SmartPark Technology Demonstration Project

U.S. Department of Transportation
Federal Motor Carrier Safety Administration

October 2013

FOREWORD

Trucker fatigue has become one of the leading causes of truck incidents on the roadway, an issue demanding the attention of regulatory agencies such as the Federal Motor Carrier Safety Administration (FMCSA). Commercial motor vehicle (CMV) drivers become fatigued when they do not comply with hours-of-service (HOS) regulations and they drive for too many consecutive hours without resting. According to recent studies submitted to Congress, one of the most significant causes of noncompliance with driving regulations is the lack of awareness of available truck parking. The SmartPark initiative, led by FMCSA, was designed to match demand for truck parking with availability. This report summarizes Phase I of that initiative, which included the demonstration of truck parking detector technologies that could be integrated into a real-time truck parking information system for use by truckers seeking out parking space availability.

This report will be of interest to both privately and publicly-operated rest areas as a potential technology to implement at their rest areas or parking facilities. The results document the performance of the detector technology at a test site on northbound I-75 in Athens, TN.

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16. Abstract

The purpose of FMCSA's SmartPark initiative is to determine the feasibility of a technology for providing truck parking space availability in real time to truckers on the road. SmartPark consists of two phases. Phase I was a field operational test (FOT) to determine the accuracy and reliability of a technology for counting truck parking space availability. Phase II focuses on disseminating truck parking availability information and determining whether the technology can be deployed to divert trucks from a filled to an unfilled parking area. This document is the final report for Phase I. In Phase I, three combinations of different technologies were subjected to field testing to ascertain their feasibility for determining truck parking space availability in real time: side (SID) scanners, overhead (OH) scanners, and light curtains (CURs), each combined with Doppler radar.

The most optimal configuration of technologies is a SID scanner combined with Doppler radar at both the ingress and egress points of the selected truck parking area. Other findings and recommendations pertain to the trade-off between accuracy and the frequency of ground-truth correction, qualitative reporting of truck parking availability to address uncertainty when the parking area is nearly full, required time for stabilizing the system, use of a vehicle classification scheme that reduces the number of vehicle classes, increased bandwidth in data transmission, and enhanced surveillance and monitoring with closed circuit television (CCTV) cameras.

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SI* (MODERN METRIC) CONVERSION FACTORS

Table of APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
In	inches	25.4	Millimeters	mm
Ft	feet	0.305	Meters	m
Yd	yards	0.914	Meters	m
Mi	miles	1.61	Kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
Ac	acres	0.405	Hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME	1000 L shall be shown in m^3	
fl oz	fluid ounces	29.57	Milliliters	mL
Gal	gallons	3.785	Liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		MASS		
Oz	ounces	28.35	Grams	g
Lb	pounds	0.454	Kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE	Temperature is in exact degrees	
°F	Fahrenheit	5 × (F-32) ÷ 9 or (F-32) ÷ 1.8	Celsius	°C
		ILLUMINATION		
Fc	foot-candles	10.76	Lux	lx
Fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		Force and Pressure or Stress		
Lbf	poundforce	4.45	Newtons	N
lbf/in^2	poundforce per square inch	6.89	Kilopascals	kPa

Table of APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
Mm	millimeters	0.039	inches	in
M	meters	3.28	feet	ft
M	meters	1.09	yards	yd
Km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE	Temperature is in exact degrees	
°C	Celsius	1.8c + 32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		Force & Pressure Or Stress		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.(Revised March 2003, Section 508-accessible version September 2009)

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LIST OF ABBREVIATIONS

Acronym	Definition
CCTV	closed circuit television
ConOps	Concept of Operations
CMV	commercial motor vehicle
CUR	light curtain detector
FMCSA	Federal Motor Carrier Safety Administration
FHWA	Federal Highway Administration
FOT	field operational test
ID	identification
ITS	Intelligent Transportation System
MM	mile marker
LAN	Local Area Network
NB	northbound
NTSB	National Transportation Safety Board
NVR	network video recorder
OH	overhead scanner detector
PR	performance requirement
PTZ	pan, tilt, and zoom
RFP	request for proposal
RV	recreational vehicle
SID	side scanner detector
SUV	sport utility vehicle
TDOT	Tennessee Department of Transportation

Acronym	Definition
USDOT	U.S. Department of Transportation

EXECUTIVE SUMMARY

This two-phase SmartPark project is intended to address FMCSA's goals of enhancing truck and motorcoach safety by better matching parking space supply and demand using Intelligent Transportation System (ITS) technology. Such technology could be effective on a broad scale and could be used to better align the high demand for truck parking with existing resources.

The objective of Phase I of the SmartPark project was to demonstrate the functionality and usefulness of three commercially available technologies designed to gather real-time parking availability information. The three technologies included overhead laser scanners, side-mounted laser scanners, and light curtains (CURs).

The laser scanners and CURs have a capability unique among vehicle detection systems: they are able to produce two-dimensional vehicle profiles, showing height (or width) and length. The detectors use laser or "light" beams to detect the presence of a vehicle. When a vehicle passes beneath the scanner's beams, the beams are either reflected (in the case of the laser scanners), or obstructed (in the case of the CURs). The concept behind the laser scanners and CURs is shown in Figure 1.

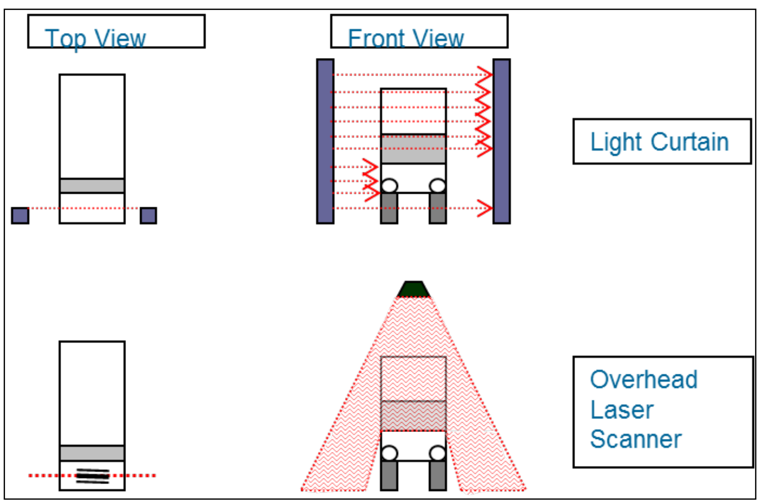

Figure 1. Diagram. Detector operational diagram.

These detection technologies were implemented at the ingress (entrance) and egress (exit) points of the selected truck parking area to monitor vehicles entering and exiting the site. A public rest area in Athens, TN was chosen for Phase I; the site is located at mile marker (MM) 45 on northbound I-75, as displayed in Figure 2. The site was chosen because it meets all the requirements established in the project's request for proposal (RFP), and because of the following ideal characteristics:

- The site was recently reconstructed and now has easily accessible truck parking spaces.
- There are single points of ingress and egress.
- Parking areas for trucks and cars are separated.

- There is ample lighting for nighttime operations.
- There are several sites upstream that meet the criteria for Phase II expansion.

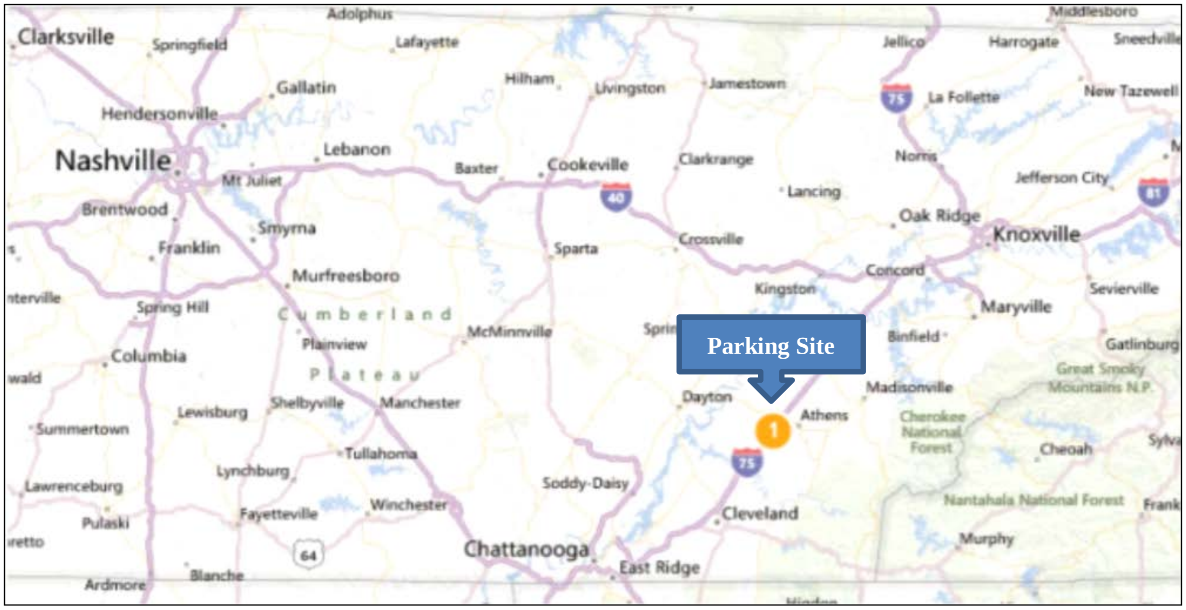

Figure 2. Map. SmartPark project site map.

While the Phase I detection technologies were prescribed in the contract documents, the specific details regarding how the devices were to be tested were not. Through the systems engineering process completed during the project, the needs, goals, functional requirements, and design requirements were established and described in detail. The systems engineering processes included the development of an implementation plan, a Concept of Operations (ConOps), performance requirements (PRs), a field operational test (FOT) plan, and an evaluation plan. The process of how the detectors would be implemented, tested, evaluated, and validated was thoroughly described through these documents

The PRs drove the overall system design and characteristics. Requirements were categorized as functional, data, interface, environmental, and PRs. The most critical of the requirements were the three PRs described in Table 1. The system's performance was measured by these three PRs; the expectation was that if the system did not meet these performance thresholds, modifications would need to be made to the technology or the implementation approach.

Table 1. SmartPark Phase I performance requirements.

Performance Requirement	Description
Performance requirement 1	The system shall maintain the parking area occupancy count to better than 95-percent accuracy.
Performance requirement 2	Classification consistency; the ingress and egress detectors must be consistent in classification with each other to a level of 95 percent.
Performance requirement 3	The system shall provide parking availability information at a minimum of 99.5 percent of the time.

Performance Requirement 1

The objective of PR1 was to verify the accuracy of the system as a whole. The system as a whole included all system components, such as the detectors, the data collection components, the hardware, software, and communications elements, and other items related to the functionality of the system. PR1 was measured using the parking space availability quantity data generated by the system and displayed on the project Web site. PR1 was evaluated using two processes: first, accuracy of the vehicle detection units was evaluated by comparing the data collected by the system to visual inspections or "ground truth" of the activity that actually occurred in the lot. The second evaluative measure was to compare the system data (over a 6-month testing period) to the number of corrections that needed to be made to reach a 95-percent accuracy level.

Performance Requirement 2

The objective of PR2 was to determine the detectors' abilities to classify vehicles similarly at varying locations. For example, as part of PR2, the number of vehicles classified as small vehicles (less than 18 feet high) at the ingress was compared to the number of vehicles classified similarly at the egress. The ability of a detector to classify vehicles similarly at the ingress and at the egress would speak to the ability of the detectors to produce similar results in varying conditions and at multiple sites.

Performance Requirement 3

The objective of PR3 was to ensure that the system was robust enough to operate continuously under all weather and environmental conditions. The system must be able to function without human intervention at all times in order to produce data 24 hours per day, 7 days per week.

The conceptual and final designs of the system were developed in accordance with the ConOps and the established PRs. Phase I's design was comprised of several significant system components, including:

- Gantry structures: used to mount the detector equipment.
- Detectors: overhead scanner detector (OH), side scanner detector (SID) and CUR.
- Onsite processor: used to process the scanner and CUR signals.
- Offsite server: used to download and store the data in a database.
- Closed-circuit television (CCTV) cameras: used for site monitoring and space availability validation (ground truth).
- Web site and data archive: used to monitor the CCTV cameras and make corrections to the Web site as needed

The detectors were deployed in the FOT in one of three possible configurations or combinations, as follows:

- Ingress—OH; egress—OH (denoted by OH/OH).
- Ingress—SID; egress—SID (denoted by SID/SID).

- Ingress—CUR; egress—OH (denoted by CUR/OH).

Using data generated from the system components, the system was evaluated against the three established PRs. The performance results are displayed in Table 2.

Table 2. Performance results.

Performance Requirement	Performance Target	Actual Performance
Performance Requirement 1	95%	OH/OH: 99.85% SID/SID: 99.82% CUR/OH: 99.34%
Performance Requirement 2	95%	OH/OH:97.64% SID/SID:96.26% CUR/OH:87.04%
Performance Requirement 3	99.5%	OH/OH:93.59% SID/SID:100% CUR/OH:81.86%

As shown in Table 3, there were two configurations of detectors for the system that exceeded the performance target established in PR1. From an operational perspective, PR1 is perhaps the most important PR, as it dictates the monitoring and correction needs of the system. Because the system is based upon a "check-in" and "check-out" process/algorithm, system errors can accumulate over time. As a result, the site must be monitored and corrected on occasion to maintain accuracy. Based on the results above and other findings in this report, the laser scanners need to be monitored and corrected approximately once per day to maintain the PR1 performance target. The CUR needs to be monitored and corrected at least twice per day to maintain the performance target. These daily monitoring requirements will vary from site to site, and are based on the overall usage of the parking area.

Table 3. Daily monitoring and correction requirements for each scanner type.

Detector	Daily Monitoring and Correction Requirement
Overhead Scanner Detector	Once per day
Side Scanner Detector	Once per day
Light Curtain Detector	Twice per day or more

Six vehicle classes (based upon length and the presence of a trailer) were developed specifically for SmartPark Phase I. While Table 2 indicates that the OH/OH and SID/SID combinations achieve PR2 performance targets; their ability to classify vehicles similarly varies significantly on a class-by-class basis. Generally, the detector units do not accurately classify vehicles based on length or the presence of a trailer. In future implementations, the classification schemes must be far less granular—incorporating just three or four classes instead of six—in order for the technologies to be effective. The classification scheme should be tailored to the needs of the parking area.

PR3 is a measure of general system availability. Reasons for system downtime include configuration issues with software and hardware, and environmental issues such as ice buildup. Downtime due to external factors (such as vandalism) was excluded from the analysis, as it was uncontrollable. While Table 2 indicates that only the SID/SID combination achieved the PR3 performance target, it is reasonable to assert that uptime of the OH/OH combination could be increased to meet the same performance target over time as the software and configuration issues are addressed. This is demonstrated by the significant reduction in downtime experienced by the detectors later in the testing period following software and configuration updates to the overall system.

Significant lessons were learned from Phase I for future implementations. Lessons and recommendations for Phase II include:

- **Phase II technology choice:** The SID should be selected as the technology used for Phase II, as it is less intrusive than the OH and exhibits less overhead and maintenance needs than the CUR. Accuracy and uptime are also optimal for Phase II use.
- **Stabilization period:** Prior to entering full testing mode, a stabilization period should occur in order to mitigate configuration and software issues.
- **Classifications scheme:** The number of vehicle classes should be reduced to enhance the practical use of the detection units, including the use of vehicle height to identify bobtails and other anomalies.
- **Bandwidth:** If possible, a higher bandwidth should be used for connection to enhance site-monitoring capabilities.
- **Surveillance:** Surveillance and monitoring capabilities should be enhanced by increasing the number of CCTV cameras, optimizing the orientation of the cameras, and using higher resolution cameras with pan, tilt, and zoom (PTZ) capabilities.

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1. INTRODUCTION

The SmartPark project is intended to address the Federal Motor Carrier Safety Administration's (FMCSA's) initiative to better match supply and demand for truck parking by using Intelligent Transportation System (ITS) technology. Such technology could be effective on a broad scale and could be used to better align the high demand for truck parking with existing resources. This type of technology could reduce the need to expand existing truck parking facilities by more efficiently and effectively utilizing existing facilities.

The SmartPark project consists of two phases. The objective of Phase I was to demonstrate the functionality and usefulness of a commercially available or near-term technology to gather real-time parking availability information. Phase I evaluated various vehicle detection units capable of collecting data to determine whether a truck parking facility is full, and if not, to indicate the number of parking spaces available.

FMCSA's contractors conducted field operational tests (FOTs) on two technologies, namely, video imaging and magnetometry. Because these technologies did not demonstrate viability for SmartPark, FMCSA decided to repeat Phase I with a different technology in collaboration with the Tennessee Department of Transportation (TDOT) on I-75 near Athens, TN. Phase II will deploy a traveler information component to the system and will demonstrate the feasibility of diverting truckers from filled parking areas to unfilled parking areas. This final report documents and describes the findings from Phase I.

1.1 PURPOSE AND GOALS OF SMARTPARK PROJECT

SmartPark will help FMCSA reach its goal to align truck parking demand and supply. Enhancing commercial motor vehicle (CMV) drivers' ability to identify and locate long-term parking spaces will help to improve the safety of commercial vehicle operations by enabling drivers to meet the HOS regulations. SmartPark is attempting to realize this goal in a two-phase project. The first phase, which is the subject of this final report, evaluated two types of detection technology. The second phase, which started in August 2013, will demonstrate a truck parking system (across multiple rest areas) that provides drivers with dynamic information about truck parking availability in real-time and helps to fulfill their parking needs.

The objective of Phase I of the SmartPark project was to demonstrate the functionality and usefulness of a commercially available or near-term technology designed to gather real-time parking availability information. Phase I evaluated various vehicle detection units capable of collecting parking availability data and communicating that information to drivers.

Two technologies were evaluated in Phase I of SmartPark:

- Laser scanner (in overhead [OH] and side [SID] configurations) and Doppler radar.
- Light curtain (CUR) and Doppler radar.

The functionality and usefulness of a technology can be quantified in several steps. The first step is to define what accuracy is in relation to said technology—that is, determining the occupancy of a parking lot. The second step is to compare the accuracy of varying combinations of the laser scanner and CUR technologies to determine an optimal combination.

As part of Phase I, a set of requirements were developed to measure and evaluate the performance of the various detection systems. The three primary performance requirements (PRs) related to measurement and evaluation of system outcomes are listed in Table 4. In order for the system to be deemed successful, it must achieve these three PRs.

Table 4. SmartPark Phase I PRs.

Performance Requirement	Description
Performance Requirement 1	The system shall maintain the parking area occupancy count to better than 95-percent accuracy.
Performance Requirement 2	Classification consistency; the ingress and egress detectors must be consistent in classification with each other to a level of 95 percent.
Performance Requirement 3	The system shall provide parking availability information at a minimum of 99.5 percent of the time.

1.2 PROJECT STAKEHOLDERS

Due to its implications for safety and general operations on the transportation network, the overall SmartPark project has a number of both public and private stakeholders. Stakeholder level of involvement varies significantly between Phases I and II due to the nature of these phases. Phase I is comprised predominantly of technology demonstration activities, which primarily involve the funding organization, the key stakeholders affected directly by the construction of the project, and those evaluating the project. Phase II includes public dissemination of information on parking location and availability, which implicates a significantly higher number of stakeholder parties. SmartPark project stakeholders are identified in Table 5, which displays stakeholder levels of involvement by Phases I and II.

Table 5. Project stakeholders.

Stakeholder	Participation	Phase I	Phase II
FMCSA	Project sponsor. Reviews Phase I results. Will determine direction for Phase II.	Yes	Yes
U.S. Department of Transportation (USDOT)/John A. Volpe National Transportation Systems Center	Provide independent evaluation of the SmartPark system.	Yes	Yes
TDOT	Oversees operation. Approval required for construction activities and use of site.	Yes	Yes
TN Highway Patrol	Provides law enforcement.	Yes	Yes
American Trucking Associations/ TN Trucking Association	Identify trucking needs.	No	Yes
Truck Drivers	Use truck parking facility and service center.	No	Yes

Stakeholder	Participation	Phase I	Phase II
ITS-TN	Provides outreach.	No	Yes
Rest Area Manager(s)	Allow use of existing infrastructure for project.	Yes	Yes
Rest Area Maintenance Personnel	Allow use of existing infrastructure for project.	Yes	Yes

1.3 HISTORY OF SMARTPARK PROJECT

In 1998, Congress directed the National Transportation Safety Board (NTSB) to review causes of truck and bus crashes. In a 2002 report, NTSB recommended that FMSCA create a guide to inform truck drivers about locations and availability of parking. Congress further mandated a study on the adequacy of truck parking by the Federal Highway Administration (FHWA). From the FHWA study, FMCSA concluded that approaches to solving the truck parking shortage fall into three major areas:

- Making underused spaces more attractive.
- Increasing the supply of spaces.
- Better matching supply and demand.

The 2002 FHWA study recommended the deployment of ITSs to provide CMV drivers with real-time information on the location and availability of parking spaces. In 2005, FMSCA initiated its truck-parking program, called SmartPark. This discretionary project intended to demonstrate the application or deployment of the latest ITS technologies to truck parking. In 2005, FMSCA issued the publication, "Intelligent Transportation Systems and Truck Parking."

Between 2007 and 2009, FMCSA awarded two contracts for field operational tests (FOTs) of two separate technologies (video imaging and magnetometry) for demonstrating the feasibility of determining parking space occupancy at truck rest areas in Massachusetts. Because neither of the two technologies was demonstrated to be feasible, FMCSA decided to repeat Phase I using two types of technology with strengths that would avoid the issues encountered in previous attempts.

The two previous SmartPark Phase I efforts yielded significant lessons learned regarding both video imaging and magnetometry technologies and the limitations of any automated system to detect parking availability. The current SmartPark project team was guided by these lessons learned and avoided many of the issues previously encountered. The primary lessons learned from the previous SmartPark projects are described in two FMCSA reports:

- "Smartpark Truck Parking Availability System: Video Technology Field Operational Test Results," Report No. FMCSA-RRT-10-002, January 2011.
- "SmartPark Truck Parking Availability System: Magnetometer Technology Field Operational Test Results," Report No. FMCSA-RRT-10-041, January 2011.

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2. PROJECT OVERVIEW

2.1 PROJECT SUMMARY AND MAJOR COMPONENTS

The basic concept of the SmartPark system is to determine the number and “class” of vehicles entering a parking area and to make the same determination for vehicles exiting the parking area. The term “class” as it is used here refers to project-specific classifications developed for SmartPark. Knowing these two determinations and the capacity of the parking area, the system can project the number of available parking spaces in the parking area. The required elements of the SmartPark system include:

- A means of automatically detecting parking space status, by monitoring both ingress and egress.
- A central database to maintain parking status and reservation information.
- Controlled access to dedicated parking areas.
- Other required functions:
  - The system must be able to count and classify vehicles entering and exiting the facility.
  - It must be easy to install and maintain.
  - It must operate unattended 24 hours per day, 7 days per week.
  - It must operate in all weather and ambient lighting conditions.
  - It must maintain a count of the available parking spaces in the facility and provide this count to authorized remote users.
  - It must provide a means for authorized users to remotely monitor the parking facility to determine the accuracy of the system.
  - It must allow authorized users to reset the count of available parking remotely.
  - It must maintain a log of vehicle entrance and exit events and system errors.

2.2 SITE SELECTION

The SmartPark request for proposal (RFP) prescribed several requirements regarding the site suitable for the SmartPark FOT:

- The test site must be a private or public truck parking area with a controlled ingress and egress from a major arterial road or highway.
- The site must be suitable for use with the detection technologies identified.
- There must be documentation of complaints about inadequate parking, need for a truck appointment or reservation system, illegally-parked trucks, or trucks queuing up to enter the site.

- There must be at least one adjacent truck parking area within 35 miles of the proposed site, capable of being accessed from the same road, with a controlled ingress and egress, and suitable for use with the identified technology.

Using the above criteria, the lessons learned from previous SmartPark Phase I efforts, and engineering knowledge and expertise, a rest area on I-75 northbound (NB) at mile marker (MM) 45 in Athens, TN was selected as the Phase I FOT site. The location of the site is displayed in Figure 3.

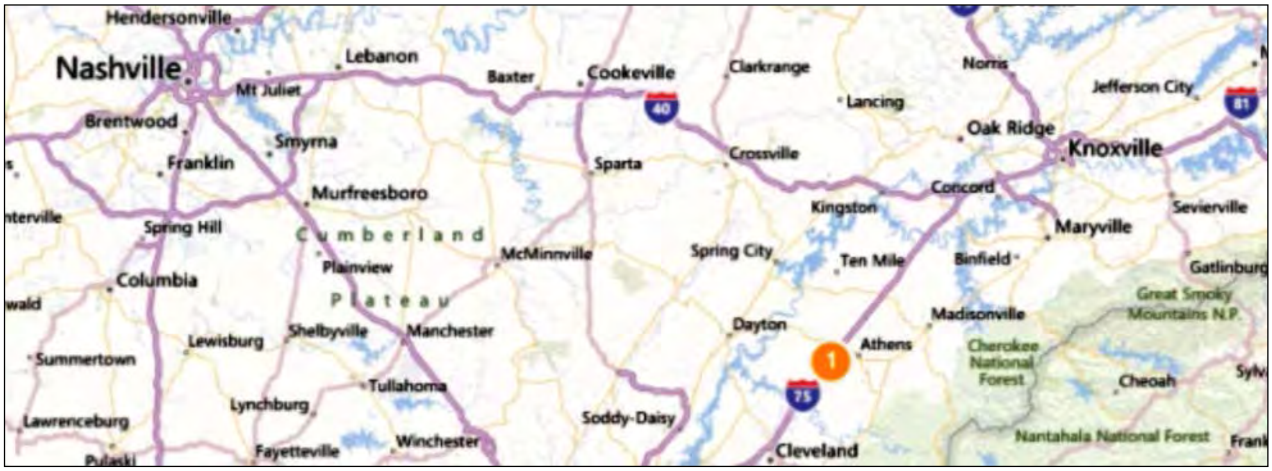


Figure 3. Map. SmartPark project site map.

The following characteristics made this site attractive for Phase I of the SmartPark project:

- The site was recently reconstructed, and now has fresh pavement and easily accessible truck parking spaces.
- It has controlled points of egress and ingress.
- It has separate car and truck parking areas.
- It has ample lighting for nighttime operations.
- There are several sites upstream that meet the criteria for Phase II expansion.

The site and most of its features are clearly visible in the satellite view provided in Figure 4. The two parking areas at the rest stop are visible in the image. The area to the right of rest stop building is for smaller vehicles only, while the truck parking area can be seen to the left and above the rest stop building and is the larger of the two parking areas.

Figure 4. Photo. SmartPark Phase I test site aerial photograph.

2.3 SYSTEM OVERVIEW AND COMPONENTS

The SmartPark system evaluated in this study consisted of two types of components:

- Detection equipment: the detection units being demonstrated and validated, including the gantries and structures to support it.
- Verification tools: technologies and installations to support the inspection, verification, and evaluation of system performance, including communications to the site, closed circuit television (CCTV) cameras, and the project Web site.

Working in concert, the detection technologies and verification tools comprise the primary components of the system. The diagram depicted in Figure 5 provides a high-level overview of the SmartPark system. The seven major components to the detection equipment and verification tools include:

- Gantry structures.
- Detectors.
- Onsite processor.
- Offsite server.

- CCTV cameras.
- Web site and data archive.

Figure 5 displays these components and provides a high-level overview of the field, communication, and back-office processing equipment.

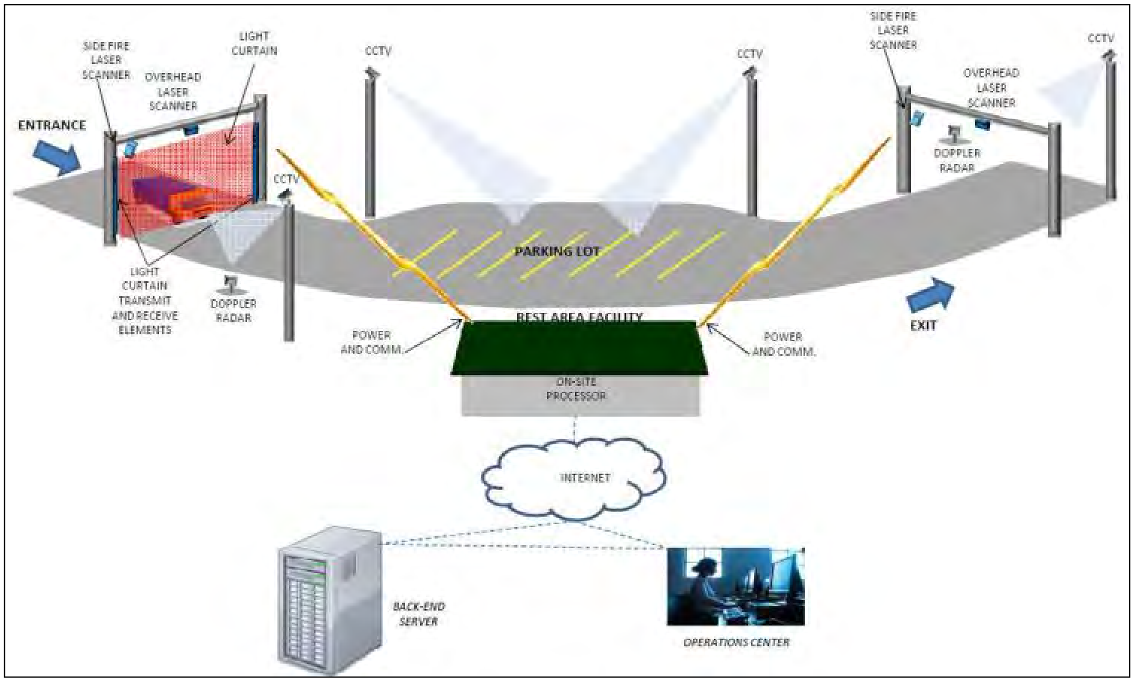


Figure 5. Flowchart. SmartPark system overview.

As displayed in Figure 5, a vehicle enters the parking area, is detected by one of the ingress detectors, and then proceeds to a parking space. Once detected, the ingress detector communicates via fiber optics to the rest area facility equipment room, where the onsite processor analyzes the detection, classifies the vehicle, and communicates with the Web site to indicate that a vehicle has entered the lot. Using this information, the SmartPark system determines how many vehicles are currently in the lot, and thus determines the number of spaces that are available. A series of seven CCTV cameras monitors the activity in the lot in order to verify lot count accuracy. The CCTV cameras can be viewed remotely from any Web browser, provided the user has proper authentication credentials.

2.4 DETECTION EQUIPMENT

2.4.1 Detector Configuration

As illustrated in Figure 5, vehicles entering or exiting the parking area passed through a gantry erected over the truck entry or exit lanes. The detection units—two laser scanners and a 10-foot CUR—were mounted on the entry gantry. **Note:** only the laser scanners were mounted to the egress gantry; there was not enough funding in the budget to mount a CUR.

The laser scanners were mounted in overhead and "side-fire" configurations; however, only one laser scanner was utilized at a time. The laser scanner would scan a line along the top or the side of the vehicle, depending on which scanner (i.e., overhead or side-fire) was active, and it would transmit the data to an onsite processor. The configuration of the detectors on the ingress gantry is displayed in Figure 6.

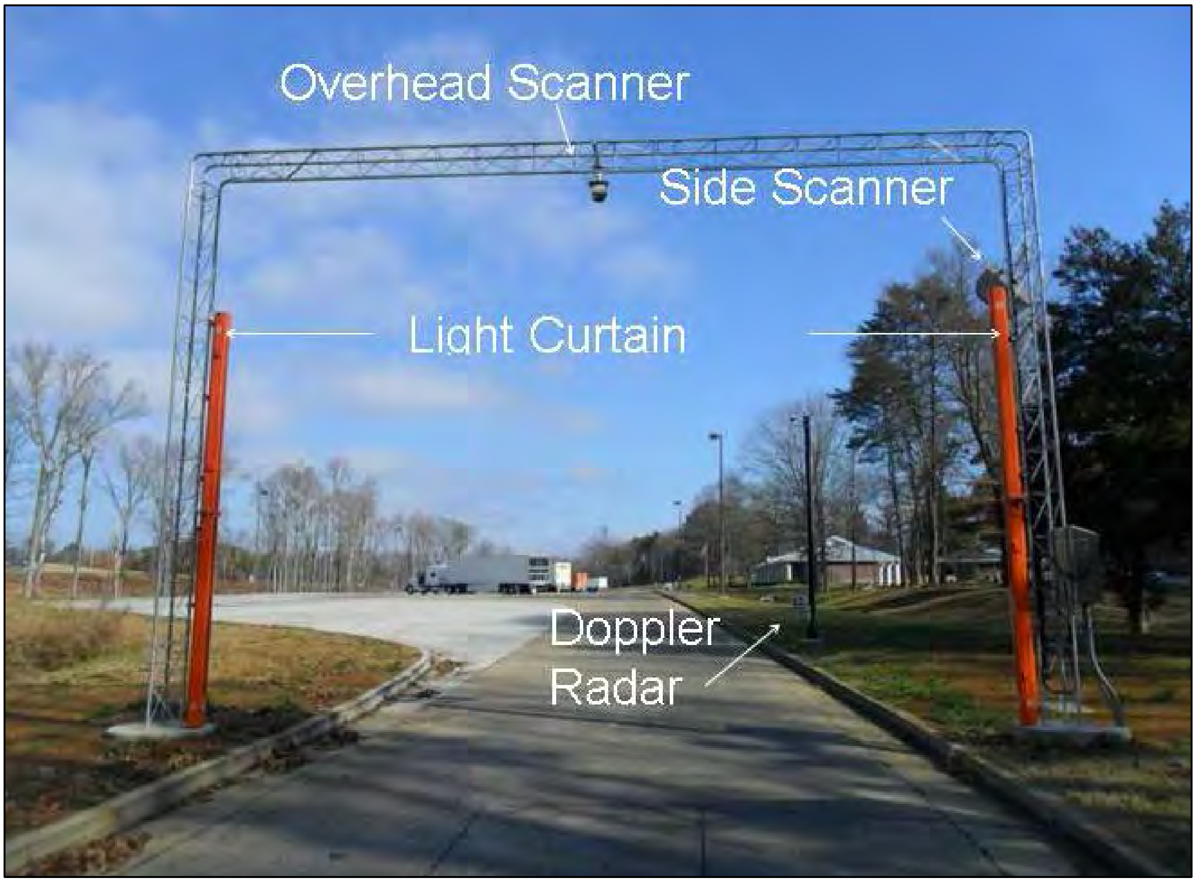


Figure 6. Image. SmartPark detector configuration at ingress.

The 10-foot CURs (the orange bars displayed in Figure 6) are actually comprised of two 5-foot CUR units stacked on top of each other vertically. The 5-foot CURs were used because the supplier did not have the 10-foot CURs in stock during procurement.

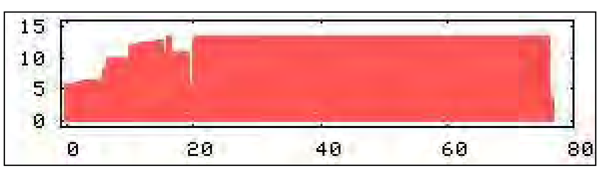


Figure 7. Typical CUR or scanner truck profile.

In addition to the laser scanners and the CUR, a Doppler radar unit was installed downstream of the gantry. The Doppler radar unit was pointed back at the oncoming vehicle in order to detect the position and velocity of the vehicle relative to the scanned line.

The laser scanners and CURs have a capability unique among vehicle detection systems; they are able to produce a two-dimensional profile of the vehicle, showing its height and length (as shown in Figure 7). The detectors use laser or "light" beams to detect the presence of a vehicle. When a vehicle passes beneath the scanner's beams, the beams are either reflected (in the case of the laser scanners), or obstructed (in the case of the CURs.) The onsite processor combines the laser or CUR scan data generated from the vehicle obstruction, and combines it with the distance and speed data provided by the Doppler radar to yield a two-dimensional profile of the vehicle. From this profile, the scanner can determine the length and precise shape of the vehicle. The system assigns a vehicle "class" based on this information. The concept behind the scanner technologies is depicted in Figure 8.

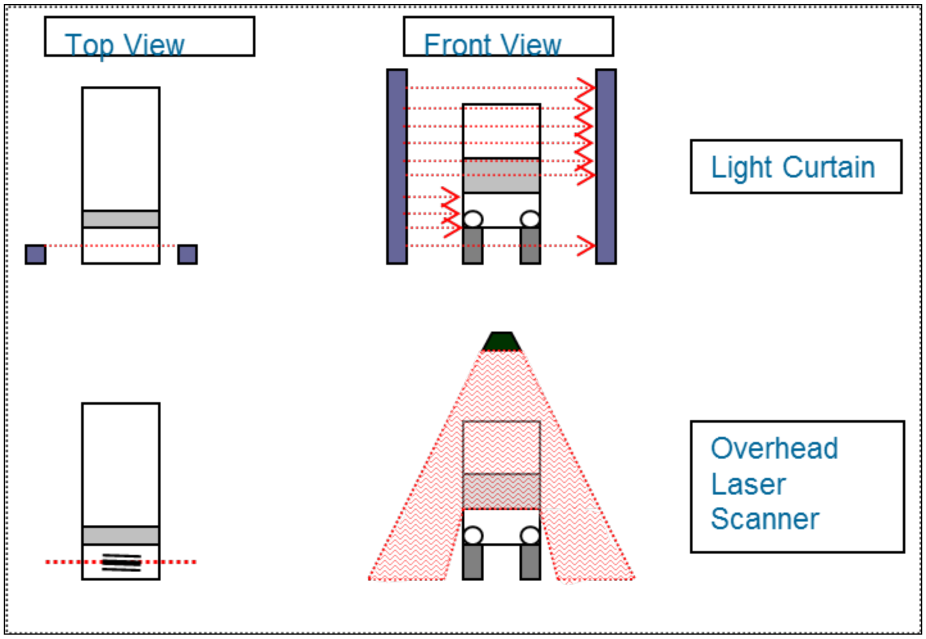


Figure 8. Diagram. Detector operational diagram.

2.4.2 Detector Processors and Automated Analysis

Data collected by the detection units themselves are processed by processing units that accompany the detectors. The processing units take the data collected by the detectors and the Doppler radar, combine it, and run it through an algorithm to produce usable data. Once processed, the data generate easily interpretable information for each vehicle: the presence of a vehicle, the length of the vehicle, the vehicle class, and a rendering of the vehicle shape. The ability of the system to produce renderings of the vehicle shape, essentially capturing a side profile of the vehicle, is what makes this system unique amongst other vehicle detectors.

In the early stages of the project, FMCSA identified the following requirements for the system, including:

- The ability to discern the difference between large vehicles and small vehicles—typical automobiles versus tractor-trailers.
- The ability to identify the presence of a trailer—large-scale freight trailers in particular.

When configuring the devices and the processors, a classification scheme was coded into the processing algorithm. The classification scheme was also developed to satisfy the requirements identified by FMCSA. The resulting classification scheme to cover all vehicles entering and exiting the lot is given in Table 6.

Table 6. SmartPark vehicle classification scheme.

Class	Description
1	Vehicles with length less than or equal to 18 feet and no trailer. For example, cars and motorcycles (this class was not typical to the site, as small vehicles are directed to an adjacent lot; however, it was adopted in case such vehicles entered into the truck parking area).
2	Vehicles with length between 18 feet and 30 feet and no trailer. For example, pickup trucks or large sport utility vehicles (SUVs).
3	Vehicles with a trailer, where the combined total length was between 5 feet and 30 feet. For example, a Class 1 vehicle towing a trailer.
4	Vehicles with length between 30 feet and 50 feet and no trailer. For example, a recreational vehicle (RV) or bus.
5	Vehicles with a trailer, where the combined total length was between 30 feet and 50 feet. For example, a Class 2 vehicle towing a trailer or truck with a short trailer, such as a pickup truck towing a horse trailer.
6	Vehicles with a trailer, where the combined total length was equal to or greater than 50 feet (truck with double trailer or long single trailer).

The classification scheme not only satisfied the needs of FMCSA, but it was specially developed with field observations in mind. For the most part, the classes are easily discernible from one another to anyone in the field attempting to conduct counts to corroborate or evaluate the system.

In addition to determining vehicle characteristics, the software determined the occupancy of the lot and the number of spaces available. High-level overviews of the ingress and egress algorithms are displayed in Figure 9 and Figure 10.

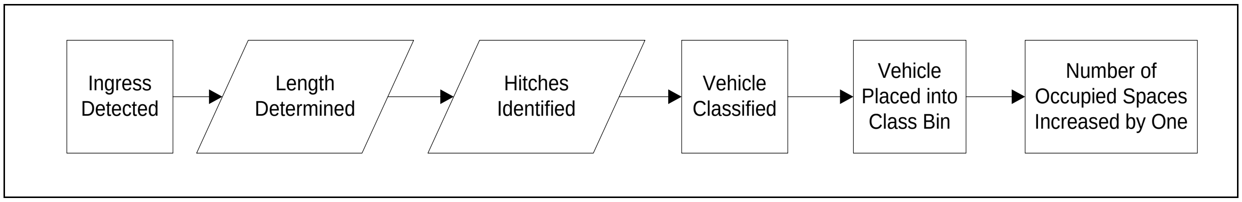


Figure 9. Flowchart. Ingress algorithm.

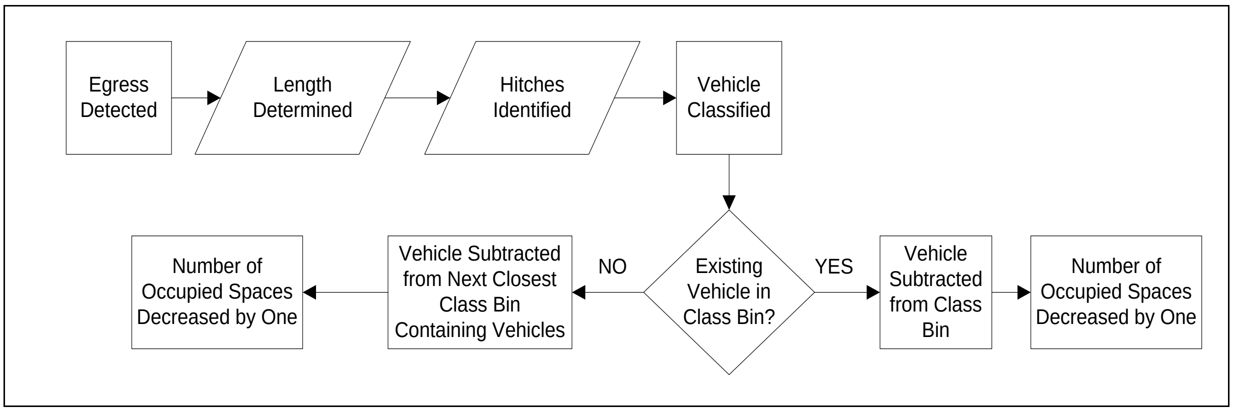


Figure 10. Flowchart. Egress algorithm.

It should be noted that the egress algorithm mimics, but does not mirror, the ingress process. An extra step is added to the egress process in order to avoid losing vehicles that are not already represented in the system. This process preserves the overall count of the system in the event that there is no vehicle in the proper bin from which to subtract. In other words, due to variations in the installation of the detector technology, a vehicle leaving the lot may be classified differently than it was classified when entering the lot. This phenomenon can occur because the orientation of the laser scanners and light beams may vary mildly between the ingress and egress installations. When classifications differ between the ingress and egress, subtracting one from the designated classification bin could result in a negative number, or would not be counted at all, thereby throwing off the overall count of the system. The extra step in the egress process ensured that while a vehicle might be classified differently at the ingress and egress, the integrity of the overall lot count would not be affected.

2.5 VERIFICATION TOOLS

To accompany the detection equipment, a series of verification tools were installed and incorporated into the overall system. The verification tools primarily included surveillance cameras and the equipment needed to support it. The primary components of the verification tools included:

- Seven CCTV cameras.
- One network video recorder (NVR).

- A remote monitoring Web site.

While the verification tools primarily confirmed the system accuracy and monitored its progress, they also made corrections to the system in real time. While the extensive features of the verification tools may not be necessary in future deployments beyond the SmartPark project, they will always be needed—to some extent—as a way to monitor the system and prevent errors from accumulating.

2.5.1 CCTV Cameras and Network Video Recorder

Seven CCTV cameras were placed strategically throughout the truck parking area to provide a means of monitoring the site from remote locations. Cameras were carefully located in order to provide visibility of all spaces within the lot as well as the ingress and egress gantries.

Cameras pointed at the parking lot were mounted on existing light poles. Cameras pointed at the gantries at the ingress and egress were mounted on poles that supported the Doppler radar equipment. Camera locations and their approximate fields of vision are displayed in Figure 11.

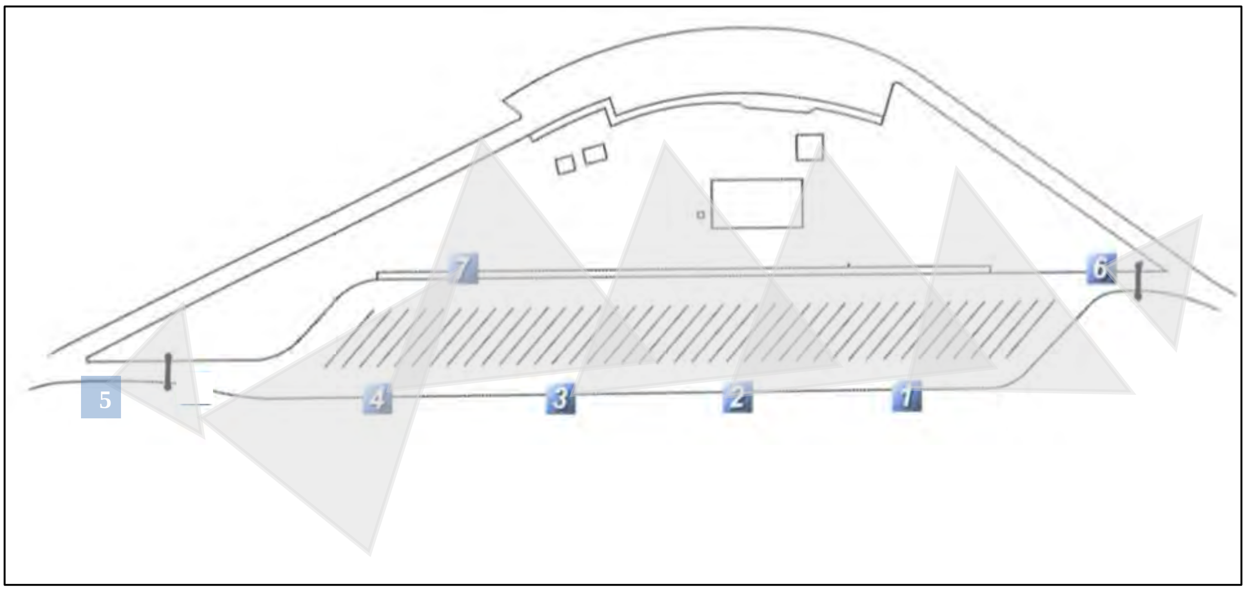


Figure 11. Diagram. CCTV camera locations and fields of vision.

Each of the CCTV cameras was linked to the central server located onsite in the rest area equipment room. From this room, the cameras were viewable, one at a time, using the Internet and the project Web site. Viewing from the project Web site was limited to a single camera at a time due to bandwidth limitations. The field of view for each of the seven cameras is displayed through snapshots in Figure 12 and Figure 13.

Figure 12. Grouped photo. CCTV camera images for cameras 1–6.

Figure 13. Photo. Image from CCTV camera 7.

2.5.2 Web Site and Interfaces

A project Web site was established to facilitate monitoring of the site in real time. Users access the site at www.fmcsasmartpark.com, where they are prompted for a username and password. From the Web site, users can access the following:

- The current occupancy of the parking lot, including available spaces, in near-real time (a maximum of 1 minute of latency occurs as a result of the system architecture and communication limitations).
- Classifications of the vehicles currently in the lot.
- Live video from any of the seven CCTVs.
- Historical data from any period that the system was in operation.
- A “corrections” button that enables manual adjustment of the lot count.

The primary screen of the Web site is shown in Figure 14. This homepage displays the current lot usage, the classifications of the vehicles in the lot, and CCTV video feeds, which can be accessed by clicking on one of the numbered icons drawn around the parking lot. From this site, the user can navigate to the data retrieval site (to access historical data) or to the reports section. The data retrieval section of the Web site, shown in Figure 15, displays all events that occur for a given adjustable date range. Any time the ingress or egress detector detected a vehicle, a unique event was created and assigned a unique event identifier. Each event description included the following characteristics:

- Time stamp.
- Event type (ingress or egress).
- Vehicle identifier (unique event ID).
- Sensor type (laser scanner versus CUR).
- Mounting configuration of the detector.

- Class of the vehicle.
- Number of spaces in use, inclusive of the event.
- Vehicle count within the lot, by class.
- Images of the vehicle associated with the event.

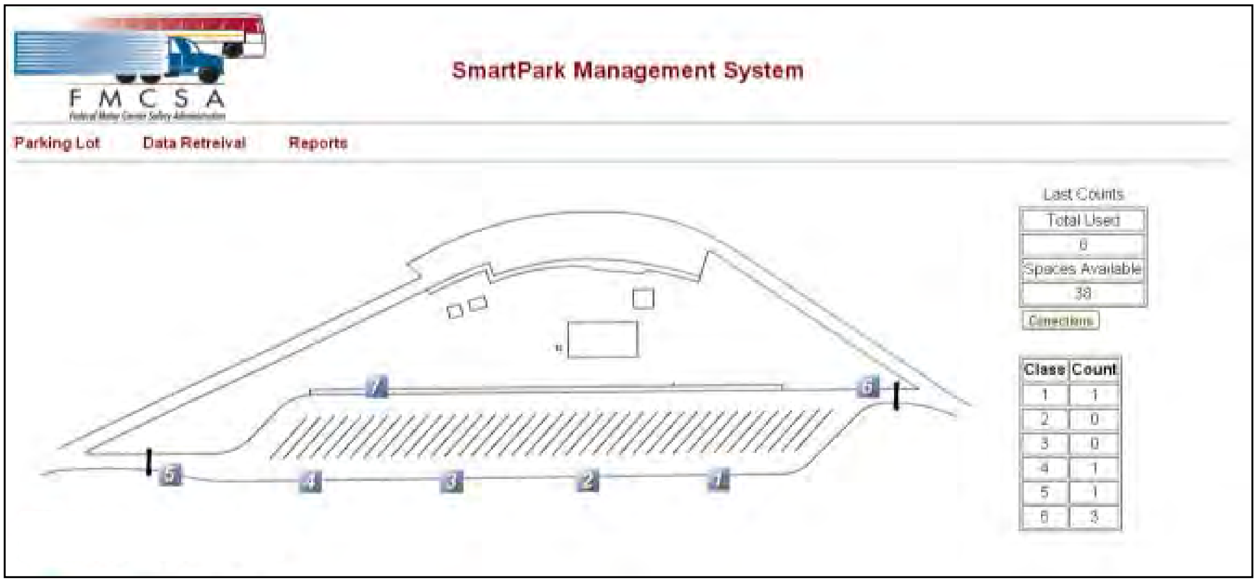
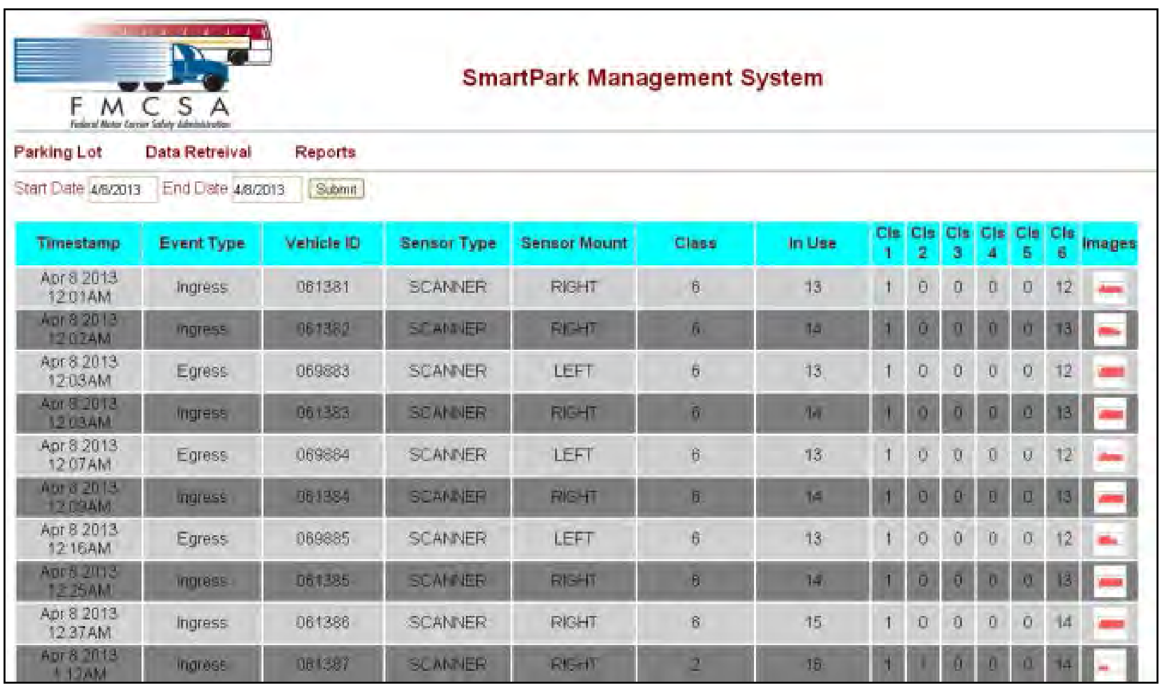


Figure 14. Screenshot. SmartPark Web site homepage.



Timestamp	Event Type	Vehicle ID	Sensor Type	Sensor Mount	Class	In Use	Cls 1	Cls 2	Cls 3	Cls 4	Cls 5	Cls 6	Images
Apr 8 2013 12:01AM	Ingress	061381	SCANNER	RIGHT	6	13	1	0	0	0	0	12	
Apr 8 2013 12:02AM	Ingress	061382	SCANNER	RIGHT	6	14	1	0	0	0	0	13	
Apr 8 2013 12:03AM	Egress	069883	SCANNER	LEFT	6	13	1	0	0	0	0	12	
Apr 8 2013 12:03AM	Ingress	061383	SCANNER	RIGHT	6	14	1	0	0	0	0	13	
Apr 8 2013 12:07AM	Egress	069884	SCANNER	LEFT	6	13	1	0	0	0	0	12	
Apr 8 2013 12:09AM	Ingress	061384	SCANNER	RIGHT	6	14	1	0	0	0	0	13	
Apr 8 2013 12:16AM	Egress	069885	SCANNER	LEFT	6	13	1	0	0	0	0	12	
Apr 8 2013 12:25AM	Ingress	061385	SCANNER	RIGHT	6	14	1	0	0	0	0	13	
Apr 8 2013 12:37AM	Ingress	061386	SCANNER	RIGHT	6	15	1	0	0	0	0	14	
Apr 8 2013 1:12AM	Ingress	061387	SCANNER	RIGHT	2	16	1	1	0	0	0	14	

Figure 15. Screenshot. SmartPark Web site data retrieval screen.

The Web site has been uniquely configured to provide the project team with as much information as possible regarding each event (i.e., ingress or egress). A critical aspect of monitoring the system is the ability to observe any errors in parking space availability. The CCTV cameras utilized at the site provide viewing capability for real-time streaming and corrections. However, the CCTV cameras also capture still images of the entire project area every time an event occurs. These images are associated with the unique vehicle/event ID and are stored in the data retrieval database. They can be recalled by clicking on the profile image for a data retrieval entry. Using these still images, a user can view activity and occupancy within the lot and compare it to the vehicle count and availability as described by the system. This provides a unique method of reviewing historical accuracy, identifying errors encountered throughout the life of the system, and identifying the causes of system errors. Sample images of typical database images are displayed in Figure 16.

Figure 16. Screenshot. Typical SmartPark database image catalog.

2.5.3 Network Video Recorder

All CCTV cameras at the site are connected to an NVR for video recording purposes. The video recorder can be activated or deactivated remotely and can only retain a limited amount of video. While recording all seven CCTV cameras, the NVR can store approximately 2-months' worth of video. When recording just the ingress and egress, the NVR can store much more video content. For the purposes of this project, the NVR is providing sample video for use during efforts to validate the vehicle detection accuracy of the system.

The NVR is accompanied by a proprietary viewer that can read the NVR's proprietary video compression algorithm and files. The video can also be converted to standardized video formats using a converter.

2.6 COMMUNICATIONS AND DATA FLOW

All equipment at the site is connected using a series of fiber optics and Ethernet, and communicates via a local area network (LAN) established for the project. The types of connections are displayed in the system design diagrams provided in Appendix A of this document. The network architecture is summarized in the diagram in Figure 17.

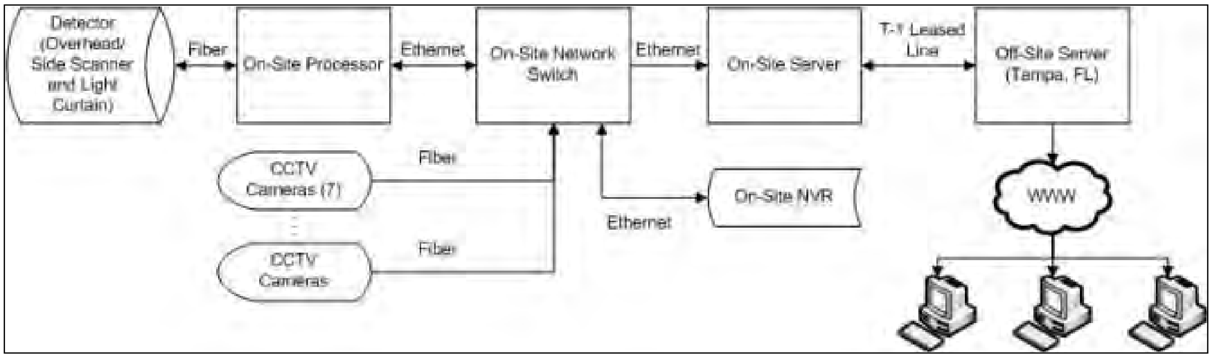


Figure 17. Flowchart. SmartPark local area network architecture summary.

A leased T-1 line connection was established at the site for all communications to and from the project site. The T-1 has a standard bandwidth of approximately 1.544 megabytes per second.

3. TESTING PERIOD

3.1 GOALS

The detector period began on September 26, 2012 and continued through April 10, 2013. The intent of the testing period was to demonstrate functionality and usefulness of the detector technologies and to gather data regarding the performance of each of the detector units.

Specifically, the following goals were accomplished during the testing period:

- **Troubleshooting**: Identified issues and barriers to successful detector operation and addressed these issues as they arose.
- **Vehicle Detection Accuracy**: Verified the accuracy of the individual ingress and egress detector units.
- **System Performance**: Verified and measured performance of the overall system, inclusive of all components. System performance was determined by evaluation of the PRs.

3.2 PERFORMANCE REQUIREMENTS

The systems engineering process completed for this project established a series of requirements by which to measure accuracy and performance of the project components. The three primary PRs are identified in Table 4.

3.2.1 Performance Requirement 1

PR1 applies to the system as a whole and is reliant upon all components of the system working together to produce accurate information. In the case of PR1, the critical piece of information is the parking availability (i.e., the number of spaces available at any given time). All components of the system work in concert with each other to provide this number. By using this PR as a measure, as many possible sources of error in the system are considered because they are intrinsic to the measure. The source of the “spaces available” measure is the project Web site, displayed in Figure 18.

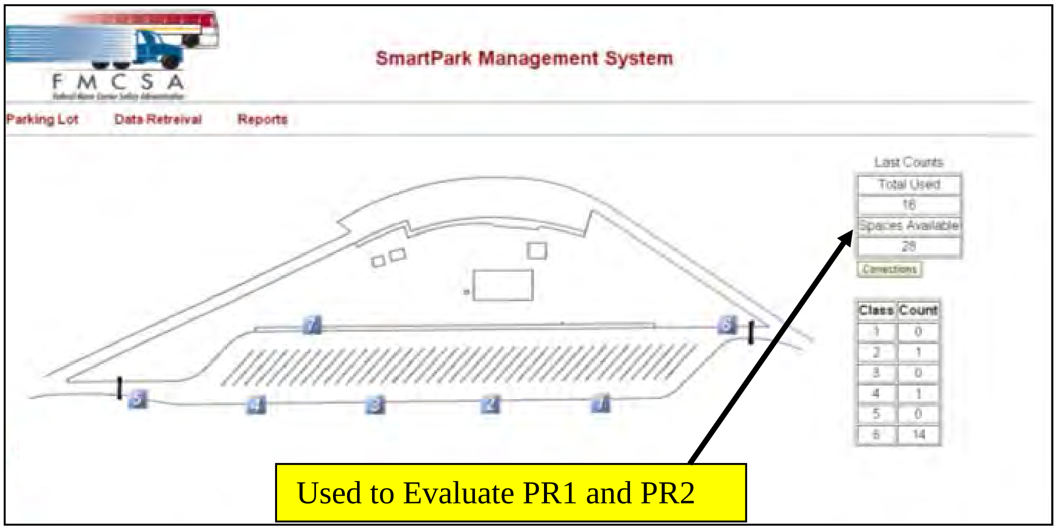


Figure 18. Screenshot. Numerical measure for PR1 and PR2 evaluations.

3.2.2 Performance Requirement 2

PR2 measures the system's capability to classify vehicles consistently across the ingress and egress detectors. The classification system for SmartPark is based upon the presence of a trailer and the length of the overall vehicle. The theory behind PR2 is that if the detection units can classify consistently across the ingress and egress detection units, then the classification scheme can be adjusted to meet the system's strengths (even if the system does not accurately determine what the vehicle is).

Classification is important because it helps to estimate the number of truck parking spaces that will actually be used by the entering vehicle. For example, depending on the layout of the parking area, a car might not use any truck parking spaces, or two straight trucks or "bobtails" might double-up in a single parking space, which would normally fit a tractor hitched with a 53-foot trailer. In addition, if the parking area has a significant number of trailer drops, distinguishing between vehicles with trailers and those without trailers becomes important.

3.2.3 Performance Requirement 3

PR3 measures system uptime. It also determines how robust the system operation is, and how it can weather environmental issues. Uptime is considered the time that the system is detecting ingresses and egresses and is displaying this information on the Web site. Uptime does not consider unusual physical disruptions to the system such as weather damage, vandalism, or other physical damage to the hardware. Uptime only considers any time that the system is not functional as a result of an internal error. An internal error is defined as an error that originated from within the system, such as a defect or software issue, and excludes errors that are due to factors external to the system such as a power outage.

3.3 DATA COLLECTION

Several types of data were collected during the testing period. Table 7 displays the types of data collected, their uses, and the PR(s) that they measure.

Table 7. Data collection methods and uses.

System Measurement	Evaluation	Verification Data	Data Source
Performance Requirement 1	Vehicle Detection Accuracy	Manual Counts	In-person Counts, Video Surveillance Footage
Performance Requirement 1	System Performance	System Count Data Manual Corrections	Data Collection System SmartPark Web site Reports
Performance Requirement 2	Classification Accuracy	Manual Counts	In-person Counts, Video Surveillance Footage
Performance Requirement 2	Classification Repeatability	System Count Data	Data Collection System
Performance Requirement 3	System Uptime	System Count Data System Alerts	Data Collection System

The testing period for the SmartPark project officially began on September 26, 2012 and continued through April 10, 2013. Manual data collection occurred at various times over the testing period.

3.3.1 Manual Data Collection Schedule and Detector Combinations

The ingress and egress locations were equipped with varying detector technologies, as displayed in Table 8. Three detector combinations were evaluated to determine the most effective combination:

- OH Scanner/OH Scanner.
- SID Scanner/SID Scanner.
- CUR/OH Scanner.

Table 8. Ingress and egress detection units.

Location	Detectors
Ingress	Overhead Scanner Side Scanner Light Curtain
Egress	Overhead Scanner Side Scanner

Data was manually collected for each detector combination. These data was then used in the evaluation process to determine the performance of each combination. The manual data collection process began in the third week of November 2012 and continued over various periods until the end of January 2013. Initially, counts were performed on the ground using personnel to monitor the ingress and egress locations. After the CCTV video cameras were set up and the NVR began recording video, visual counts were able to be done remotely by monitoring live and recorded video of the field CCTV cameras. Camera video was viewed using proprietary video surveillance software.

The software provided a live stream of the cameras at both the ingress and egress gantries (to monitor vehicles entering and leaving the rest area), as well a stream of each of the other cameras (to verify the number of vehicles parked in the lot). Video from each camera was also recorded digitally for future playback. The video player software provided the capability to watch several weeks' worth of historical video from a remote location and the ability to review data from varying dates in order to achieve a complete dataset. The person assigned as counter was able to watch the live video and manually record each ingress and egress, as well as the corresponding vehicle classification. Table 9, Table 10, and Table 11 contain the date and time of each manual count, the date on which it was performed, and the detector combination used at the time of the count.

Table 9. Manual data collection schedule (OH/OH scanner combination).

Date	Time Period	Date Performed	Collection Method	Ingress Count	Egress Count
11/18/2012	12–8 p.m.	11/18/2012	Field	142	142
11/19/2012	5–9 a.m.	11/19/2012	Field	47	66
11/19/2012	9 p.m.–1 a.m.	11/19/2012	Field	59	29
11/20/2012	4 p.m.–12 a.m.	11/20/2012	Field	144	117
11/21/2012	5–10 a.m.	11/21/2012	Field	66	99
12/6/2012	5–12 a.m.*	1/14/2012	Video	358*	359*
12/7/2012	12–3 a.m.*	1/15/2012	Video	358*	359*
12/7/2012	5–9 AM	1/15/2012	Video	76	110
12/7/2012	9 p.m.–12 a.m.	1/17/2012	Video	31	19
12/10/2012	5–8 a.m.	1/18/2012	Video	34	49
12/21/2012	5 a.m.–1 p.m.	12/21/2012	Video	103	131
12/26/2012	12–5 p.m.	12/26/2012	Video	78	83
12/28/2012	11 a.m.–3 p.m.	12/28/2012	Video	60	63
			Total:	**1,199**	**1,267**

Note: *Denotes a contiguous period across days.

Table 10. Manual data collection schedule (SID/OH scanner combination).

Date	Time Period	Date Performed	Collection Method	Ingress Count	Egress Count
12/10/2012	1–5 p.m.	12/10/2012	Video	74	78
12/10/2012	9 p.m.–12 a.m.	1/18/2012	Video	42	14
12/11/2012	4 p.m.–12 a.m.	12/11/2012	Video	120	82
12/12/2012	5 a.m.–1 p.m.	12/12/2012	Video	150	179
12/13/2012	5–12 a.m.*	12/13/2012	Video	382*	386*
12/14/2012	12–6 a.m.*	12/13/2012	Video	382*	386*
12/17/2012	1–5 p.m.	12/17/2012	Video	92	84
12/18/2012	5–10 a.m.	12/18/2012	Video	84	121
12/18/2012	6–9 p.m.	12/18/2012	Video	63	55
1/3/2013	5–10 a.m.	1/3/2013	Video	67	91

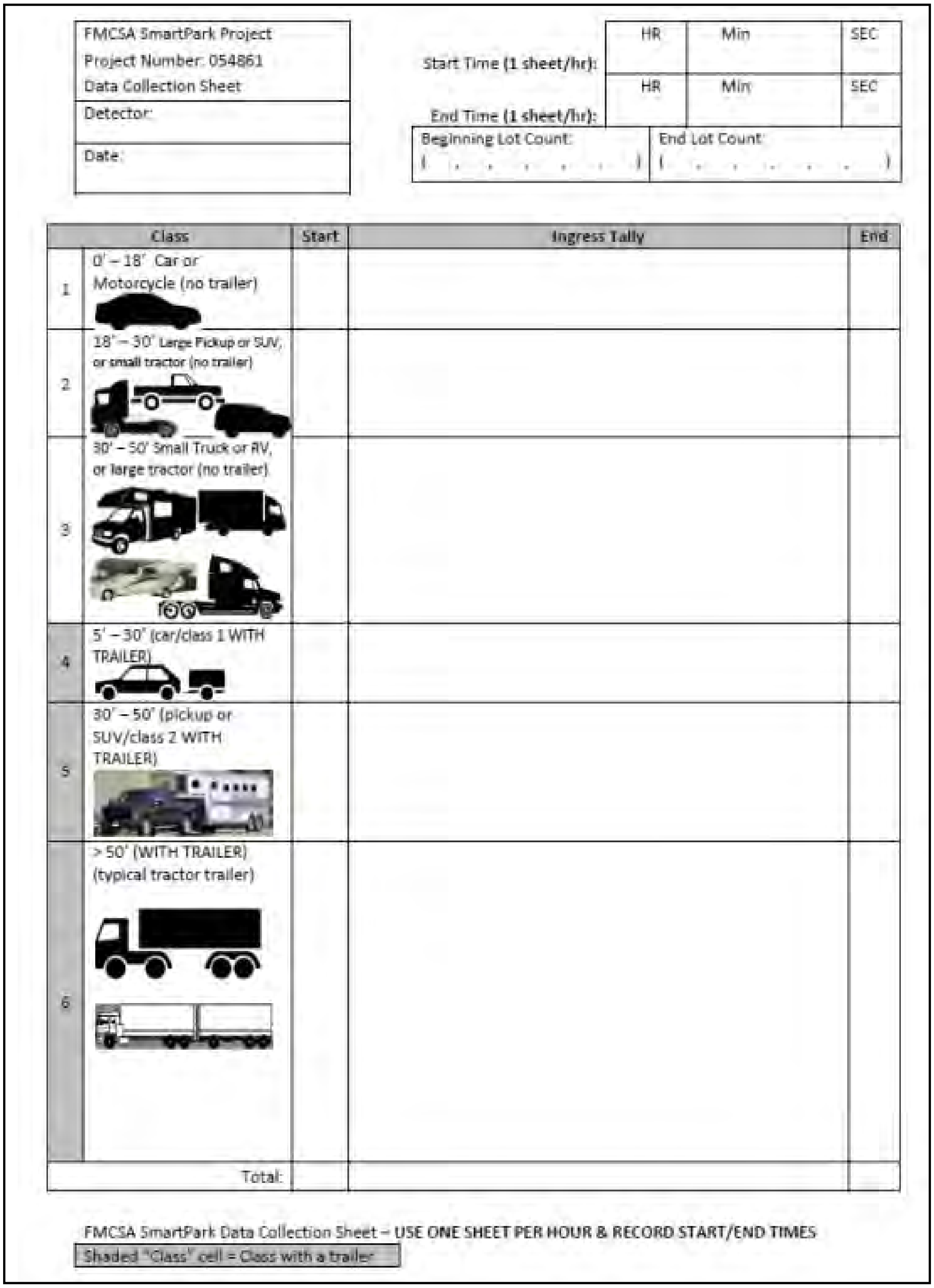
Date	Time Period	Date Performed	Collection Method	Ingress Count	Egress Count
1/3/2013	9 p.m.–12 a.m.	1/3/2013	Video	29	17
1/4/2013	5 a.m.–1 p.m.	1/4/2013	Video	125	150
			Total:	**1,228**	**1,257**

Note: *Denotes a contiguous period across days.

Table 11. Manual data collection schedule (OH scanner/CUR combination).

Date	Time Period	Date Performe d	Collection Method	Ingress Count	Egress Count
1/10/2013	2–12 p.m.	1/22/2013	Video	170	147
1/14/2013	5–10 a.m.	1/22/2013	Video	61	76
1/14/2013	6 p.m.–12 a.m.	1/23/2013	Video	98	58
1/15/2013	5–10 a.m.	1/23/2013	Video	81	117
1/15/2013	6–12 p.m.	1/23/2013	Video	92	58
1/16/2013	5–10 a.m.	1/24/2013	Video	86	120
1/16/2013	10 a.m.–1 p.m.	1/25/2013	Video	54	57
1/16/2013	6 p.m.–12 a.m.	1/24/2013	Video	100	62
1/17/2013	5–12 a.m.	1/17/2013	Video	324	341
			Total:	**1066**	**1036**

Each count was performed using the data-recording sheet shown in Figure 19. The person assigned as counter used one data-recording sheet per hour and tallied each event in the section of the sheet corresponding to the appropriate class. The project staff member made note of the number of vehicles parked in the rest area at the beginning and end of each hour, and the exact start and end time for each count. This information was then compared to the system data to compare the accuracy of each detector combination. Data was collected for each detector combination until at least 1,040 vehicle ingress events were recorded. The overall number, 1,040, was the number determined to be the minimum statistically-significant sample size. However, the detector data was compiled from various periods, adversely affecting the overall statistical significance. To enhance the significance of the samples, a sample size of at least 320 vehicles for at least one period within the data collection phase was included in the analysis.



FMCSA SmartPark Project
Project Number: 054861
Data Collection Sheet
Detector:
Date:

	HR	Min	SEC
Start Time (1 sheet/hr):			
End Time (1 sheet/hr):			

Beginning Lot Count: (, , , , ,) End Lot Count: (, , , , ,)

	Class	Start	Ingress Tally	End
1	0' – 18' Car or Motorcycle (no trailer)			
2	18' – 30' Large Pickup or SUV, or small tractor (no trailer)			
3	30' – 50' Small Truck or RV, or large tractor (no trailer)			
4	5' – 30' (car/class 1 WITH TRAILER)			
5	30' – 50' (pickup or SUV/class 2 WITH TRAILER)			
6	> 50' (WITH TRAILER) (typical tractor trailer)			
	Total:			

FMCSA SmartPark Data Collection Sheet – USE ONE SHEET PER HOUR & RECORD START/END TIMES
Shaded "Class" cell = Class with a trailer

Figure 19. Manual count data recording sheet.

3.4 ISSUES ENCOUNTERED

3.4.1 Vehicle Obstruction

Using video to conduct manual counts led to several issues. Being in a remote location, the viewer was not able to walk through the site and visually confirm the presence or absence of vehicles. The way the CCTV cameras were oriented, it was possible for the presence of one tractor-trailer to obstruct the view of the space next to it. As a result, when parked next to large tractor-trailers, smaller vehicles would not be visible to the person assigned as counter. This presented an issue when performing the initial and final counts of the system for the periods listed in Table 9, Table 10, and Table 11.

To resolve this issue during a period of manual counting, the person assigned as the counter would monitor the spaces as large vehicles left the site. If the vehicle revealed a smaller vehicle behind it, and that vehicle was not observed entering the site during the testing period, that vehicle would be recorded as part of the initial count for that period. This methodology minimized the issues presented by vehicle obstruction.

3.4.2 Clarity of Spaces

When viewing the video feeds, it was sometimes unclear where the field of view of one camera began and the other ended. This sometimes resulted in double counting of vehicles (counting them once from one camera and again while viewing the neighboring camera). This issue was particularly prominent when toggling between views from cameras one and two, two and three, and three and four. This issue was minimized by experience of the person assigned as counter. Eventually, the person assigned as counter became aware of where spaces started and ended for each camera view.

To mitigate confusion in future phases of SmartPark, spaces in the lot will have some sort of pavement marking to more easily distinguish among them in the video.

3.4.3 Nighttime Visibility

When conducting counts at night, the nighttime resolution of the camera made it difficult to accurately identify vehicles and vehicle classifications. Figure 20 displays a nighttime camera view from Camera 4. While the image has decent resolution, it displays the difficulty of counting vehicles at night, given the shadows, vehicle obstructions, low light, and vehicles parked illegally behind the delineated spaces. These issues were of particular concern when performing counts at the beginning and end of a count period. To avoid this, manual counts were either started or ended during daylight hours wherever possible. Using this methodology, the vehicle counts at the beginning and end of a count period could be compared and corroborated with the number of detections. Once the data was collected for a given period, the corrective analysis was completed to make certain that the number of ingresses and the number of vehicles at the site in the beginning of the period were equal to the number of egresses and number of vehicles in the lot at the end of the period.

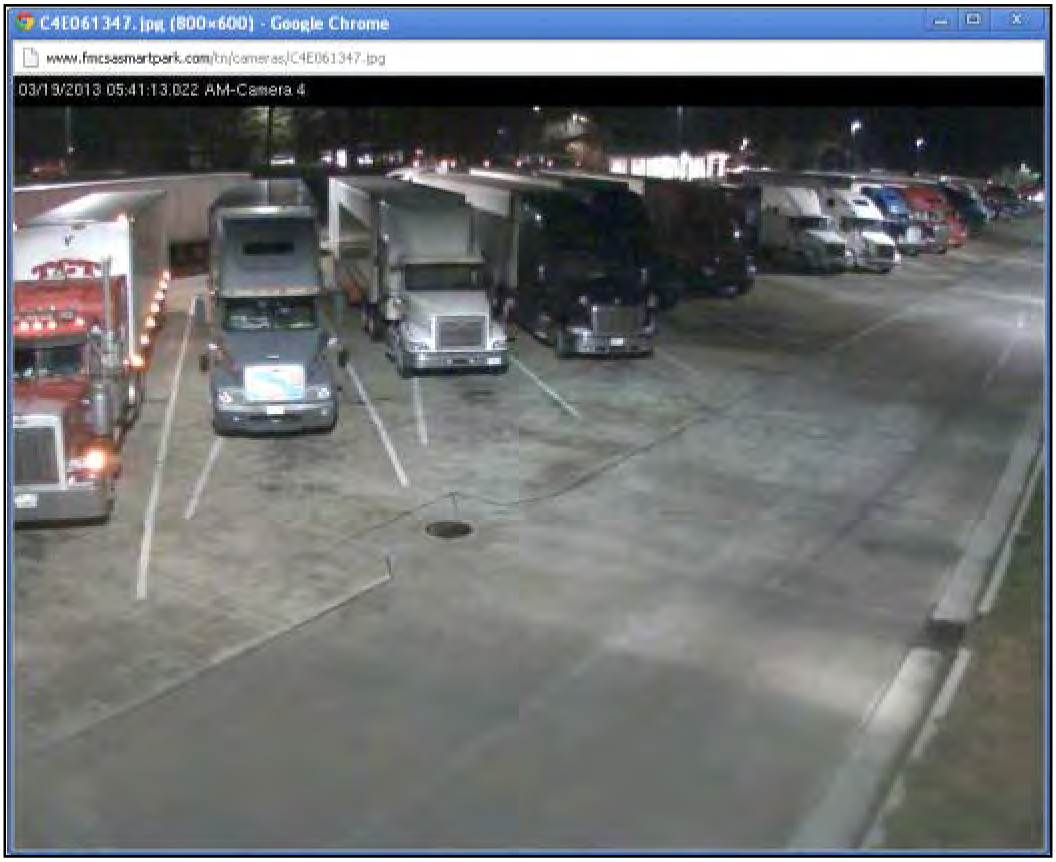


Figure 20. Photo. Nighttime view of the parking lot from camera 4.

3.4.4 Data Collection System Schedule

Over the 6-month testing period, data was consistently gathered and stored in the data collection database. A dataset was compiled for analysis for each of the detector combinations, omitting any system outage that occurred and any time that the system was taken offline for maintenance. The date ranges for each of the detector combinations are displayed in Table 12. The table represents the datasets that will be used for analysis in the evaluation of system performance, specifically PR1 and PR2.

Table 12. Date ranges by detector combination for system performance analysis.

Detector Combination	Period Name	Date Range
Overhead Scanner/Overhead Scanner	OO1	11/09/12–11/22/12
Overhead Scanner/Overhead Scanner	OO2	12/03/12–12/10/12
Overhead Scanner/Overhead Scanner	OO3	12/20/12–12/27/12
Overhead Scanner/Overhead Scanner	OO4	12/28/12–01/02/13
Overhead Scanner/Overhead Scanner	OO5	01/23/13–02/22/13
Light Curtain/Overhead Scanner	CO1	11/26/12–11/28/12
Light Curtain/Overhead Scanner	CO2	12/27/12–12/28/12
Light Curtain/Overhead Scanner	CO3	01/10/13–01/23/13
Light Curtain/Overhead Scanner	CO4	03/04/13–03/19/13

Detector Combination	Period Name	Date Range
Side Scanner/Side Scanner	SS1	11/28/12–11/28/12
Side Scanner/Side Scanner	SS2	12/10/12–12/19/12
Side Scanner/Side Scanner	SS3	01/02/13–01/10/13
Side Scanner/Side Scanner	SS4	02/22/13–03/04/13
Side Scanner/Side Scanner	SS5	3/29/13–4/10/13
Light Curtain/Side Scanner*	N/A	11/28/12–12/03/12
Light Curtain/Side Scanner*	N/A	12/19/12–12/20/12

*Note: The light curtain/side scanner combination was not part of the original testing program. However, it was activated to gather some data for possible future analysis. This data was not compiled and analyzed in this report, but it is available for further evaluation.

The data ranges from November 9, 2012 to April 10, 2013, and excludes system outages and offline periods. The testing period began on November 9, 2012 because prior to this date, the system underwent a general troubleshooting and issue correction period. Prior to November 9, 2012, the detectors were not considered ready for data gathering.

3.5 SYSTEM OUTAGES

Several system outages occurred during the testing period. System outages can be caused by any number of issues, but are generally categorized as one of the following:

- **Environmental:** Weather conditions such as snow, ice, or extreme temperatures causing the system to malfunction for a long period of time.
- **Physical:** A physical issue with the equipment, such as an impact to a detector by a truck, or vandalism.
- **Communications:** Loss of communication with the testing equipment caused by a failure of the leased line to the site.
- **Configuration:** An error as a result of one of the technological components of the system, such as a software issue, a data processing issue, a Web site issue, or a network issue.

Data gathered during periods of system outages will not be included in the system performance evaluation for PR1 or PR2. A summary of the outage periods is displayed in Table 13. .

Table 13. SmartPark system outages.

Detector Combination	Outage Date Range	Duration	Category	System Outage/Issue
Overhead Scanner/Overhead Scanner	11/15/2012	0 days 3.5 hours	Configuration	Software algorithm anomaly. Software update applied.
Overhead Scanner/Overhead Scanner	11/22/2012–11/26/2012	3 days 22 hours	Configuration	Software issue. Software update applied.

Detector Combination	Outage Date Range	Duration	Category	System Outage/Issue
Light Curtain/Overhead Scanner	1/18/2013–1/23/2013	5days 15 hours	Environmenta l	Ice buildup prevented curtain detection.
Light Curtain/Overhead Scanner	3/5/2013–3/29/2013	24 days	Physical	Doppler radar removed from pole and unplugged from system due to possible vandalism or truck impact. Radar was remounted.
Light Curtain/Side Scanner	11/29/2012	10 hours	Configuration	Doppler radar at ingress malfunctioned. A server reset was performed.
	Total:	**34 days 3 hours**		

4. RESULTS

4.1 DATASETS FOR ANALYSIS

At the conclusion of the testing period, data was extracted from the system for analysis. Different datasets were used to analyze different PRs. Datasets may have omitted certain periods of operation if they were not applicable to the analysis of a PR.

4.1.1 Performance Requirement 1

PR1 pertains to accuracy. It states, "The system shall maintain the parking area occupancy count to better than 95-percent accuracy." Accuracy is dependent upon two primary points of analyses:

- Vehicle Detection Accuracy: How accurate are the detectors at detecting vehicles?
- System Performance: How accurate is the lot count that is displayed on the project Web site?

The above analysis considered the full period of testing for each of the detector combinations wherein the system was in normal operation. The periods of testing that were evaluated included the periods identified in Table 12, not counting the outage periods identified in Table 13. During the outage periods, the system experienced an extraordinary, non-functioning mode and the accuracy of the system was implicitly in error; therefore, it was omitted from the evaluation.

4.1.2 Performance Requirement 2

PR2 pertains to classification consistency. It states, "The ingress and egress detectors must be consistent in classification with each other to a level of 95 percent."

To effectively evaluate the system with respect to this PR, the dataset for each of the detector combinations included the full period of testing during which the system was in normal operation. Similar to the dataset for PR1, the periods of testing that were evaluated included the periods identified in Table 12 not counting the outage periods identified in Table 13.

4.1.3 Performance Requirement 3

PR3 pertains to system availability. It states: "The system shall provide parking availability information at a minimum of 99.5 percent of the time." The analysis to evaluate performance of the system against PR3 included the entire test period from November 9, 2012 through April 10, 2013, with the exception of the periods where the system was experiencing any "physical outage," as defined in the previous section. The dataset thus excluded the 24-day period in March 2013, when the Doppler radar unit had been vandalized.

The physical outage experienced in March of 2013 was longer than a typical outage due to unavailability of staff to repair the damaged infrastructure. The Doppler radar was removed from the mounting structure and was found on the ground nearby the pole. The cause of the damage is unknown; however, it can presumably be attributed to either vandalism or impact by a passing vehicle. Outages caused by vandalism and collisions were omitted from the PR3 analysis because the period of these types of outages do not represent normal operations and were caused by external factors outside the control of the system.

4.2 REST AREA USAGE DATA

The rest area at MM 45 was selected for this project for a variety of reasons, including its high usage rate. When investigating whether or not the site was suitable for the project and met the RFP requirements, the project team gathered anecdotal evidence of the site's overcrowding/use from the rest area manager and staff.

The data collected throughout the testing period corroborates the heavy usage of the site. The graph displayed in Figure 21 demonstrates average usage (parking lot occupancy) on an hour-by-hour basis for the duration of the test period ranging from November 9, 2012 to April 10, 2013. The graph displaying average usage demonstrates that the site typically approaches the maximum capacity of the lot, which is 44 spaces. The graph shows that the peak hours of operation are from approximately 8 p.m. (hour 20) to 8 a.m. the next day.

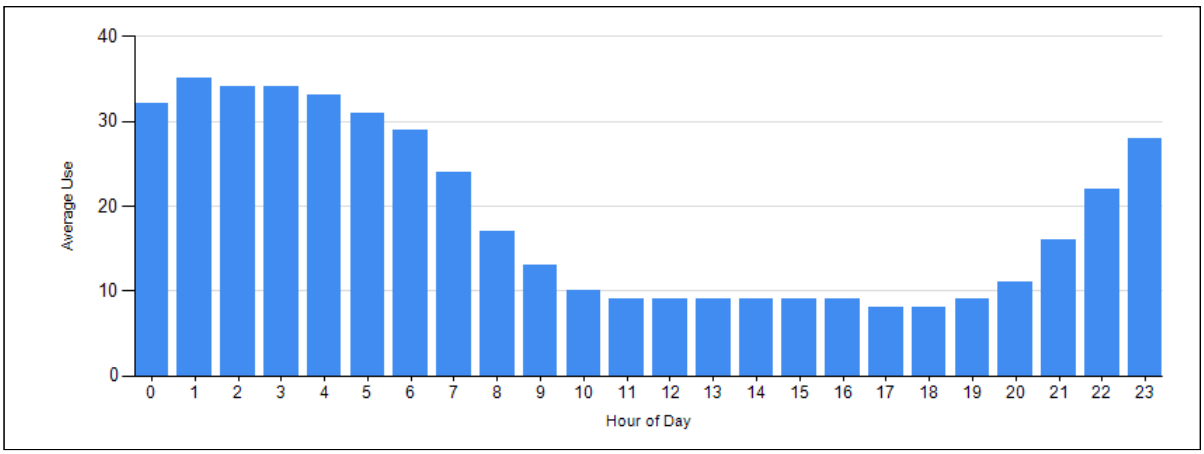


Figure 21. Bar graph. Average of parking space usage by hour of day over test period (24-hour clock time is being used).

4.3 PERFORMANCE REQUIREMENT ANALYSIS

Each of the PRs was evaluated separately using the datasets as described above. The equations and methodologies used to perform the analyses were documented in the Evaluation Plan submitted to FMCSA.

4.3.1 Performance Requirement 1

There were two components involved in the evaluation of PR1.

- **Vehicle Detection Accuracy:** Determining the accuracy of the units to detect vehicles.
- **System Performance:** Determining performance of the system as a whole by measuring the accuracy of the lot usage statistic presented on the system Web site.

4.3.1.1 Vehicle Detection Accuracy

To determine vehicle detection accuracy of the equipment, manual observations were conducted for a minimum of 1,040 vehicles at the ingress and egress of each detector combination. These observations were then compared to the detections logged in the system database contained in the data retrieval page of the project Web site.

Results for the vehicle detection accuracy are summarized in Table 14, Table 15, and Table 16. Accuracy was calculated according to the equations in Figure 22. The equation was applied to both the ingress and egress detectors in each of the detector combinations.

Table 14. OH/OH vehicle detection accuracy summary.

Class	Total Observed Ingresses	Total Observed Egresses	Total System Ingresses	Total System Egresses
1	20	19	16	22
2	16	16	41	35
3	18	19	3	2
4	78	76	102	118
5	88	92	35	28
6	9,76	1,040	1,002	1,062
Totals:	**1,196**	**1,262**	**1,199**	**1,267**

Total Ingress Error: 11—0.92%
Total Egress Error: 8—0.63%
Total Ingress Accuracy Rate: 99.08%
Total Egress Accuracy Rate: 99.37Total System Accuracy: 99.23%

Table 15. SID/SID vehicle detection accuracy summary.

Class	Total Observed Ingresses	Total Observed Egresses	Total System Ingresses	Total System Egresses
1	8	8	10	12
2	21	20	45	41
3	28	30	2	1
4	70	77	117	119
5	62	57	7	11
6	1,046	1,059	1,047	1,073
Totals:	**1,235**	**1,251**	**1,228**	**1,257**

Total Ingress Error: 7—0.57%
Total Egress Error: 12—0.96%
Total Ingress Accuracy Rate: 99.43%
Total Egress Accuracy Rate: 99.04%
Total System Accuracy: 99.24%

Table 16. CUR/OH vehicle detection accuracy summary.

Class	Total Observed Ingresses	Total Observed Egresses	Total System Ingresses	Total System Egresses
1	7	7	13	10
2	19	18	58	30
3	1	0	8	4
4	79	82	72	89
5	36	39	8	12
6	929	896	907	891

Total Ingress Error: 9
Total Egress Error: 8
Total Ingress Accuracy Rate: 99.16%
Total Egress Accuracy Rate: 99.23%
Total System Accuracy: 99.2%

$$A = 1 - \left| \frac{\sum |observed\ errors|}{in_{obs}} \right|$$

- Where A = accuracy of the detection unit being evaluated.
- Observed errors = the number of errors (missed detections or double detections) observed during field count.
- in_{obs} = ingresses observed in the field (presumed to have a very high level of accuracy).

Figure 22. Formula. Vehicle detection accuracy equation.

All detector combinations performed well within the PR of 95-percent accuracy. Furthermore, they all performed with minimal error of less than 1 percent.

The sample size of 1,040 vehicles for each detector combination was compiled from a number of periods of observation. The number of periods and the quantities of vehicles identified in those periods varied based on the detector combination. The total number of errors that occurred over all the data collection periods is displayed in each of the results tables. During some periods, the errors were negative and during others, they were positive. As shown in the equation in Figure 22 the absolute value of these errors was used in the vehicle detection accuracy calculation.

Findings from an external, third party analysis of the data resulted in a significant level of accuracy. Based on these encouraging external results, a 95-percent confidence level was determined to be acceptable when determining the uncertainty limits of the vehicle-detection accuracy results. To achieve a confidence level of 95 percent, a minimum of 350 vehicles were gathered during at least one contiguous period of manual data collection for each combination, with the exception of the CUR/OH. Table 17 displays the sample sizes collected and the margins of error or confidence intervals for each of the detector combination results with a confidence level of 95 percent.

From the analysis presented in Table 17 it can be determined that the vehicle detection accuracy rates are—with a 95-percent confidence level—within the margin of error identified for each of the detectors. While the error rates for the vehicle detection accuracy analysis (for each of the detectors) is within 1 percent, the margin of error indicates that the actual rates may be greater than this.

Table 17. Sample sizes and margins of error at a 95-percent confidence level.

Detector Combination	Sample Size Ingress	Sample Size Egress	Margin of Error Ingress	Margin of Error Egress
Overhead Scanner/Overhead scanner	386	391	4.94%	4.91%
Side Scanner/Side Scanner	382	386	4.97%	4.94%
Light Curtain/Overhead Scanner	324	341	5.40%	5.26%

4.3.1.2 System Performance

The system performance analysis examines the entire period of testing for each of the detector combinations, which includes a much larger sample size than the evaluation of vehicle detection accuracy. The analysis for system performance is based upon the number of compiled "corrections" made to the system throughout the test period, and the total volume of vehicles to pass through the detection units.

System corrections are defined as the manual adjustments made to the system during the testing period, wherein the system count was adjusted or corrected to match the actual conditions. Corrections were made using real-time streaming video as a means of determining the number of vehicles in the lot. Manual corrections were made through an interface on the project Web site.

The volume component of the calculation relies on a presumed rate of error of the detection units determined in the vehicle detection portion of the analysis. Volumes extracted from the system are presumed to have an error rate comparable to the rate determined through manual observation and inspection. The equations used to determine system performance are defined in Figure 23, Figure 24, and Figure 25.

$$E = \sum |System\ Corrections|$$
$$V = \{in * c_{in} + eg * c_{eg}\}$$

- Where: E = system error
- Where: V = volume; in = ingresses; eg = egresses; c_{in} = ingress correction factor; c_{eg} = egress correction factor.

Figure 23. Formula. System performance error and volume equations.

The ingress and egress correction factors are defined in Figure 24.

$$c_{in} = 1 - \frac{(in_d - in_{obs})}{in_{obs}}$$
$$c_{eg} = 1 - \frac{(eg_d - eg_{obs})}{eg_{obs}}$$

- Where in_d = ingresses detected; in_{obs} = ingresses observed; eg_d = egresses detected; and eg_{obs} = egresses observed.

Figure 24. Formula. Ingress and egress correction factor equations.

$$R = E/V$$
$$A = 1 - R$$

- Where R = error rate; E = system error; V = volume; and A = accuracy.

Figure 25. Formula. Error and accuracy rate equations.

The correction factors used in the equations above were derived from the vehicle detection data presented earlier. The correction factors are displayed in Table 18.

Table 18. Correction factors.

Overhead Scanner Detector	C_{in}	0.998
Overhead Scanner Detector	C_{eg}	0.993
Side Scanner Detector	C_{in}	1.007
Side Scanner Detector	C_{eg}	0.994
Light Curtain Detector	C_{in}	1.005

The correction factors were included in the initial formulas to account for any systematic error observed while determining vehicle detection accuracy. Systematic error is defined as the tendency for the detector to err in one direction or another—either systematically missing vehicle detections or double counting vehicles. Correction factors were calculated from more than 1,000 vehicles observed at each of the detector locations. As shown in Table 18, all the correction factors are within 0.007 of 1, indicating that very minimal systematic error was witnessed during the data gathering period. Due to the closeness of the correction factor to one, it was assumed to be one for all calculations performed in this report.

Each of the detector combinations was tested across multiple time periods within the overall testing schedule. The results from each of the periods were calculated, and then were compiled to determine a final overall system performance number. A summary of the results is located in Table 19.

Table 19. System performance summary.

Detector Combination	Total Errors E	Total Volume V	Error Rate R	Accuracy Rate A
Overhead Scanner/Overhead Scanner	58	37,703	0.154%	99.86%
Side Scanner Detector/Side Scanner Detector	53	29,094	0.182%	99.818%
Light Curtain Detector/Overhead Scanner Detector	54	8,150	0.66%	99.34%

Detailed breakdowns of the system performance results by detector combination are located in Table 20, Table 21, and Table 22. Each of these tables provides a detailed log of the data from each of the testing periods of each of the detector combinations. The tables contain details regarding each of the testing periods, such as the number of ingress and egress detections, the accuracy for the period, and the ingress and egress accuracy breakdown.

Table 20. Overhead Scanner/Overhead Scanner Detector System performance results.

Period	Date Range	Total Errors	Net Detections: Ingresses	Net Detections: Egresses	Total Volume	Error Ratio Per Ingress	Error Ratio Per Egress	Total Period Error Ratio
OO1	11/09/12–11/22/12	18	4,648	4,630	9,278	0.389%	0.387%	0.19%
OO2	12/03/12–12/10/12	4	2,388	2,377	4,765	0.168%	0.168%	0.08%
OO3	12/20/12–12/27/12	5	1,230	1,223	2,453	0.407%	0.409%	0.20%
OO4	12/28/12–01/02/13	4	1,001	1,013	2,014	0.400%	0.395%	0.20%
OO5	01/23/13–02/22/13	27	9,595	9,598	1,9193	0.281%	0.281%	0.14%
Total:		**58**	**18,862**	**18,841**	**37,703**			**Average: 0.154%**

Table 21. Light Curtain Scanner/Overhead Scanner Detector System performance results.

Period	Date Range	Total Errors	Net Detections: Ingresses	Net Detections: Egresses	Total Volume	Error Ratio Per Ingress	Error Ratio Per Egress	Total Period Error Ratio
CO1	11/26/12–11/28/12	29	855	829	1,684	3.392%	3.498%	1.72%
CO2	12/27/12–12/28/12	2	247	243	490	0.810%	0.823%	0.41%
CO3	01/10/13–01/18/13	20	2,458	2418	4,876	0.814%	0.827%	0.41%
CO4	03/04/13–03/05/13	3	558	542	1,100	0.538%	0.554%	0.27%
	Total:	**54**	**4,118**	**4,032**	**8,150**			**Average: 0.66%**

Table 22. Side Scanner Detector/Side Scanner Detector System performance results.

Period	Date Range	Total Errors	Net Detections: Ingresses	Net Detections: Egresses	Total Volume	Error Ratio Per Ingress	Error Ratio Per Egress	Total Period Error Ratio
SS1	11/28/12	3	77	73	150	3.896%	4.110%	2.00%
SS2	12/10/12–12/19/12	26	3,181	3,156	6,337	0.817%	0.824%	0.41%
SS3	01/02/13–01/10/13	12	2,668	2,653	5,321	0.450%	0.452%	0.23%
SS4	02/22/13–03/04/13	3	3,378	3,368	6,746	0.089%	0.089%	0.04%
SS5	3/29/2013–4/10/2013	9	5,274	5,266	10,540	0.171%	0.171%	0.09%
Total:		**53**	**14,578**	**14,516**	**29,094**			**Average: 0.182%**

The system, including each detector configuration, far exceeded the performance target for PR1. The rest area chosen experiences a large number of vehicles on a daily basis, which would figure into the practical application of this error rate. On a typical day, approximately 330 vehicles pass through the site. For practical use, the error rates for each of the detection units were converted to per-vehicle rates by dividing the number of errors by the number of vehicles to pass through the site during the testing phase. The number of vehicles to use the site during the testing phase is estimated by dividing the total volume used in the PR1 calculation by two, which represents a vehicle entering and exiting the site.

The basis of PR1 is that the system may experience no more than a 5 percent error. Applying this from an operations standpoint, a 5 percent error means that the system is incorrect by approximately 2 out of the 44 spaces. At the error rates experienced during the test period, the site would hit the 5 percent error mark every 2 days using the OH/OH combination, every 1.5 days using the SID/SID combination, and twice per day using the CUR/OH configuration. These rates are displayed in Table 23. While all three detector combinations operated above 99-percent accuracy, the difference between the accuracy of the curtain and the overhead and side scanners is stark on a day-to-day basis.

Table 23. Error rates by vehicles.

Detector Combination	Error Rate
Overhead Scanner/Overhead Scanner	1 in 325 vehicles
Side Scanner/Side Scanner	1 in 275 vehicles
Light Curtain Scanner/Overhead scanner	1 in 75 vehicles

4.3.2 Performance Requirement 2

PR 2 is the measure of the ability of the detector combinations to classify vehicles similarly at both the ingress and egress locations. To complement this analysis, each detector's ability to accurately classify vehicles was first determined from the manual count data collected from the vehicle detection accuracy evaluation.

4.3.2.1 Classification Accuracy

Table 24, Table 25, and Table 26 display the results of classification accuracy for each of the three detector combinations. The tables describe the results in two ways: classification ratio and ingress and egress accuracy. The classification ratio describes whether the detector tended to underclassify or overclassify vehicles. Where a class has a ratio greater than one, the detector typically counted more vehicles in that class than actually entered the lot. Where a class has a ratio less than one, the detector typically counted fewer vehicles than actually entered the lot. The size of the ratio is directly proportional to how often the detector erred in classifications. The ingress and egress accuracy columns indicate how accurate the number of detections was for a given class within the testing period. The accuracy number was calculated by comparing the total detections identified by the SmartPark system with the total number of detections counted by personnel during each of the manual count periods (described in Table 9, Table 10, and Table 11). The error of the system is the difference between the manual counts and the system counts. Note that the total error is the absolute value of all instances of missed classifications and overclassifications. The accuracy numbers were calculated by compiling the errors from each of the manual count periods, then dividing by the total number of vehicles of that class that entered the lot according to the system. Where the number of errors was greater than the number of vehicles entering the lot (according to the system), the errors were instead divided by the number of vehicles that actually entered the lot (according to the manual counts).

The results presented in Table 24, Table 25, and Table 26 display general benchmarks for how well the SmartPark detectors classify vehicles according to the qualifiers contained in the classification scheme. Generally, none of the detectors are capable of classifying accurately under conditions where the classifications are based upon vehicle length and hitches. The obvious exception to this is the ability of each detector combination to classify Class 6 vehicles (large tractor-trailers).

Table 24. OH/OH combination classification accuracy.

Class	Ingress Errors Total	Egress Errors Total	Ingress Classification Ratio	Egress Classification Ratio	Ingress Accuracy	Egress Accuracy	Classification Accuracy Difference
1	9	8	0.76	1.10	43.75%	65.22%	21.47%
2	29	21	2.61	2.17	38.30%	46.15%	7.86%
3	16	17	0.16	0.15	15.79%	15.00%	0.79%
4	32	47	1.34	1.55	70.91%	62.99%	7.92%
5	58	66	0.38	0.32	38.30%	31.96%	6.34%
6	41	54	1.02	1.02	96.21%	95.28%	0.92%

Table 25. SID/SID combination classification accuracy.

Class	Ingress Errors Total	Egress Errors Total	Ingress Classification Ratio	Egress Classification Ratio	Ingress Accuracy	Egress Accuracy	Classification Accuracy Difference
1	8	4	1.25	1.50	20.00%	66.67%	46.67%
2	24	23	2.14	2.05	46.67%	43.90%	2.76%
3	27	32	0.07	0.03	6.90%	0.00%	6.90%
4	51	46	1.67	1.55	56.41%	61.34%	4.93%
5	55	50	0.11	0.19	11.29%	12.28%	0.99%
6	21	22	1.00	1.01	97.99%	97.95%	0.04%

Table 26. CUR/OH combination classification accuracy.

Class	Ingress Errors Total	Egress Errors Total	Ingress Classification Ratio	Egress Classification Ratio	Ingress Accuracy	Egress Accuracy	Classification Accuracy Difference
1	6	7	1.86	1.43	53.85%	30.00%	23.85%
2	39	20	3.05	1.67	32.76%	33.33%	0.57%
3	7	4	8.00	0.00	12.50%	0.00%	12.50%
4	27	15	0.91	1.09	62.50%	83.15%	20.65%
5	30	27	0.22	0.31	23.08%	30.77%	7.69%

Class	Ingress Errors Total	Egress Errors Total	Ingress Classification Ratio	Egress Classification Ratio	Ingress Accuracy	Egress Accuracy	Classification Accuracy Difference
6	26	17	0.98	0.99	97.13%	98.09%	0.96%

To determine classification consistency (also referred to as classification repeatability or similarity), the classification accuracy rates of the ingress and egress detectors were compared in the "Classification Accuracy Difference" columns in Table 24, Table 25, and Table 26. The difference in classification accuracy between the ingress and egress detectors for each combination provides an initial look at the repeatability of classes across the detectors. PR2 requires 95-percent accuracy in repeatability across the detectors. The classification accuracy difference numbers may only be as large as 5 percent to remain within the PR2 requirement. Across all 3 detector combinations, the "Classification Accuracy Difference" column (in Table 24, Table 25, and Table 26) shows that—this 95-percent consistency requirement was met in only 8 out of 18 types of classification (6 classes x 3 detector combinations = 18 total types of classification). However, these numbers provide just a benchmark for comparison, as the sample size gathered manually contained limited samples for Classes 1‒5.

4.3.2.2 Classification Consistency/Repeatability

To further analyze the SmartPark system's ability to classify vehicles consistently, a larger dataset was compiled and analyzed. Data from the SmartPark data collection system was compiled from each of the detector test periods from the 6-month testing period, as described in Table 12. The overall classification consistency calculation was then completed for each of the three datasets using the formulas in Figure 26. In addition, individual accuracy rates were calculated for each of the classes. Overall results are located in Table 27.

$$E_c = |in_c - eg_c|$$
$$V_c = \{in_c * c_{in} + eg_c * c_{eg}\}/2$$
$$R_c = E_c/V_c$$
$$A_c = 1 - R_c$$

- E_c = class error.
- A_c = accuracy of classifying Class “C” vehicles.
- R_c = error rate of classifying Class “C” vehicles.
- V_c = volume of Class “C” vehicles.
- in_c = ingresses in that class.
- eg_c = egresses in that class.
- c_{in} = ingress correction factor.
- c_{eg} = egress correction factor.

Figure 26. Formula. Classification consistency/repeatability equations.

Note that all correction factors are equal to one for this analysis due to the absence of any systematic error in the data.

In the results table, the errors represent the sum of the misclassifications across all periods. For this quantity, the absolute value of the miscalculations from each period was used to obtain a more accurate estimate of the error rate. Using this approach, periods that experienced positive error rates do not negate periods that experienced negative error rates.

Table 27. Class consistency results summary.

	Class	E_c	V_c	R_c	A_c
Overhead Scanner Detector/Overhead scanner detector	1	31	244	12.70%	87.30%
Overhead Scanner Detector/Overhead scanner detector	2	35	578	6.06%	93.94%
Overhead Scanner Detector/Overhead Scanner Detector	3	18	72	25.00%	75.00%
Overhead Scanner Detector/Overhead Scanner Detector	4	161	1,588	10.14%	89.86%
Overhead Scanner Detector/Overhead Scanner Detector	5	135	407	33.17%	66.83%
Overhead Scanner Detector/Overhead Scanner Detector	6	63	15,965	0.39%	99.61%
OH/OH	**Total**	**443**	**18,854**	**2.35%**	**97.65%**
Side Scanner Detector/Side Scanner Detector	1	38	178	21.35%	78.65%
Side Scanner Detector/Side Scanner Detector	2	156	588	26.53%	73.47%

	Class	E_c	V_c	R_c	A_c
Side Scanner Detector/Side Scanner Detector	3	20	28	71.43%	28.57%
Side Scanner Detector/Side Scanner Detector	4	124	1,668	7.43%	92.57%
Side Scanner Detector/Side Scanner Detector	5	40	232	17.24%	82.76%
Side Scanner Detector/Side Scanner Detector	6	166	11,864	1.40%	98.60%
SID/SID	**Total**	**544**	**14,558**	**3.74%**	**96.26%**
Light Curtain Detector/Overhead Scanner Detector	1	77	82	93.90%	6.10%
Light Curtain Detector/Overhead Scanner Detector	2	80	167	47.90%	52.10%
Light Curtain Detector/Overhead Scanner Detector	3	18	22	81.82%	18.18%
Light Curtain Detector/Overhead Scanner Detector	4	26	315	8.25%	91.75%
Light Curtain Detector/Overhead Scanner Detector	5	14	50	28.00%	72.00%
Light Curtain Detector/Overhead Scanner Detector	6	53	3,440	1.54%	98.46%
CUR/OH	**Total**	**268**	**4,076**	**6.58%**	**93.42%**

The results from the OH/OH and SID/SID detector combinations are highly favorable with respect to the overall accuracy rate. Individual accuracy rates vary somewhat across the classes. The systems' ability to classify very large vehicles (i.e., Class 6) is the most robust, and includes much larger sample sizes than the other classes. Results from some of the classes, such as Class 3, are based upon very small sample sizes, and as a result do not have a high degree of confidence.

Results from the CUR/OH detector combination show some obvious shortcomings in the system's ability to consistently classify smaller vehicles. This is a direct result of shortcomings with the installation of the system. A significant drawback of the CUR as it is configured at the site is that it is mounted such that the first light beam of the CUR is approximately 15 inches above the ground. This height causes the CUR to misclassify smaller vehicle/trailer combinations (such as Classes 3 and 5) because the hitch itself is lower than the CUR. As a result, the CUR counts the smaller vehicle and the trailer as two separate vehicles instead of one single vehicle with a trailer. An example of this is displayed in Figure 22, where a small, Class 5 pickup/trailer combination is split into a Class 2 vehicle and a Class 1 vehicle.

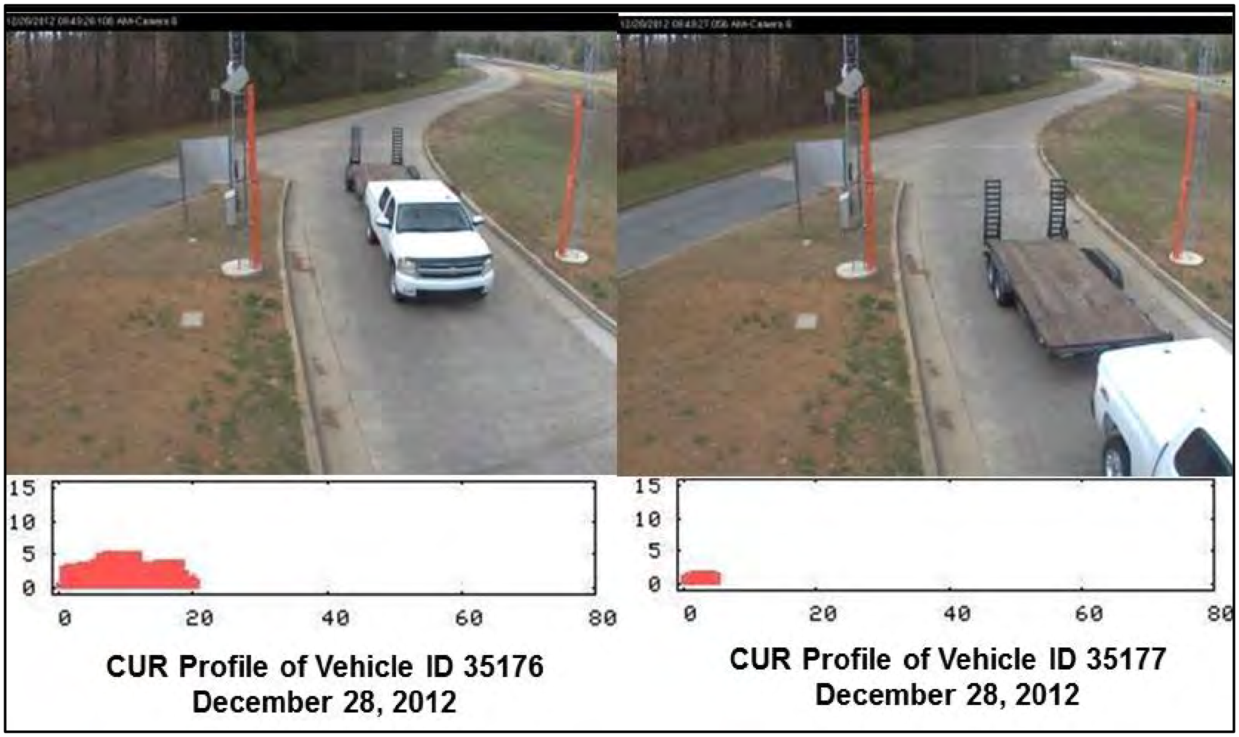


Figure 22 Grouped image. CUR double detection.

Once again, the CUR/OH combination is highly accurate when classifying larger, Class 6 vehicles. The combination reveals significant difficulty classifying smaller vehicles similarly across the ingress and egress.

More detailed data regarding the performance of the three detector combinations in relation to PR2 is displayed in Table 28, Table 29, and Table 30.

Table 28. OH/OH detector classification consistency by testing period.

Period	Class	Ingress	Egress	E_c	Abs (E_c)
OO1	1	20	21	-1	1
OO1	2	61	57	4	4
OO1	3	3	5	-2	2
OO1	4	174	192	-18	18
OO1	5	61	48	13	13
OO1	6	1,970	1,987	-17	17
OO2	1	39	37	2	2
OO2	2	80	80	0	0
OO2	3	10	15	-5	5
OO2	4	192	223	-31	31
OO2	5	81	51	30	30
OO2	6	1,853	1,845	8	8
OO3	1	3		3	3
OO3	2	1	2	-1	1
OO3	3			0	0
OO3	4	9	12	-3	3
OO3	5	3	1	2	2
OO3	6	70	72	-2	2
OO4	1	31	21	10	10
OO4	2	53	58	-5	5
OO4	3	1	5	-4	4
OO4	4	174	196	-22	22
OO4	5	52	34	18	18
OO4	6	2,077	2,063	14	14
OO5	1	42	42	0	0
OO5	2	58	52	6	6
OO5	3	12	10	2	2
OO5	4	123	144	-21	21
OO5	5	40	30	10	10
OO5	6	955	945	10	10
OO6	1	30	27	3	3
OO6	2	62	67	-5	5
OO6	3	19	16	3	3
OO6	4	97	112	-15	15
OO6	5	35	27	8	8
OO6	6	758	764	-6	6
OO7	1	81	93	-12	12
OO7	2	269	255	14	14
OO7	3	23	25	-2	2
OO7	4	738	789	-51	51
OO7	5	202	148	54	54
OO7	6	8,282	8,288	-6	6

Note: See Table 12. for the date range corresponding to the abbreviated code shown in the "Period" column.

Table 29. SID/SID classification consistency by testing period.

Period	Class	Ingress	Egress	E_c	Abs (E_c)
SS1	1			0	0
SS1	2	1	2	-1	1
SS1	3			0	0
SS1	4	8	6	2	2
SS1	5		1	-1	1
SS1	6	68	64	4	4
SS2	1	33	29	4	4
SS2	2	112	95	17	17
SS2	3	5	3	2	2
SS2	4	269	271	-2	2
SS2	5	18	30	-12	12
SS2	6	2744	2728	16	16
SS3	1	21	26	-5	5
SS3	2	93	74	19	19
SS3	3	5	5	0	0
SS3	4	241	226	15	15
SS3	5	18	25	-7	7
SS3	6	2,290	2,297	-7	7
SS4	1	32	50	-18	18
SS4	2	148	128	20	20
SS4	3	3	6	-3	3
SS4	4	370	379	-9	9
SS4	5	63	53	10	10
SS4	6	2,762	2,752	10	10
SS5	1	77	88	-11	11
SS5	2	271	249	22	22
SS5	3	11	18	-7	7
SS5	4	756	807	-51	51
SS5	5	128	126	2	2
SS5	6	4,031	3,978	53	53

Note: See Table 12 for the date range corresponding to the abbreviated code shown in the "Period" column.

Table 30. CUR/OH classification consistency by testing period.

Period	Class	Ingress	Egress	E_c	Abs (E_c)
CO1	1	51	7	44	44
CO1	2	38	27	11	11
CO1	3	10	3	7	7
CO1	4	53	58	-5	5
CO1	5	7	11	-4	4
CO1	6	696	723	-27	27
CO2	1	9	5	4	4
CO2	2	21	9	12	12
CO2	3		1	-1	1
CO2	4	29	34	-5	5
CO2	5	6	8	-2	2
CO2	6	182	186	-4	4
CO3	1	47	23	24	24
CO3	2	124	74	50	50
CO3	3	19	10	9	9
CO3	4	173	188	-15	15
CO3	5	25	33	-8	8
CO3	6	2,070	2,090	-20	20
CO4	1	13	8	5	5
CO4	2	24	17	7	7
CO4	3	1		1	1
CO4	4	48	47	1	1
CO4	5	5	5	0	0
CO4	6	467	465	2	2

Note: See Table 12 for the date range corresponding to the abbreviated code shown in the "Period" column.

4.3.3 Performance Requirement 3

PR3 is the measure of the proportion of time that the system was functional within the testing period. The evaluation for PR3 is confined to time periods wherein the system was in "typical operations," and no extraordinary circumstances were prevalent. The parameters for evaluation exclude periods where the system was deliberately taken offline or where there was physical damage to the system preventing it from functioning properly. The rationale for this is that the PR3 measure is being used to determine system reliability in a practical application. Reliability is based upon typical operations, and is independent of "acts of God" or periods where the system was deliberately offline for system calibration or adjustment.

Table 13 displays all the outages that occurred during the testing period (from November 9, 2012 through April 10, 2013). For the purposes of PR3 evaluation, the physical error (e.g., the Doppler radar being removed, see "Physical" under "Category" in Table 13) encountered in the month of

March is not counted toward the calculation. The periods of downtime contributing to the system uptime calculation are displayed in Table 31 .

Table 31. System downtime used in PR3 evaluation.

Detector Combination	Outage Date Range	Duration	Category	System Outage/Issue
OH/OH	11/15/2012	4 hours	Configuration	Software algorithm anomaly. Software update applied.
OH/OH	11/22/2012–11/26/2012	3 days 22 hours	Configuration	Software issue. Software update applied.
OH/OH	2/2/2013	1 hour	Configuration	There was a disruption in service at the ingress detector that prevented the system from acknowledging ingresses. Issue fixed itself.
CUR/OH	1/18–23/2013	5 days 15 hours	Environmental	Ice buildup prevented curtain detection.
CUR/SID	11/29/2012	10 hours	Configuration	Doppler radar at ingress malfunctioned
	Total Downtime:	**10 days**		

Based on the outages identified in Table 31 and the parameters for evaluation of PR3, there are 128 days within the project testing period that represent typical operations. The system uptime equation used to evaluate the system is displayed in Figure 28 and the system uptime statistics are presented in Table 32.

$$U = 1 - \frac{D}{T}$$

– Where U = uptime; D = downtime; T = total testing time.

Figure 28. Formula. Uptime calculation equation.

Table 32. System uptime (PR3) results.

Detector Combination	OH/OH	SID/SID	CUR/OH	Total
Total Testing Time (Days)	65	50	31	128
Downtime (Days)	4.167	0	5.625	9.79
System Uptime	93.59%	100.00%	81.86%	92.35%

The SID/SID combination met the system uptime requirement of 99.5 percent, while the other two experienced issues that prevented them from satisfying PR3. The downtime experienced by the CUR/OH combination was the result of environmental factors, as ice built up on the CUR. The downtime experienced by the overhead detector was the result of configuration issues that were fixed by implementing software fixes. Each repair to the system included preventative measures to reduce the probability of the issue occurring again.

4.4 DISCUSSION

4.4.1 Accuracy

Overall, the SmartPark system exceeded many of the PRs. All of the results are summarized in Table 33. The SID combination did satisfy PR3, while the other detectors encountered some issues and fell somewhat short. In addition, the CUR/OH detector combination did not meet the requirements for classification consistency, falling short by approximately 8 percent. However, the CUR results are skewed due to the installation at the site. The results of PR2 are very different when examined by class, as discussed in this section.

Table 33. Overall SmartPark results.

Performance Requirement	Performance Target	Detector	Actual Performance
PR 1	95%	OH/OH	99.85%
PR 1	95%	SID/SID	99.82%
PR 1	95%	CUR/OH	99.34%
PR 2	95%	OH/OH	97.64%
PR 2	95%	SID/SID	96.26%
PR 2	95%	CUR/OH	87.04%
PR 3	99.5%	OH/OH	93.59%
PR 3	99.5%	SID/SID	100%
PR 3	99.5%	CUR/OH	81.86%

4.4.2 Performance Requirement 1

As described in previous sections, in an operations environment where the system is actively in use, it would require monitoring and intervention by maintenance or operations personnel on a periodic basis. Based purely on the number of corrections made to the system during testing, the periods between corrections that would be required to maintain 95-percent accuracy vary from once every 2 days for the OH/OH combination to twice per day for the CUR/OH combination.

The PR1 analysis is based upon the number of corrections made to the system during the testing period. Using this logic, it is assumed that errors accumulate between corrections. Throughout the testing period, however, corrections were made at varying intervals for each of the detector combinations. As a result, there are sometimes gaps of several days between corrections. To evaluate the behavior of the system between these corrections, data was compiled for each of the testing periods, and errors were identified at 8-hour intervals between each correction. The errors were then plotted on a time versus error graph to determine the variability in errors over time.

When viewing error information distributed over time, one can see the variability of the detector error between the corrections made to the system. Graphs were generated for every test period for each of the three detector combinations. The graphs display the errors observed through the data collection system every 8 hours over the course of the testing periods, as well as any corrections made throughout the period. Errors were quantified by selecting a Vehicle ID from the data collection system on the SmartPark Web site, manually counting vehicles that can be seen in the images associated with that Vehicle ID, then comparing these manual counts to the lot usage number identified by the system. The difference between the manual and system counts is the presumed error at that particular point in time.

There are two possible sources of the variations displayed in the graphs: counting errors that occur when visually inspecting lot occupancy, and detector errors. Counting errors can occur due to issues described previously in the document, such as poor visibility of the spaces, occlusion of smaller vehicles behind larger vehicles, and poor nighttime visibility. Counting errors are intrinsic to the graphs presented here, as it would have taken significant effort to identify all possible errors and to correct for them. Counting errors may account for small peaks in the graphs between one or two points in time, but should not affect the overall trends presented in the data. Trends of error are manifestations of errors from the detectors themselves.

In the data presented here, positive errors are a result of the system displaying more vehicles in the lot than there actually are, while negative errors are a result of the inverse.

4.4.2.1 Overhead Scanner/Overhead Scanner Combination

Plots of error versus time for the OH/OH combination are displayed in Figure 23, Figure 24, Figure 25, Figure 26, and Figure 27.

The graphs depict “spikes” or oscillations of error between the times when corrections were made. These oscillations typically occur during overnight hours, when lot usage is at its highest. Generally, the peaks occur in the hours leading up to midnight and continue through the early morning. The simplest, most likely explanation of why this phenomenon occurs is that during hours of increased activity, errors are caused by vehicles being classified as two separate vehicles, and combination vehicles are being grouped together as single vehicles. When truckers follow each other closer than 10 feet, they have a higher likelihood of being grouped together as a single vehicle. Conversely, when trucks have particularly large spaces between the tractor and trailer, they have a higher likelihood of being grouped as two separate vehicles.

From the data presented, the largest spike in error over a single day is approximately four vehicles. Were the system to be incorrect by four vehicles, this would cause lot accuracy to decrease to 91 percent. As a result, the OH/OH combination should be monitored at least once per day in order to maintain an accuracy rate of 95 percent. However, while spikes of four vehicles in one 24-hour period do occur, they do not occur frequently, with only six instances over the entire testing period for the OH/OH combination.

The only instance of a jump in error greater than four occurs in Figure 27. This caused a system error that lasted for 1 hour, and it skewed the count within the lot until a correction was made.

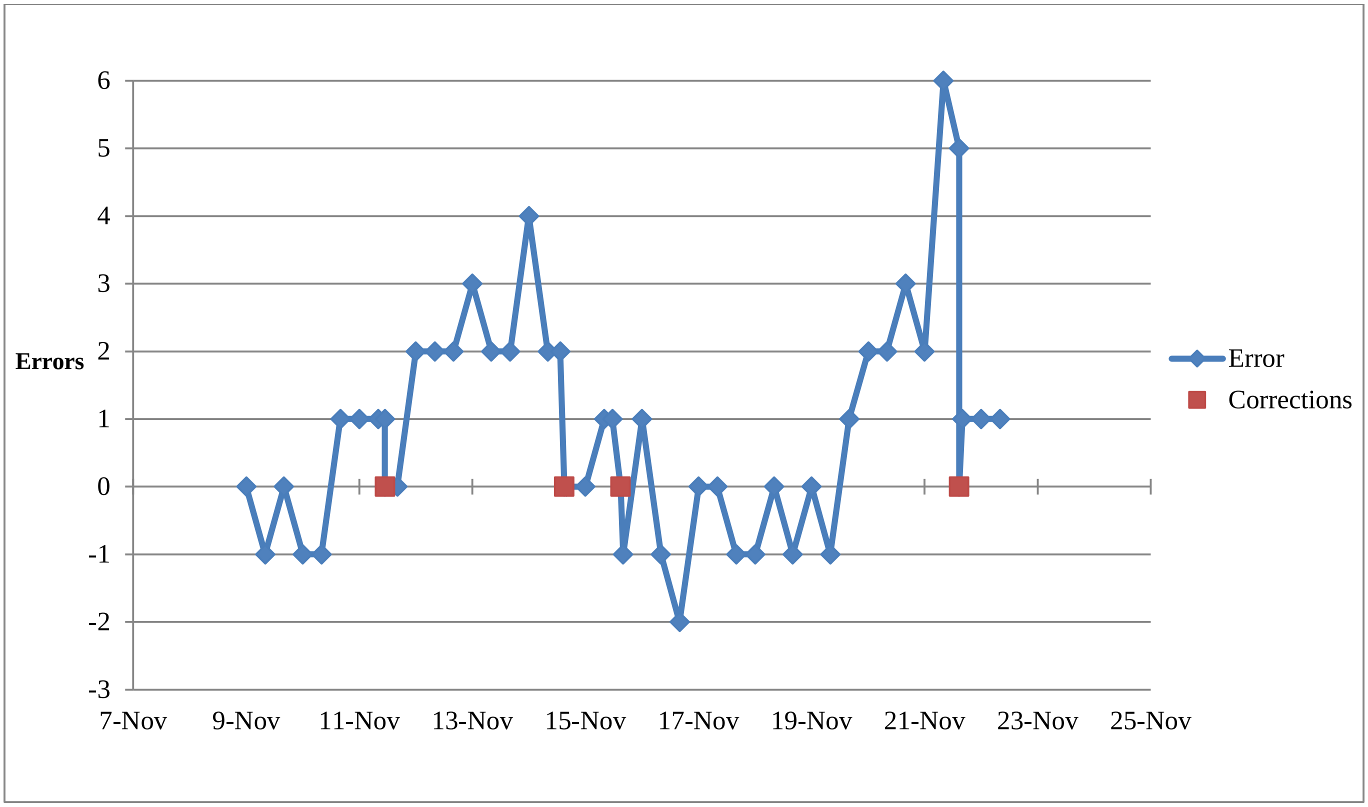


Figure 23. Graph. OH error distribution—period OO1 (2012).

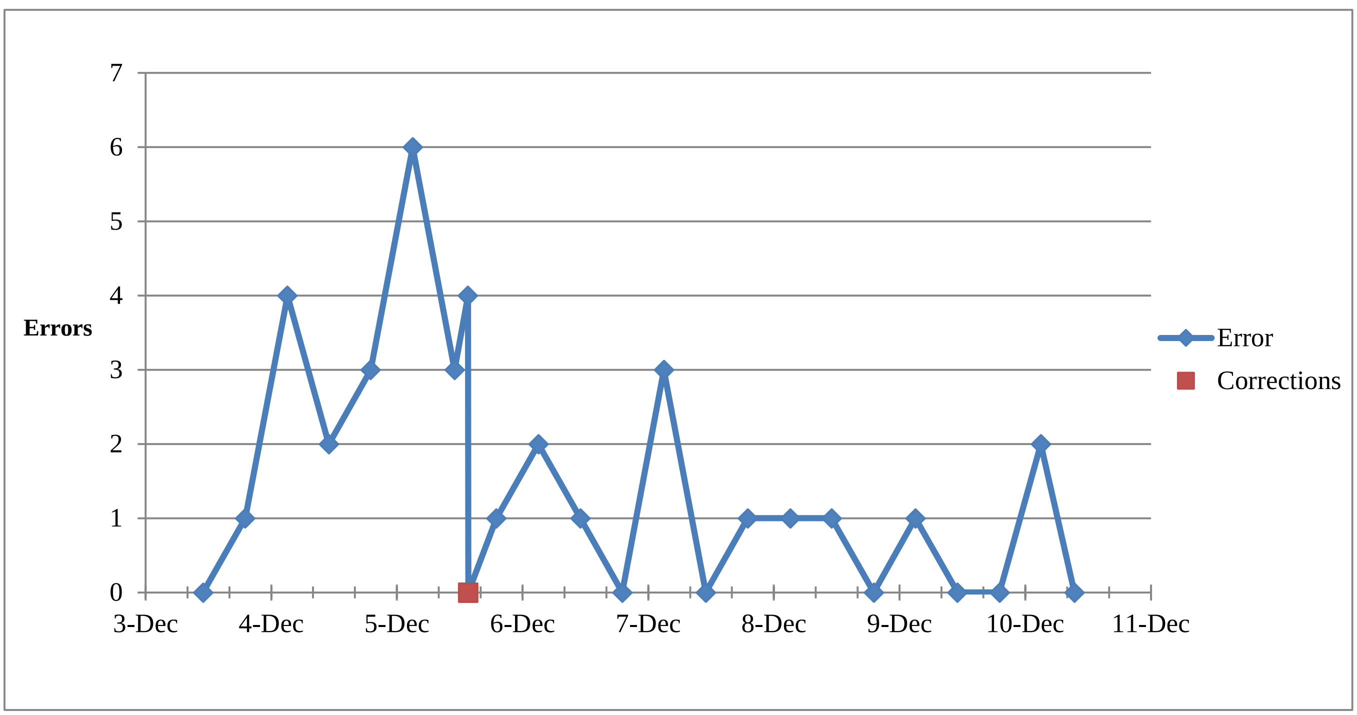


Figure 24. Graph. OH error distribution—period OO2 (2012).

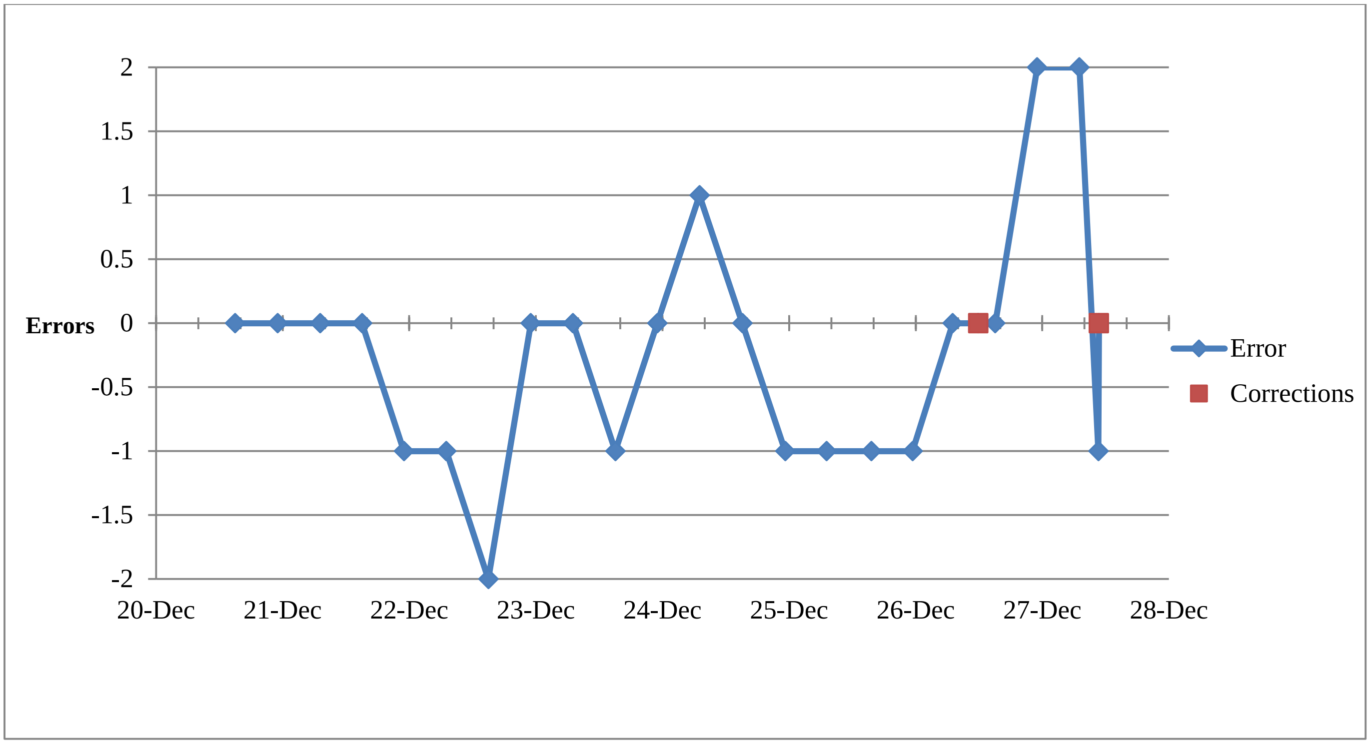


Figure 25. Graph. OH error distribution—period OO3 (2012).

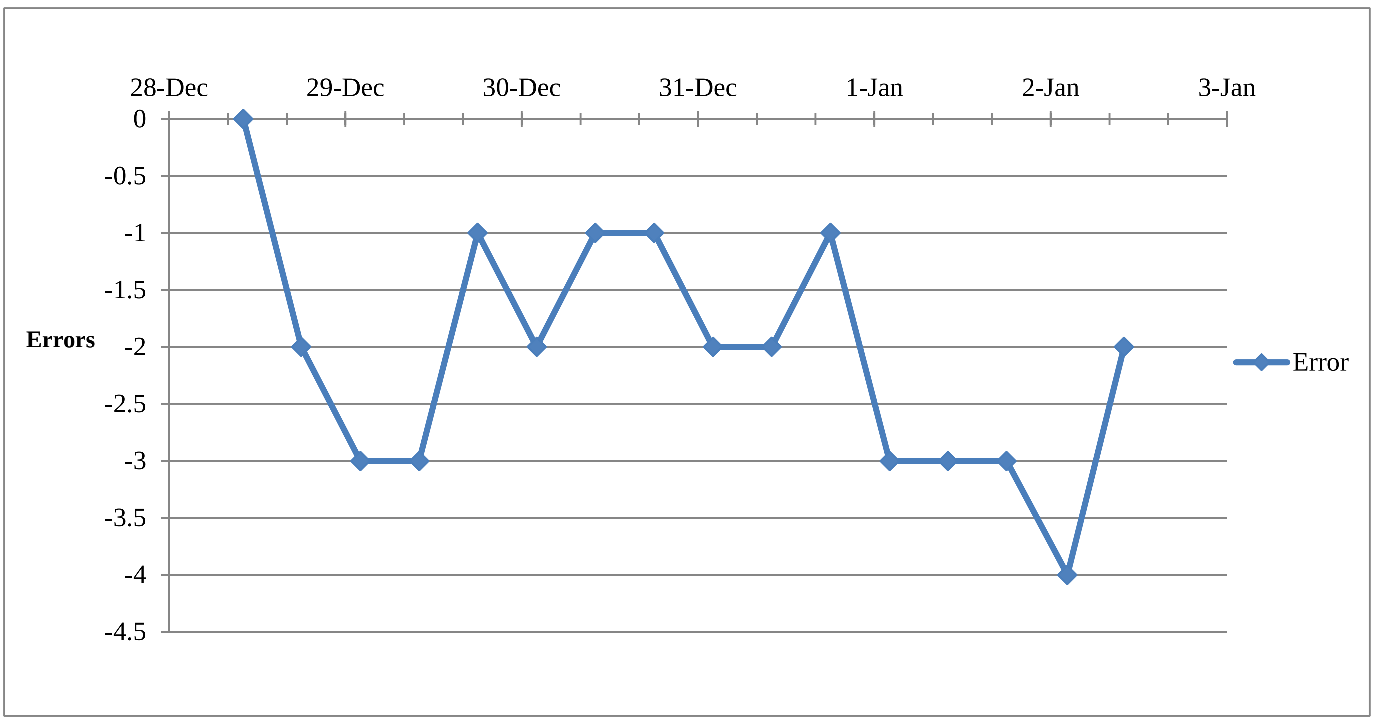


Figure 26. Graph. OH error distribution—period OO4 (2012).

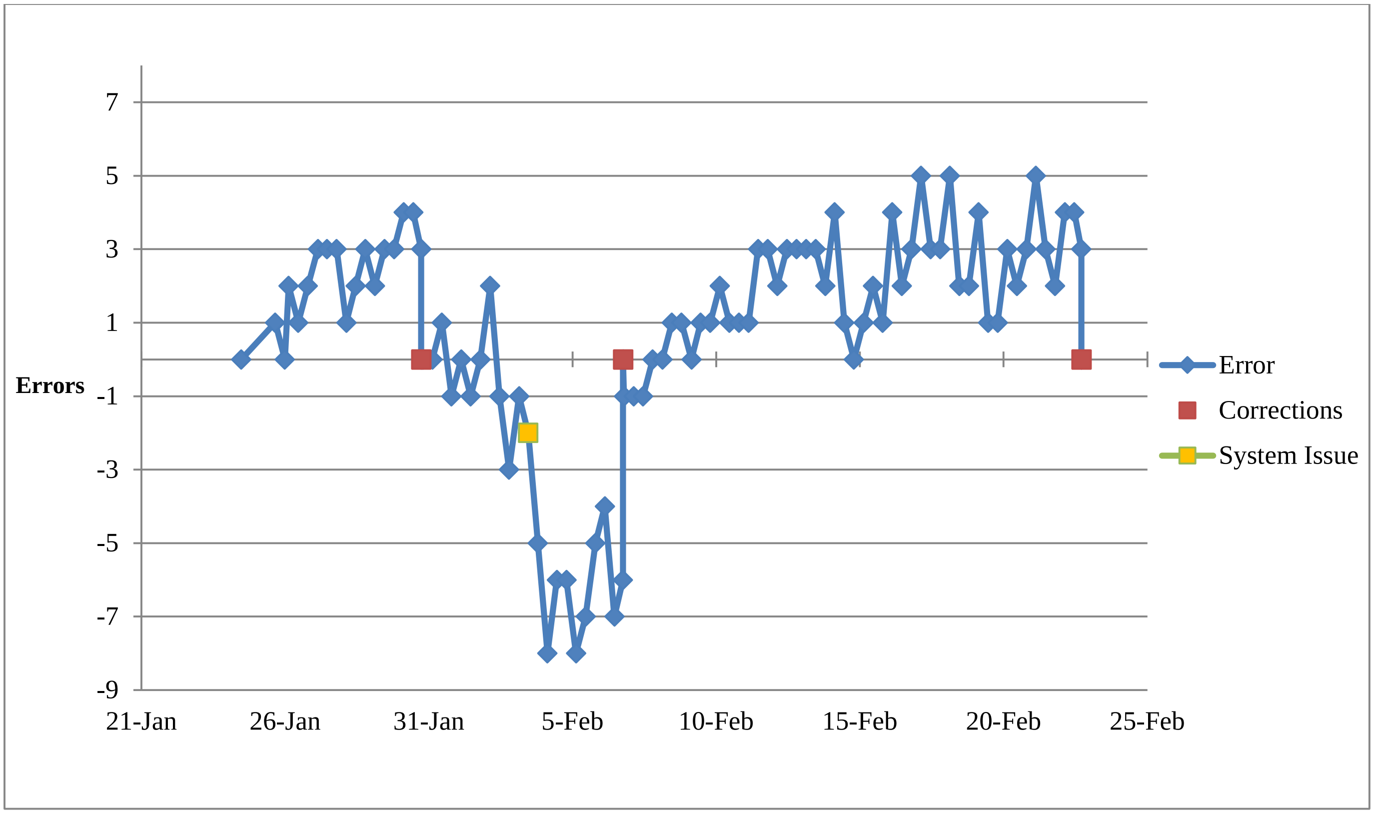


Figure 27. Graph. OH error distribution—period OO5 (2012).

4.4.2.2 Side Scanner/Side Scanner Combination

Error distribution during the SID/SID combination is displayed for each of the testing periods in Figure 28, Figure 29, Figure 30, and Figure 31 (note that period SS1 is omitted from the chart analysis due to the short length of the period). Similar to the OH/OH combination, the SID/SID combination experienced oscillations or spikes in error. Again, these spikes generally occurred during overnight hours when activity in the lot was at its peak. However, despite these peaks, the lot error generally accumulated in a single direction over time, generally experiencing positive error rates, or determining that there were more vehicles in the lot than there actually were. This phenomenon can again be explained by assuming that the detector double counted vehicles with long hitches. Negative errors can be explained by this same phenomenon occurring when vehicles exited the lot, driving the number of egresses upward and the overall lot count lower than it should have been.

From the data presented, the largest spike in error over a single day was approximately seven vehicles. Were the system to be incorrect by seven vehicles, this would cause lot accuracy to decrease Due to the oscillations experienced with the SID/SID combination, the system would need to be checked daily (at a minimum) to maintain accuracy within 95 percent. In order to guarantee accuracy at this level, the site should be monitored approximately twice per day, given that the greatest spike in error was seven vehicles. Alternatively, the accuracy requirement could be loosened so that it is more operationally appropriate. Note that only one spike of seven vehicles occurred over the testing period, indicating that visual inspection error could have contributed to that particular spike in error. Furthermore, spikes of 6 only occurred twice over the testing period, and spikes of 5 occurred only 10 times over the duration of the testing period.

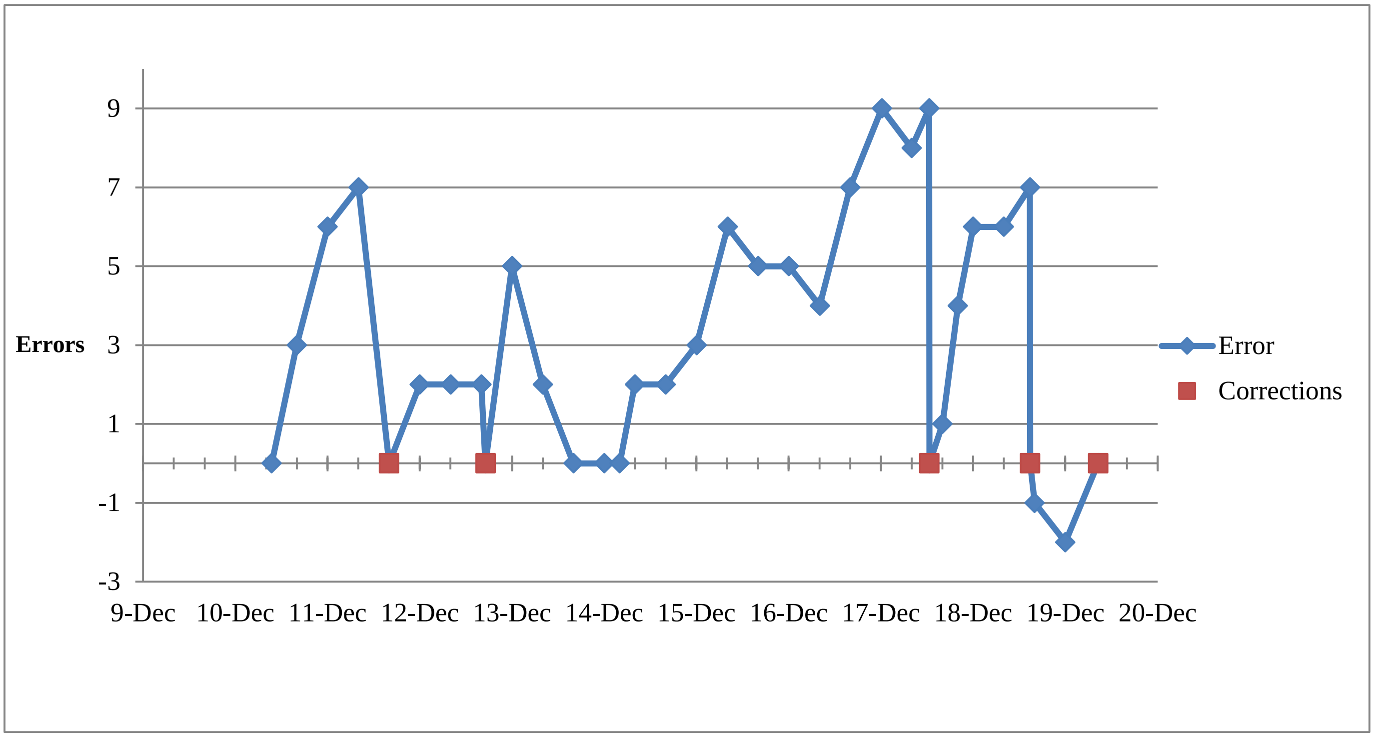


Figure 28. SID error distribution—period SS2 (2012).

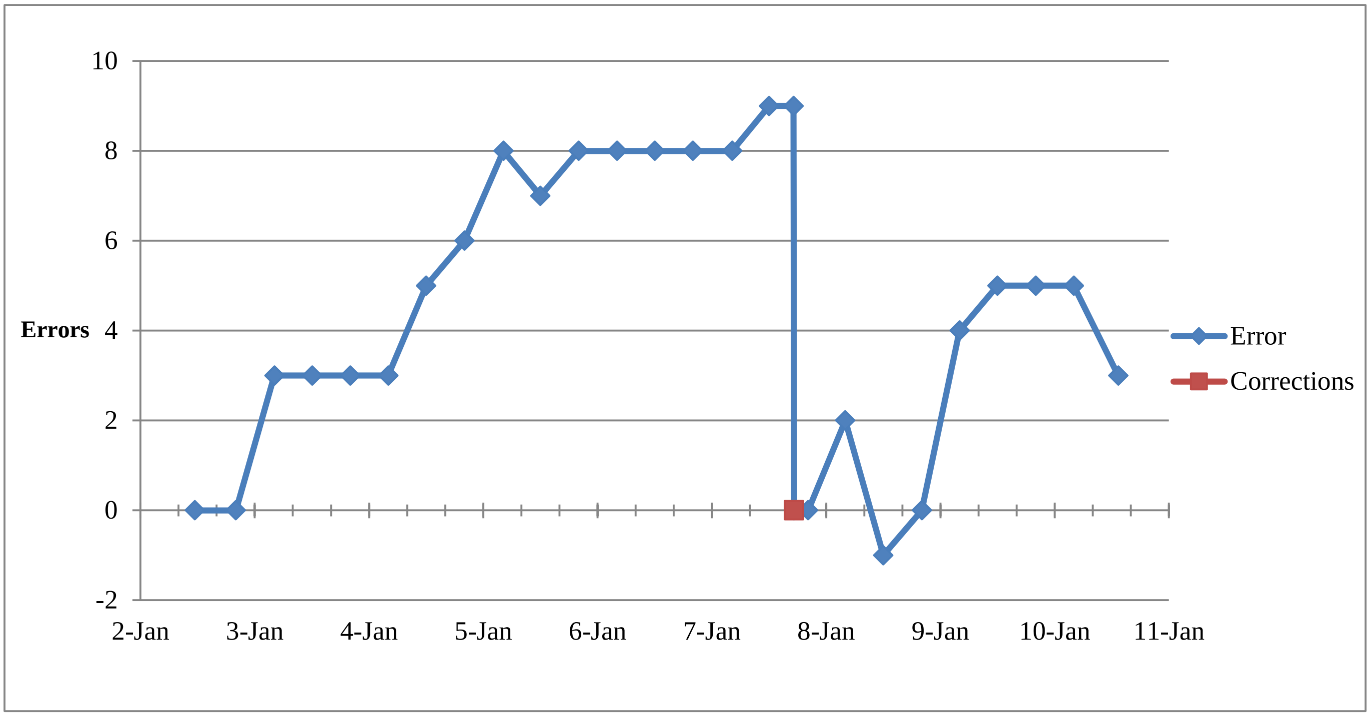


Figure 29. SID error distribution—period SS3 (2012).

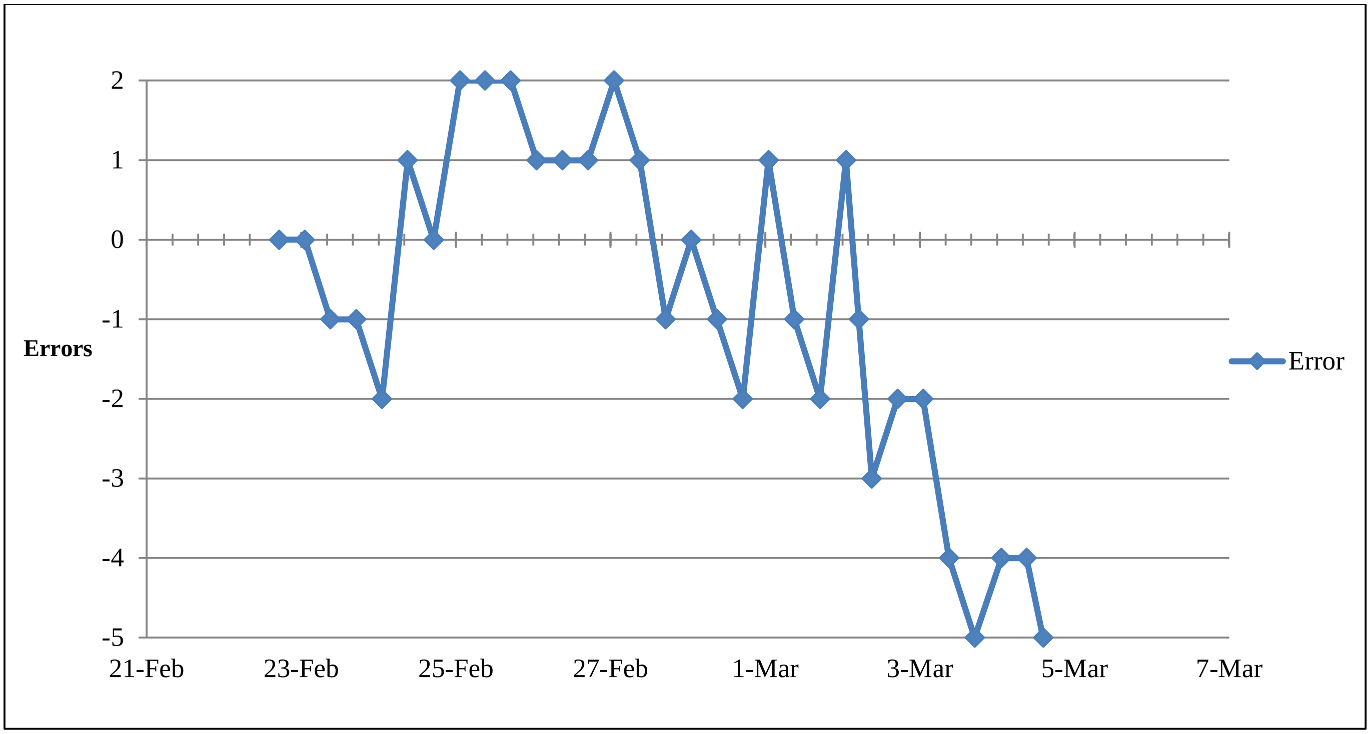


Figure 30. SID error distribution—period SS4 (2012).

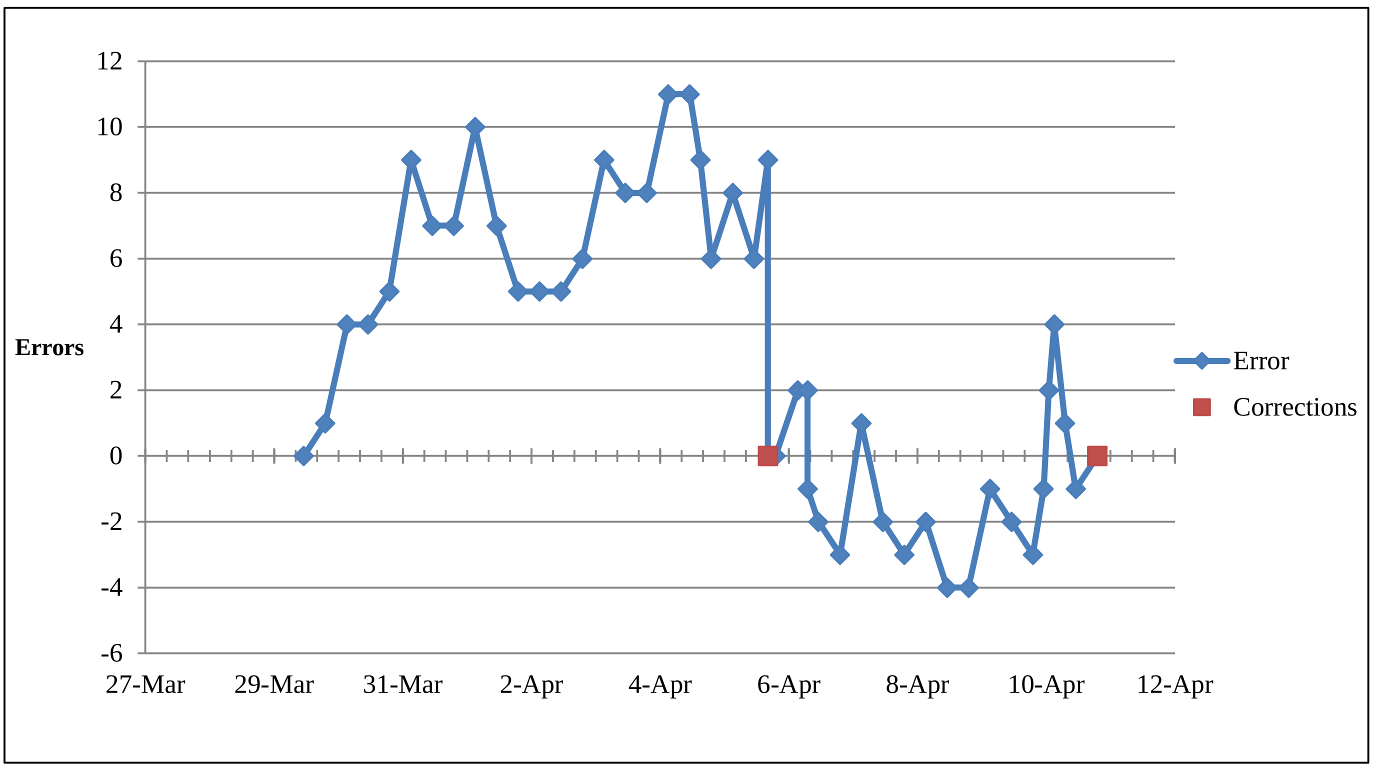


Figure 31. SID error distribution—period SS5 (2012).

4.4.2.3 Light Curtain/Overhead Scanner

Error distribution during the CUR/OH combination is displayed for each of the testing periods in Figure 32, Figure 33, Figure 34, and Figure 35. Unlike the other detector combinations, very little oscillation occurred with the CUR combination. Errors almost exclusively accumulated in the positive direction, wherein the system lot count was higher than the actual number of vehicles in the lot. Moreover, while the data appear to have far fewer spikes than the other combinations, errors accumulated much more rapidly.

The positive errors with the CUR combination can be described almost exclusively by the system's tendency to count single vehicles with low-lying hitches as two separate vehicles. The tendency for this to happen is a direct result of the shortcomings of the installation, where ground conditions did not permit proper mounting height for the CURs.

Were the CUR to be used by operators in its current location, the system would require manual corrections at least twice per day to maintain 95-percent accuracy of the lot count. To achieve a reduced maintenance requirement, the site would need to be reconstructed, including curb removal and excavation of the soil to lower the gantry configuration.

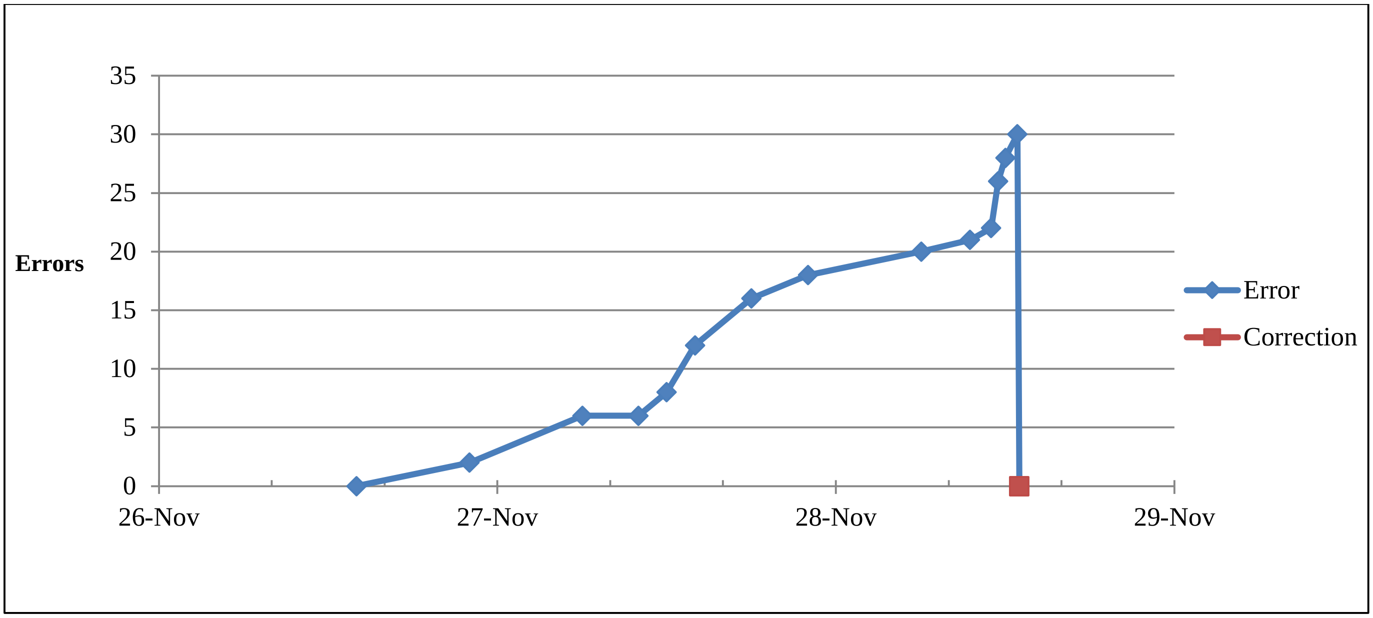


Figure 32. CUR error distribution—period CO1 (2012).

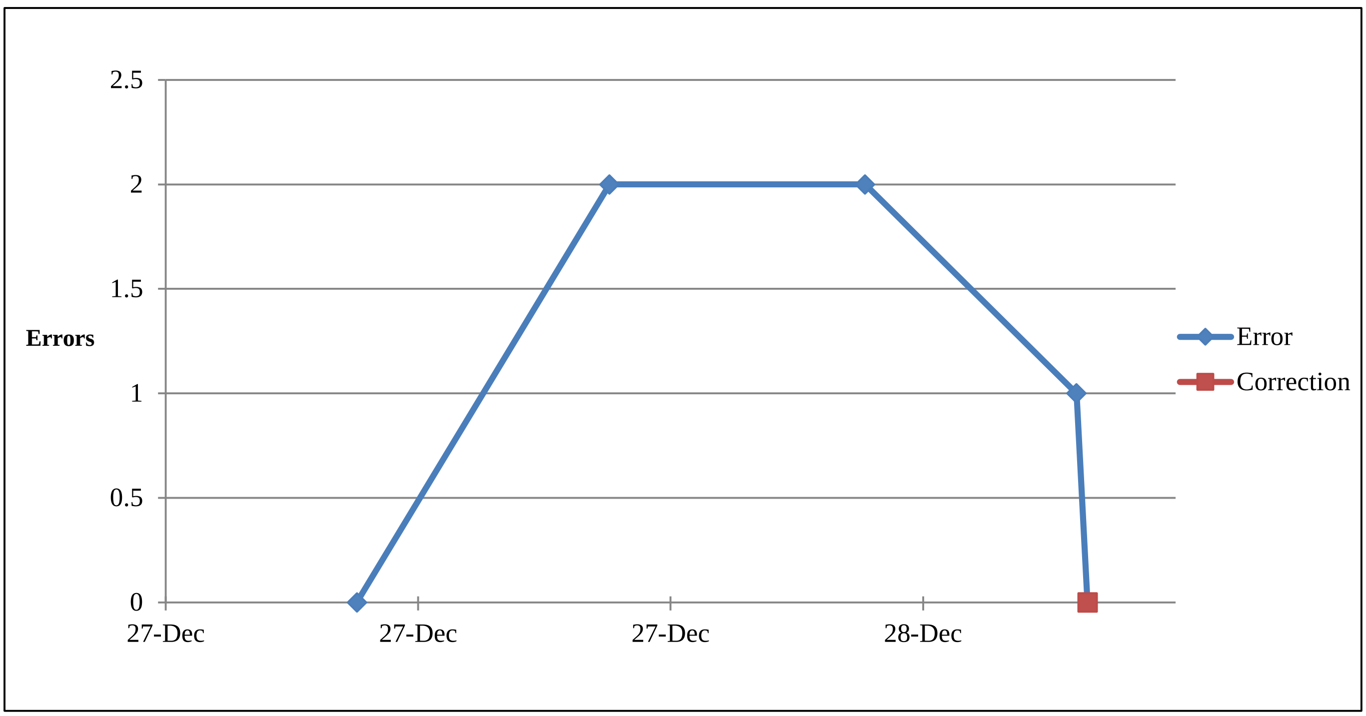


Figure 33. CUR error distribution—period CO2 (2012).

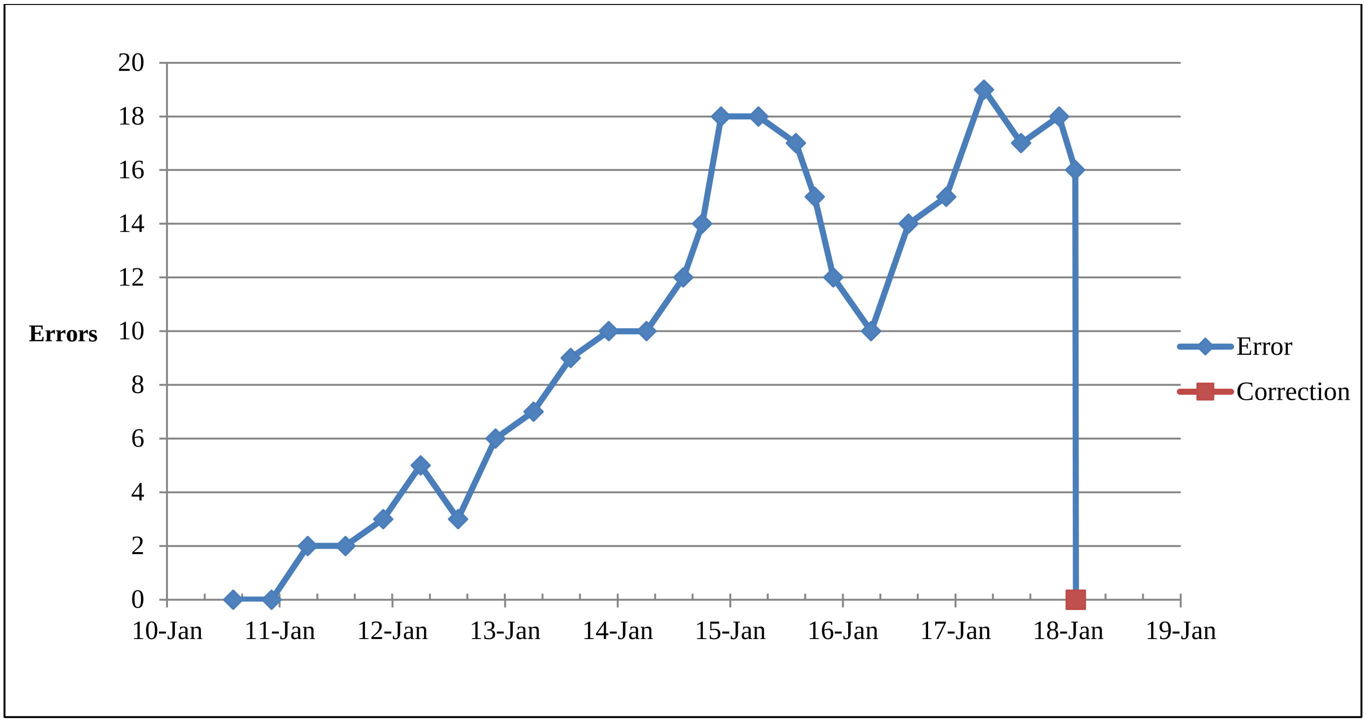


Figure 34. CUR error distribution—period CO3 (2012).

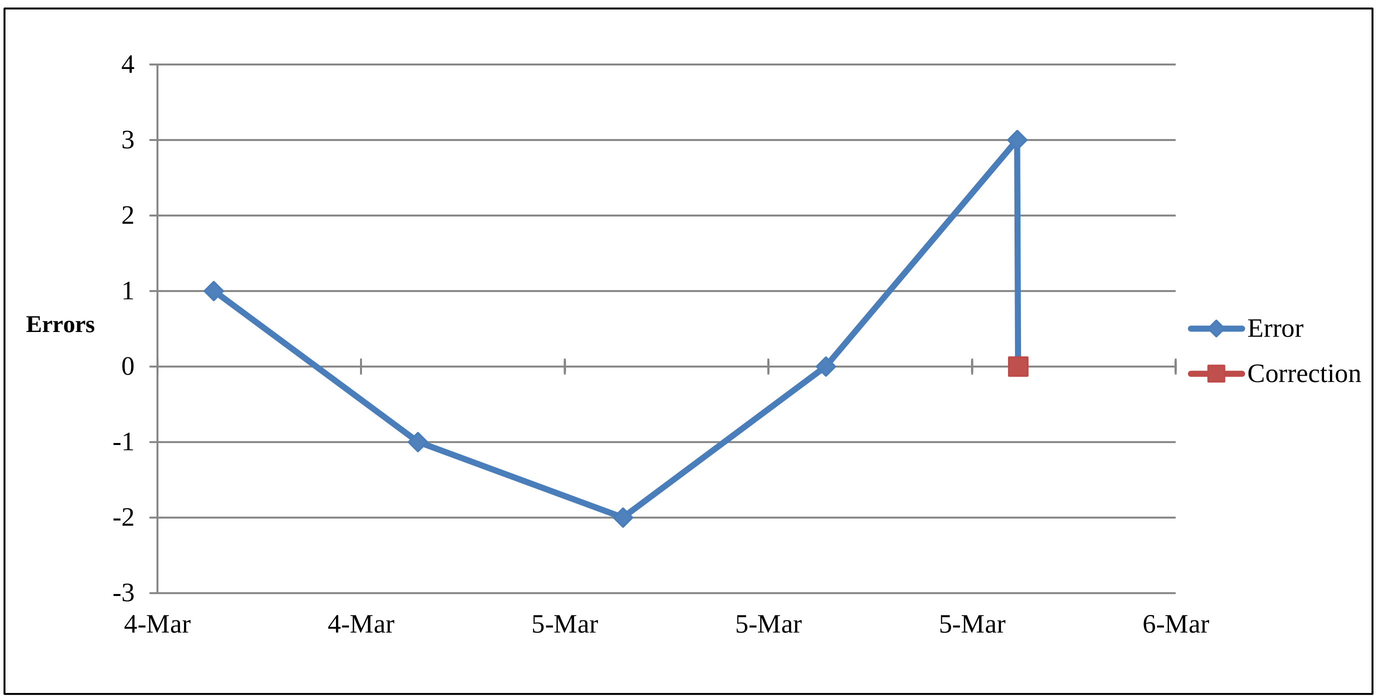


Figure 35. CUR error distribution—period CO4 (2012).

4.4.3 Performance Requirement 2

Regarding total number of errors, two of the three detector combinations exceeded the target performance of PR2, primarily due to the excellent performance in classifying the largest vehicle class (tractor-trailers). However, on a class-by-class basis, none of the detectors achieved the classification consistency required by PR2. This result is disappointing, as the detector installations are very similar, but they do not yield similar results.

The CUR/OH combination fell far short of the PR2 performance target due to the height at which it was installed. In addition, the CUR combination utilizes two detector types, making an "apples-to-apples" comparison impossible. Generally, the CUR's full capabilities were not completely tested in this demonstration project.

Several observations are presented here regarding the findings shown in Table 28, Table 29, and Table 30, including methodologies for improving classification consistency of the detectors. The discussion in this section will be considered when defining the classification scheme for Phase II and future deployments.

4.4.3.1 Overhead/Overhead

The OH/OH combination experienced the best classification accuracy of the three combinations. Through examining the data, the detector did experience some misclassification issues, in particular Classes 1, 3, and 5.

By examining Table 27 if the class errors (E_c) of Class 1, Class 2, and Class 3 are compared across the testing period, the negative classifications and positive classifications within these classes nearly cancel each other out ("net out"). By combining these three classes into one single class of length (0–30 ft), the net error could be reduced from +84 to +10, presuming the majority of the errors are contained within these classes. If these three classes were combined, the E_c of this class would be closer to 1.1 percent as opposed to the current 12.76 percent, 6.09 percent, and 25 percent of Classes 1, 2, and 3 respectively (see Table 27).

The other problematic class is Class 5, which includes a vehicle with a trailer where the combined length is between 30–50 ft. Examining the class errors for Class 4 and Class 5, by combining the two classes, the net error nearly approaches zero, suggesting that most of the Class 4 misclassifications are attributed to Class 5. Over the entire test period, the class error for Class 4 was -161, meaning that 161 vehicles were Class 4 at the ingress, but were another class at the egress. The classification error of Class 5 over the test period was +135. Combining -161 with +135 results in just -26 errors left unaccounted for. If these two classes were combined, the new E_c of this class would be closer to 1.3 percent as opposed to the current 10.18 percent and 33.33 percent for Classes 4 and 5 respectively.

The new accuracy rates of the collapsed classes are displayed in Table 34.

Table 34. OH classification accuracy of collapsed classes.

Class	Size	Volume*	New E_c	New R_c	New A_c
1	0–30 ft	893	10	1.12%	98.88%
2	30–50 ft	1,994	-26	1.30%	98.70%
3	50 ft +	15,964.5	1	0.01%	99.99%

*Note: Volumes differ slightly from those displayed in Table 27 due to rounding. Volume for this calculation requires dividing the total ingresses and egresses by two in order to determine the number of vehicles that pass through both the ingress and egress detectors.

The classification accuracy of larger tractor-trailers is 99.1 percent, making this the most consistent of the classes.

From the discussion here, the OH/OH detector combination appears to have the following strengths:

- Classifies small vehicles similarly.
- Classifies tractor-trailers similarly.
- Classifies vehicles with or without trailers similarly between 30–50 ft.

4.4.3.2 Side Scanner/Side Scanner Combination

An exercise similar to the one performed above was also completed for the SID/SID combination. Classes 1, 2, and 3 have the highest misclassification rates of the SID/SID combination, peaking at 71.43 percent for Class 3 (see Table 27). If these three classes are collapsed into a single class, the net errors, or E_c, of the new single class drops from +129 to +39. This reduces the error rate New R_c to 5.05 percent from 21.35 percent, 26.53 percent, and 71.43 percent of Classes 1, 2, and 3, respectively (see Table 35).

When examining misclassification rates of Classes 4 through 6, it is apparent that the misclassifications of Class 4, (–45), the positive misclassifications of Class 5, (+5), and the positive misclassifications of Class 6 (+76) net out to +23. Combining these three classes reduces the misclassifications down from 172 and the new error rate (R_c) becomes 0.17 percent.

The new accuracy rates of the collapsed classes are displayed in Table 35.

Table 35. SID classification accuracy rates of collapsed classes.

Class	Size	Volume	New E_c	New R_c	New A_c
1	0–30 ft	793	39	4.92%	95.08%
2	30 ft +	13,755	23	0.17%	99.83%

*Note: Volumes differ slightly from those displayed in Table 27 due to rounding. Volume for this calculation requires dividing the total ingresses and egresses by two in order to determine the number of vehicles that pass through both the ingress and egress detectors.

From the discussion here, the SID/SID detector combination appears to have the following strengths:

- Classifies small vehicles similarly (0–30 ft).
- Classifies larger vehicles similarly (> 30 ft).

4.4.3.3 Light Curtain/Overhead Scanner

The glaring issue with the CUR/OH detector combination is apparent misclassification of Class 1 vehicles. The reason for this, which was mentioned earlier in this report, is that the CUR is mounted at a height that prevents it from identifying small trailer hitches. As a result, the CUR consistently double counted Class 3 and Class 4 vehicles that had hitches that were low to the ground. Instead of properly classifying these vehicles as one, the curtain broke them into two separate vehicles, hence double counting the vehicle. This incorrectly increased the number of Class 1 vehicles in the system, which is represented in the error rate of 93.9 percent. If left uncorrected, this issue would inflate the lot count in the system, incorrectly decreasing the number of available spaces.

The mounting height issue is also likely responsible for the error rate of Class 2 of 47.62 percent. The error rate for Class 2 is likely incorrect because of the misclassification of vehicle/trailer combinations as two vehicles, where the trailer was classified as Class 2.

From the discussion here, the detector combination appears to have the following strengths:

- Classifies tractor-trailers similarly.
- Classifies large vehicles similarly (> 30 ft).

Classification data collected from the CUR/OH detector combination is difficult to interpret, as a different detector type was used at the egress than at the ingress. The classification inconsistency between the ingress and egress produced by the system is directly attributed to the differing technologies and their characteristics. In addition, the mounting height of the CUR caused significant errors that skewed the overall results, making interpretation of the data even more difficult. Generally, the CUR needs to be mounted very low to the ground in order to be highly effective, which is a significant constructability concern to be discussed later in the report.

4.4.4 Performance Requirement 3

The SID/SID detector combination achieved 100 percent system uptime. Other scanner combinations, for a variety of reasons, did not achieve the PR3 goal of 99.5 percent system uptime. Given that the system was a completely original creation, a considerable stabilization period was required. This stabilization period, where the system revealed its weaknesses, interfered with the testing period, despite the upfront troubleshooting period of approximately 1 month.

Throughout the test period, as issues would arise, the project team would address them in a timely manner. The typical time it took to address an issue was approximately a day or two, but this period varied depending on the severity and nature of the problem. Generally, most of the “configuration downtime” occurred toward the beginning of the test period, within 1–2 months of the testing period commencing. The most significant of these was the approximately 4-day period in November of 2012. Whenever possible, when configuration downtime occurred, the project team implemented a solution that would be long lasting and rectify the problem. The team avoided simply restarting the system or its components wherever possible, and would thoroughly diagnose and address the issue. Because of this forward-looking approach, the system did not experience any configuration errors after November 2012.

The two periods of downtime that occurred in 2013 were lengthy, but they were not a result of system malfunctions. The outage in January 2013 was attributed to ice buildup on the CUR, which prevented the system from accurately detecting vehicles. Nothing could be done regarding this issue until the ice melted. The period of downtime in March was the result of a physical disruption to the system, wherein the ingress Doppler radar was removed from the pole. It is unknown if the physical damage was the result of vandalism or vehicle impact. The issue could not be rectified for a significant amount of time due to scheduling issues with project staff specially qualified to rectify this type of error (note that this downtime period was not included in the system uptime calculations in the evaluation of PR3).

4.4.5 Lessons Learned

4.4.5.1 Constructability

Doppler Radar

One of the most significant drawbacks of the detection units is the amount of equipment that is required. They each require two pieces of field equipment, the detector, and the Doppler radar unit. The Doppler radar unit must be placed approximately 60 feet downstream of the detection unit, and must be pointed at an angle of 15 degrees from the centerline of the roadway. In addition, the unit must be placed approximately 3 feet off the ground. While it was shown through testing that if these conditions are met, the detection units are highly accurate in detecting vehicles, the operating conditions are highly specific. The geometry of a site that utilizes the technology must be conducive to the placement of the Doppler radar unit.

In addition to geometric concerns, the Doppler radar units are accessible to pedestrians. The mounting configuration leaves the units susceptible to vandalism or interference. If the unit is not mounted properly, its angle can be interfered with, which would have an impact on the accuracy of the detector. Caution must be taken when mounting the Doppler radar units to make certain that they are enclosed in a tamper-resistant casing. The mounting fixture must also be resistant to adjustment by simple forces or tools.

One instance of interference occurred during the testing period, when the ingress Doppler radar unit was removed from its mounting. While the cause of this damage is unknown, it revealed the need for a strengthened approach to mounting the units. In future implementations, cameras monitoring the site should be able to view the Doppler radar locations in order to identify malicious activity. Furthermore, cameras should be visible to anyone near the detection units to deter such activity.

Light Curtain Mounting

Phase I revealed the effects that the mounting of the CUR has on the ability of the detector to classify vehicles with hitches. The CUR is comprised of three units: the light-beam-emitting unit, the light-beam-receiving unit, and the Doppler radar. The light-emitting unit is mounted securely to one side of the roadway, and the receiving unit is carefully mounted on the opposite side of the roadway and aligned so that it can intercept the light beams emitted from the opposite unit. The curtain's ability to detect vehicles is limited to whatever passes between the two 10-ft tall curtain units. With a detection height limited to 10 ft, the curtain must be mounted nearly on the ground in order to detect low-lying hitches and trailers.

When the CURs were initially mounted to the gantries, the bottom light beam was approximately 18 inches above the roadway. At a height of 18 inches, the CUR was higher than some smaller hitches. As a result, the curtain classified smaller vehicle/trailer combinations as two separate vehicles. In late December 2012, the curtain height was adjusted to the lowest level permitted by the site conditions—15 inches above the ground. Site conditions—in particular, the curb height at the edge of the roadway and the height of the gantry foundations—precluded a mounting height any lower than 15 inches above the ground. While this adjustment enhanced the accuracy of the CUR, the detector still occasionally improperly classified small vehicle/trailer combinations as two separate vehicles.

Thus, the CUR's accuracy and capabilities were not fully measured due to the site conditions and the mounting.

Environmental Discussion

While weather was not consistently tracked throughout the project, testing periods for each of the detectors included winter weather conditions. The only weather-related drawback observed at the site was the ice that developed on the CUR. The ice prevented the CUR from functioning properly, and caused a system outage. Ice did not affect the side or overhead scanners, both of which utilized heaters to prevent ice from building up on the detector surface.

Configuration

All the detection units, including the CUR, SID, and OH scanners, have configurable parameters that affect their ability to classify trailers. A threshold is set for each of the units regarding how far apart the two bodies can be to still be classified as one and the same vehicle. As an example, assume that the parameter is set at 6 feet. If a vehicle and its trailer are less than 6 feet from each other and connected by a small hitch that was undetected by the detection units, the vehicle would be classified as a single vehicle with a trailer. If the vehicle and its trailer are separated by more than 6 feet, they would be classified as two separate vehicles. This threshold, currently set at 4 feet, is adjustable to meet the conditions of the site. Despite setting this parameter to 4 feet, the CUR still experienced issues with counting small vehicle/trailer combinations as two separate vehicles.

4.4.6 Maintainability

Regardless of accuracy, the system requires periodic observation and occasional maintenance. System observation is required on a routine basis in order to make system corrections. A qualified technician should always be available to respond to detector issues and to rectify any damage that might occur to the system.

As described in previous sections, troubleshooting occurred during the first several months of the testing period. The troubleshooting period resolved unanticipated integration and configuration errors that arose. By the end of November 2012, the system stabilized and no significant configuration issues arose. Several software patches were applied to the detector firmware, and these patches enhanced the performance of the overall system. While the system has stabilized for Phase I, subsequent phases may require an experienced configuration expert to address software or programming issues that might occur.

4.4.7 Safety

Regarding exposure to the detection beams, the laser and light technologies pose no safety issues to motorists. As Class 1 lasers, the detection units comply with Title 21 of the Code of Federal Regulations, Section 1040.10, with the exception of the deviations as per Laser Notice No. 50, June 2007. The lasers operate at a wavelength of 925 nanometers, constituting invisible infrared light, which is not harmful to the human eyes or skin. Motorists exposed to the detection unit lasers will not be harmed in any way. The Class 1 status of the detection units is documented in the units' manuals.

4.5 UNANTICIPATED OUTCOMES

Apart from the desired enhancements anticipated by the SmartPark system, the project has had several positive externalities. Rest area staff members have generally observed these outcomes, and they have conveyed the information to the project team during site visits.

4.5.1 Increased Site Usage

Rest area managers and personnel have described an increase in parking activity at the site. According to them, truck operators have noticed the CCTV cameras at the site, which have enhanced their feeling of safety and security. Feeling safer, truck operators have increased their usage of the site, resulting in crowding during overnight peak hours. No data is available to quantify the change in usage beyond the firsthand accounts of the rest area staff.

4.5.2 Decreased Negative Activity

Prior to installing the system, rest area staff removed a significant amount of garbage from the rest area parking lot. After installation of the CCTV cameras and the SmartPark system, littering dramatically decreased. In addition, prior to system installation, there were suspicious activities reported to the rest area staff. According to rest area staff, suspicious activity is practically nonexistent at the site now that the CCTV cameras are present. Rest area staff members speculate that the cameras and the system as a whole have discouraged users from engaging in littering and suspicious activities.

4.6 PHASE II CONSIDERATIONS

Phase I provided the project team with significant knowledge and lessons learned. These lessons learned are described below, and will be incorporated wherever possible in Phase II.

4.6.1 Enhanced Camera Coverage

Remotely monitoring the project site requires robust camera coverage of the system. In the current configuration, seven CCTV cameras were used to monitor the spaces at the site. The cameras were configured to view every space in the lot, provided that only tractor-trailers used the lot, and provided they pulled all the way forward in the parking spaces. During normal operations, however, a variety of vehicle types use the site, including smaller trailer combinations. View of smaller vehicles can be obstructed when larger tractor-trailers park in the adjacent spots. Obstructed vehicles are very difficult to identify and quantify while making system corrections, which impacts the accuracy of the parking system correction itself. In future phases, additional CCTV cameras will be installed wherever possible to view the parking spaces from multiple angles. The project team will also consider using pan/tilt/zoom (PTZ) capable cameras so that the views can be adjusted remotely to inspect the site.

Cameras were also used to monitor the ingress and egress locations. The cameras at these locations were pointed directly toward the entering vehicles, resulting in significant glare during the evening hours. Measures will be taken to prevent this in future phases, such as different camera orientation or the use of different camera types.

The resolution of the CCTV cameras used in Phase I was somewhat limited by the bandwidth to the site and the type of cameras selected for installation. Higher resolution CCTV cameras will be considered to enhance the ability to view the site and the ability to identify and properly classify vehicles.

Possible methods for enhancing CCTV camera coverage include:

- Increase the number of cameras used to provide multiple views of all spaces.
- Orient cameras to view spaces head-on to minimize obstructed views.
- Install cameras on high poles to maximize viewing area and minimize obstructed views.
- Install PTZ cameras.
- Install higher resolution cameras.
- Install cameras with enhanced night vision.
- Further illuminate the parking lot to enhance nighttime viewing of the site.

4.6.2 Enhanced Pavement Markings

While the CCTV camera surveillance system provides views of each of the parking spaces at the site, it is difficult to identify where the field of vision of one camera ends and the next camera begins. In future phases, the project team will consider implementing visual markers on the pavement to identify the limits of each camera’s field of vision.

4.6.3 Communications Bandwidth

For Phase I, a T-1 line was installed to the site to transmit the information, including the data received from the detectors and the CCTV video, from the site to a remote server and user workstations. The T-1 connection, while sufficient for the components of Phase I, only provides a bandwidth of 1.544 megabytes per second. This low bandwidth had implications for the amount of data that could simultaneously be transferred over the connection. For example, only one CCTV camera can be viewed from the site at a time using the compression system installed at the site, due to bandwidth limitations. Streaming multiple cameras would have clogged the T-1 line and would have prevented transmission of detection datasets to the offsite server.

The project team is in discussion with TDOT to use their fiber optic network to communicate with the site in future phases. Fiber optic cable already exists within approximately 2 miles of the Phase I site, and it runs just outside the proposed Phase II site. TDOT has agreed to allow the project team to utilize this fiber network for Phase II operations if the preferred site is selected. TDOT has also indicated that if the fiber optics are extended to the Phase I project site, the project team could retrofit the Phase I system to utilize this fiber, as well. Fiber optics would increase bandwidth to the site exponentially, as it is capable of delivering bandwidth in the range of gigabytes per second (versus megabytes per second).

4.6.4 Detector Selection

As stated in the RFP, subsequent phases of SmartPark must use either the same technology combinations or equivalent sensors. From the results presented here, including the constructability concerns, the most viable technology for future use would be the SID scanners. The following elements factor into this decision:

- Mounting; The SID scanners can be mounted on a wooden or steel pole on the side of the road, making it the least intrusive option. The CUR requires two structures to mount the curtains on either side of the roadway. The OH scanners require a gantry or overhead style structure that protrudes over the roadway.
- Accuracy: The accuracy rate of the SID scanner is comparable to that of the OH scanner. The slight premium in accuracy does not justify the added cost of using the OH scanners.
- Constructability: While the OH scanners require a structure over the roadway, the SID scanners can be mounted on any vertical structure on the side of the roadway. The side-mount configuration is more conducive to varying field conditions, as it can even be mounted to existing structures if necessary.
- Cost: The SID and OH scanners cost considerably less than the CURs to install and maintain. The CURs would require higher voltage to power the heaters required for winter operations, and maintenance personnel would have to access the site to perform routine cleaning. The SID and OH scanners do not require the electricity draw or the maintenance needed by the CURs. As mentioned above, the SID scanners do not require mounting hardware to protrude over the roadway, and can be mounted less intrusively on the side. This side configuration reduces the engineering and construction costs associated with the overall installation.

4.6.5 Vehicle Classification Scheme

Based on the analyses presented in this report, the classifications scheme used for Phase I was too granular for the capabilities of the detector used. The detectors could not properly classify vehicles of varying lengths, nor could they strongly classify vehicles similarly across two detector stations. However, the data does suggest that the detectors can generally distinguish larger vehicles from smaller vehicles with relatively high accuracy.

Moving forward into Phase II and future implementations, a collapsed classification scheme should be used (as suggested in Table 35) if SID scanners are selected as the technology. The classifications should leverage the height data that is unique to the laser scanners and CURs. For example, in future implementations, a “bobtail” or tractor category could be used to determine when trucks without trailers enter and exit the lot.

In addition, the detector classes do not discriminate between typical tractor-trailers and tractors with multiple trailers or oversized loads. Future phases should incorporate an additional class for vehicles larger than a typical tractor-trailer combination. Future classification schemes will consider the average lengths displayed in Table 36, in particular the average length of a typical Class 6 vehicle. Table 36 excludes any vehicle longer than 90 feet in the average calculation to avoid skewing the data based on double and triple trailers.

Table 36. Average vehicle length by detector.

Class	OH Ingress Vehicles	OH Ingress Avg. Length (ft)	OH Egress Vehicles	OH Avg. Length (ft)	SID Ingress Vehicles	SID Ingress Avg. Length (ft)	SID Egress Vehicles	SID Egress Avg. Length (ft)	CUR Ingress Vehicles	CUR Ingress Avg. Length (ft)
1	277	14	400	14	333	13	449	14	292	13
2	660	24	964	25	1,125	24	1,188	24	374	23
3	84	27	132	27	53	26	88	26	65	36
4	1,691	40	2,872	40	3,032	40	3,716	40	540	38
5	541	40	614	40	450	41	535	40	65	38
6	17,501	75	26,941	72	21,031	74	25,991	71	5,803	71

4.7 CONCLUSIONS

4.7.1 Accuracy

The accuracy rates of the OH/OH and SID/SID detector combinations are encouraging, and are the most positive results of SmartPark efforts thus far. These two combinations appear to achieve similar accuracy ranges, making either combination a viable option for future deployment. The two scanner combinations also demonstrated success in consistent classification. During Phase II, the accuracy of the detectors will be tested under new and different geometric conditions at a second truck-parking site.

The CUR combination, while achieving less than satisfactory results during this phase, could potentially yield better results given different site conditions. Despite this, the project team does not anticipate deploying the CUR at the proposed Phase II location due to geometric constraints and field conditions, and the cost and practical issues of maintenance. The ingress and egress to the site at the Phase II site are significantly larger than the Phase I site, making it impractical to implement the CUR or OH scanner technology.

While the system as designed and operated in Phase I did not support more granular length-based classifications, it will likely support a more simplified classification scheme of three to four classes based on less granular length breakdowns. For example, a scheme could be based on classifying vehicles from zero to 30 feet, from 30–80 feet, and 80 feet and above. In addition, the detector technologies could leverage the unique ability to incorporate height into their classifications, which was only examined in a very limited sense in Phase I through the classification of vehicles with tow hitches.

4.7.2 System Management

The results of Phase I identified a rate of detector accuracy greater than 99 percent for the SID and OH scanners, which, as standalone technologies unpaired with complementary systems, makes the detectors among the most accurate that can be expected from commercial, off-the-shelf technology. However, despite this rate of accuracy, the site inevitably will require monitoring on a periodic basis. As shown in previous sections, to maintain 95-percent accuracy of the lot count, even the OH scanners require intervention at least every day to guarantee compliance with this PR. From an operational perspective, the accuracy limit of the lot should be determined on a site-by-site basis, as this threshold will vary based on the number of spaces in a given parking area.

The results of Phase I make it clear that at least minimal management of a system such as this is required. While management of the site might not require intensive surveillance, occasional check in and correction will be required on a periodic basis. Thus, some sort of site surveillance must be a part of any system. For sites that are managed locally, visual inspection and system correction by local personnel on a periodic basis would be expected. For sites with no local presence, such as an unmanned public rest area, surveillance equipment (e.g., CCTV cameras) and remote monitoring and management capabilities must be a part of the system.

In order to maintain 95-percent accuracy at the site, each of the detector combinations would need to be monitored on a daily basis to maximize accuracy. Optimally, the site should be checked just prior to or in the middle of the peak period, which begins around 11 p.m. or 12 a.m. on a typical weekday. This schedule may present an issue for operators given typical work hour shifts. As a result, the lot should at least be monitored at the end of the shift that is closest to the peak hour. Additionally, making corrections during or close to the peak hours is also challenging due to the significant number of vehicles in the lot. Making corrections prior to or after the peak period would be much easier. Ease of correction and the most useful time of making the correction should be factored into the maintenance schedule for the site.

Due to the variation in errors that occur over a given day, the detectors have the possibility of spiking and throwing the lot count off by more than the two permitted errors. If the lot count is significantly off during typical operations, truckers could receive incorrect data and learn not to trust the system.

To avoid issues with users trusting the system, truckers could be supplied with less refined information. For example, instead of providing truckers with an exact number of spaces, the lot system could inform truckers of the following:

- Spaces available.
- Almost full.
- Lot full.

Where the message "spaces available" indicates that spaces are plentiful and should be displayed whenever 75 percent or more of the spaces are available; "almost full" indicates that spaces are limited and should be displayed when the lot is 75–95 percent full; "lot full" indicates there is a high likelihood that there are no spaces available and should be displayed when the lot is 95–100 percent full. However, the type of information to post to truckers is a policy decision that must be made by the system owner. The availability of maintenance staff to monitor and update the site will be the driving factor in the type of information provided to truckers in a large-scale deployment.

While accuracy rates are a factor in determining the requirements for managing the site, other factors also may require visual inspection and monitoring. For example, during the testing period, two periods of downtime arose that were not related to configuration or system errors, but were environmental or physical issues. During these issues, the system accuracy plummeted. In one instance, the ice on the CUR caused system downtime, and in another instance the Doppler radar was removed from its mount. Without systematic monitoring of the site, operators might not have been aware of these two issues, and the system would have begun projecting highly inaccurate data. As a possible rectification of this issue, the project team developed automated error alerts that are sent to user email accounts in the event that the signal is lost to the detectors. While these error alerts could be a significant source of error reduction, they may not be able to identify all system malfunctions.

4.7.3 Next Steps: Phase II

Because preliminary results from Phase I were successful, FMCSA proceeded to Phase II in June of 2013. Phase II has seven tasks, of which the two main tasks are to: (a) demonstrate how truck parking availability information can be disseminated; and (b) demonstrate how two adjacent truck parking areas can be networked to divert trucks from a filled parking area to an unfilled area. Task (c) is the conversion of temporary equipment to permanent installation so that the State agency can continue using the technology. Other tasks include:

- Task (d), which adds the capability for recording historical use for purposes of forecasting parking availability.
- Task (e), which serves to maximize use of the truck parking area by assigning single-unit trucks or bobtails to park one behind the other in one parking lane according to chronological order of departure.
- Task (f), which adds the capability for reserving a truck parking space.

- Task (g), which is to compile a business plan for sustaining the operation and maintenance of truck parking technology. Phase II is scheduled to be completed by November 2014.

REFERENCES

1. FMCSA 2012-2016 Strategic Plan.

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