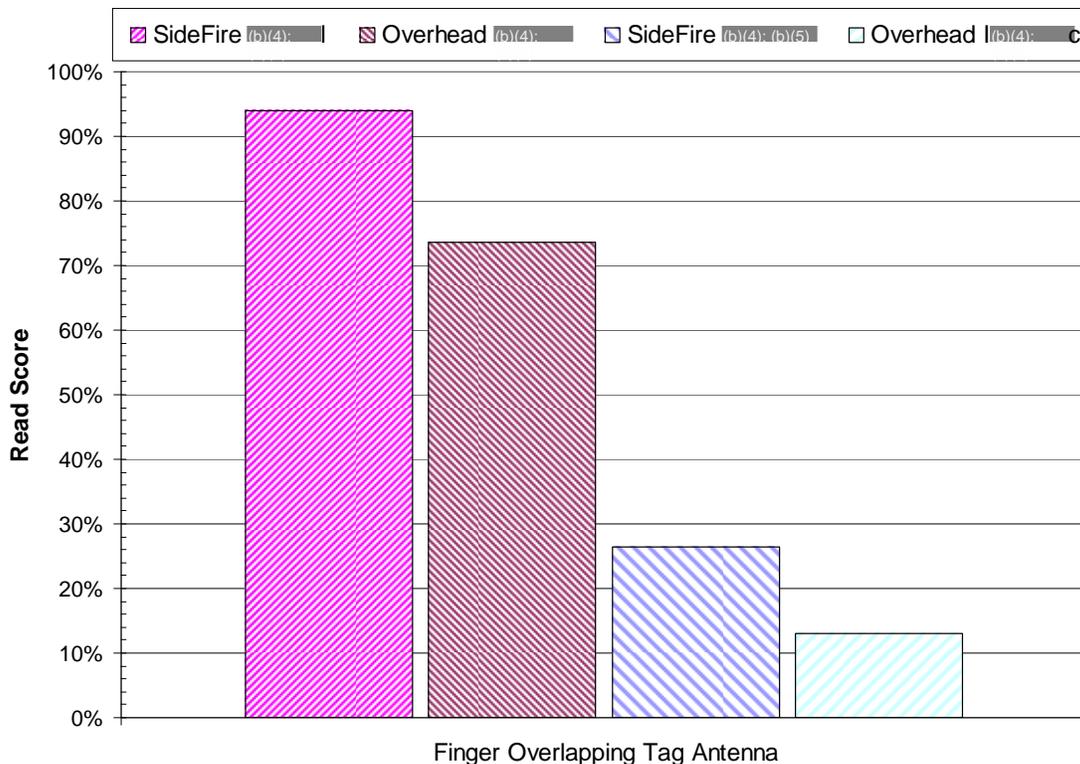


Figure 4-3 Read Score for Finger Overlap Handling



4.3 ANTENNA CONFIGURATION

Comparing the (b)(4); (b)(5) high power side fire and overhead configurations, Figure 4-4 shows the performance of side fire to be superior to that of overhead. This was true for both (b)(4); (b)(5) and (b)(4); (b)(5) systems. Statistical testing of the performance difference for the (b)(4); (b)(5) systems indicates that the side fire's performance exceeds that of the overhead by anywhere from four to nine percent (see Figure 4-4).

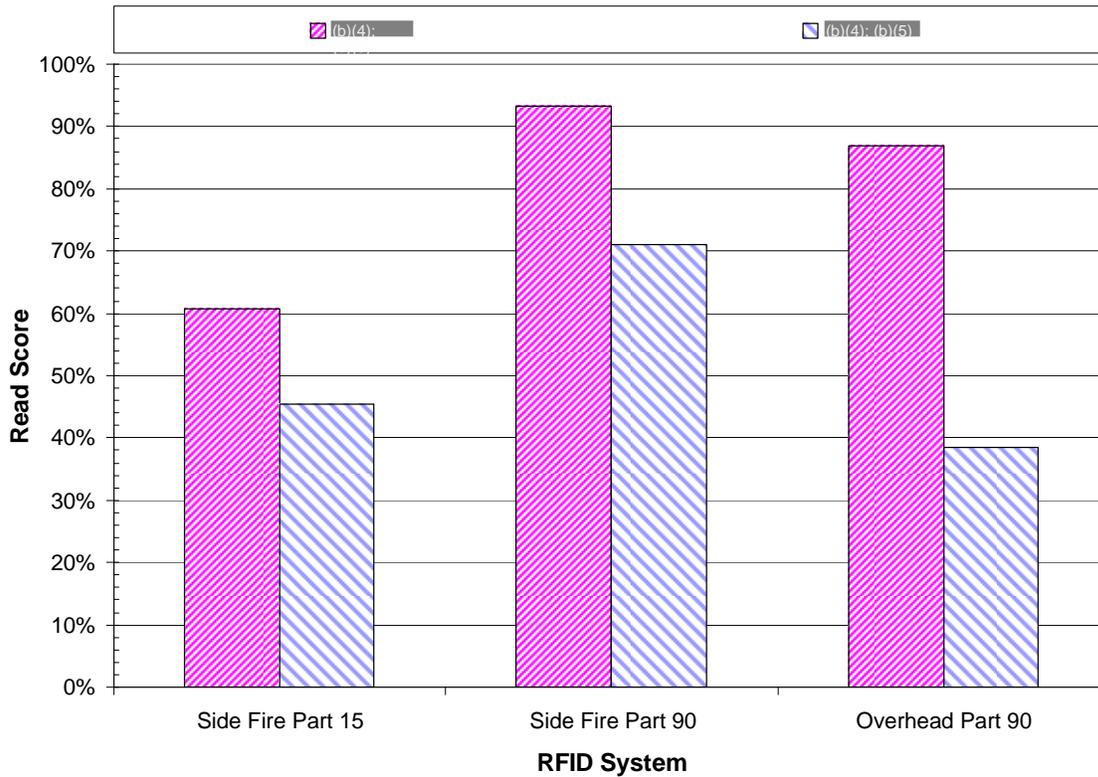


Figure 4-4 Read Score versus Antenna Configuration



4.4 VEHICLE SPEED

Unexpectedly, there was not as great a drop off in performance of the RFID systems when compared to speed. Figure 4-5 shows the read scores plotted against speed for side fire high power, with trend lines plotted as well.

Figure 4-5 shows that for the (b)(4); (b)(5) side fire high power, we should expect to see some performance degradation as speeds increase. Further testing would need to be conducted to determine if any reduction of speed is needed at a POE in real-world situations.

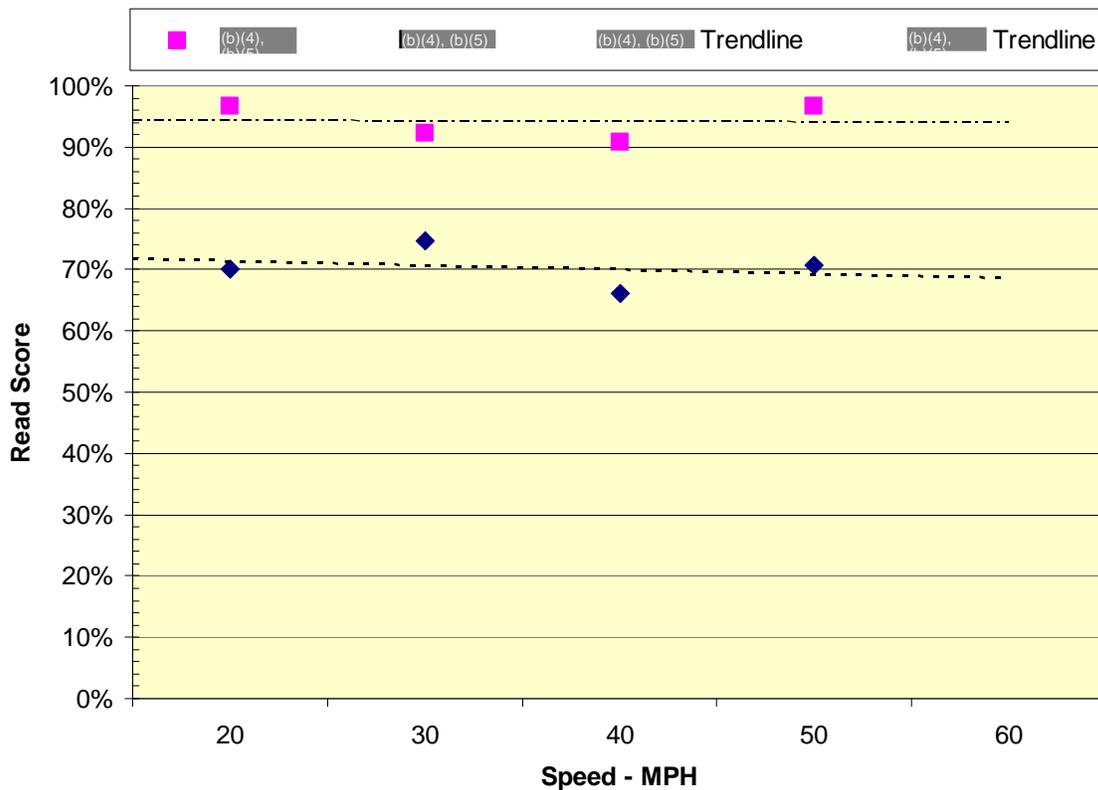


Figure 4-5 Read Score versus Speed



4.5 TAG TYPE

Figure 4-6 shows the relationship between read score and the tag type. The data from Figure 4-6 indicates that there is not a substantial difference in performance attributable to the tag type for (b)(4); (b)(5) cards showed a minor performance improvement relative to their label (for most speeds), while the I (b)(4); (b)(5) cards outperformed their labels by a greater margin.

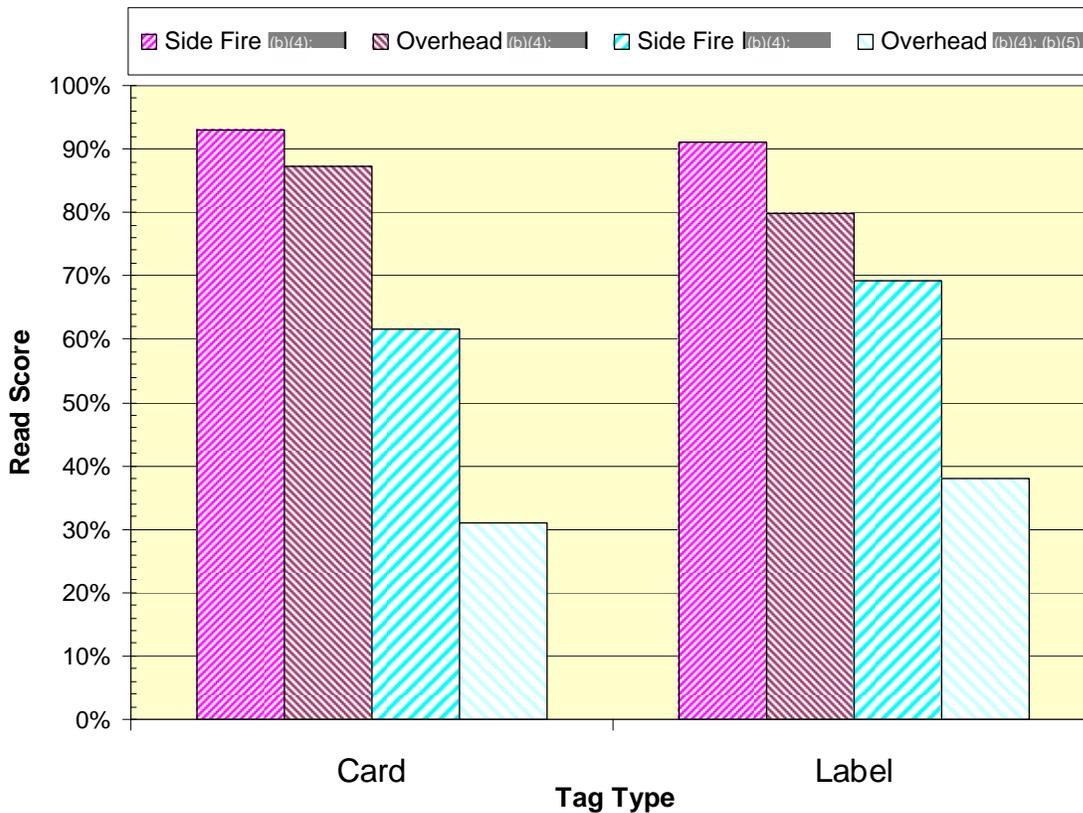


Figure 4-6 Read score versus Tag Type



4.6 VEHICLE TYPE

In this comparison, (b)(4); (b)(5) performed better relative to (b)(4); (b)(5). The pattern of side fire surpassing overhead was reversed in the instance of trucks and buses (see Figure 4-7), with the possible explanation that the overhead antennas were better positioned to read tags in these much taller vehicles.



Figure 4-7 Read Score versus Vehicle Type

4.7 TINTED WINDOWS

Previous experiences with vehicles that have after-market tinted windows have shown that it can seriously affect the reading of RFID tags. Therefore, a specially equipped vehicle was employed to test the effect of tinted window vehicles. This Raytheon supplied vehicle had all windows treated with a Mylar film tinting product. Mylar was shown to degrade the RF signal significantly - the Mylar film was tested by wrapping a tag within it.

Tests were then conducted with the windows closed tight and again with the four side windows ajar about an inch apiece. A second, untreated vehicle was run adjacent to the vehicle with tinted windows to better simulate the effects of operating in traffic.



As expected, the window tinting did present a serious impediment to reading tags within the closed vehicle. Neither vendor's overhead system was able to read tags in the vehicle with tinted windows, regardless whether the windows were closed or ajar. The (b)(4); (b)(5) side fire system was able to read tags within the car with tinted windows only four out of 50 attempts with the windows closed, and seven times out of 50 with the windows slightly ajar. The (b)(4); (b)(5) side fire system was somewhat more successful having a read score of 56% equally with the windows closed and with the windows ajar.

4.8 NUMBER OF TRAVELERS PER VEHICLE

Tag Density is a way of referring to the number of travelers in a vehicle. Higher densities are generally buses or mini-vans. Refer to Figure 4-8 for a chart relating system performance to tag density. As indicated by the chart, there is a familiar performance drop-off for side fire to overhead, and from (b)(4); (b)(5) to (b)(4); (b)(5). Data was not available for speeds of 30 MPH for five tags (a single sedan of travelers), but the performance remains relatively flat across the speeds and tag densities, at least for (b)(4); (b)(5).

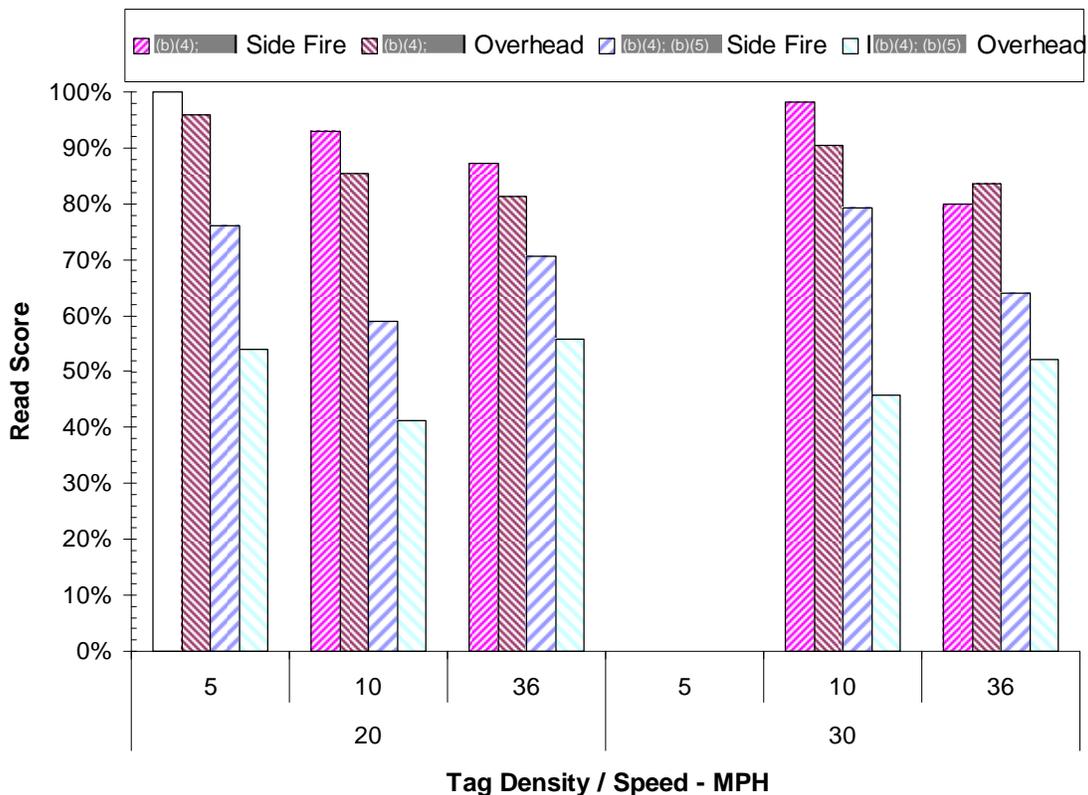


Figure 4-8 Read Score versus Tag Density

4.9 ADDITIONAL OBSERVATIONS

Many observations were made of a qualitative nature during the evaluation. These observations included the results of vendor-specific tests, potential interference between



antennas, and other vendor qualification comments. These points are collected and expanded here.

4.9.1 ALTERNATIVE TEST CONFIGURATIONS

Each vendor provided was allowed to perform a set number of test configurations that were not part of the core set of test configurations used to evaluate each vendor's performance. The alternative test configurations were tested near the end of each vendor's testing period.

The (b)(4); (b)(5) team chose to demonstrate the performance of (b)(4); (b)(5) that was said to offer higher performance in both read distance and read speed. (b)(4); (b)(5) It replaced the overhead, high power readers and added antennas. (b)(4); (b)(5)

Performance of this system was noticeably better than the system (b)(4); (b)(5) fielded as part of the main evaluation. For tags presented in the best performing orientation, horizontally, near the vehicle's side windows, the read score was about 98%. However, testing indicated that this system suffered identically in manner and extent to the fully evaluated overhead system. That is, when presented a tag in any of the other orientation other than held horizontally toward the vehicle's side window, its read performance degraded to near zero.

Additional runs for (b)(4); (b)(5) were conducted to test a theory that the overhead antennas were interfering with side fire antennas. To perform the test, the overhead system was turned off, and the side fire system antennas were redirected to optimize it as a stand-alone system. Two additional antenna pairs were added to the poles in the median strip. These changes better illuminated the lanes and acted to limit reflections from the sides of large vehicles (truck and bus) as there was evidence that they had desensitized the system's receivers. No experimental equipment was introduced during these tests. These modifications significantly improved the overall performance of the (b)(4); (b)(5) side fire, high power system. A more detailed description of the effects of interference is presented in the next section.

4.9.2 INTERFERENCE

During testing, it was discovered that the decision to perform both high power side fire and overhead reader and antenna systems at the same time in order to gather more data within the timeframe allotted for testing, may have introduced interference between the two systems. Such interference had the potential of degrading each system's performance.

The results of testing did show evidence of interference. However, its presence provided the unintended benefit of highlighting the potential for interference between different POE functions, such as between the entry and exit lanes. As a result, these tests partially quantified the performance loss that might be expected, and permitted the demonstration of some effective methods for mitigating such loss.



In particular, both vendors requested and were granted time to demonstrate the extent to which either systems' performance (side fire or overhead) was degraded by fielding the overhead and side fire systems within 50 feet of each other.

The testing performed for (b)(4); (b)(5) with the high power overhead system on, and the high power side fire system off, did not demonstrate any interference. That is, comparisons of sets of tests with both systems on and with the side fire system off showed no statistically significant difference in performance.

However, with the overhead system off, and the side fire system on, there was a difference. In addition to turning the overhead system off, the side fire antennas were rotated about 15 degrees toward the lanes. The results for five tags optimally presented at the side window in each of two sedans traveling at 50 MPH improved from a read score of $80\pm 0\%$ during initial testing to $97\pm 5\%$ for the tests with the side fire system only. Unfortunately, the extent of this interference was not fully appreciated, and due to time limitations, more extensive testing was not performed to fully map the effect on the overall results. All that can be said from the available data is that some degradation resulted from operating both the side fire system and the overhead system in proximity to each other.

The result of this test did demonstrate the best (b)(4); (b)(5) performance produced during testing; that is for side fire and well presented tags at the side window. However, this one result for (b)(4); (b)(5) does not imply that tag mishandling performance for their systems would improve significantly.

Two effects influenced the results of these added tests, the interference of RF emissions from the overhead system, and the effect of rotating the side fire antennas towards the test lanes. The rotation of the antennas probably contributed to the exhibited performance improvement as well as reducing the performance for tags oriented in the face front condition which had a read score of just 60% in the testing.

As with (b)(4); (b)(5) the adverse contribution of (b)(4); (b)(5) side fire operation on their overhead system's performance was not significant. However, the converse effect of the overhead system on the side fire's performance was measurable. These performance impacts were the result of both the RF emissions from the overhead systems and compromises made by (b)(4); (b)(5) engineers while configuring the system upon its installation. For this reason, a representative slice of the test matrix was revisited to quantify the performance improvement that could be achieved in a stand-alone environment.

The performance improvement in the stand-alone side fire, high power system was already mentioned above in the context of the testing with the sedan with specially tinted windows. In addition, testing with a tour bus was repeated. This resulted in a performance increase from about 81 ± 2 percent to about 97 ± 1.5 percent. The impact on other measurements was not as evident because of the high performance level exhibited in the initial round of testing for the system setup in a less than optimum configuration.

In addition to the improved results for buses, detection of tags within the tinted vehicle improved dramatically for (b)(4); (b)(5) equipment using this revised configuration,



reaching over 70 percent when the windows of the vehicle were closed, and rising to nearly 90 percent when the windows were set ajar by about one inch. This was a surprising and welcome result, demonstrating the viability of an RFID solution in capturing RFID tags in a vehicle with metal-tinted windows.

It should be noted that all of the results and comparisons for both vendors described outside of this section were for the initial test conditions, that is, with both high power systems in operation at the same time. The results provided here illustrate the potential for higher performance in a POE deployment, where it will not be necessary to operate two dissimilar systems in close proximity.

4.9.3 OBSERVATIONS OF VENDOR CAPABILITIES

It is noted here that the two vendors exhibited markedly different strengths in fulfilling their obligations under this effort. Both provided the SBA team what was needed to meet the demanding test requirements and schedule. However, each brought a different set of expertise and breadth of domain knowledge to the effort.

The (b)(4); (b)(5) team demonstrated a clearer understanding of the unique difficulties a transportation application represented and best applied their available equipment and techniques to field a high quality system in a short time and under trying conditions. However, the equipment provided exhibited a limited range of adaptability.

(b)(4); (b)(5) on the other hand, seemed to be somewhat unfamiliar with the demands of the transportation environment presented them. However, their technology and systems provided significantly more adaptability. Though it took more time and effort to configure their systems for testing because of their unfamiliarity, the end result performed nearly flawlessly, providing a high level of performance.



5.0 RECOMMENDATIONS

Based on the data outlined in section 4, a number of recommendations can be made.

Recommendation 1: (b)(4); (b)(5) equipment should be considered for use in Increment 2C.

Although a recommendation is made here, additional considerations need to be taken into account in determining which vendor's equipment to use for Increment 2C. For example, although the RF Feasibility Study addressed the overall technical performance of each vendor's equipment over a wide variety of test configurations, the study did not perform a cost-benefit analysis of one vendor's equipment versus another. (b)(4); (b)(5)

However, according to the test results, not using the (b)(4); (b)(5) equipment most likely will result in a decrease in the ability of the Increment 2C system to successfully capture the a-ID of traveler's exiting the U.S. in vehicles. The impact on operations of missing a potentially significant number of traveler exits would then need to be considered.

Two main factors drive to the recommendation that (b)(4); (b)(5) equipment be used

(b)(4); (b)(5) equipment had statistically significant better performance in reading tags across all test permutations. As shown in Section 4, (b)(4); (b)(5) equipment performed better than the (b)(4); (b)(5) team's equipment in every category. In nearly every case, the difference was statistically significant. Considering that the impact of missing tags as travelers traverse U.S. borders may impact traveler re-entry, status management, and enforcement, it is imperative that the system be capable of reading as close to 100% as possible.

(b)(4); (b)(5) tags were significantly affected by tag orientation. As illustrated in Section 4.2.2, (b)(4); (b)(5) tags were significantly affected by tag orientation. For example, Figure 4-3 shows that when the (b)(4); (b)(5) tag was oriented vertically (90 degrees to the floor), the read score was only 15%. Considering the difficulty that can be expected getting the traveler community to cooperate by properly displaying the RFID enabled document, the advantage offered by a tag that is readable over a wide range of orientations is significant. This applies not only to traveler's in vehicles, but also to pedestrian entry and exit where a traveler must hold the tag. When holding a tag, travelers and are more likely to orient the tag in various ways. The ability to hold or orient the tag in different ways without reducing read rates should also reduce the need for additional outreach that teaches travelers how to hold or position a tag in a particular manner.

Recommendation 2: Traveler action should be taken into consideration as part of the Increment 2C vehicle exit solution.

The amount of traveler action required to enable the successful read of their a-ID upon vehicle exit at land POEs in Increment 2C can vary from completely passive to overtly active. On one end of the spectrum, the traveler would be required to perform no action



whatsoever, carrying (for example) their RFID tag in their luggage in the trunk of the vehicle, without regard for any action on their part when exiting the U.S. On the other end of the spectrum, a traveler would be required to raise their tag, grasping the card in a specific manner, and holding it close to the window in a certain orientation. The following recommendations influence the amount of interaction the traveler should have to undergo in Increment 2C to obtain the best read rates for vehicle exit.

Recommendation 2a: RFID tags should be held up to the window, or placed securely on the dash, back shelf, seat, or window

These five options yielded the best results, and there was no statistically significant difference between them. As shown in Figures 4-2 and 4-3, (b)(4); (b)(5) tags, when held by the traveler, or placed on the window, dash, back deck, or seat, yielded read scores in the high nineties to 100% using side fire, high power readers.

Recommendation 2b: RFID tags should be placed away from the traveler's body

The results of placing an RFID tag in a breast pocket was nearly zero percent, as shown in Figure 4-2. This result was anticipated. Based on the results of the (b)(4); (b)(5) Study, RFID vendor, and RF engineering experience, significant amounts of water can absorb RF energy. Therefore, any tag held very close to the body effectively negates the ability to read the RFID tag. This will have implications on the ability for a traveler to simply carry their RFID tag in a pant or shirt pocket, or wallet. Note however, that any space between the RFID tag and the body (e.g., as in a loose-hanging coat) should improve the read rate.

Recommendation 2c: RFID tags should not overlap other tags

Based on results from the (b)(4); (b)(5) Study, and on RFID vendor and RF engineering experience, overlapping RFID tags decreases the ability for those tags to be read. RFID tags are tuned to respond to a specific frequent range, so that when tags are in close proximity, they detune each other. This behavior seriously degrades the ability to read any of the tags. As shown in Attachment C, when holding multiple passports (two or four) at the same time, the ability to read the tags, depending on the vendor, dropped from 30 to zero percent. Note however that only low power readers were used in that test.

Recommendation 3: Where possible, antennas for vehicle exit should be configured in the 'side fire' position

As shown in multiple figures in Section 4, there was slightly better performance using side fire antennas versus overhead antennas. For example, the (b)(4); (b)(5) results displayed in Figure 4-4 show that for a variety of test configurations, side fire antenna read scores at high power were four to nine percent better than overhead antenna read scores.

Overhead antennas are a viable option, but should only be used where facility constraints preclude the use of side fire systems, and then only if the operational impacts of dealing with missed traveler exits are acceptable.

Recommendation 4: Readers for vehicle exit should be operated at high power levels.



As shown in multiple figures in Section 4, in all test configurations where low power versus high power was compared, the high power system showed a significantly better read score percentage than the low power system. The results of this testing, as compared to the (b)(4); (b)(5) study which only used low power readers, showed a significant improvement in the ability to read tags above 35 MPH.

Recommendation 5: Additional testing should be conducted to further improve system performance before Increment 2C POC implementation.

It was evident that additional refinements, which were not possible during the RF Feasibility Study, could further improve performance. Because the construction of islands between exit lanes may not be feasible within the Increment 2C timeframe, additional testing should be conducted on the use of different overhead antenna configurations, and the use of side fire antennas with center lane antennas turned off. It is less clear that acceptable performance can be attained using side fire antennas without antennas installed between vehicle exit lanes. However, given the relatively good performance of overhead antenna configurations, additional testing should be conducted to see if overhead antenna performance could be improved.



6.0 IMPACT OF RECOMMENDATIONS

The impacts of the recommendations listed in Section 5 on the Increment 2C solution varies by office within US-VISIT program. Although not exhaustive, the following items point out areas that will require additional attention in constructing the complete Increment 2C solution.

Facilities Management – Because the RF Feasibility Study recommends side fire antennas, Facilities Management needs to address the construction of new islands between vehicle exit lanes, if applicable and possible within the Increment 2C timeframe. Facilities Management will need to consider the environmental impact, if any, on potential vehicle exit speed caused by the addition of islands. Facilities will also need to determine if existing poles and conduit can support side fire antennas, or if new poles need to be installed.

Mission Operations Management – Besides the operations impact of the addition of RFID equipment at the Increment 2C POC POEs, Mission Operations Management needs to consider the impact of (potential) vehicle exit speed reductions caused by the introduction of islands between vehicle exit lanes. If, due to limited timeframe, islands cannot be constructed between vehicle exit lanes, and an overhead antenna configuration is chosen, Mission Operations will need to determine the anticipated additional loss of traveler a-ID capture at exit, and subsequent impact of that traveler's re-entry into the U.S. on entry operations. For example, if a policy is adopted to question a traveler who is performing a re-entry without an exit, there will be an impact on entry operations for every traveler whose a-ID was missed at exit.

Outreach Management – Outreach Management will need to develop a comprehensive plan for the public outreach concerning the deployment of the new RFID technology. The success of the use of RFID enabled document to assist in traveler management is dependent upon the traveler presenting the RFID enabled document. Outreach Management will need to include outreach that informs travelers of the nature and use of RFID technology at the borders including the way in which the tags need to be placed or held within a vehicle when exiting the U.S.

Chief Strategist – The Chief Strategists Office will need to remain cognizant of the results of this study, specifically the need for some traveler interaction, and the RFID infrastructure and RFID tags (essentially documents) being introduced, and their ramifications on future increments.