SmartPark Technology Demonstration Project, Phase II: Final Report

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

May 2018

FOREWORD

Trucker fatigue has become one of the leading causes of truck incidents on the roadway and demands the attention of regulatory agencies such as the Federal Motor Carrier Safety Administration (FMCSA). Truckers become fatigued when working for too many consecutive hours without rest. According to recent studies submitted to Congress, one of the most significant causes of truck drivers not complying with hours-of-service (HOS) regulations is the lack of awareness of available truck parking. This report summarizes Phase II of the SmartPark initiative led by FMCSA to better inform truckers of available truck parking. Phase I of the project demonstrated 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. Phase II consisted of designing and deploying a truck parking information system to inform truckers of parking availability at two parking facilities within the same corridor. The objective was to provide truckers with real-time information they could use to decide where to park, enabling easier adherence to HOS regulations.

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 and dissemination technology at two test sites on northbound I-75 near Athens, TN and Cleveland, TN.

NOTICE

QUALITY ASSURANCE STATEMENT

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FMCSA-RRT-16-024		

4. Title and Subtitle	5. Report Date
SmartPark Technology Demonstration Project – Phase II Final Report	**May 2018**
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
Von López-Jacobs, PE	

9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Gannett Fleming, Inc. **207 Senate Avenue** **Camp Hill, PA 17011**	11. Contract or Grant No.

12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
U.S. Department of Transportation **Federal Motor Carrier Safety Administration** **Office of Analysis, Research, and Technology** **1200 New Jersey Ave. SE** **Washington, DC 20590**	**23 August 2011 – 26 September 2016** 14. Sponsoring Agency Code **FMCSA**

15. Supplementary Notes

Contracting Officer's Representative: Quon Kwan, Technology Division, FMCSA

16. Abstract

The purpose of FMCSA's SmartPark project was to determine the feasibility of a technology for providing truck parking space availability information in real time to truckers on the road. SmartPark consisted of two phases. Phase I was a field operations test to determine the accuracy and reliability of a technology for counting truck parking space availability. Since Phase I was successful, the project proceeded to Phase II.

This document is the final report for Phase II. In Phase II the focus of the project was to pilot a truck parking information system and analyze the efficacy of this system. The truck parking availability information system consisted of dynamic message signs (DMSs), a mobile application, a public Web site, and an interactive voice response system (IVR) to disseminate the real-time information. The analysis examines the system against the performance measures.

17. Key Words	18. Distribution Statement
Truck parking, truck parking space availability, traveler information, truck parking information, intelligent transportation system, side scanner, overhead scanner, light curtain, Doppler radar	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	**Unclassified**	**73**	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized.

SI* (MODERN METRIC) CONVERSION FACTORS

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 (volumes greater than 1,000L 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 (2,000 lb)	0.907	megagrams (or “metric ton”)	Mg (or “t”)
		Temperature (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

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 (2,000 lb)	T
		Temperature (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 and 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.)

TABLE OF CONTENTS

LIST OF FIGURES (AND FORMULAS)

LIST OF TABLES

LIST OF ACRONYMS, ABBREVIATIONS, AND SYMBOLS

Acronym	**Definition**
ATMS	Advanced Traffic Management Systems
CCTV	closed circuit television
ConOps	Concept of Operations
CPR	Component Performance Requirement
C#	C sharp (a programming language)
DMS	dynamic message sign
FCC	Federal Communications Commission
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FTP	file transfer protocol
GF	Gannett Fleming
HTML	Hyper Text Markup Language
HTTP	Hyper Text Transfer Protocol
ITS	intelligent transportation system
IVR	interactive voice response
LAN	local area network
mbps	megabytes per second
MM	Mile Marker
NB	Northbound
PIN	personal identification number
PTZ	pan/tilt/zoom
REST	Representational State Transfer
RFP	request for proposals
RITA	Research and Innovative Technology Administration

Acronym	Definition
SQL	Structured Query Language
SPMS	SmartPark Management System
SPR	System Performance Requirement
TDOT	Tennessee Department of Transportation
TDS	Transport Data Systems
UDP	User Datagram Protocol
USDOT	United States Department of Transportation
VDC	voltage direct current
VMT	vehicle miles traveled
VPN	virtual private network
WAN	wide area network
WWW	World Wide Web
XML	Extensible Markup Language

EXECUTIVE SUMMARY

The primary mission of the Federal Motor Carrier Safety Administration (FMCSA) is to reduce fatalities, injuries, and crashes involving large trucks and motorcoaches. FMCSA and the motor carrier industry have been successful in reducing the industry's fatality rate since 1996. FMSCA set a safety performance target of no more than 0.117 fatalities per 100 million total vehicle miles traveled (VMT).[(1)] When identifying the factors that affect safety, driver fatigue is an obvious culprit. Driver fatigue is implicated in 13 percent of all truck crashes annually.[(2)] While there are many factors that contribute to driver fatigue, locating available overnight parking is one of the most significant ways to manage and reduce it. Advances in technology now make it possible to provide real-time parking availability information to truck drivers in a way that does not compromise the ability of the operator to drive safely.

The two-phase SmartPark project was intended to address FMCSA's goals of enhancing truck and motorcoach safety by better connecting demand for truck parking to available supply 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.

In Phase II, SmartPark demonstrated the efficacy of detection technology and the usefulness of disseminating truck parking availability information to truckers and motorcoach drivers.

Phase I tested laser scanning and light curtain technology to determine if either was appropriate for use in truck parking applications. The measures of effectiveness were captured in performance measures that included uptime requirements and performance targets. It was determined that side and overhead scanning technologies were the most effective and cost efficient technologies for "check-in/check-out" truck parking applications. In Phase II, side-fired laser side scanners were implemented at the ingress and egress points of the truck parking areas used for the project to monitor vehicles entering and exiting the site. A public rest area near Athens, TN was chosen for Phase I; the site is located at mile marker (MM) 45 on I-75 Northbound (N), as displayed in Figure 1. During Phase II, an additional site was added at a non-operational weigh station at MM23 on I-75 N, 22 miles from the Phase I site. The sites were chosen because they met all the requirements established in the project's request for proposal (RFP). Also, based on lessons learned from previous SmartPark efforts, the sites were a textbook case for demonstrating functionality of the system because they exhibited the following characteristics:

- Recently reconstructed, with easily accessible truck parking spaces.
- Single points of entrance and exit.
- Separated car and truck parking areas.
- Ample lighting for nighttime operations.

[1] Reference: FMCSA 2012-2016 Strategic Plan
[2] The Large Truck Crash Causation Study - Analysis Brief, Federal Motor Carrier Safety Administration, Office of Research and Analysis, Publication No. FMCSA-RRA-07-017, July 2007.

Figure 1. Map. SmartPark project locations (courtesy of Google Maps).

The systems engineering process established the needs, goals, functional requirements, and design requirements for SmartPark. The systems engineering processes included the development of an implementation plan, a Concept of Operations (ConOps), performance requirements, a field operations test plan, and an evaluation plan. Systems engineering ensured that the final outcome of SmartPark Phase II met the goals and needs established for the project by FMCSA and supported the FMCSA's overall mission.

Phase I established the validity of the SmartPark technology for use in a smart parking system. Phase II expanded this system to include traveler information dissemination. The results of Phase I can be found in the final report, which is published on FMCSA's website.

Table 1. Critical system performance requirements.

Requirement Identification	Description
Component Performance Requirement (CPR) 1	The sensors shall determine the length of vehicles and classify all vehicles with no more than 1% false or missed detections.
CPR2	The sensors shall collect parking availability information 99% of the time.
CPR3	The sensors shall determine the length of vehicles and classify all vehicles with no more than a 5% rate of erroneous classification.
System Performance Requirement (SPR) 1	The system shall provide truck parking availability information 99% of the time.
SPR2	The system shall provide truck parking availability information at 95% accuracy.
SPR3	The system shall have fewer than 5% false detection alarms.
SPR4	The system shall provide truck reservation capability 99% of the time.

The objective of System Performance Requirement (SPR) 1 was to verify the overall accuracy of the system in disseminating parking information. SPR1 was measured by comparing overall system operation time (6-month testing period) with time that the system was offline for any reason. Offline time included any downtime caused by weather, equipment malfunctions, or utility outages.

The objective of SPR2 was to determine whether the collected data reflected actual conditions of the parking lots seen via cameras and whether the data was correct 95 percent of the time. This was done by visually inspecting the camera feeds via the online management site and counting the number of vehicles in the lot. That number was then compared to the lot counts on the management Web site derived from the detectors. The system was calibrated this way once per day, and the results were recorded. The absolute value of the calibrations was then compared to the total number of entries recorded by the SmartPark System. This provided the basis of the SPR2 measurement.

The objective of SPR3 was to ensure that the system exhibited a limited number (ideally zero) of false detections, in order to keep the system accurate. The system must be able to distinguish whether a detection is a vehicle or a false detection, such as heavy rain. This was checked by evaluating large sets of data over time and comparing the number of corrections made to the system with the number of overall detections.

The objective of SPR4 was to confirm whether users could make or cancel reservations through the public Web site, interactive voice response (IVR), and mobile applications (apps) with no more than 1 percent outage during the test period. This was done by showing that the parking reservation system was operational during the testing period more than 99 percent of the time.

The conceptual and final designs of the system were a result of the systems engineering process, done in accordance with the ConOps and performance requirements documents. The Phase II design was comprised of several significant system components, described below:

- **Detectors:** Side-mounted infrared laser scanners used to detect vehicles at ingress and egress.
- **Doppler radars:** Used to provide velocity and length information of a vehicle relative to the laser scanner.

- **On-site processor:** Used to process the scanner and light curtain signals.
- **Off-site server:** Used to download and store data in a database.
- **Closed-circuit television (CCTV) cameras:** Used for validating site space availability (ground truth).
- **Web site and data archive:** Used to monitor the CCTV cameras and make corrections to the site as needed.
- **Dynamic message signs (DMSs):** Utilized to disseminate parking availability information to users on the roadway.
- **Interactive voice response (IVR) system:** Truck drivers were able to call 1-844-SMART-PK to check parking availability at the site and reserve a parking space.
- **Mobile application:** Truck drivers were able to use the application on a smartphone to check parking availability at the site and reserve a parking space.

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

Table 2. Summary of performance results.

Requirement	Performance Target	Actual Performance
CPR1	99%	99.23%
CPR2	99%	73.5%
CPR3: **MM23**	95%	Class SV: 98% Class LV: 97% Class OV: 18% Class BT: 100%
CPR3: **MM45**	95%	Class SV: 22% Class LV: 97% Class OV: 65% Class BT: 71%
SPR1	99%	100%
SPR2	95%	100%
SPR3	95%	**MM23:** 92% **MM45:** 93%
SPR4	99%	100%

RESULTS DISCUSSION

The SmartPark project demonstrated the viability of a truck parking information system. The results here show that with proper management, the system provided highly accurate information via the truck parking information system. This is evident in the results for Component Performance Requirement (CPR) 1, CPR 3, SPR1, SPR2, and SPR 3. The analysis for these requirements indicate that the system was capable of:

1. Detecting vehicles accurately.
2. Providing highly reliable truck parking availability information.

The end result was that truckers using the site could rely on the data displayed on the DMSs and the electronic platforms to locate available parking.

The results also demonstrate the challenges, constraints, and drawbacks of the approach taken in the SmartPark project.

Detector Limitations

The detectors, if installed properly, are able to accurately identify vehicles entering and exiting a site. However, given the "check-in-check-out" approach to detecting parking occupancy, any error from the detectors compounds over time. Even small error rates can result in the traveler information component disseminating incorrect information after 1–2 days without intervention. The system must be calibrated at least once per day to maintain acceptable accuracy levels.

Detector accuracy is heavily dependent upon proper installation. Manufacturer recommendations should be followed precisely to ensure effective detections. During the testing period the orientation of one detector was altered due to impact by a truck. After this impact the detector accuracy was reduced and the system needed to be taken offline until the orientation could be rectified. The detectors are highly sensitive to orientation with respect to the roadway.

Classification

For both phases of SmartPark, the detectors were programmed to classify vehicles based on length and place them into bins. Phase I results showed the limitation of classifying vehicles based on length, as the accuracy rate across the six bins of vehicle lengths was low. Length was used again in Phase II but with a reduced number of bins, with each bin covering a different range of vehicle lengths. The results of Phase II confirmed the limitation of the detectors when classifying vehicles.

Unmanaged Sites

Phase II included a reservation concept that relied on an honor system to work properly. The system was not patrolled or managed on a daily basis. With no incentive to observe the rules of the reservation system, truckers simply did not use it.

Traveler Information Utility

The traveler information system built for Phase II included DMSs, an IVR system, a mobile application, and a public Web site. Data collected on usage of the various components showed that the most useful aspect of the traveler information system was by far the DMS, which reached all passing motorists and was strategically placed to maximize the utility of the information. Participating truckers generally did not download the mobile application, and hits on the public Web site were limited.

LESSONS LEARNED

Phase II validated that a system like SmartPark is viable as a traveler information system. The key lessons learned from the two phases of the SmartPark program are as follows:

- **Management:** Any technological system must be managed. However, a check-in/check-out style system requires up to daily management procedures to be successful.
- **Usage:** Truckers acclimated to the system and used it as a means of determining where to park. They relied on the data, and usage at both lots increased significantly from before the project began.
- **Future Deployments:** Future deployments could benefit from an alternate style of parking detection that does not result in compounding error.
- **Communication:** Robust communications are highly recommended in any traveler information system, and truck parking is no exception. When communications go down, the accuracy of the information broadcast to the public is affected.
- **Mobile Applications:** Truckers are accustomed to using mobile applications and could benefit significantly from having access to truck parking information via this method, as well. However, a standalone application limits the number of users. Usage would be far more widespread if the data becomes open and available for integration with other applications that are already in use.
- **Reservations:** The reservation component of the system will only work if it is enforced. Truckers will park wherever possible in order to avoid driving while sleepy or tired.
- **Infrastructure:** SmartPark used a significant number of cameras to provide ground truth information. Future deployments will ideally replace all the static cameras with pan/tilt/zoom (PTZ) cameras, also reducing the number of cameras needed. There is an ongoing need, however, to be able to view the entire parking facility in order to perform calibrations and identify issues on site.

1. INTRODUCTION

The primary mission of the Federal Motor Carrier Safety Administration (FMCSA) is to reduce crashes, injuries, and fatalities involving large trucks and buses. When identifying the factors that affect safety, driver fatigue is an obvious culprit. Driver fatigue is an associated factor in about 13% of truck crashes,[(3)] and the CMV driver was either fatigued or asleep in 1.4 to 1.9 percent of fatal truck crashes from 2013 to 2015.[(4)] While there are many factors that contribute to driver fatigue, locating available overnight parking is one of the most significant ways to manage and reduce it. Advances in technology now make it possible to provide real-time parking availability information to truck drivers in a way that does not compromise the ability of the operator to drive safely.

Since the advent of modern trucking operations, demand for truck parking has been increasing due to several factors:

1. The growth in trucking, which reflects population increases and economic markets – particularly the growing volume of imports that serve the Nation’s consumers and industry.
2. Recent updates to Federal hours-of-service regulations require that drivers rest for longer periods, which translates into an increase in demand for truck parking, while the supply of truck parking has not kept pace.

At the Federal level, several studies and initiatives, including the Federal Highway Administration (FHWA) Truck Parking Report completed as a result of Jason’s Law,[(5)] have identified strategies to mitigate truck parking deficiencies.

The strategies identified include partnerships and policy recommendations, capacity enhancements, and innovative use of technology. A more comprehensive strategy would combine: partnering among private and public entities, addressing policy issues prohibiting innovative solutions, implementing proper planning mechanisms, and using technology and innovative design practices.

In 2007, FMCSA solicited proposals to implement pilot tests to demonstrate a system for conveying real-time information on parking availability for truckers on the road.

As a result, FMCSA pursued this SmartPark demonstration project to quantify the accuracy of the measurement technologies used to determine parking occupancy. The primary objective of SmartPark was to ***demonstrate technology that conveys parking availability to truckers in real-time on the road***. SmartPark’s intent was to realize this objective in a two-phase project. The first phase demonstrated the detection technology with equipment installed at a rest area at mile marker (MM) 45 on I-75 northbound (N) in Tennessee. The second phase demonstrated a truck parking system that provides drivers with

---

[3] Federal Motor Carrier Safety Administration, Office of Research and Analysis, “The Large Truck Crash Causation Study – Analysis Brief,” Publication No. FMCSA-RRA-07-017, July 2017.

[4] Federal Motor Carrier Safety Administration, Office of Analysis, Research & Technology, “Large Truck and Bus Crash Facts 2015,” Publication No. FMCSA-RRA-16-021, November 2016.

[5] http://www.ops.fhwa.dot.gov/freight/infrastructure/truck_parking/jasons_law/truckparkingsurvey/jasons_law.pdf

information and allows them to utilize the system to fulfill their parking needs. The second phase also added an additional site at MM23.

The objective of Phase II was to create and test the use of a smart parking travel corridor. The concept was to create a similar smart parking rest area near the Phase I rest area and to create a traveler information system to which the parking areas were linked. Using the real-time data, truckers would be able to make more informed decisions regarding where to park within the corridor. In addition, Phase II included a parking reservation system to enable truckers to reserve spaces in advance of arriving at the parking areas.

Phase II required expansion of the system to a location in the same corridor and direction as the Phase I site (MM45 on I-75 N in Tennessee). The project request for proposal (RFP) required that a site be selected within 35 miles of the Phase I rest area, which was located on I-75 N at MM45. A non-operational weigh station at MM23 on I-75 N was selected for Phase II. This site was selected for its proximity to the Phase I site and because of trucker familiarity with the site (as it was already utilized by truckers for short- and long-term parking). This document provides an analysis of the results of the Phase II investigation.

1.1 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 that FHWA complete a study on the adequacy of truck parking. From the FHWA study,(6) 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 connecting supply and demand.

The 2002 FHWA study recommended the deployment of intelligent transportation systems (ITS) to provide commercial motor vehicle 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 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 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 new types of technology

[6] https://www.fhwa.dot.gov/publications/research/safety/01158/01158.pdf

with strengths that would avoid the issues encountered in the previous attempts. In 2011, FMSCA decided to evaluate overhead laser scanning combined with Doppler radar technology and a side-mounted light curtain combined with Doppler radar technology. Since the side-mounted light curtain combined with Doppler radar technology proved to be viable, it was deployed in both testing sites in Phase II of the project to cover a larger continuous travel corridor. The focus in Phase II was to demonstrate technologies for disseminating truck parking availability information in real-time and to demonstrate networking parking areas to better communicate available supply of parking.

1.2 PROJECT STAKEHOLDERS

Due to its implications for safety and general operations on the transportation network, the overall SmartPark project had a number of both public and private stakeholders. Table 3 presents the stakeholders affected by this project. The Tennessee Department of Transportation (TDOT) was a primary stakeholder and was included in all significant communications, meetings, and deliverable reviews. Phase II directly affected a wider number of stakeholders due to the traveler information component of the project. While not directly providing quantifiable input for evaluation, truck drivers themselves were affected by the project and contributed to the data collected. Public and private sector stakeholders included:

Table 3. Project stakeholders.

Stakeholder	Involvement	Primary Stakeholder?	Involved in Phase I Testing?	Involved in Phase II Testing?
FMCSA	Project sponsor.	Yes	Yes	Yes
United States Department of Transportation (USDOT)/Volpe Center	Provided independent evaluation of the SmartPark system.	Yes	Yes	Yes
TDOT	Oversaw operation. Approval required for construction activities and use of site.	Yes	Yes	Yes
Tennessee Highway Patrol	Responsible for law enforcement.	No	Yes	Yes
American Trucking Association/Tennessee Trucking Association	Identified trucking needs. Educated potential users regarding the system.	No	No	Yes
Truck Drivers	Used truck parking facility and service center. Used the Phase II traveler information systems.	Yes	No	Yes
ITS-Tennessee	Outreach to trucking associations.	No	No	Yes

[This page intentionally left blank.]

2. PROJECT OVERVIEW

2.1 PROJECT SUMMARY AND MAJOR COMPONENTS

The basic concept of the SmartPark system was to determine the number and "class" of vehicles entering and exiting a 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 could deduce the number of available parking spaces in the parking area and disseminate information regarding the availability of parking at the lot. The required elements of the SmartPark system after Phase II implementation consisted of the following:

- A means of automatically detecting parking space status by monitoring ingress and egress.
- A central database to maintain parking status and reservation information.
- Controlled access to dedicated parking areas.
- Other required functions/characteristics (user needs) of the system:
  - Ability to count and classify vehicles entering and exiting the facility.
  - Easy installation and maintenance.
  - Operate unattended 24 hours per day, 7 days per week.
  - Operate in all weather and ambient lighting conditions.
  - Maintain a count of the available parking spaces in the facilities and provide this count to authorized remote users.
  - Provide a means for authorized users to remotely monitor the parking facility to determine the accuracy of the system.
  - Allow authorized users to remotely reset the count of available parking.
  - Maintain a log of vehicle entrance and exit events and system errors.

2.1.1 Site Selection

The SmartPark RFP prescribed several requirements regarding the SmartPark field operations test site:

- Test site must be a private or public truck parking area with controlled ingress from and egress to a major arterial road or highway.
- The site must be suitable for use with the detection technologies identified.
- There must be documentation of any (i) complaints about inadequate parking, (ii) need for a truck appointment or reservation system, (iii) trucks illegally parked, and/or (iv) trucks queuing up to enter the site.
- There must be at least one adjacent truck parking area (i) within 35 miles of the proposed site, (ii) capable of being accessed from the same road, (iii) with controlled ingress and egress, and (iv) 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 N at MM45 near Athens, Tennessee was selected as the Phase I field operations test site. A site at MM23 near Cleveland, Tennessee was chosen as the second site in Phase II. The locations of the sites are displayed on the map in Figure 2.

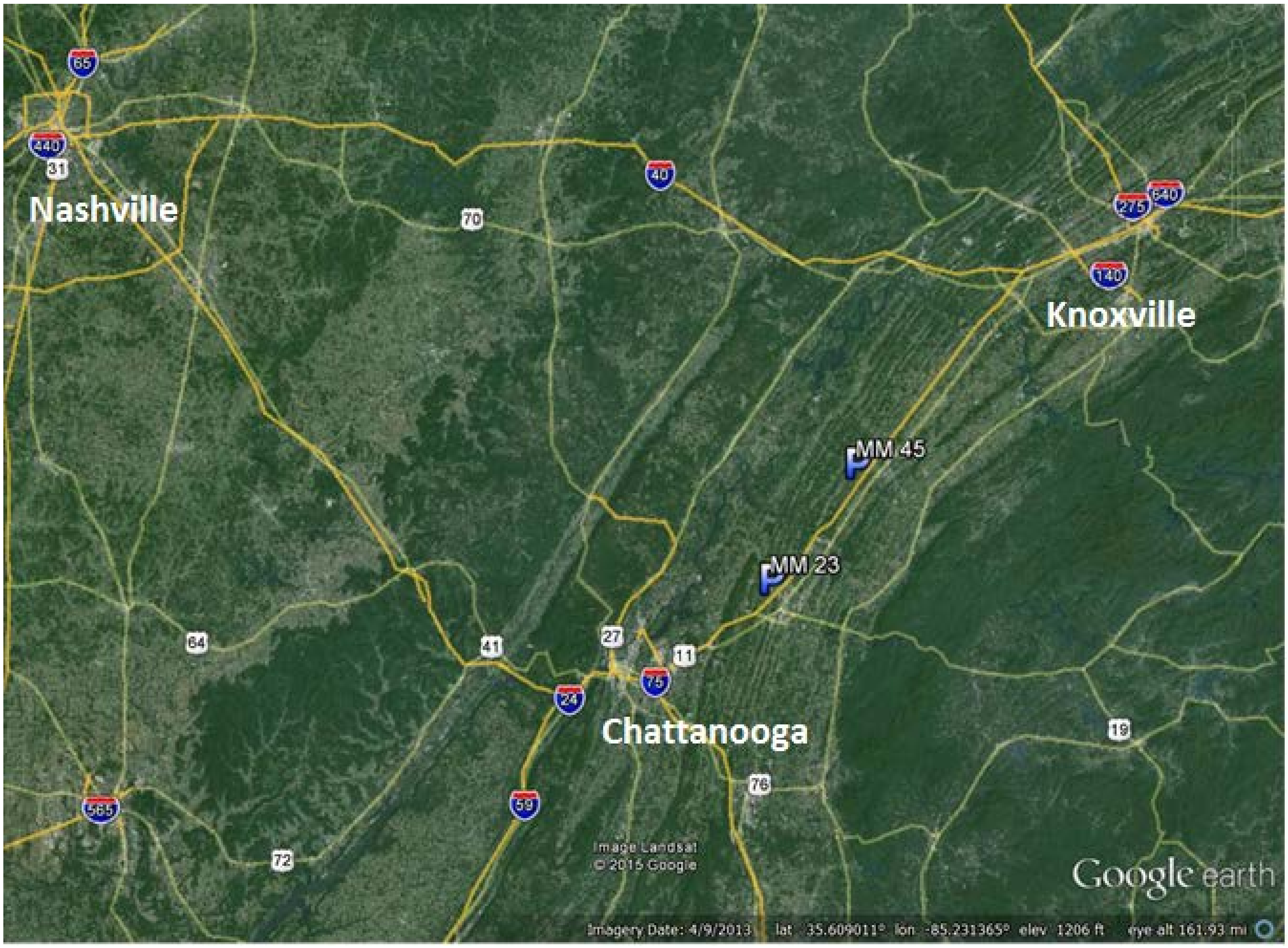


Figure 2. Map. SmartPark project sites.

The following characteristics made the MM23 site attractive for this project:

- With the cooperation and generosity of TDOT Region 2, the site had recently been reconstructed to enable this project, offering fresh pavement and easily accessible truck parking spaces.
- It had controlled points of egress and ingress.
- It consisted only of designated truck parking areas.
- It had 25 available truck parking spaces.

The site as it looked before its renovation can be seen in the satellite view provided in Figure 3.

As part of the renovation, Gannett Fleming (GF) installed lighting fixtures, advisory signage, and all field equipment related to the SmartPark system. The lighting fixtures were intended to enhance safety at the site and encourage truckers to feel more comfortable using the parking spaces.

Figure 3. Photograph. MM23 test site satellite image before renovation (courtesy of Google Maps).

2.2 SYSTEM OVERVIEW AND COMPONENTS

The Phase II system concept was similar to that of Phase I, but it only utilized a single detection technology that was proven to be reliable in Phase I. Vehicles entering and exiting the parking area passed through scanners at the truck entry and exit lanes (see Figure 4). Vehicles entering the parking area passed by a side scanner mounted beside the entry lane. The laser scanners scanned the side of the vehicle and transmitted the data to an on-site server. The layout of the egress point was a mirror of the ingress, and the same data was collected as at ingress.

In addition to the laser scanners, a Doppler radar unit was installed downstream of each gantry. The Doppler radar unit pointed back towards the oncoming vehicle in order to detect the position and velocity of the vehicle relative to the scanned line. The Doppler radar unit measured velocity, which was used to calculate the length of the truck. The on-site server combined the side scanner information and the length information (provided by the Doppler radar) to provide a profile of the vehicle. A classification of the vehicle was assigned based on this information.

A camera was mounted on each gantry and positioned to view vehicles as they passed through the gantry. Each camera took and archived a snapshot of the vehicle as it moved past the gantry. Additional cameras were mounted at strategic locations in the parking area to provide full coverage of the parking facilities at any time.

The data collected at the site were stored in the data center. Each ingress or egress event was documented and included detector identification number (ID), date, time, length, profile, and class of entering/exiting vehicle (in accordance with the classification scheme contained in the Phase II Concept of Operations), number of vehicles in the lot, and still-images from each of the cameras in the parking facility. From this data, parking space availability was estimated.

The parking system employed a capacity and occupancy algorithm at the on-site processor to calculate the number of available spaces at the rest area using information gathered by the detection system. The parking system allowed manual changes to the number of vehicles in the parking area (by classification), by an authorized user. Manual changes were necessary to calibrate the site on a daily basis. Calibrations ensured that errors did not accumulate during site operation. Each calibration was stored in a log for historical analysis purposes. The event log included all detections and classifications from all sensors, detector identification (whether an event was at an ingress or egress), user accesses, and any user changes.

The capacity and occupancy data from the new Phase II site was used in conjunction with the data from the Phase I site to disseminate parking information to users for both sites (MM23 and MM45) using dynamic message signs (DMSs), a SmartPark Web site, and a new SmartPark mobile application. These new features were also used to employ a new reservation system through which users could reserve select spots within each of the two parking lots.

The overall setup of the SmartPark system is displayed in Figure 4.

Figure 4. Diagram. SmartPark system overview.

2.2.1 System Hardware

Side-Mounted Infrared Laser Scanner

The laser scanner swept a laser beam in an arc across the roadway and received a reflection from anything in the path of the beam to scan the vehicle in the roadway in two dimensions. Its on-site processor combined this information with the speed and vehicle length measurements generated by the Doppler radar to produce a profile of the vehicle. The scanner operated at a rate of 75 scans per second, which is equivalent to a bandwidth of 38.4 kbps. For this type of system, it was proposed to use an angular scanning resolution of 4 degrees. The laser scanner operated from a 24-volt direct current (VDC) power supply.

The laser scanners were able to produce a two-dimensional profile of the vehicle, showing its height and length (Figure 5). The detectors used laser beams to detect the presence of a vehicle. The on-site processor combined the laser data generated from the vehicle obstruction 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 could determine the length and precise shape of the vehicle. The system assigned a vehicle "class" based on this information. Regarding exposure to the detection beams, the laser technologies posed no safety issues to motorists. This topic is discussed in more detail later in this report.

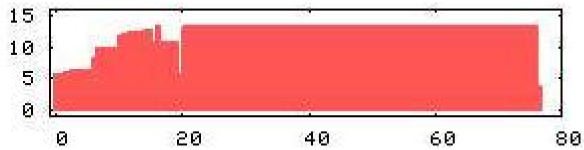


Figure 5. Image. Typical scanned truck profile.

Doppler Radars

The Doppler radars were self-contained, stand-alone units used to provide velocity and length information of a vehicle relative to the laser scanner. The radars used in the study had Federal Communications Commission (FCC) approval and utilized very low power. (The FCC regulation is in place to make sure that electronic equipment that is not intended for use as communications do not produce interference [transmission or broadcast noise] with equipment intended for use as communications. It is not a health-risk-related regulation like the one mentioned in Section 4.5.2 regarding the laser scanner.)

On-Site Processors

There were three processors at each site. One processor analyzed and interpreted the ingress detector data, the second had the same function for the egress detector, and the third combined and stored the data locally before transmission to the off-site data center. The two on-site processors were contained in a communications equipment room in the MM45 rest area and in a field hub cabinet at the MM23 parking area. The on-site processor had multiple serial ports for interfacing with the field devices and an Ethernet port for external interfaces. The Ethernet port was connected to an Ethernet switch/router/firewall. At MM45, the switch connected to a T-1 line obtained from AT&T for internet access. At MM23, the switch connected to cable internet obtained from a local cable service provider.

Off-Site Data Center

The off-site data center was housed at GF's data facility in Tampa, FL.

Closed Circuit Television Cameras

Fixed closed circuit television (CCTV) cameras were utilized for the surveillance of the parking area and ingress and egress points. The cameras were used to assist GF in evaluating the performance of the sensors.

The cameras were configured to stream full-motion h.264 video. H.264 video is a type of video compression standard within the camera and digital video industry. Resolution and frame-rate were consistent with the bandwidth limitation imposed by the communications medium at each site. All cameras output a single video image for storage on the processor when triggered by a detector.

Dynamic Message Signs

Electronic signs disseminated information to users on the roadway. The signs displayed pre-set automatically updated messages (the signs updated every minute) pertaining to the availability of parking spaces at the project sites.

2.2.2 Detector Processors and Automated Analysis

Data collected by the detection units were analyzed by processing units that accompanied the detectors. The processing units took the data collected by the detectors and the Doppler radar, combined them, and ran it through an algorithm to produce vehicle data. Once processed, the data generated 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 made this system unique amongst other vehicle detectors.

During the development of the systems engineering documents and the needs definition processes, FMCSA identified the following system functional requirements:

- Discern the difference between large vehicles and small vehicles: typical automobiles versus tractor trailers.
- 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 in response to the requirements identified by FMCSA. The original resulting classification scheme to cover all vehicles entering and exiting the lot is given in Table 4. This classification was simplified for Phase II from six bins to four, changing the range of lengths fitting into each new bin.

Table 4. SmartPark vehicle classification scheme.

Class	Description
SV	"Small Vehicles" – Vehicles with length between 0 and 30 feet. For example, passenger cars, pickup trucks, or sport utility vehicles (SUVs).
LV	"Large Vehicles" – Vehicles with length between 30 and 90 feet. A typical tractor-trailer and large-sized recreational vehicle fall into this category.
OV	"Oversized Vehicles" – Vehicles with length over 90 feet. This encompasses everything else that the previous class does not, for example: double trailers, oversized loads, and irregularly shaped large vehicles.
BT	"Bobtails" – Tractors without trailers. The ability to discern this category was unique to SmartPark's detection method. This class relied on the pattern recognition algorithm recognizing the vehicle profile in lieu of measuring the vehicle length to determine the type of vehicle.

The classification scheme not only satisfied the needs of FMCSA, but the scheme was specially developed with field observations in mind. For the most part, the classes were 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 6 and Figure 7, respectively.

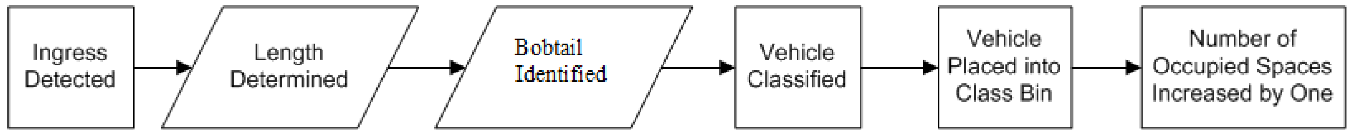


Figure 6. Ingress algorithm.

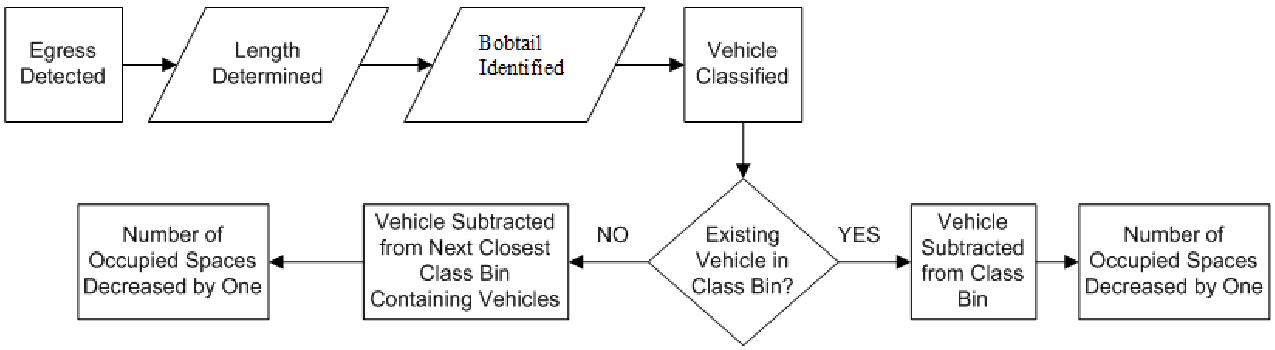


Figure 7. Egress algorithm.

The egress algorithm used in the analysis mimics the ingress process. An extra step was added to the egress process to avoid losing vehicles not already represented in the system. Due to variations in the installation of the detector technology between ingress and egress of a site, a vehicle leaving the lot may have been classified differently than it was classified when entering the lot. When departing a site, if there were no vehicles of the classification assigned by the egress detector, then the exiting vehicle would be subtracted from the next-closest class bin with one or more vehicles in it. This process preserved the overall count of the system in the event that there was no vehicle in the proper bin from which to subtract. When classifications differed between a vehicle's ingress and egress, subtracting from the classification bin designated by the egress detector could have resulted in a negative number (if the classification bin already had a value of zero), or the egress 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 may have been classified differently at the ingress and egress, the integrity of the overall lot count was not affected. If the lot count was already zero, the system would effectively erase an egress event's effect on the count.

2.3 VERIFICATION TOOLS

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

- Ten CCTV cameras at MM45 and eight CCTV cameras at MM23.

- Remote monitoring Web site.

While the primary purpose of the verification tools was to confirm the system's accuracy ("ground-truth") and monitor its progress, they were also vital for calibrating the system in real-time (that is, correcting the truck counts). While the verification tools may not be used as frequently in future deployments of the SmartPark system, they were the only means used to monitor the system and prevent errors from accumulating during the field operations test.

2.3.1 CCTV Cameras

CCTV cameras were placed strategically throughout the rest area and truck parking area to provide a means of monitoring the site from remote locations. Cameras were carefully located such that the cameras provided 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 or new 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 for each site are displayed in Figure 8 and Figure 9 (the different colors within the figures are to help separate camera fields of vision).

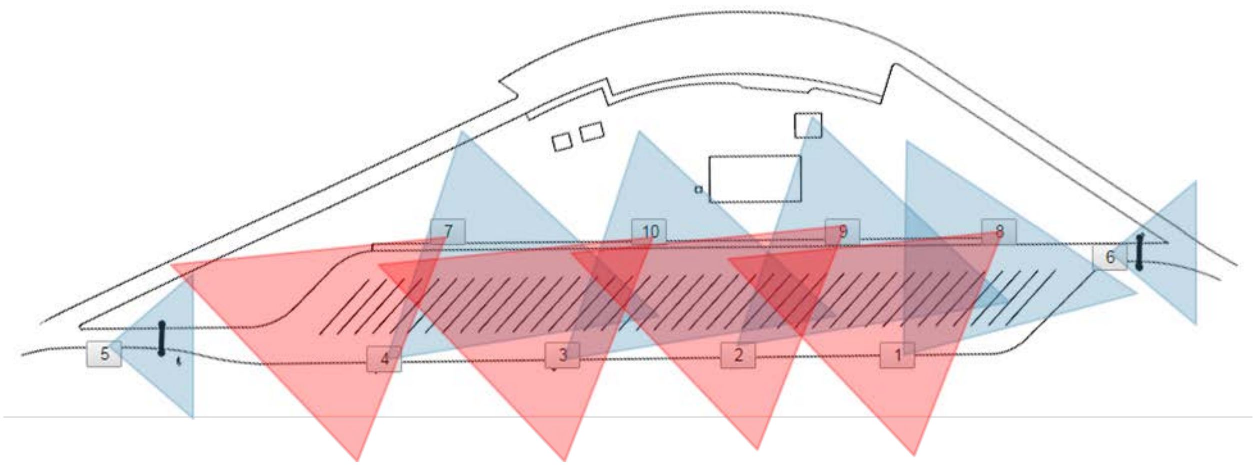


Figure 8. CCTV camera locations and fields of vision for MM45.

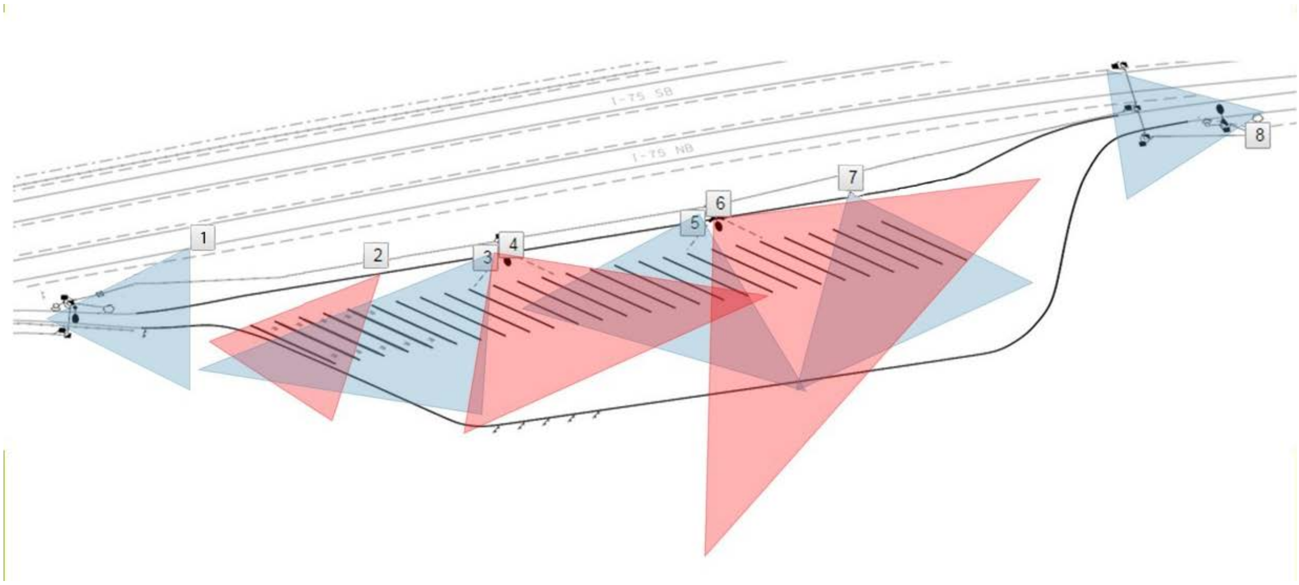


Figure 9. CCTV camera locations and fields of vision for MM23.

Each of the CCTV cameras was linked to the on-site data server for their parking site. Each of 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 of the connection to the rest area site. The fields of view of the MM45 rest area cameras are displayed through snapshots in Figure 10 and the fields of view of the MM23 site cameras are displayed in Figure 11.

Figure 10. Grouped image. CCTV camera images for MM45 SmartPark site.

Figure 11. Grouped image. CCTV camera images for MM23 SmartPark site.

2.3.2 Management Web site and Interfaces

A project Web site was established to facilitate monitoring of the site in real time. Users (law enforcement) could access the site at http://manage.smartparkingusa.com, where they were prompted for a username and password. From the Web site, users could access:

- Current occupancy of the parking lot, including available spaces, in near real time (a maximum of 1 minute of latency occurred as a result of the system architecture and communication limitations).
- Classifications of the vehicles currently in the lot.
- Live video from any of the CCTV cameras at MM45 and MM23.
- Historical data from any period that the system was in operation.
- A “corrections” button that enabled manual calibration of the lot count.

The primary screen of the Web site is shown in Figure 12. This homepage displayed the current lot usage, the classifications of the vehicles in the lot, and the CCTV video feeds, which could be accessed by clicking on one of the numbered icons drawn around the parking lot. From this site, the user could 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 14, displayed all events that occurred 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 (side scanner).
- Mounting configuration of the detector.
- Class of the vehicle (according to Table 4).
- Number of spaces in use, inclusive of the event.
- Vehicle count within the lot, by class.
- Images of the vehicle associated with the event (e.g., Figure 13).

The Web site was configured to provide the project team with as much information regarding each event (i.e., ingress or egress) as possible. A critical aspect of monitoring the system was to be able to observe any errors in parking space availability. The CCTV cameras utilized at the site provided viewing capability for real-time streaming and corrections. However, the CCTV cameras also captured still images of the entire project area every time an event occurred. These images were associated with the unique vehicle/event ID and stored in the data retrieval database. They could be recalled by clicking on the profile image for a data retrieval entry. Using these still images, a user could view activity and occupancy within the lot and compare it to the vehicle count and availability being given by the system.

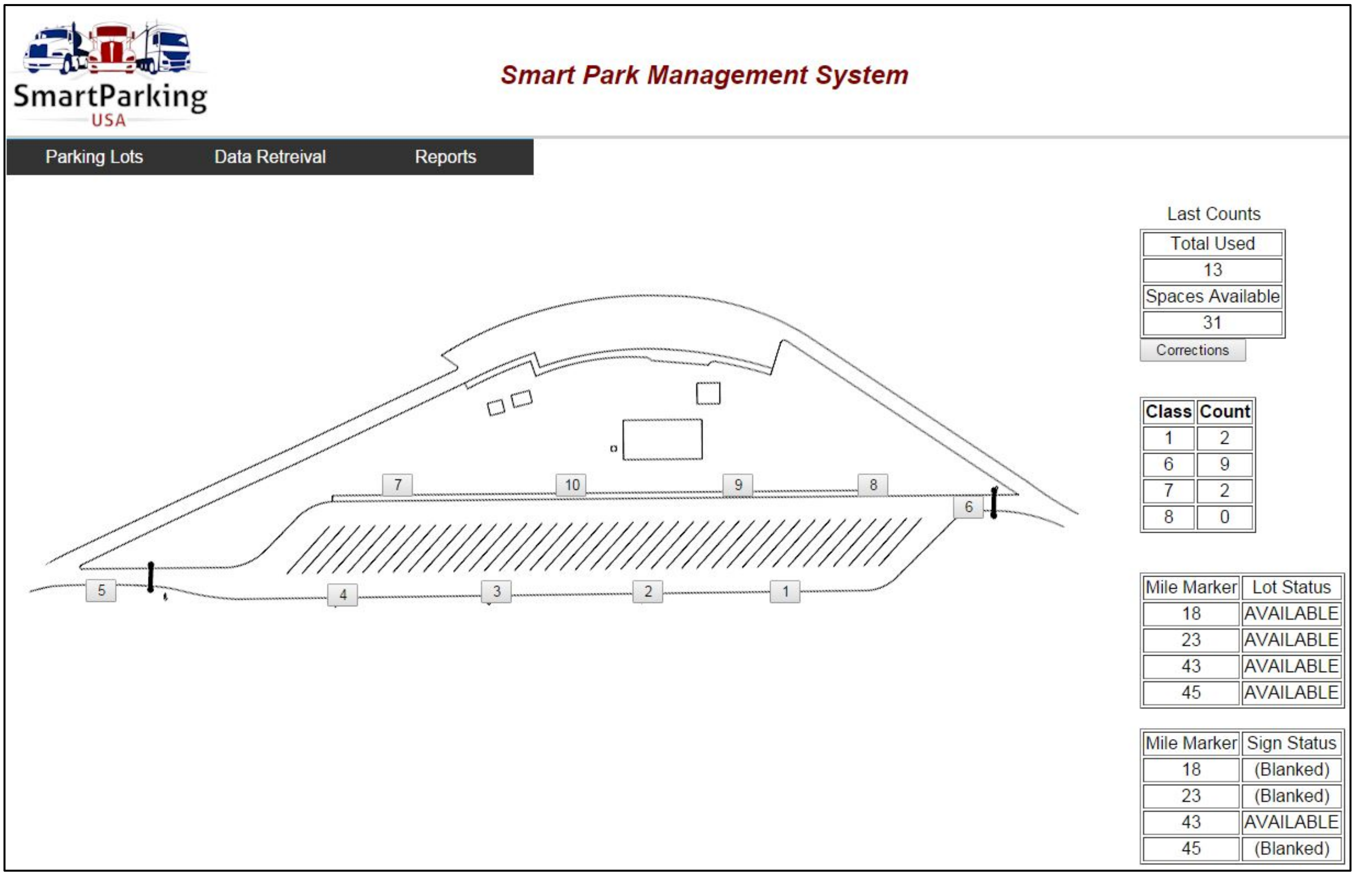
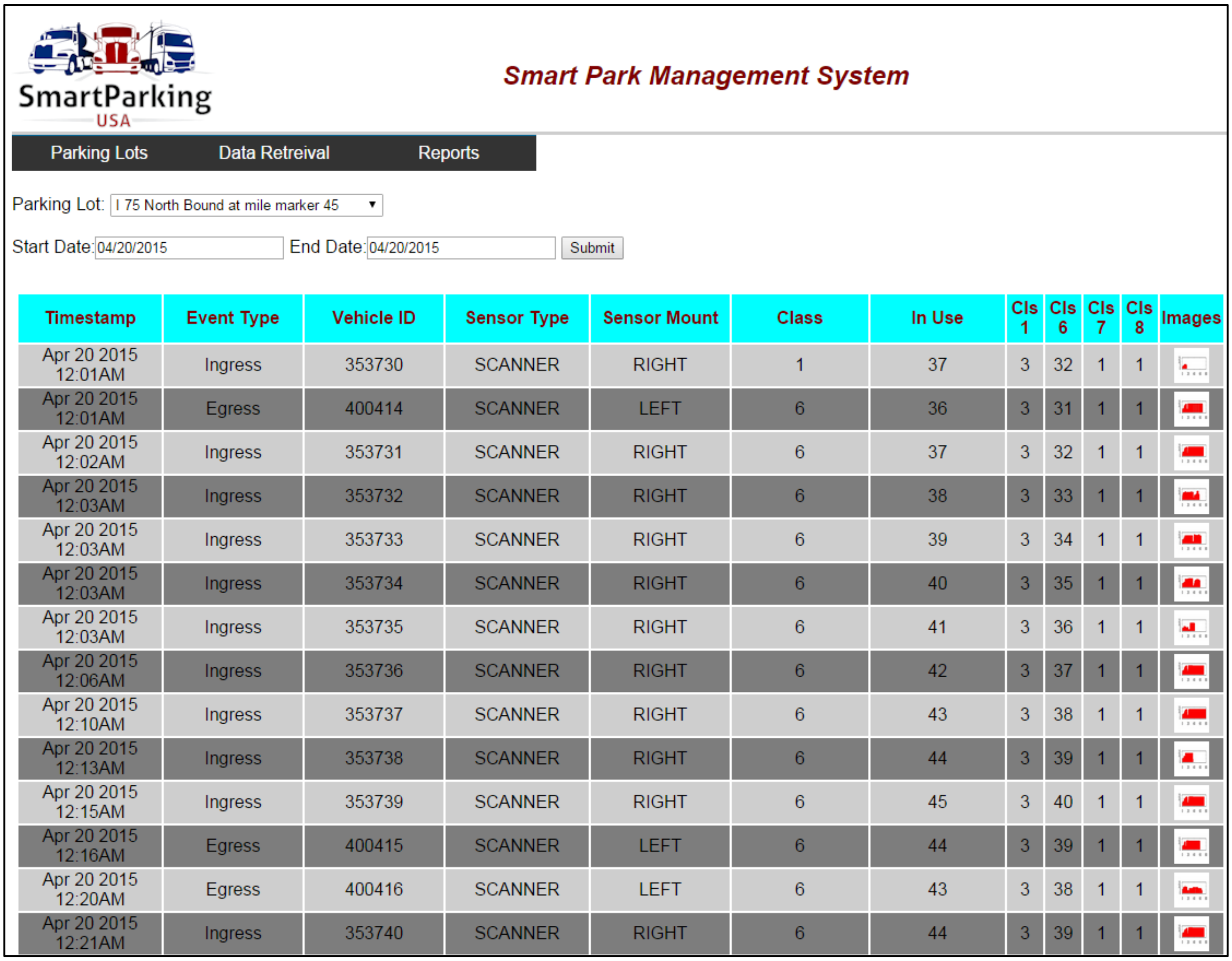


Figure 12. Screenshot. SmartPark Web site homepage.

Figure 13. Typical SmartPark database image catalog.



SmartParking USA

Smart Park Management System

Parking Lots | Data Retreival | Reports

Parking Lot: I 75 North Bound at mile marker 45

Start Date: 04/20/2015 End Date: 04/20/2015 Submit

Timestamp	Event Type	Vehicle ID	Sensor Type	Sensor Mount	Class	In Use	Cls 1	Cls 6	Cls 7	Cls 8	Images
Apr 20 2015 12:01AM	Ingress	353730	SCANNER	RIGHT	1	37	3	32	1	1	
Apr 20 2015 12:01AM	Egress	400414	SCANNER	LEFT	6	36	3	31	1	1	
Apr 20 2015 12:02AM	Ingress	353731	SCANNER	RIGHT	6	37	3	32	1	1	
Apr 20 2015 12:03AM	Ingress	353732	SCANNER	RIGHT	6	38	3	33	1	1	
Apr 20 2015 12:03AM	Ingress	353733	SCANNER	RIGHT	6	39	3	34	1	1	
Apr 20 2015 12:03AM	Ingress	353734	SCANNER	RIGHT	6	40	3	35	1	1	
Apr 20 2015 12:03AM	Ingress	353735	SCANNER	RIGHT	6	41	3	36	1	1	
Apr 20 2015 12:06AM	Ingress	353736	SCANNER	RIGHT	6	42	3	37	1	1	
Apr 20 2015 12:10AM	Ingress	353737	SCANNER	RIGHT	6	43	3	38	1	1	
Apr 20 2015 12:13AM	Ingress	353738	SCANNER	RIGHT	6	44	3	39	1	1	
Apr 20 2015 12:15AM	Ingress	353739	SCANNER	RIGHT	6	45	3	40	1	1	
Apr 20 2015 12:16AM	Egress	400415	SCANNER	LEFT	6	44	3	39	1	1	
Apr 20 2015 12:20AM	Egress	400416	SCANNER	LEFT	6	43	3	38	1	1	
Apr 20 2015 12:21AM	Ingress	353740	SCANNER	RIGHT	6	44	3	39	1	1	

Figure 14. Screenshot. SmartPark Web site data retrieval screen.

2.4 COMMUNICATIONS AND DATA FLOW

All equipment at both sites were connected using a series of multimode fiber optics and Ethernet and communicated via a local area network (LAN) established for the project. The sites were interconnected via a wide area network (WAN) created by leasing lines from internet service providers: T-1 connection at MM45 and cable internet at MM23. The network architecture is summarized in the diagram in Figure 15.

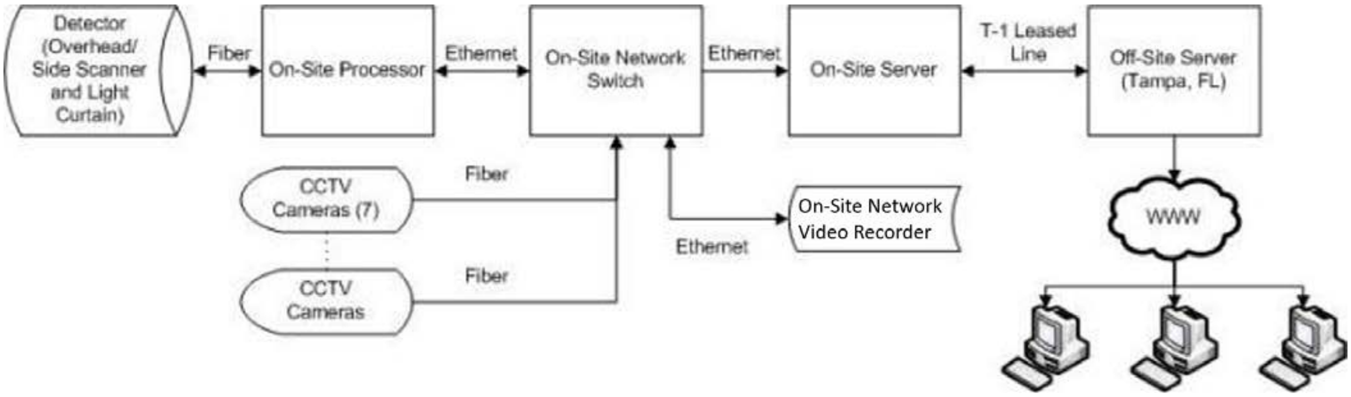


Figure 15. Diagram. SmartPark local area network architecture summary.

A leased T-1 line connection was established at the MM45 site for all communications to and from the project site. The T-1 had a standard bandwidth of approximately 1.544 megabytes per second (mbps). At the MM23 site, cable internet from a local service provider was established. The bandwidth of this connection was approximately 500 mbps.

SmartPark utilized several services to exchange data internally and to send data externally. The protocols are summarized in Figure 16. These various protocols were used to complete functions within the SmartPark system to capture, record, and process data.

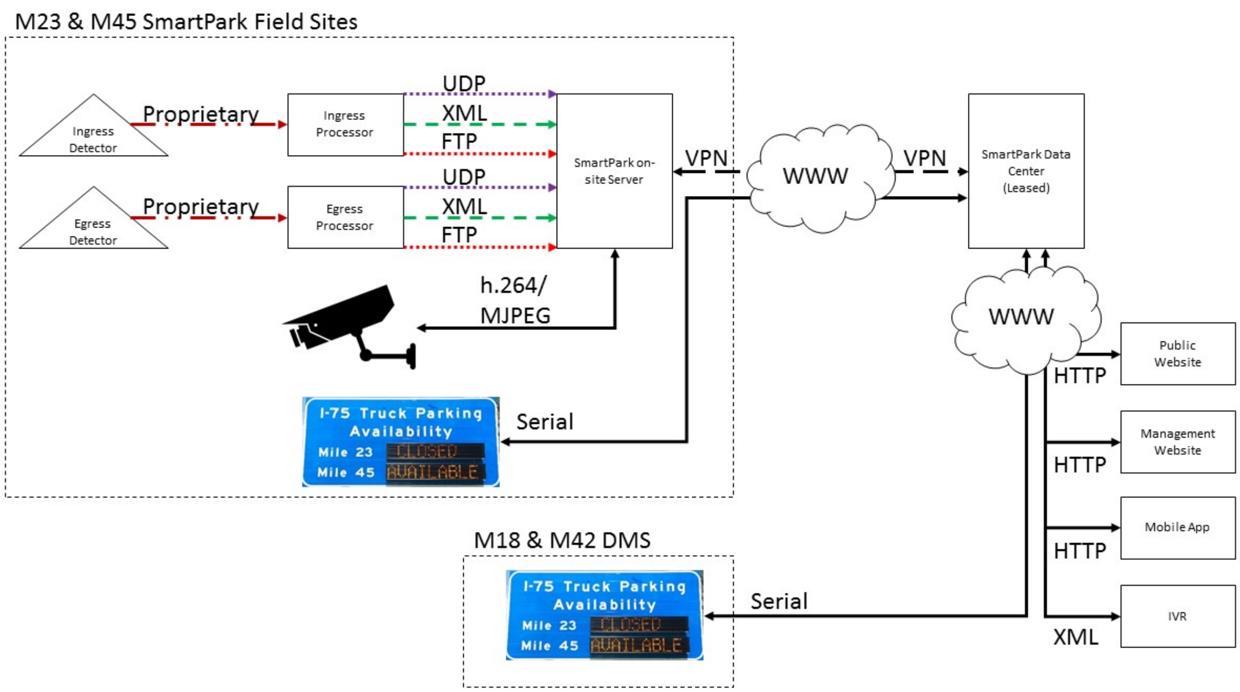


Figure 16. Diagram. SmartPark protocols.

The processes are described in detail below, including each one's location, source information, author, and purpose within the SmartPark system.

- Transport Data System (TDS) processing software:
  - Location: TDS ingress and egress computers.
  - Source information: proprietary code.
  - Author: Transport Data Systems.
  - Purpose: Processed the data inputs from the radar/scanner combinations at each ramp and generated a profile and classification for each vehicle. The software also kept track of the total occupancy of the lot and provided a trigger to the image grabber software. Output a profile image and an extensible markup language (XML) file description of the event, both of which were sent via file transfer protocol (FTP) to the image processor.
- Lot count updater:
  - Location: GF image processors.
  - Source information: C#, source code provided.
  - Author: GF.
  - Purpose: This program, implemented as a representational state transfer (REST) Web service, allowed an admin user on the SmartPark management Web site to issue a calibration count to the TDS software.
- Image grabber:
  - Location: GF image processors.
  - Source information: C#, source code provided.
  - Author: GF.
  - Purpose: Accepted triggers over a user datagram protocol (UDP) port from the TDS ingress and egress processors. When a trigger came in, the program requested a snapshot from each of the cameras at that moment and stored them locally.
- XML processor:
  - Location: GF server.
  - Source information: C#, source code provided.
  - Author: GF.
  - Purpose: Processed XML files from the TDS software and inserted records for each event into a structured query language (SQL) database.
- Sign control:
  - Location: GF server.
  - Source information: C#, source code provided.
  - Author: GF.
  - Purpose: Sent messages to the project's six DMS signs.

- Public Web site:
  - Location: GF server.
  - Source information: C#, JavaScript, and hypertext markup language (HTML), source code provided.
  - Author: GF.
  - Purpose: Public Web site to display status information to the public.
- Management Web site:
  - Location: GF server.
  - Source Information: C#, JavaScript, and HTML, source code provided.
  - Author: GF.
  - Purpose: Management site to view cameras and update lot counts.
- Interactive Voice Response (IVR) software:
  - Location: GF server and service provider Tropo.
  - Source information: Javascript and HTML, source code provided.
- Phone app:
  - Location: Apple and Android stores (free app).
  - Source information: Javascript, compiled by Adobe Phone Gap. Source code provided.
  - Author: GF.
  - Purpose: Phone app to view lot status and, if desired, make reservations.

In addition to the custom software, several commercial applications were installed to help system management and transmission of files. These are described below:

- Hamachi VPN – This is a software-based virtual private network (VPN) product from LogMeIn, Inc. that establishes point-to-point or point-to-multipoint connections. It was installed on the server and on each site's image processor computer. In addition to providing a path for the image and XML files to be transferred, all management access was conducted through this VPN connection.
- SyncBackPro – This software by 2BrightSparks, Ltd was used to transfer the following files at the indicated rates:
  - Images from MM23 and 45: once per minute.
  - XML files from MM23 and 45: once per minute.
  - Archive of images over 6 months old: once per day.
  - Backup of database: once per day.

  This program triggered the XML processor program each time it downloaded new files.
- Tropo – This service provided IVR services for the 1-844-SMARTPK phone number.

- Adobe PhoneGap – This service was used to build iPhone and Android applications from a single JavaScript code base.

2.5 INFORMATION DISSEMINATION SYSTEM

Phase II of the SmartPark project introduced four public interfaces: the public Web site, the IVR system, DMSs, and the mobile application.

2.5.1 Public Web site

The public Web site, found at www.smartparkingusa.com, allowed users to view availability of truck parking at the two sites and make reservations. This Web site enabled users to register for the reservation service and provided them with a 5-digit personal identification number (PIN) which they could use to log in when using the IVR. Their login credentials could be retrieved through a “Forget password or PIN?” link in the system which automatically sent the user an e-mail with the requested credentials. On the Web site, users could create and manage reservations as well as view availability information without logging in or registering. The parking availability could be viewed for both sites at any given time, and the estimated availability could be viewed for a future time. Current availability was displayed by clicking the “Now” button and was described as “Available,” “Limited,” or “Lot Full” (quantitative thresholds are given later under “Dynamic Message Signs”). These categories were based on the proportion of available spaces in the lot at the time in question. Future availability was categorized as “High,” “Medium,” or “Low.” This future availability was estimated by using historical availability data for the day and time entered by the user. An example of this capability is presented in Figure 17, below.

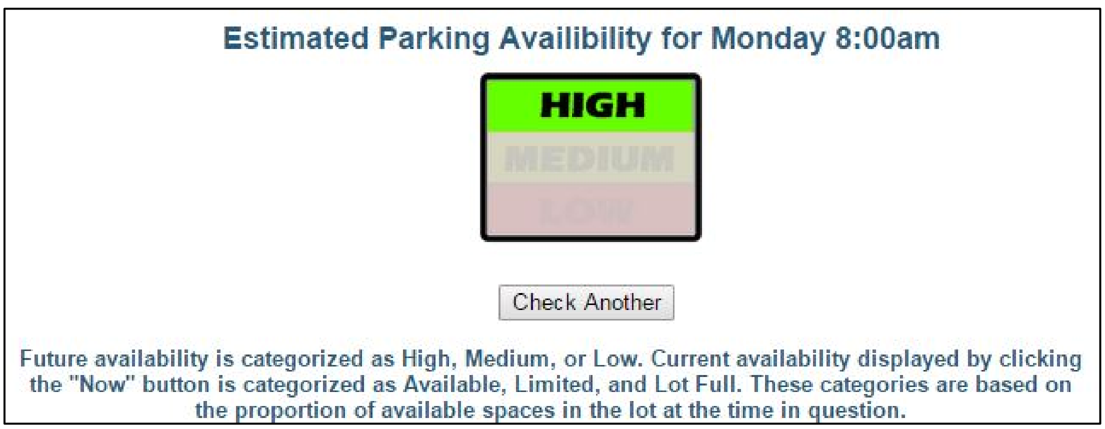


Figure 17. Screenshot. Parking availability on public Web site.

2.5.2 Mobile application

The mobile SmartPark application could be downloaded on the Google Play market and the Apple App store for free. The mobile application had the same capabilities as the public Web site but was more easily accessible “on-the-go” because it was optimized for use on smartphones. The application addressed safety concerns by utilizing the phone’s GPS coordinates and/or accelerometer to disable the application over a predetermined speed to prevent users from using the application while driving. An example of the look and feel of the application can be seen in Figure 18.

Figure 18. Grouped image. Mobile application example screens.

2.5.3 Interactive Voice Response (IVR) Phone system

For users who did not have access to the internet, Phase II provided a phone system to create and manage reservations. The system was reached by dialing 1-844-SMART-PK. The phone system utilized third-party-provided IVR technology to provide an interactive phone system with simple prompts intended to guide the user through the process of checking availability or creating and managing a reservation. The phone system provided the user with a unique reservation confirmation number, similar to the mobile application or the Web site, which gave the user the opportunity to manage this reservation until it expired or was cancelled by the user.

2.5.4 Dynamic Messaging Signs

The SmartPark information dissemination process employed "Type-A" DMS inserts to provide information to motorists. A sign was placed at the entrance of each site and a sign was placed 1 mile in advance of each site for a total of four sign locations.

The signs varied in message content based on where they were deployed in relation to the parking areas. The sign placed at Mile 18 and the sign placed near Mile 23 had parking information for both the MM23 and MM45 lots. An example of what the signs looked like can be seen in Figure 19. The signs near Mile 43 and Mile 45 only contained availability information about the Mile 45 lot because they were downstream of MM23. An example of what the signs looked like can be seen in Figure 20.

The "Type-A" DMS insert displayed parking availability according to the thresholds, as follows:

- "Available" – more than 4 spaces available.
- "Limited" – 2 to 4 spaces available.
- "Full" – 1 space available.

Figure 19. Photograph. Sign type upstream of MM23.

Figure 20. Photograph. Sign type upstream of MM45 and downstream of MM23.

The purpose of these signs was to provide information on parking lot availability to the motorists so that they could make informed decisions prior to reaching either rest stop.

2.6 RESERVATION CONCEPT

A reservation system was implemented at both parking facilities. Five spaces at each site were reserved for reservations. Truckers could make reservations using any of the traveler information dissemination programs, with the exception of the DMS. Each reserved parking space was marked clearly with signage designated to that space (see Figure 21).

There was no formal enforcement of the use of these reserved spaces. Therefore, an honor system was used.

Users were able to cancel a reservation, end a reservation early, or report a failed reservation (another vehicle was parked in their allotted spot at the time of their reservation) by using the “manage reservation” feature through the mobile application, the Web site, or the phone system. Users were also requested to check in upon their arrival in order to ensure a successful reservation in the system. It was intended that the user employ these features to ensure the reliability of the reservation system. This created a vested interest for the users who would have liked to see the system operate properly.

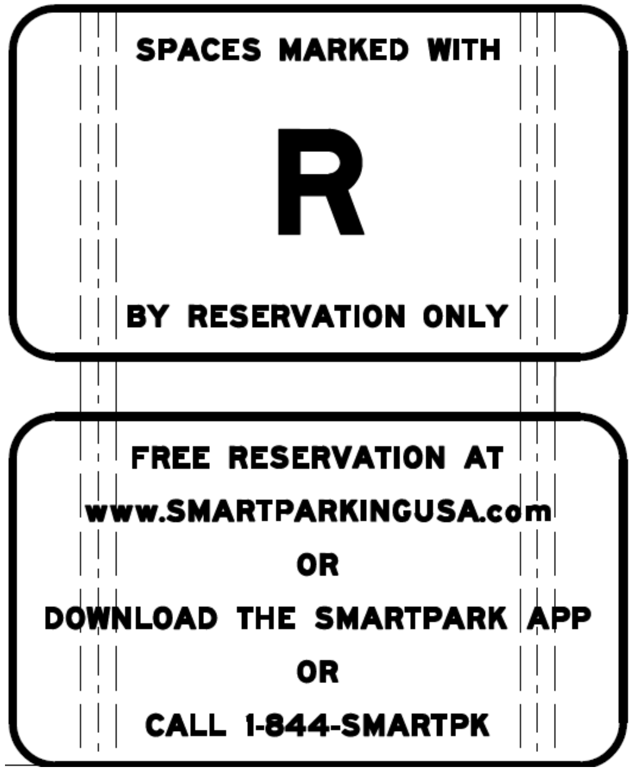


Figure 21. Image. Reserved space information static sign examples.

[This page intentionally left blank.]

3. TESTING PERIOD

3.1 GOALS

Contractually, the detector equipment required a 6-month testing period. This period began on March 24, 2016, and ended on September 26, 2016, when the contract also expired. The intent of the testing period was to demonstrate functionality and usefulness of the detector technologies and gather data regarding the performance of each of the detector units. The data were used to analyze the accuracy and effectiveness of each of the detector units, and consequently of the overall system.

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

- **Troubleshooting:** Identify issues and barriers to successful detector operation and address these issues as they arise.
- **Vehicle detection accuracy:** Verify the accuracy of the individual ingress and egress detector units.
- **System performance:** Verify and measure performance of the overall system, inclusive of all components. System performance is determined by evaluation of the performance requirements.

3.2 PERFORMANCE REQUIREMENTS

The systems engineering process completed for this project established a series of requirements (component performance requirements [CPRs] and system performance requirements [SPRs] by which to measure accuracy and performance of the project components. By meeting or exceeding these set requirements, the system would be deemed viable for future use. The seven performance requirements are identified in Table 5.[7]

Table 5. SmartPark Phase II performance requirements.

Requirement Identification	Description
CPR1	The sensors shall determine the length of vehicles and classify all vehicles with no more than 1% false or missed detections.
CPR2	The sensors shall collect parking availability information 99 percent of the time.
CPR3	The sensors shall determine the length of vehicles and classify all vehicles with no more than a 5% rate of erroneous classification.
SPR1	The system shall provide truck parking availability information 99 percent of the time.
SPR2	The system shall provide truck parking availability information with 95 percent accuracy.
SPR3	The system shall have fewer than 5 percent false detection alarms.
SPR4	The system shall provide truck reservation capability 99 percent of the time.

[7] See "SmartPark Project – Phase II Performance Requirements V1.3," prepared by Gannett Fleming in January 2014.

3.2.1 CPR1 and CPR3

Compliance with CPR1 and CPR3 demonstrated the system's accuracy in determining the length of all vehicles and classifying them into the correct classes. The classification system for SmartPark was based upon the length and shape of a detected vehicle. CPR1 refers to the detector equipment and the algorithm used to calculate lengths using speed measurements from the Doppler radar, and it was reliant on both the algorithm and the detector having been correct and having functioned well together.

Classification was important because it helped to estimate the number of truck parking spaces that would actually be used by an 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. Also, if the parking area had a significant number of trailer drops, distinguishing between vehicles with trailers and those without would become important.

3.2.2 CPR2

CPR2 measured the system's ability to collect parking availability information. It also measured the aptitude of the ingress and egress detectors. CPR2 tested the field readiness of the equipment by measuring uptime versus downtime caused by internal factors.

3.2.3 SPR1

SPR1 measured the system's capability to disseminate parking availability information.

3.2.4 SPR2

SPR2 evaluated the accuracy of the information displayed to truckers via the dissemination system.

3.2.5 SPR3

SPR3 evaluated the accuracy of the detection system as a whole and limited the tolerance threshold for "false positive" notifications. This SPR was a direct result of the false alarms experienced during Phase I caused by heavy rain, snow, and other environmental factors.

3.2.6 SPR4

SPR4 measured the uptime of the traveler information system. It was not affected by system outages, as these were measured by CPR2. SPR4 specifically evaluated uptime of the traveler information components as related to a fully functioning system.

3.3 DATA COLLECTION

In Phase I, performance of the detection units was evaluated with a high degree of scrutiny. Phase II built upon this evaluation while minimizing duplication. Hence, manual counts were not considered necessary during the Phase II evaluation. In lieu of manual counts, the SmartPark management system's data retrieval system was relied upon to conduct evaluations.

The testing period for SmartPark Phase II officially began on March 24, 2016, and continued through September 26, 2016. All data were logged in the SmartPark management system and could be accessed via the data retrieval option on the Web site. Each weekday during the testing period, an operations person performed a system calibration, each of which was recorded in a database. All evaluations of performance requirements used the data retrieval and system calibration database.

3.4 SYSTEM OUTAGES

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

- **Environmental:** 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 resulting from 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 were not to be included in the system performance evaluation for SPR1 or SPR2. A summary of the outage periods is displayed in Table 6 and Table 7. The 86.5-day failure at the MM23 site was caused by a failure in one of the processors that interprets the laser scanner data. The 12.125-day outage at the MM45 site was caused by a vehicle striking the pole supporting the ingress laser scanner, negatively altering the sensor’s orientation and ability to detect vehicles.

Table 6. SmartPark MM23 system outages.

Outage Date Range	Duration	System Outage/Issue
4/6/2016-4/7/2016	1 Day	Software
4/27/2016	1 Day	Software
5/5/2016	4 Hours	Software
5/25/2016-8/19/2016	86.5 Days	Hardware
Total	**88.75 Days**	**-**

Table 7. SmartPark MM45 system outages.

Outage Date Range	Duration	System Outage/Issue
3/31/2016-4/2/2016	3 Days	Software
4/20/2016	1 Day	Software
5/9/2016	0.5 Hours	Software
7/20/2016	1 Day	Software
8/4/2016	1 Day	Software
8/24/2016	1 Day	Software
9/1/2016-9/13/2016	12.125 Days	Infrastructure
Total	**19.125 Days**	**-**

3.4.1.1 Issues Encountered

Heavy Rain Events

Prior to the start of the official testing period, both SmartPark sites were monitored for anomalies and potential issues. During this period, it was found that during heavy rain events, the ingress and egress detectors perceive rain droplets as though they were vehicles entering or exiting the lot. This occurred most often in the ingress detector in the MM45 lot than in the egress detector. The false detections drove up the number of vehicles that the system believed were in the lot, giving false availability information (by incorrectly reducing the number of available spaces). An example of a false ingress detection occurred on August 23, 2015, at 8:07 a.m. (see Figure 22). As can be seen in the image, the system believed a vehicle entered the lot even though there is no vehicle near the ingress in the camera still for Camera 6. The profile included in the event log shows that the detectors were sensing “sheets” of rain as they fell from above, resulting in the false detection of a Class OV (oversized) vehicle. This issue was resolved whenever a manual correction was done for the lots through the SmartPark Management System.

Figure 22. Image. False detection caused by rain in MM45.

This issue was subsequently addressed with the manufacturer by adjusting the algorithm that interpreted the scanner data and produced vehicle profiles. Following the adjustment, no further rain-caused false detections were identified (after a cursory review).

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 to count. To resolve this issue during a period of manual counting, the person assigned as the counter to the MM45 site needed to look at cameras 7, 8, 9, and 10, which showed the back of the parked vehicles. At MM23, however, cameras were established on just one side of the lot due to limitations presented by the site's geometry. When the lot had vehicles parked in front of the cameras, this did allow for some visual obstruction of the far side of the lot, where trucks could (but were not supposed to) park along the wide unmarked aisle or throughway.

Clarity and Visibility of Spaces

When viewing the video feeds, it could be unclear where the field of view of one camera began and the other ended. This could result in potentially double counting vehicles while performing a calibration. This issue was particularly prominent when toggling between views from cameras 1 and 2, 2 and 3, and 3 and 4 in the MM45 lot. This issue was minimized by experience in performing calibrations.

Prior to the start of the testing period, the lot at MM23 had severe issues with lines of sight when viewing from the cameras. There were spaces which could not be seen within any of the camera views. This issue was resolved by installing new lenses on the cameras in that lot. Each space in the lot could then be seen through the cameras.

Figure 23. Photograph. Nighttime view of the parking lot from Camera 4 in MM45.

Nighttime Visibility

When conducting counts at night, the nighttime resolution of the cameras made it difficult to accurately identify vehicles and obtain vehicle classifications. Figure 23 displays a nighttime camera view from Camera 4 at MM45. While Figure 23 displays decent resolution, the image shows the difficulty of counting vehicles at night, given the shadows, vehicle obstructions, low light, and vehicles parked illegally behind the delineated spaces. To avoid this, calibrations throughout the testing period were conducted during daylight hours. The calibration methodology compared the visual vehicle counts with the number of vehicles reported by the system.

4. RESULTS

4.1 DATASETS FOR ANALYSIS

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

4.1.1 CPR 1

Component performance requirement (CPR) 1 pertains to accuracy. It states: “The sensors shall determine the length of vehicles and classify all vehicles with no more than 1 percent false or missed detections.” This performance requirement evaluated the ability of each of the four detection units to accurately detect the presence of a vehicle.

The CPR1 analysis considered the full period of testing for each of the detector combinations wherein the system was in normal operation. The testing period contained all dates within the 6-month designated testing period, except the time that the system was experiencing an outage. During the outage periods, the system was in non-functioning mode, and the accuracy of the system was implicitly in error; therefore, outage periods were omitted from the evaluation.

4.1.2 CPR 2

CPR2 pertains to system uptime. It states: “The sensors shall collect parking availability information 99 percent of the time.”

To effectively evaluate the system with respect to this performance requirement, the dataset included the full testing period of 6 months. Similar to the dataset for CPR1, the entire 6-month testing period was included in this evaluation, but the evaluation considered the outage periods identified in Table 6 and Table 7.

4.1.3 CPR 3

CPR3 pertains to the ability of the system to classify vehicles in the new classification scheme. It states: “The sensors shall determine the length of vehicles and classify all vehicles with no more than a 5 percent rate of erroneous classification.”

Class accuracy was determined using a continuous dataset taken over a period of 1 day at each of the parking facilities. During these 1-day periods, each event was visually inspected for classification accuracy.

4.2 GENERAL USAGE DATA

When selecting the sites for the SmartPark pilot, one of the objectives was to pick sites that were heavily used by truckers or that had the potential to be useful to a large number of truckers. Positioning

SmartPark on I-75 was strategic in that it is a heavily used trucking corridor. Usage at the lots over the 6-month period showed that the facilities were in fact heavily used.

Table 8. MM23 total activity.

Site	Ingresses Detected	Egresses Detected	Total
MM23	18,301	18,504	36,805

Table 9. MM45 total activity.

Site	Ingresses Detected	Egresses Detected	Total
MM45	70,231	74,081	144,312

Table 8 and Table 9 display the total detections collected by the sensors. The discrepancies between the numbers are accounted for in the accuracy analysis. Detector accuracy varied based on setup orientation and environmental factors that altered or adjusted the orientation (such as truck collisions). This explains the greater number of egresses detected (rather than ingresses) at both sites.

The activities recorded in Table 8 and Table 9 do not capture all activity that occurred at the sites because they exclude periods of system outages. Because the MM23 site had such an extensive outage period, this is particularly relevant to that location. The data also contain some minimal level of error that was not stripped out. However, the numbers provide insight into the overall usage of parking facilities on I-75 N.

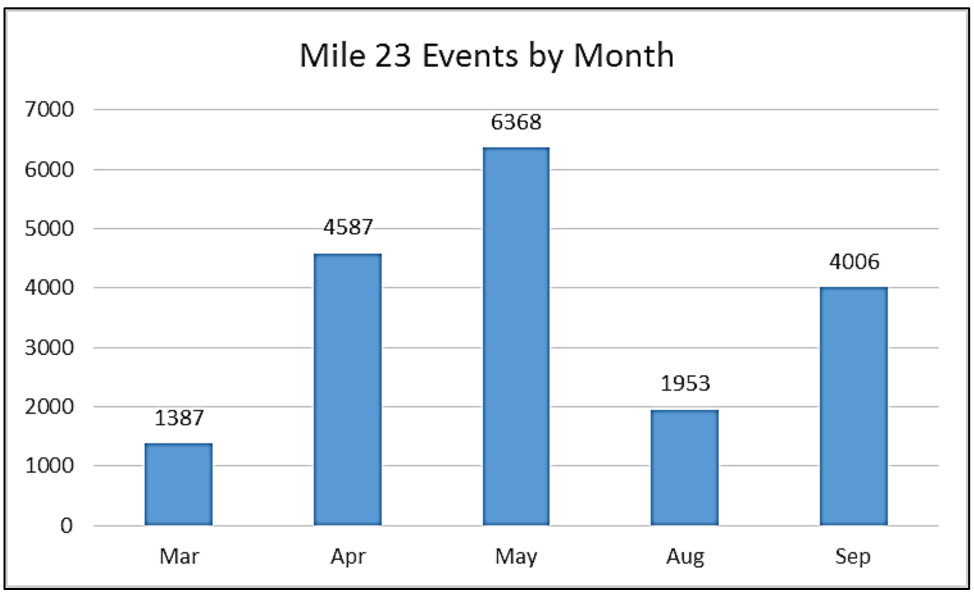


Figure 24. Bar chart. MM23 number of vehicles by month.

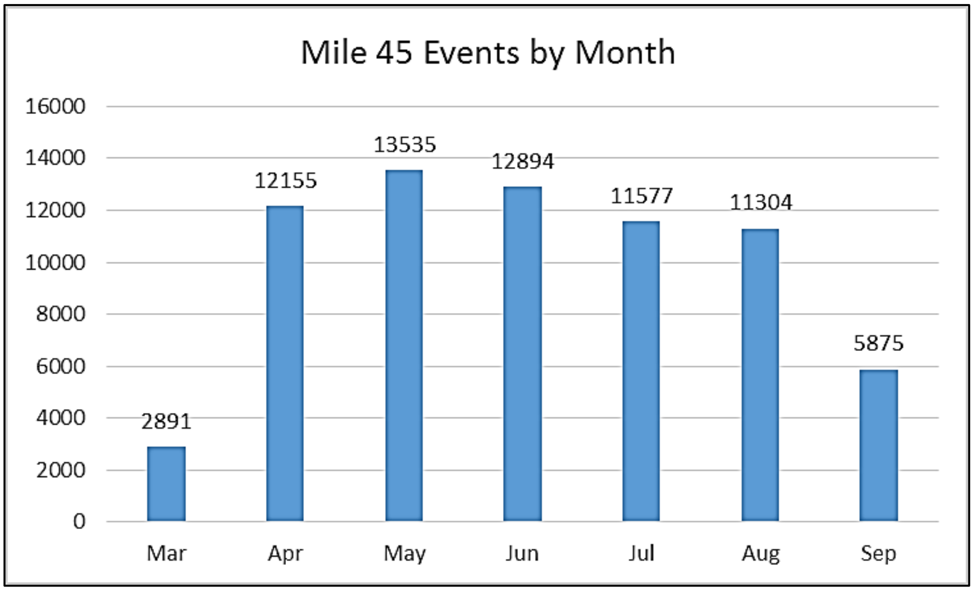


Figure 25. Bar chart. MM45 number of vehicles by month.

Figure 24 and Figure 25 display the number of daily ingresses at MM23 and MM45, respectively. Ingresses are an approximation of the total number of vehicles that used the facility. April and May represent the best months to compare usage across the two facilities since there was relatively little outage during this period. During April, MM23 experienced approximately a third (or 37.7 percent) of the activity as MM45. During May 2016, this increased to approximately half (or 47 percent) of the activity. However, upon closer inspection, the increase in usage is an anomaly. Figure 26 shows the daily usage at the MM23 location for each day during the testing period, less any outages. The spikes that occurred on May 2, 3, and 4 of 2016 are attributed to the Highway Safety Patrol using the site as a temporary weigh/inspection station. As a result, every truck on the interstate was required to pass through the site, inflating the daily usage numbers.

When usage is examined across day of week, MM23 also experienced approximately one-third to one-half of the usage that MM45 did (Figure 30).

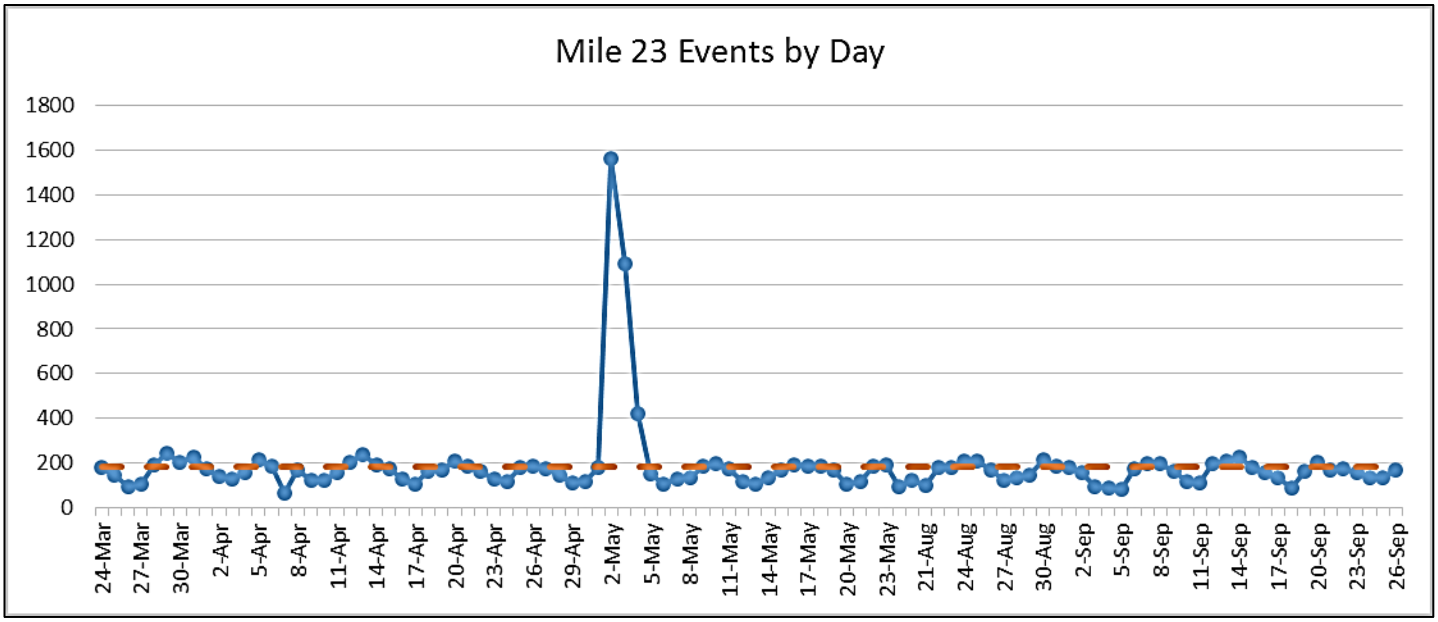


Figure 26. Line graph. MM23 daily usage statistics.

MM45 did not experience any usage anomalies when compared to MM23's temporary upsurge. MM45's usage was consistent across the testing period (Figure 27).

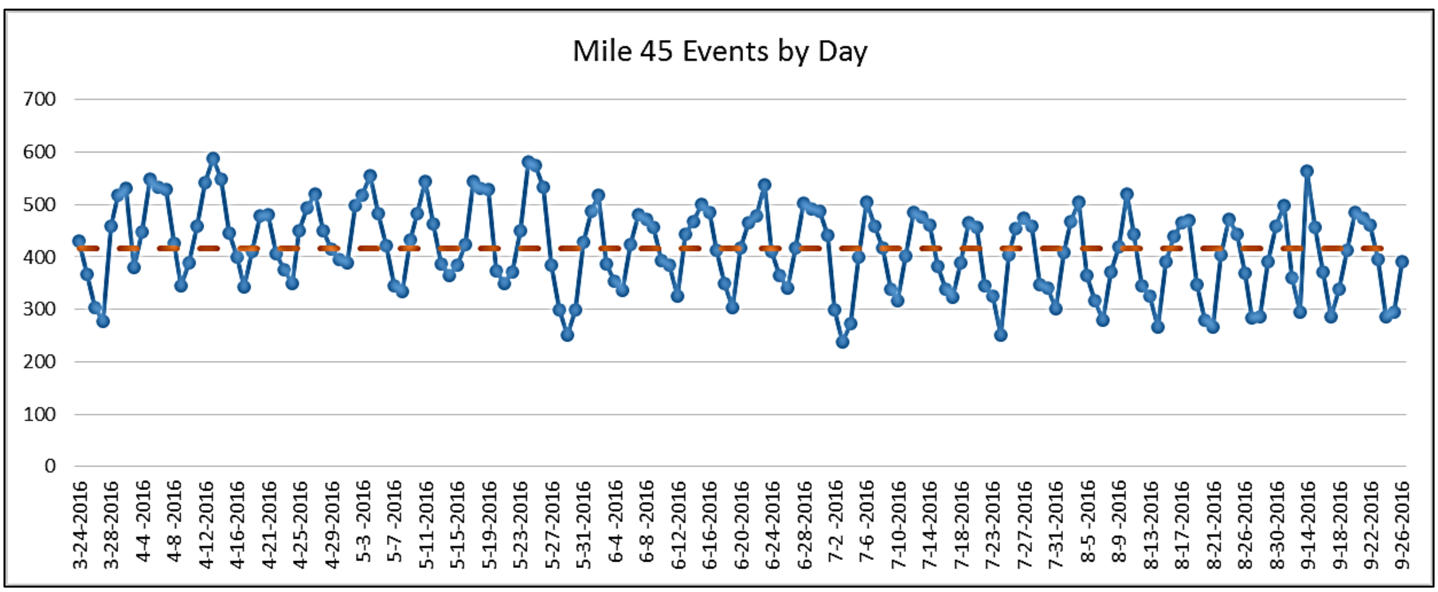


Figure 27. Line graph. MM45 daily usage statistics.

Oscillations in usage over a week occurred across the two parking locations. For both sites, the lower numbers of activities were observed on Sundays. However, the peak day of the week differed between the two sites. Peak usage at MM23 occurred on Mondays, whereas peak usage at MM45 occurred on Wednesdays.

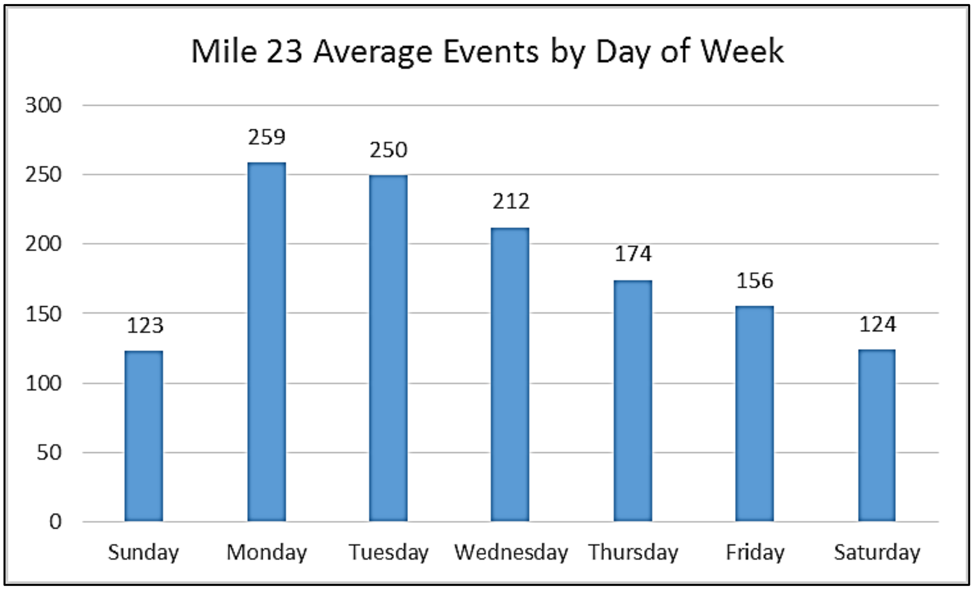


Figure 28. Bar chart. MM23 average events by day of week.

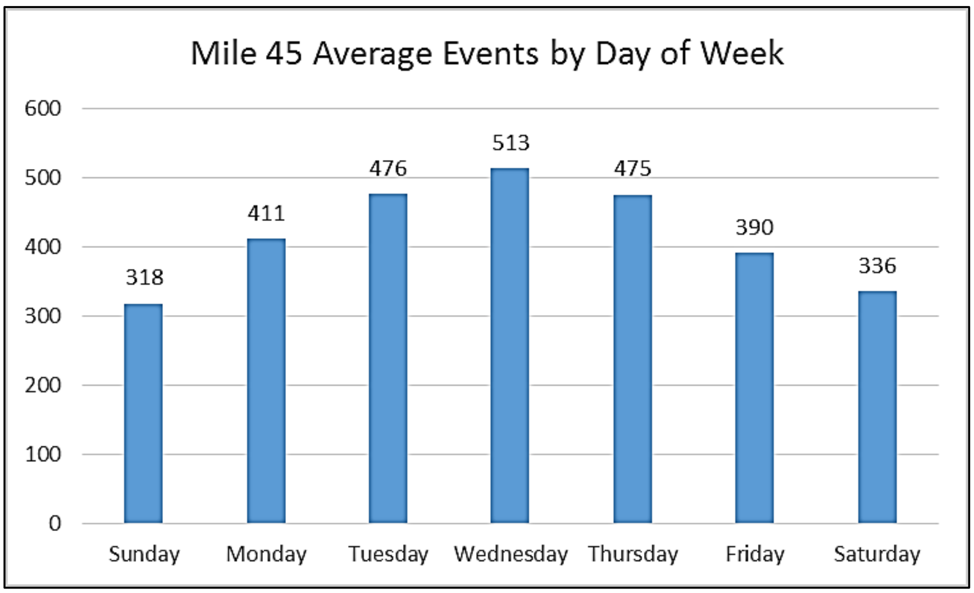


Figure 29. Bar chart. MM45 average events by day of week.

When compared on an hour-by-hour basis, both sites exhibited similar qualities. Peak hours were by far the overnight hours. Presumably, truckers were trying to meet their hours-of-service requirements by using the lots during these overnight hours.

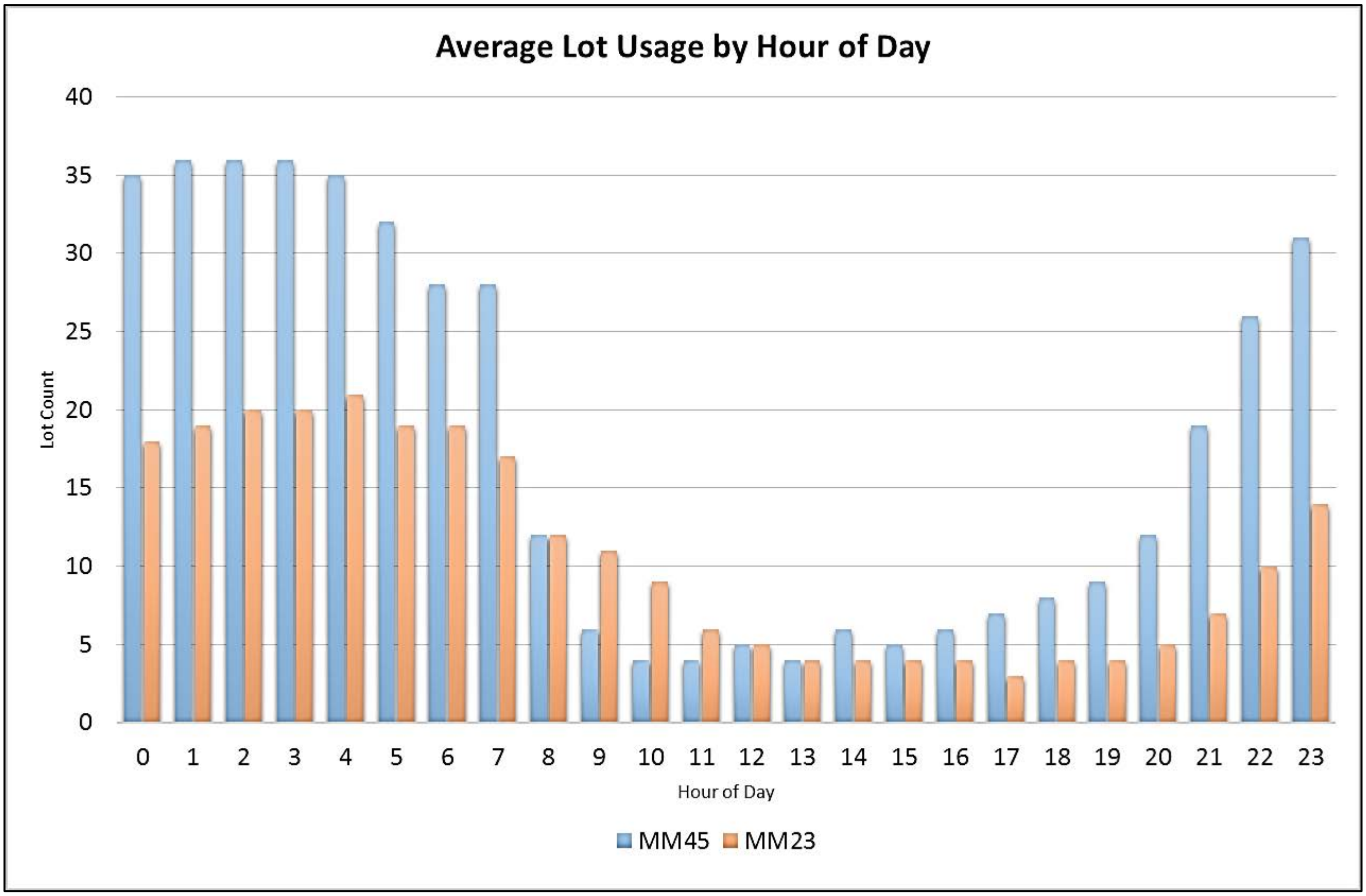


Figure 30. Bar chart. Lot usage by hour of day.

4.3 PERFORMANCE REQUIREMENT ANALYSIS

Each of the performance requirements were evaluated separately using the dataset as described earlier. The equations and methodologies used to perform the analyses are documented in the Evaluation Plan(8) submitted to FMCSA in 2015.

4.3.1 CPR1

The system performance analysis examined the entire 6-month period of testing for each facility. The analysis for system performance was based upon the number of calibrations made to the system throughout the test period and the total volume of vehicles to pass through the detection units.

System calibrations ("E" in the equation displayed in Figure 31) 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. Calibrations were made every weekday throughout the testing period using

[8] Evaluation plan approved by FMCSA on September 17, 2015.

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 website.

The equations used to calculate the overall error ratio, R, and accuracy, A, are given in Figure 31:

$$E = \sum |System\ Calibrations|$$

$$\boldsymbol{V = \{in + eg\}}$$

$$R = E/V$$

$$A = 1 - R$$

Figure 31. Equations. System performance error and volume.

Where: E = total system calibrations,

Where: V = volume, in = ingresses, eg = egresses,

Where: R = error rate, E = total system calibrations, V = volume, and A = accuracy.

Table 10. MM23 accuracy results (CPR1).

Ingress Events	Egress Events	"E" Calibrations	Error Rate "R"	Accuracy "A"
17,540	17,720	272	0.0077	0.9923

Table 11. MM45 accuracy results (CPR1).

Ingress Events	Egress Events	"E" Calibrations	Error Rate "R"	Accuracy "A"
70,231	74,081	1,173	0.00813	0.992

Table 10 shows that the MM23 system far exceeded the accuracy requirement at 99.23 percent. Further, the changes made during calibrations generally accounted for the discrepancy in egress and ingress events.

For the MM45 site, Table 11 shows a discrepancy of approximately 3,850 vehicles, where more vehicles exited the site than entered the site. Between the Phase I and Phase II programs, the ingress detector at

MM45 was struck by a truck and its orientation altered. Though this was repaired, it did not return the detector to its original orientation, and a lingering tendency to miss ingress detections remained.

While the discrepancy in ingresses and egresses is 3,850, the system calibrations total just 1,173, which is far lower. The difference is explained by the algorithm used for the traveler information system. The algorithm did not allow the count in the parking facility to go below zero, which would have produced a negative vehicle count. In effect, this erased the egress counts when the lot count was zero, but trucks continued to exit, therefore requiring fewer calibrations. This phenomenon occurred most frequently in the mornings when most of the trucks departed the facility. As a result, this excess of egress events had little practical impact on the usefulness of the data disseminated to the public, since the lot at that time was generally closer to being empty and there was truck parking space availability.

The system, including each detector configuration, far exceeded the performance target for CPR1 based on the results shown in Table 10 and Table 11. On a typical day, approximately 183 vehicles passed through the MM23 site and 416 vehicles at the MM45 site.

4.3.2 CPR2

The objective of CPR2 was to measure the proportion of the testing period that the system was functional. The evaluation for CPR2 was confined to time periods wherein the system was in “typical operations” and no extraordinary circumstances were prevalent. The parameters for evaluation excluded 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 CPR2 was used to determine system reliability in a practical application. Reliability was based upon typical operations and was independent of “acts of God” or periods where the system was deliberately offline for system calibration or adjustment.

Table 12 and Table 13 display the outages that occurred at each of the parking facilities and which of these outages were included in the uptime calculation based on the equation in Figure 32.

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

Figure 32. Equation. Uptime calculation.

Where U = uptime, D = downtime, and T = total testing time.

Table 12. MM23 system uptime (CPR2) data.

Outage Date Range	Duration	System Outage/Issue	Included in Analysis
4/6/2016-4/7/2016	1 Day	Software	1 Day
4/27/2016	1 Day	Software	1 Day
5/5/2016	4 Hours	Software	4 Hours
5/25/2016-8/19/2016	86.5 Days	Hardware	86.5 Days
Total	**88.67 Days**	-	**88.67 Days**

Table 13. MM45 system uptime (CPR2) data.

Outage Date Range	Duration	System Outage/Issue	Included in Analysis
3/31/2016-4/2/2016	3 Days	Software	3 Days
4/20/2016	1 Day	Software	1 Day
5/9/2016	0.5 Hours	Software	0.5 Hours
7/20/2016	1 Day	Software	1 Day
8/4/2016	1 Day	Software	1 Day
8/24/2016	1 Day	Software	1 Day
9/1/2016-9/13/2016	12.125 Days	Infrastructure	n/a
Total	**19.146 Days**	**-**	**7 Days 0.5 Hours (168.5 Hours)**

Table 12 and Table 13 show that some significant outages occurred during the testing period, while Table 14 summarizes the performance requirement. The outage causes fall into three categories – software, hardware, and infrastructure. Software and hardware issues are included in the overall uptime calculation because they relate to the resiliency of the system. Software issues include errors in transmission protocols or programming that cause issues for the system to retrieve, record, or broadcast parking data. Hardware issues include functionality of the field equipment.

One major hardware issue occurred during the testing period: one of the processors that interpreted the laser scanner data failed at the MM23 location. This failure prevented detections from being accurately identified and recorded, preventing the system from displaying accurate data. The duration of this hardware failure was included in the system downtime for the MM23 location.

One infrastructure issue occurred during the testing period. The ingress pole at MM45 was struck by a vehicle and shifted from the proper angle of projection. This was considered an extraordinary occurrence and was not the fault of the system itself, rather the result of an uncontrollable factor. The bent pole caused the ingress detector to frequently miss detections, disrupting the quality of the availability data. The bent pole occurred on September 1, 2016, and was repaired on September 14, 2016. During the period when the pole was bent, the system detected 4,982 ingresses and 4,163 egresses, counting 819 more ingresses than egresses. The system counted many vehicles twice because of the disrupted pole orientation despite it not detecting some vehicles at all. In the 13 days following the pole's repair (14–26 September), the system counted 5,203 ingresses and 5,221 egresses, leaving a discrepancy of just 18 vehicles. These remaining vehicles can likely be attributed to the number of trucks remaining in the parking area at the end of the day on September 26.

Table 14. CPR2 uptime results.

Site	Number of Testing Days	Number of Malfunction Days	Downtime	Uptime
MM23	187	88.75	0.47	0.525
MM45	173.875	7	0.0403	0.96
Total	**360.875**	**95.75**	**0.265**	**0.735**

4.3.3 CPR3

Accuracy of classification was defined as the ability of each detector and the processing system at each parking facility to correctly classify vehicles into one of four pre-determined bins (as mentioned previously, the class definitions below were unique to this project; see Table 4 for more details):

- **Small vehicles (SV):** Includes passenger cars, pickup trucks, and SUVs.
- **Large vehicles (LV):** Includes typical tractor-trailers and large-sized recreational vehicles.
- **Oversized vehicles (OV):** Includes double trailers, oversized loads, and irregularly shaped large vehicles).
- **Bobtails (BT):** Includes tractors without trailers.

Activity over an entire day was observed at each SmartPark facility (through their CCTV cameras), during which time each entry in the SmartPark system was checked against visual observation. The results were then used to calculate the classification accuracy of each individual detector at both facilities and the overall accuracy of each facility. The equation for calculating classification accuracy appears in Figure 33.

$$CA_n = 1 - \left|\frac{\sum |observed\ errors|}{CA_{obs}}\right|$$

Figure 33. Equation. Classification accuracy (CPR3).

Where CA_n = class accuracy of the specific vehicle class (n) observed at the detector, observed errors = the number of errors in classification for a specific vehicle class observed during field count, and CA_{obs} = observed vehicles of the vehicle class in question from manual counts.

The results of the CPR3 analysis are displayed in Table 15 through Table 20. Vehicle classes are defined and described in Table 4.

Table 15. MM23 ingress classification results (CPR3).

Class	Observed	System	Difference	Error %	Accuracy
SV	19	19	0	0%	100%
LV	178	184	6	3%	97%
OV	9	3	6	67%	33%
BT	1	1	0	0%	100%

Table 16. MM23 egress classification results (CPR3).

Class	Observed	System	Difference	Error %	Accuracy
SV	23	24	1	4%	96%
LV	194	201	7	4%	96%
OV	8		8	100%	0%
BT	1	1	0	0%	100%

Table 17. MM23 overall classification results (CPR3).

Class	Total Observed	Total System	Difference	Error %	Accuracy
SV	42	43	1	2%	98%
LV	372	385	13	3%	97%
OV	17	3	14	82%	18%
BT	2	2	0	0%	100%

Table 18. MM45 ingress classification results (CPR3).

Class	Observed	System	Difference	Error %	Accuracy
SV	26	65	39	150%	0%
LV	412	372	40	10%	90%
OV	11	14	3	27%	73%
BT	4	3	1	25%	75%

Table 19. MM45 egress classification results (CPR3).

Class	Observed	System	Difference	Error %	Accuracy
SV	28	31	3	11%	89%
LV	425	436	11	3%	97%
OV	12	1	11	92%	8%
BT	3	2	1	33%	67%

Table 20. MM45 overall classification results (CPR3).

Class	Total Observed	Total System	Difference	Error %	Accuracy
SV	54	96	42	78%	22%
LV	837	808	29	3%	97%
OV	23	15	8	35%	65%
BT	7	5	2	29%	71%

Generally, the detectors classified larger vehicles quite well, with 97 percent accuracy identifying Class LV vehicles across both parking lot systems. Class LV vehicles include tractor trailers of standard size but exclude double trailers and shorter rigid box trucks. The system had difficulties discerning other classes, however. Seeing as the results were limited to 1 day of counts, the total number of vehicles passing through MM23 was 433, while MM45 experienced 924. The cross sections of vehicles fitting into classes SV, OV, and BT are decidedly small, exacerbating the error rates.

4.3.4 SPR1 and SPR2

SPR1 is the uptime of the traveler information component of the system. SPR2 is the accuracy of the system, which is the same as CPR1. The traveler information system was fed by the data center, so provided there was no downtime at the data center and the field components were operational, the results of SPR1 and SPR2 should be high and should be similar. During the SmartPark testing period, SPR1 and SPR2 were identical. The DMS, IVR, and Web site had no downtime other than when the system itself experienced downtime. This was verified through manual inspections during calibrations performed by operations staff. Calibrations were completed every weekday, during which the functionality of the traveler information components was also verified and recorded.

Because the sites were integrated together, the management Web site was used as a proxy to confirm functionality of the public Web site, as well. The IVR and mobile applications drew upon the data center. If the data center connection was available, the IVR and mobile application were, as well.

The most visible component of the traveler information system was the DMS network. Four sign locations had small DMSs that displayed parking availability to passing truckers, reaching all that passed the signs. The accuracy and functionality of the signs were verified in two ways. First, the SmartPark management site displayed two statuses: lot status and sign status. Lot status showed what was being sent to the DMS based on the current parking lot count at the parking facility. Sign status was the status being returned by the sign to verify that the proper message was being displayed. Both statuses were recorded during calibrations.

For an added layer of verification, operators visually verified the status of each DMS through SmartPark's "selfie cam" system. Small, low-resolution cameras were constructed upstream of each DMS and the operators could view these in real time to verify that a sign was broadcasting the appropriate message (see Figure 34, Figure 35, Figure 36, and Figure 37). Operators used these selfie cams during each calibration to verify the sign statuses, which were logged and recorded. There was no instance within the uptime period established in CPR2 where the DMS message on the selfie cams deviated from its reported message on the management site.

Figure 34. Photograph. Mile 18 DMS selfie camera view.

Figure 35. Photograph. Mile 23 DMS selfie camera view.

Figure 36. Photograph. Mile 42 DMS selfie camera view.

Figure 37. Photograph. Mile 45 DMS selfie camera view.

Figure 37 shows a partial sign display because the refresh rate on this camera was restricted by the bandwidth of the T-1 connection that connected the MM45 facility to the SmartPark WAN. The low bandwidth required the selfie camera to operate at a low refresh rate, making the DMS message appear to be flashing or blinking. The screen capture in Figure 37 shows the sign mid-refresh. However, this does not mean the sign was malfunctioning.

4.3.5 SPR3

SPR3 pertains to the accuracy of the message displayed by the traveler information system versus the actual conditions within the parking facilities. There were several times during the testing period where, when the calibration occurred, it affected the message being displayed on the signs. Therefore, in the period prior to the calibration, the signs were displaying the wrong message. Each instance where this occurred was investigated to understand the duration of the incident.

Many of the issues encountered with sign accuracy pertained to software and connectivity problems within the SmartPark system (see Table 21 and Table 22). Many of these issues were resolved during the testing phase, but some may persist in the future. Connectivity was particularly significant for communications between the signs and the off-site data center, and between the on-site data server and the off-site data center. The VPN connection established between the two SmartPark sites and the data center, for example, dropped on occasion during the project. This had an immediate impact on the ability to disseminate parking data to the traveler information system, while having just a temporary and recoverable impact on the system as a whole.

Table 21. SmartPark traveler information system outages (SPR3).

Site	Error Date in 2016	Error Duration	Error Type	Description
MM23	May 3	1 Day	Blanked display	Sign software issue
MM23	May 5-10	6 Days	Blanked display	Sign hardware issue
MM23	May 11	2 Hours	Incorrect display	General calibration error
MM23	May 25	0.5 Day	Incorrect display	SmartPark system outage
MM45	May 3-11	8 Days	Blanked display	Sign hardware issue
MM45	July 21-24	4 Days	“OPEN” display	Connectivity Issue

Table 22. SmartPark traveler information system accuracy results (SPR3).

Site	Error Duration	Site Uptime	Error	Accuracy
MM23	7.58 Days	98.25 Days	8%	92%
MM45	12 Days	166.875 Days	7%	93%

4.3.6 SPR4

SPR4 evaluates the uptime of the reservation system. The reservation system was fed by the data center via the internet. The connection between the data center and the internet was never severed, so it is reasonable to assert that the reservation system was accessible throughout the testing period.
User feedback was gathered via email by users that had questions or issues with the reservation system. Only approximately five e-mails were received, and none of them pertained to reservation system uptime. They were mostly questions regarding how the reservation system worked.

4.4 DISCUSSION

4.4.1 CPR1

CPR1 focused on the accuracy of the SmartPark system as a whole. It should be noted that the accuracy of the system slightly fell in comparison with the Phase I results for a similar performance measure. This was due mostly to the change in methodology of calculating the accuracy rate to more accurately reflect field conditions. The accuracy formula used for this final evaluation deviated from the Evaluation Plan originally submitted to the FMCSA to more accurately reflect conditions that operators might experience. The original formula divided calibrations by the sum of ingress and egress events. While this is an accurate way of empirically determining error of the detectors, it is less useful from an operational perspective. Operationally, the most important data point is the performance of the system per vehicle that passes through the lot. To achieve this number, the ingress and egress activities were averaged instead of summed.

For the MM23 site to maintain 95 percent accuracy, the count could be off by just one vehicle, as the site only had 25 designated parking spaces. Since the site experienced approximately 300 vehicles per day, this would mean calibrating the site approximately 2-3 times per day to maintain the accuracy target.

For the MM45 site to maintain 95 percent accuracy, the count could be off by just 2 vehicles, as the site only had 44 designated parking spaces. Since the site experienced approximately 450 vehicles per day, this would mean that this site must also be calibrated approximately 2-3 times per day to maintain the accuracy target.

Operationally, these imposed minimal burdens on an existing staff member, as the calibrations took just minutes to complete.

4.4.2 CPR2

Both SmartPark locations experienced significant outages during the testing period. One outage, at MM23, was a system error attributed to faulty hardware provided by one of the suppliers. The other outage at MM45 was caused by an infrastructure incident in which a vehicle struck the pole. The former outage was included in the uptime calculation because it was a result of a system fault. The latter infrastructure issue was excluded from uptime calculations because it was a result of external forces.

Regardless of inclusion in the uptime calculation, this testing period highlighted the types of issues that can arise during operation.

Overall, the two sites did not meet the performance requirement of system uptime. However, the issues that were addressed during the testing period were mostly addressed for the long term: replacing faulty equipment and fine-tuning the system as a whole. Following all the repairs, the system appeared to stabilize and no other issues arose.

4.4.3 CPR3

Accuracy of classification was a significant issue for the technology during Phase I, and it continued to be a problem in Phase II. The system only hit this performance requirement for Class LV vehicles, attaining 97 percent accuracy. A greater understanding of the classifications could be achieved by examining a larger sample size.

One of the key objectives of this performance requirement in Phase II was to understand the effectiveness of the detectors in classifying tractors without trailers, or “bobtails,” as they are called colloquially. Classifying these would require the detectors to read the *shape* of the vehicle, making this classification process unique. The laser scanners were able to interpret unique shapes, and this performance measure was intended to test if this feature could be utilized effectively for operational purposes. During the period of analysis, very few bobtails, Class BT vehicles, were detected. During the overall period of performance, just 230 out of 36,805 total detections (ingress or egress) were bobtails at

MM23, and only 1,129 activities out of 144,312 total at MM45 were bobtails. Bobtails comprised just 0.62 percent and 0.78 percent of all detector activities, respectively.

It is not possible to identify bobtails that the detectors missed since there is no recorded video of the parking facilities. It is possible, however, to examine the recorded ingress/egress activities to determine the accuracy of the events that did occur.

One month of data was analyzed from both facilities. The quantity of results differed between the sites due to the variations in average usage between the two parking facilities. At the MM23 location, 47 Class BTs/bobtails were identified at the ingress from April 10, 2016, through May 10, 2016. Each Class BT was verified using the images captured by the SmartPark Management System (SPMS), making accuracy of detected Class BTs 100 percent. For the same period, 69 Class BTs were identified at the egress, and 67 of them were verified visually through the SPMS, making the accuracy of detected Class BTs 97 percent. Overall, during the 1-month period, the accuracy of the detectors was 98 percent for all detected Class BTs.

Table 23. MM23 Class BT accuracy.

Facility	Location	Class BT Detected	Errors	Accuracy
MM23	Ingress	47	0	100%
MM23	Egress	69	2	97%
MM23	Total	116	2	98%

The MM23 results do not imply that the accuracy of Class BT detection was 98 percent. In reality, it was likely much lower because some Class BT vehicles were likely missed, and some Class BT vehicles were probably classified as other vehicle types.

At MM45 during the period of September 13, 2016, through October 15, 2016, 240 Class BTs were detected. Just 11 of these were classified improperly. MM45 achieved overall 95 percent accuracy of those vehicles that were classified as Class BT. This is similar to the accuracy rates experienced at MM23.

Table 24. MM45 Class BT accuracy.

Facility	Location	Class BT Detected	Errors	Accuracy
MM45	Ingress	120	8	94%
MM45	Egress	120	3	98%
MM45	Total	240	11	96%

On the whole, the detector technology sufficed for the purpose of detecting and counting trucks but should not be used for the purpose of classifying vehicles by length. While it may have been better than other technologies available, its use for classifying vehicle length is highly sensitive to variations in installation and configuration, making it difficult to rely upon the results. The authors thought that classifying vehicles' lengths could be helpful in either identifying trailer drops or fitting two Class BT trucks or "bobtails" in a single space to maximize use of the available parking space capacity.

4.4.4 SPR1 and SPR2

SPR1 measured the uptime of the traveler information components and the ability of the components to accurately reflect the system status. These performance measures did not measure the accuracy of the system, rather, the connections between the data collection and traveler information systems (Figure 4). No issues occurred during the testing period to sever the connection between the traveler information components and the SmartPark data collection or management system. The signs, IVR, mobile application, and Web site all continuously displayed the information from the management and data collection systems.

SPR1 and SPR2 exhibit the reliability and robustness of the SmartPark traveler information system and management as a whole. Operationally, very little needed to be done to maintain the connections between the components.

4.4.5 SPR3

The analysis showed that the traveler information system generally only displayed incorrect information when the detection system was in error or when the signs were manually overridden by operators to reflect a system outage. SPR3 is highly dependent upon proper operations, namely the frequency of calibrations and the general accuracy of the system. If operators diligently calibrate and monitor the system, the traveler information system should consistently display accurate information.

Effective maintenance of the system also increases the accuracy of the system. Reparative maintenance and ongoing monitoring of the system for connectivity issues prevents incorrect information from being displayed. The critical component of the system is the DMS subsystem, as it reaches all potential users.

4.4.6 SPR4

The reservation system was a special part of this pilot to test whether a reservation system could work without enforcement, relying on an honor system. The reservation component was not widely adopted by truck users—just 21 reservations were attempted during the 1 year plus that the system was active (the reservation system was operational before the 6-month field operations test). Truckers generally disregarded the signs that indicated which spaces were designated for reservations only. Without enforcement and extensive public education, the reservation component will likely not be an effective user service.

4.5 LESSONS LEARNED

4.5.1 Laser Scanner Orientation

Prior to the testing period and at one point during the test period, a laser scanner was impacted by a vehicle, changing its orientation. The Phase II results show a decrease in accuracy from Phase I, part of which can be attributed to the pole and angle of scanning being disturbed. After the Phase II incident, accuracy decreased sharply at the detector unit that was struck. During this time the system was taken offline at that parking facility because the results corrupted the system’s overall accuracy.

4.5.2 Safety

Regarding exposure to the detection beams, the laser technologies used posed 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 (nm), which is in the spectrum of invisible infrared light, which is not harmful to the human eyes or skin. Motorists exposed to the detection unit lasers were not being harmed in any way. The Class 1 status of the detection units is documented in the units' manuals.

4.5.3 Traveler Information

This is one of the first truck parking information systems of its kind where truckers could access parking information online. There is no doubt that this information is valuable. However, based on data collected during SmartPark, the DMSs were overwhelmingly the most effective means of disseminating traveler information.

To use the mobile application and to make reservations or check historical data on the Web site, users had to register. The number of registrations can be used as a proxy for overall use of the e-kiosk components of the SmartPark traveler information system. In total, approximately 550 unique users registered for the system. Most likely these 550 users did so in order to access the mobile application, which requires registration to access. While it is difficult to know how many trucks passed by the DMSs on a daily basis, it is possible to estimate this number from the temporary inspection station established by the Tennessee Highway Patrol at MM23 on May 2, 2016. During this period, all trucks were required to exit I-75 N and enter the MM23 facility. On May 2, 2016, approximately 1,600 vehicles entered the lot for inspection. Each of these trucks passed by the Mile 18 DMS. When compared to the 550 registered SmartPark users, it is clear that the DMSs reached a much wider audience.

Despite the lopsided results, mobile applications and Web sites should not be disregarded or marginalized as traveler information tools. The relatively low usage of the SmartPark e-kiosk components can likely be attributed to several factors, including the lack of general availability of real-time truck parking information. Truckers were not used to the availability of such data and as a result were less likely to adopt and trust it. The SmartPark traveler information system components were also not broadly advertised (advertising was not within the scope of the project). A strong marketing campaign could potentially have boosted awareness and use of the system.

4.6 FUTURE DEPLOYMENT CONSIDERATIONS

Throughout the two phases of SmartPark, the project team gathered significant experience that can help make future deployments successful.

4.6.1 Enhanced Camera Coverage

Cameras are an effective means of monitoring activity and system accuracy at the site. However, enhanced CCTV installations such as full grade, 50–70-foot ITS cameras with pan/tilt/zoom (PTZ) capability would eliminate many of the issues faced during operation. Improved cameras would make calibrations much easier by allowing operators to view more of a lot, zoom in and out to examine areas of occlusion, and obtain a much more comprehensive view of all areas of a lot to identify any abnormal activity.

Installing a single, high-mounted, PTZ camera would also eliminate the need for the numerous cameras used to perform calibrations in the field operations test. This would reduce ongoing bandwidth costs to the site and reduce maintenance costs by minimizing the quantity and type of field equipment.

4.6.2 Enhanced Pavement Markings

While the CCTV camera surveillance system provided views of each of the parking spaces at the sites, it is difficult to identify where the field of vision of a non-PTZ camera ends and the next non-PTZ camera begins. In future phases, visual markers should be positioned on the pavement to identify the limits of camera fields of vision. Numbering parking spaces would also simplify the calibration procedures.

4.6.3 Communications Bandwidth

For Phases I and II, a T-1 line was installed to the MM45 site to transmit 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 SmartPark components at the MM45 facility, only provided a bandwidth of 1.544 megabytes per second (mbps). This low bandwidth had implications for the amount of data that could simultaneously be transferred over the connection. For example, to conserve bandwidth, only one CCTV camera could be viewed from the site at a time using the compression system installed at the site. Streaming multiple cameras would have clogged the T-1 line and prevented transmission of detection datasets to the off-site server. Any future ITS-grade CCTV camera would require greater bandwidth than that provided by the T-1 line. Until the WAN connection to MM45 is upgraded, the MM45 site cannot receive as many enhancements. This issue could be rectified by the future owner, TDOT, by connecting the site to its existing fiber optic network.

4.6.4 Vehicle Classification Scheme

The detectors should not be relied upon for highly accurate classifications, but they were highly effective at detecting the presence of vehicles in general. Moving forward to future implementations, the existing four-class system (SV, LV, OV, and BT) would provide sufficient information to SmartPark operators. Each of these categories could be used to determine general usage characteristics of the parking facilities

The system’s classification ability could also be a valuable source of baseline information regarding the site. The detectors, for example, can somewhat inform an operator when a bobtail enters the lot. This is useful to know when the site is being utilized for trailer drops. The system could also inform operators when an oversized load enters the facility, allowing them to check logs for permits and to potentially issue safety warnings to the vehicle if conditions have changed since they obtained the permit. The vehicle classification scheme would have very limited value in trying to fit two bobtails into a regular truck parking space in order to maximize using the parking space capacity of a site.

4.6.5 Field Hardware Maintenance

Leading up to and during the Phase II testing period, both sites and the traveler information DMSs experienced hardware malfunctions, leading to system outages. As hardware problems occurred, the project team did everything they could to fully replace or repair any defective hardware in order to maximize the life of the system as a whole. During the project, a DMS, a detector unit, and a sensor processing server were all replaced with new units. Wherever possible, environmentally protected equipment was installed, ensuring operability during extreme weather events and across as many environmental factors as possible. Despite the use of environmentally protected equipment, the owner should proactively engage in preventative maintenance and be diligent in paying attention to network components. Quick response times to issues minimizes downtime caused by hardware problems.

4.6.6 Reservations

The reservation component of the traveler information system was not utilized by truckers. Only 21 reservation attempts were made. There were no signs on site that indicated the reserved spaces were enforced in any way. An implicit honor system was in effect for a reservation—if a trucker did not have a reservation, he was expected to park in an unreserved space. It is reasonable to assert that the truckers neither took the reservation component seriously nor observed the honor system once it was clear that the reservations were not backed by enforcement. The reservation component should be removed from further SmartPark deployments unless the system owner commits to all aspects of the service, including monitoring of the facilities and enforcement of the rules.

[This page intentionally left blank.]

5. CONCLUSIONS

A system like SmartPark is viable as a traveler information system that provides dynamic truck parking availability information to truck drivers. The key lessons learned from the two phases of the SmartPark program are:

- **Management:** Any technological system must be managed. However, a check-in/check-out style system requires regular management procedures to be successful.
- **Usage:** Truck drivers acclimated to the system and used it as a means of determining where to park. Usage at both lots increased significantly from before the project began.
- **Future Deployments:** Future deployments could benefit from an alternate style of parking detection that does not result in compounding error when determining occupied trucking spaces.
- **Communication**: Robust communications are highly recommended to any traveler information system, and truck parking is no exception. When communication goes down, the accuracy of the information broadcast to truck drivers is affected.
- **Mobile Applications:** Truck drivers are accustomed to using mobile applications and could benefit significantly from having access to truck parking information via this method, as well. However, a stand-alone application limits the number of users. Usage would be far more widespread if the data became open and available for integration with other applications that are already in use.
- **Reservations:** The reservation component of the system did not work on an honor system during the field test; it would only work with enforcement. Enforcing a reservation system would be a complicated issue; it would be dangerous for law enforcement to force a fatigued truck driver to continue driving instead of allowing the driver to use a parking space already reserved by someone else. This is especially true if an enforcement officer would be causing the truck driver to violate HOS regulations by forcing them to continue driving.
- **Infrastructure:** SmartPark used a significant number of cameras to provide ground truth information. Future deployments will ideally replace static cameras with ITS-grade cameras with PTZ, also reducing the number of cameras needed. There is an ongoing need, however, to be able to view the entirety of a parking facility to perform calibrations and identify issues on site.