SmartPark Truck Parking Availability System: Video Technology Field Operational Test Results

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

January 2011

FOREWORD

This report presents the results of a field operational test (FOT) of an innovative system to monitor parking availability in a public truck parking area. The system used an off-the-shelf video-based traffic monitoring system. The self-contained monitoring equipment was solar-powered and used Ethernet radios to transmit vehicle entrance and exit events to an onsite, networked computer. Four Web cameras mounted on the service center building provided real-time views of the entire parking area to enable collection of ground truth data on facility occupancy. The FOT consisted of functional and performance tests. Initial tests found the vehicle detection accuracy met the desired 96 percent accuracy, but accuracy of vehicle length detection was below the required accuracy. Night detection was less accurate, primarily due to multiple detections of individual vehicles. Final tests occurred following improvements to the image processing software. The authors' vehicle presence detector configuration and vehicle length detection algorithm was more accurate than the detector configuration that used the system's capabilities alone. Hardware problems with the outbound camera and the less than required accuracy of the vehicle classification prevented evaluation of facility occupancy estimates.

NOTICE

Technical Report Documentation Page—Form DOT F 1700.7 (8-72)

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FMCSA-RRT-10-002		

4. Title and Subtitle	5. Report Date
SMARTPARK TRUCK PARKING AVAILABILITY SYSTEM: VIDEO TECHNOLOGY FIELD OPERATIONAL TEST RESULTS	**January 2011**
	6. Performing Organization Code
7. Author(s) **Judith Gertler, James Murray**	8. Performing Organization Report No. **DGOV.080019**
9. Performing Organization Name and Address **Foster-Miller, Inc. 350 Second Avenue Waltham, MA 02451-1196**	10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address **U.S. Department of Transportation Federal Motor Carrier Safety Administration 1200 New Jersey Ave SE Washington, DC 20590**	13. Type of Report **Final Report** 14. Sponsoring Agency Code

15. Supplementary Notes

This project was funded by the Federal Motor Carrier Safety Administration.
The Contracting Officer's Technical Representative was Quon Kwan.

16. Abstract

This report presents the results of a field operational test (FOT) of an innovative system to monitor parking availability in a public truck parking area. The system used an off-the-shelf video-based traffic monitoring system. The self-contained monitoring equipment was solar-powered and used Ethernet radios to transmit vehicle entrance and exit events to an onsite, networked computer. Four Web cameras mounted on the service center building provided real-time views of the entire parking area to enable collection of ground truth data on facility occupancy. The FOT consisted of functional and performance tests. Initial tests found the vehicle detection accuracy met the desired 96 percent accuracy, but accuracy of vehicle length detection was below the required accuracy. Night detection was less accurate, primarily due to multiple detections of individual vehicles. Final tests occurred following improvements to the image processing software. The authors' vehicle presence detector configuration and vehicle length detection algorithm was more accurate than the detector configuration that used the system's capabilities alone. Hardware problems with the outbound camera and the less than required accuracy of the vehicle classification prevented evaluation of facility occupancy estimates. Because the video-based technology did not meet the performance requirement for vehicle classification accuracy, the FMCSA will be repeating the field operations test with another technology to be announced.

17. Key Words	18. Distribution Statement
image analysis, remote monitoring, truck parking, vehicle detection.	**No restrictions**

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	**Unclassified**	**93**	

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

SI* (MODERN METRIC) CONVERSION FACTORS

Table of APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
In	Inches	25.4	millimeters	mm
Ft	Feet	0.305	meters	m
Yd	Yards	0.914	meters	m
Mi	Miles	1.61	kilometers	km
		AREA		
in²	square inches	645.2	square millimeters	mm²
ft²	square feet	0.093	square meters	m²
yd²	square yards	0.836	square meters	m²
Ac	Acres	0.405	hectares	ha
mi²	square miles	2.59	square kilometers	km²
		VOLUME	Note: Volumes greater than 1000 L shall be shown in m³	
fl oz	fluid ounces	29.57	milliliters	mL
Gal	Gallons	3.785	liters	L
ft³	cubic feet	0.028	cubic meters	m³
yd³	cubic yards	0.765	cubic meters	m³
		MASS		
Oz	Ounces	28.35	grams	G
Lb	Pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE	Temperature is in exact degrees	
°F	Fahrenheit	5 × (F-32) ÷ 9 or (F-32) ÷ 1.8	Celsius	°C
		ILLUMINATION		
Fc	foot-candles	10.76	Lux	lx
Fl	foot-Lamberts	3.426	candela/m²	cd/m²
		Force and Pressure or Stress		
Lbf	Poundforce	4.45	newtons	N
lbf/in²	poundforce per square inch	6.89	kilopascals	kPa

Table of APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
Mm	Millimeters	0.039	inches	in
M	Meters	3.28	Feet	ft
M	Meters	1.09	yards	yd
Km	Kilometers	0.621	miles	mi
		AREA		
mm²	square millimeters	0.0016	square inches	in²
m²	square meters	10.764	square feet	ft²
m²	square meters	1.195	square yards	yd²
Ha	Hectares	2.47	acres	ac
km²	square kilometers	0.386	square miles	mi²
		VOLUME		
mL	Milliliters	0.034	Fluid ounces	fl oz
L	Liters	0.264	gallons	gal
m³	cubic meters	35.314	cubic feet	ft³
m³	cubic meters	1.307	cubic yards	yd³
		MASS		
G	Grams	0.035	ounces	oz
Kg	Kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE	Temperature is in exact degrees	
°C	Celsius	1.8C + 32	Fahrenheit	°F
		ILLUMINATION		
Lx	Lux	0.0929	Foot-candles	fc
cd/m²	candela/m²	0.2919	Foot-Lamberts	fl
		Force & Pressure or Stress		
N	Newtons	0.225	poundforce	lbf
kPa	Kilopascals	0.145	poundforce per square inch	lbf/in²

* 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 APPENDICES

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

Acronym	Definition
C	Celsius
CI	confidence interval
DCMS	data collection and management system
FMCSA	Federal Motor Carrier Safety Administration
FOT	field operational test
FOV	field of view
GB	gigabyte
h	hour(s)
ISO	International Standards Organization
mi	miles(s)
mi/h	miles per hour
min	minute(s)
MTTR	mean time to repair
s	second(s)
SBPU	solar battery power units

EXECUTIVE SUMMARY

The Federal Motor Carrier Safety Administration (FMCSA) and the motor carrier industry have been successful in reducing large truck and bus fatality rates since 1996, but truck driver fatigue continues to be a contributory factor in crashes that result in fatalities. Many factors contribute to driver fatigue, and drivers must be able to locate available parking to rest. Advances in technology may make it possible to provide real-time parking availability information to truck drivers. FMCSA funded the SmartPark program to evaluate technologies that offer the potential to monitor truck parking availability and to convey parking status information to truck drivers.

Truck drivers typically park either in publicly owned roadside rest areas or at privately owned truck stops. In the absence of a reservation system, a driver must stop at every location along the driver's route to determine parking space availability. If parking spaces are not available at a given location, the driver must travel to the next. Parking areas are not evenly spaced; if a driver finds no parking space at the last area before a long stretch of road, the driver has two choices: park illegally along the roadside or continue driving illegally in violation of hours-of-service rules. A method is needed for a unified communication system to show parking availability.

The objective of FMCSA's SmartPark Phase I program was to evaluate a technology capable of collecting data to determine whether a truck parking area is full, and if not full, to indicate the number of spaces available. This Phase I field operational test (FOT) involved installation and testing of an off-the-shelf traffic monitoring system on the entrance and exit ramps to the Charlton Westbound Service Center, a public truck parking area on the Massachusetts Turnpike (Interstate 90). The SmartPark video system described in this report uses the Autoscope® video-detection system to monitor truck entrances and exits from the service center.

SMARTPARK VIDEO TECHNOLOGY CONCEPT

Operational needs served as the basis for the design of the SmartPark video system. These needs included the ability to count and classify vehicles entering and exiting the facility, continuous unattended operation, and the ability to distinguish between vehicles based on overall vehicle length.

This report intends to determine whether a video-based vehicle detection system designed for traffic monitoring applications has potential for monitoring trucks entering and exiting a truck parking facility. Further, the system would then calculate parking availability information that could, ultimately, be conveyed in real-time to drivers before they arrive at the facility so they would know if there is parking space for their trucks.

The SmartPark video system automatically counted vehicles entering and exiting the facility using video cameras that monitored the entrance and exit ramps to the truck parking area at the Charlton Service Center without the involvement of human operators. It used this information to determine a count of available truck parking spaces. Image processing software in the cameras was designed to detect when a vehicle appears in the image. The image processing software distinguished between trucks, tractors, and other vehicles based on overall vehicle length. Vehicle detections were transmitted from the cameras to the onsite computer, which recorded this information and made it available to authorized users via a secure Internet connection. Authorized users were able to sign in to the onsite computer and retrieve current parking information as well as historical data.

The Autoscope Solo® Terra™ video detection system was the key element of the SmartPark video system. Each camera was powered by a rechargeable battery and solar panel unit. Image processing software was integrated with the camera. The cameras communicated wirelessly with the onsite computer via Ethernet radios. Four Web cameras were mounted on the roof of the service center building to capture live views of the entire truck parking area for ground truth data to confirm actual facility occupancy. The onsite computer was connected to the internet via a router and high speed digital subscriber line connection.

TEST SITE

The Charlton Westbound Service Center was the test site for the Phase I FOT. This facility features well-defined entry and exit ramps. The entrance ramp splits, with cars going to the left and trucks to the right. The service center has an unstriped parking lot with space for approximately 30 trucks. The truck entrance ramp routes trucks to the parking and truck fueling areas at the back of the service center building. Trucks leave the service area via an exit ramp used by both cars and trucks. Heaviest truck volumes occur 11 a.m–2 p.m. on weekdays and may exceed 60 vehicles per hour (h).

CONCEPT OF OPERATIONS

The *SmartPark Concept of Operations*(1) includes operational scenarios that describe the operation of the system. The method of calculation for available parking spaces is of particular interest. Each vehicle-length category was assigned a parking space factor. The total space occupied is the weighted sum of the count for each individual length category multiplied by its parking space factor. Available parking is the facility capacity less the total space occupied.

SYSTEM REQUIREMENTS

System requirements were based on the concept of operations. The requirements were grouped into the following categories:

- Functional requirements.
- Performance goals.
- Interface requirements.
- Data requirements.
- Non-functional requirements.
- Enabling requirements and constraints.

TEST PLAN

The test plan consisted of two sets of tests to determine whether this system met functional requirements and performance goals. The design of the test plan assured the tests covered each of the requirements in the *SmartPark Performance Requirements*.[(2)] The functional tests were pass/fail and included tests of:

- Vehicle detection and classification.
- Vehicle count.
- Event recording.
- Secure user access.
- Adherence to International Standards Organization (ISO) 9000[(3)] quality procedures, operational environment, and system constraints.

The operational performance tests involved collecting appropriate data to determine the extent to which the system met the performance goals in the *SmartPark Performance Requirements*.[(2)] The *SmartPark Field Operations Test Plan*[(4)] contains detailed descriptions of the tests. The *SmartPark Evaluation Plan*[(5)] describes the methods of analysis for the performance tests. The performance tests covered:

- Vehicle detection and classification accuracy.
- Availability and reliability.
- Accuracy of vehicle count and parking availability.
- Accuracy of parking availability notification.

TEST PROCEDURE

The video system configuration allowed performance testing to be conducted remotely. No onsite activity was required to set up the tests, to collect test performance and data, or to analyze test data. The SmartPark video system ran continuously and unattended throughout the test period. It was not started and stopped for tests. The only activity required for testing was collection of test data from the system. The tester signed into the service center system and initiated recording of video data from each camera. If the test also required parking lot images, a batch file for each roof camera was created to record images at selected times. Once created, the system operated unattended for the duration of the test. During the test, the system recorded both video and detector data on the service center personal computer (PC). At the conclusion of the test, the tester downloaded the video and detector data to the authors’ server, where all data analysis occurred.

TEST RESULTS

Initial review and testing of the system led the authors to conclude that the equipment vendor's software, while detecting and classifying the majority of the vehicles, was not performing with sufficient accuracy. Additionally, the tests indicated night vehicle detections were less accurate than day detections due to multiple-false detections. While the vendor worked to resolve these issues, the authors developed a method, using the detector configurations provided by the equipment software, to detect vehicles and determine their length.

Initial Tests

Functional tests were conducted in July 2008 using the authors' detection algorithm. All functional tests were completed except the operational environment test. Tests during day, night, and rain were conducted, but other weather conditions did not occur. Temperatures did not reach the required extremes. This was considered acceptable because the other conditions were expected to be encountered over the course of the operational test. All functional tests were passed successfully except nighttime vehicle detection and classification, and vehicle count. Performance tests found the detection rate for both cameras met the 96 percent accuracy performance requirement, but length classification was 86.3–96.5 percent for the inbound camera and 80.5–94.6 percent for the outbound camera. In terms of both vehicle detection and length classification, the inbound camera appeared to perform more accurately. Night detections were characterized by false vehicle detections triggered by headlights.

Final Tests

In May 2009, the equipment vendor provided a pre-release beta version of revised software. Final system testing began after the new software was installed and tested. During review of the new software, the authors discovered the outbound camera had developed a moisture leak behind the lens; the camera image could not be analyzed accurately. The lead time required to obtain and install a replacement camera ruled out this option. Therefore, final tests were conducted with only the inbound camera. The final tests evaluated the authors' vehicle detection and length detection algorithm, along with three detector configurations designed by the vendor.

Functional test results showed the video system passed all functional tests except two, which were due to hardware problems. Performance tests for vehicle detection and vehicle length classification were also conducted. Tests of the video detector configurations during the day and the night indicate the detector configurations performed below the target accuracy level (96 percent) for vehicle detection (74–91 percent). For length classification, one detector configuration met the required performance level. Subsequent tests focused on the authors' algorithm. Detection accuracy during the day was 95–99 percent while length classification accuracy was 87–94 percent. Two night tests each had different outcomes, one indicating exceptionally accurate results (vehicle count: 99 percent, length classification: 99 percent), and the other showing over-detection of vehicles (vehicle count: 110 percent, length classification: 93 percent). A statistical hypothesis test with the combined data from the day test found the system accuracy for vehicle detections would be at least 96 percent. A similar test with the night data found based on a statistical hypothesis test, the length classification accuracy would be at least 96 percent, but the system would over-detect vehicles. Table 1 summarizes the overall results of the tests relative to the performance requirements, and reflects the data from the hypothesis tests.

Table 1. SmartPark Video System Performance Summary

Performance Goal No.	Performance Requirement	Criterion	Results
PG1	The system shall detect individual vehicles entering the parking area to an overall accuracy of better than 96%.	vehicle count/ground truth ≥ 96% but ≤100%	Day—97.7%—pass Night—103.7%—fail
PG2	The system shall classify individual vehicles entering the parking area to an overall accuracy of better than 96%.	correct classifications/ ground truth ≥ 96%	Day—91.7 %—fail Night—96.6%—pass
PG3	The system shall detect individual vehicles exiting the parking area to an overall accuracy of better than 96%.	vehicle count/ground truth ≥ 96%	Could not complete test due to outbound camera failure.
PG4	The system shall classify individual vehicles exiting the parking area to an overall accuracy of better than 96%.	correct classifications/ ground truth ≥96%	Could not complete test due to outbound camera failure.
PG5	The system availability shall be at least 99%.	up time/total time ≥ 99%	Pass—99.4%
PG6	The average downtime per system failure (i.e., mean time to repair; MTTR) shall be less than 4 h.	average outage < 4 h	Fail—average outage was 24 hr due to lack of constant monitoring and need to visit site.

The performance test also addressed system availability and reliability. During a period of 17 months, March 2008–July 2009, there were three instances when the SmartPark video system was unavailable. Overall system availability was 99.4 percent. The only equipment reliability problem was a moisture leak in the outbound video camera that occurred approximately 14 months after installation. Unfortunately, this failure prevented completion of all of the planned tests.

OPERATIONAL TEST EXPERIENCE

Based on the final tests with the inbound camera, the SmartPark video system met the performance requirement for vehicle detection during the day. The authors’ detection and length classification algorithm met the performance requirement at night, but day performance was not at the level prescribed in the performance requirements. The system operated continuously except for three instances that required a manual restart.

CONCLUSIONS AND RECOMMENDATIONS

The primary conclusion of this field operational test is that a video-based vehicle detection system designed for traffic monitoring applications has potential for monitoring trucks entering and exiting a truck parking facility, but the detection accuracy did not meet the requirements for the SmartPark application. The software and detector configurations used in this FOT did not achieve the desired 96 percent vehicle detection accuracy. The authors' approach, which uses a presence detector configuration based on the system's capabilities and the authors' developed algorithm, performed better with regard to both vehicle detection and length classification, and achieved the performance goal in most, but not all, tests. This approach shows promise, but improvements in the image processing algorithms of the system are required to improve the performance of the authors' method. Based on discussions with the vendor, the authors believe these improvements are possible and should be pursued.

The FOT experience provided validation of the system configuration. In particular, the test illustrated it is possible to configure and operate a traffic-monitoring system with solar power. The field operational test also demonstrated the feasibility of wireless transmission of video images and data via Ethernet radios that are capable of transmission by line of sight up to several miles, depending on local conditions. This capability would allow remote parking sites to transmit data to a central location with a computer.

The authors' system included secure remote access to the test site. The authors were able to make changes to the detector configurations, upgrade software, run tests, capture still images, and download video and data from tests all without visiting the site. However, it was not possible to view video in real-time; a higher bandwidth data line would provide this capability. The results indicate that installation and operation of a video-based system within a traffic operations center is practical and feasible.

1. INTRODUCTION

The Federal Motor Carrier Safety Administration (FMCSA) and the motor carrier industry have been successful in reducing large truck and bus fatality rates since 1996, but truck driver fatigue continues to be a contributory factor in crashes that result in fatalities. While many factors combat driver fatigue, locating available parking is an important one. Advances in technology may make it possible to provide real-time parking availability information to truck drivers in a way that would not compromise the ability of the operator to drive safely. FMCSA funded the SmartPark program to evaluate technologies—including video—that offer the potential to monitor truck parking availability and to convey that information to truck drivers to enable them to decide whether or not to stop at a parking area to rest.

1.1 OBJECTIVES

FMCSA sponsored the SmartPark initiative to demonstrate whether commercially available or near-term technology could convey continuous parking availability information in real-time to drivers. The objective of FMCSA's Phase I program was to evaluate technologies capable of collecting data to determine whether a truck parking facility is full, and if not, to indicate the number of parking spaces available. FMCSA selected two technologies for evaluation in Phase I. The SmartPark video system, described in this report, uses the Autoscope® video detection system, which is designed to provide junction control, traffic data collection and incident detection for roadways, to monitor truck movements into and out of a public truck parking facility. If Phase I test results were positive, FMCSA planned a subsequent phase to test the feasibility of communicating parking availability information to truck drivers within 50 miles of the test site.

1.2 OVERALL APPROACH

This field operational test (FOT) involved the installation of an off-the-shelf video-based traffic monitoring system on the entrance and exit ramps to a truck parking facility. The first step was development of the concept of operations for the system.[1] Performance requirements[2] were then established. The FOT plan[4] specified functional and performance tests to evaluate the system against the performance requirements. The evaluation plan[5] prescribed the methods of analysis to assess the system against the performance goals. Once the system was operational in accordance with the test plan, the functional tests were performed, followed by the performance tests. The test plan was designed to establish whether the system accurately:

- Detected vehicles entering and exiting the parking area.
- Determined the length of the vehicles.
- Counted the number of available truck parking spaces.

1.3 SCOPE OF PROJECT

Phase I involved installing and evaluating the SmartPark video system's ability to accurately detect, and classify by length, vehicles entering and exiting the truck parking facility at the Charlton Westbound Service Center on the Massachusetts Turnpike (Interstate 90). The initial project scope also included validating the accuracy of parking availability information.

1.4 ORGANIZATION OF THE REPORT

Section 2 provides a description of the SmartPark video system and the test site. An overview of the test plan as well as the results of the initial and final tests is in Section 3. Section 4 discusses the test results. Conclusions and recommendations are in Section 5. The appendices contain the SmartPark performance requirements and the detailed test results, which are summarized in Section 3.

2. SYSTEM DESCRIPTION

The following sections describe the operational requirements that were the basis for the design of the SmartPark video system, the overall SmartPark concept and the concept of operations, components of the Phase I system, and the test site.

2.1 OPERATIONAL NEEDS

Regardless of the technology utilized, the SmartPark video system would be required to meet the following operational needs:

- The system must be able to count and classify vehicles entering and exiting the facility.
- The system must be able to distinguish between vehicles based on overall vehicle length.
- The system must be able to distinguish between vehicles at varying separations and speeds.
- The system must be easy to install and maintain.
- The system must operate unattended continuously.
- The system must operate in all weather and ambient lighting conditions.
- The system must maintain a vehicle count of the available parking in the facility and provide the information to authorized remote users.
- The system should provide a means for authorized users to remotely monitor the parking facility to determine the accuracy of the system.
- The system must allow authorized users to reset the available parking count remotely.
- The system should maintain a record of vehicle entrance and exit events, and system errors.

2.2 SMARTPARK VIDEO SYSTEM CONCEPT

The SmartPark video system was designed to automatically monitor the entrance and exit of the truck parking facility at the Charlton service center without the involvement of human operators. The system counted trucks and other vehicles as they entered and exited the facility and used this information to determine available truck parking spaces. Authorized users viewed the count of available truck parking spaces. In future phases of the SmartPark program, the information would be conveyed to truck drivers real-time to assist them in locating safe, legal parking.

The SmartPark video system counted vehicles entering and exiting the facility using video cameras that monitored the entrance and exit ramps. The cameras were equipped with image processing software designed to detect when a vehicle appears in the image. Figure 1 shows an image from a camera of a tractor-trailer exiting the Charlton service center. The black and green lines in the image are, respectively, inactivated and activated detectors used to count vehicles and determine vehicle length. The image processing software distinguished between trucks, tractors, and other vehicles based on overall vehicle length. Vehicle detections were transmitted from the cameras to the onsite computer which recorded this information and made it available to authorized users via a secure Internet connection.

Figure 1. Autoscope Image of Tractor Trailer Exiting Charlton facility

The onsite computer receives the entrance and exit events, and adjusts the vehicle count currently in the facility. It uses the vehicle counts and a user-specified lot capacity to determine the available parking in the facility. It also maintains records of entrance and exit events, system errors, and available parking throughout the day.

Authorized users signed in to the onsite computer and retrieved the current parking availability, vehicle counts, historical data, and event and error records for analysis.

2.3 PHASE I VIDEO SYSTEM COMPONENTS

Figure 2 presents the principal components of SmartPark video system. Video cameras monitored the entrances and exits to parking facilities. Vehicle entrance and exit data was transmitted wirelessly from the cameras to an onsite computer via Ethernet radios. The cameras and radios were powered by standalone solar battery power units (SBPUs). In order to validate the vehicle parking counts, the Phase I SmartPark video system also included four Web cameras that together provide a complete view of the entire truck parking area as shown in Figure 3 through 6. The Web cameras were connected directly to the onsite computer. Remote users had access to the computer via a secure Internet connection, and viewed the camera data as well as the Web camera images in order to verify parking availability counts.

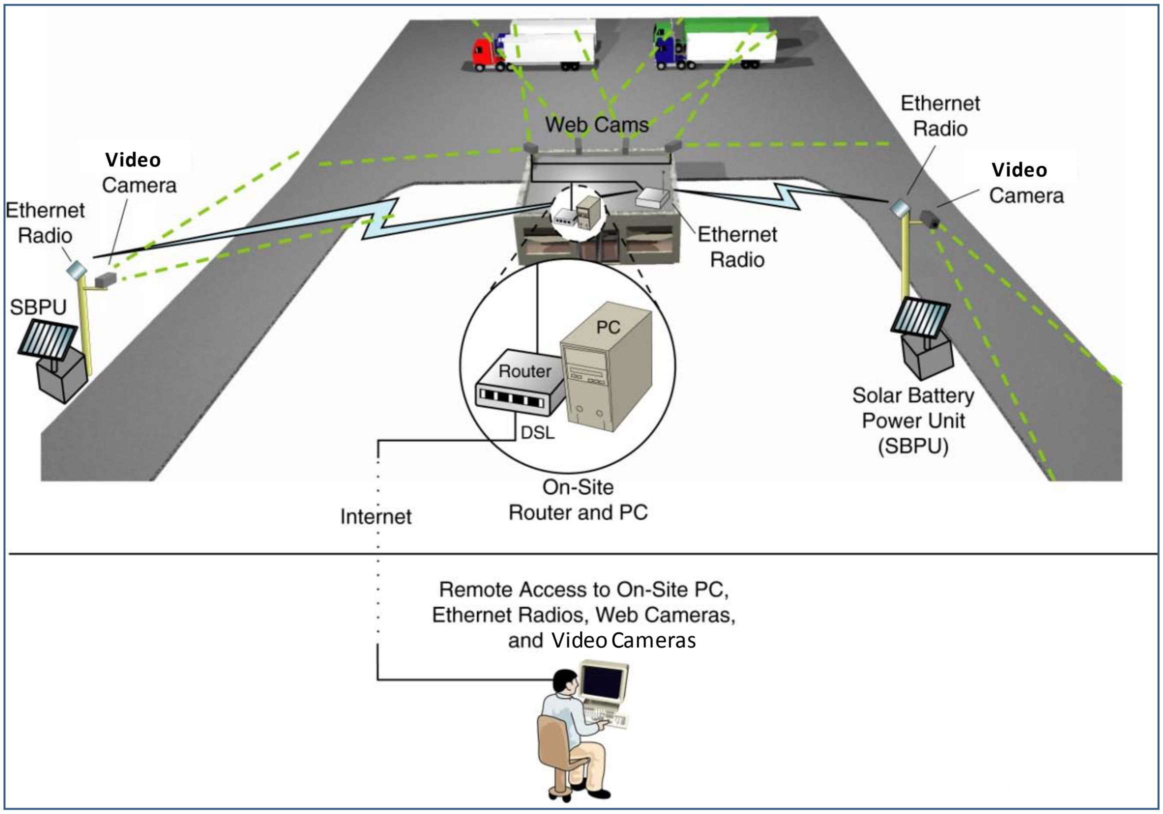

Figure 2. SmartPark Video System Components

Figure 3. View of Truck Parking Area from Web Camera Facing East

Figure 4. View of Truck Parking Area from Web Camera Facing Northeast

Figure 5. View of Truck Parking Area from Web Camera Facing Northwest

Figure 6. View of Truck Parking Area from Web Camera Facing West

2.4 SYSTEM COMPONENTS

This subsection provides a description of each of the SmartPark video system components.

2.4.1 Video Detection System

The video system is a field-proven video vehicle-detection system used in Intelligent Transportation Systems worldwide (See Figure 7). The initial camera selected for the system was the Solo Pro II, which was first released in 2002. However, once the project was under way, the video camera vendor released a newer model. The authors opted to use the new model primarily because it provided digital video from the camera, Where as the older model provided analog video output and would have required additional equipment to convert the analog video to digital video. The older equipment would have required an additional 15 watts of power as well as additional space and weight at the poles not only for the components, but also for larger batteries. The fact that the older model was transitioning to legacy status also influenced the decision to use the newer model. The vendor assured the image processing algorithms on the Solo Terra were superior to the older model algorithms and the newer model would be suitable for use in low-light conditions.

Figure 7. Video Camera

The image resolution of the video camera is 768 × 494 pixels. Video output from the camera is provided using MPEG-4 compression.

A rechargeable battery and solar panel unit powered each camera thus providing continuous operation (See Figure 8 and Figure 9). Vehicle recognition software and hardware were integrated with the camera, eliminating the need for a control box or dedicated computer to perform this function.

Figure 8. Inbound Pole Showing (from bottom) Ethernet Radio, Solar Battery Power Unit (SBPU), and Video Camera

Figure 9. Batteries Used to Store Power from Solar Panels

2.4.2 Web Cameras

The SmartPark video system utilized low-cost exterior Web cameras, manufactured by IQinVision, for manual data collection and system verification in Phase I (See Figure 10). The Web cameras provided live views of the entire truck parking area for ground truth for lot occupancy. They provided instantaneous access to images of the parking facility thus significantly reducing the cost of manual data collection while increasing the availability of the data. They also provided a low-cost, accurate method of counting actual occupancy for system calibration. The camera has a 2 Megapixel resolution.

Figure 10. IQinVision Web Cameras

2.4.3 Ethernet Radios

The SmartPark video system utilized Ethernet radios to transmit video images and data from the cameras to the Charlton service center computer. The radios use directional antennas to provide extended range and high data rates (See Figure 11). Using the 802.11 G wireless protocol (a wireless Ethernet standard), the radios provided sufficient throughput for live streaming video and event data from both video cameras simultaneously. The pole mounted radios used power-over-Ethernet provided by injectors powered by the solar-power units. A single roof-mounted radio communicated with both pole-mounted radios using two directional antennas (See Figure 12).

Figure 11. Pole-Mounted Ethernet Radio with Directional Antenna

Figure 12. Single Roof-Mounted Ethernet Camera, Radio, and Directional Antennas

2.4.4 Onsite Computer

The onsite computer (see Figure 13) was installed in a secure enclosure located in a locked electrical room. The computer was connected to the video cameras through Ethernet radios and hardwired to the roof-mounted Web cameras. The computer was connected to the Internet via a Cisco router and high speed digital subscriber line (DSL) connection. One hour of continuous video data from all six cameras using medium data compression required approximately .8 gigabytes (GB) of data. The computer had local storage of 200 GB providing the ability to store approximately 200 h of continuous video data from all cameras. Video storage was only used for system performance evaluation and was not part of the detection, classification, and parking management functionality.

Figure 13. The Onsite Computer Mounted in the Electrical Room

2.5 SYSTEM CAPABILITIES

The SmartPark used a video system used cameras to detect vehicles as they entered and exited the parking facility. Video cameras monitored the entrance and exit to the facility and processed the video images using the system’s detection and classification algorithms. The video camera systems and detection and classification algorithm were configured to detect and differentiate vehicles by overall vehicle length.

Initially, the system was configured to use a speed-volume detector. The detector detected vehicle presence, speed, and length. When the detector did not provide the required accuracy, the authors implemented a series of presence detectors. Presence detectors activated when a vehicle crossed the detector in the image and deactivated when the vehicle cleared the detector. The detector data was stored in log files on the onsite computer and updated every 15 minutes. The authors also developed a computer program to process the detector data, and generate vehicle counts and classifications. The vehicle counts are presented in the results section of this report.

The vendor of the system also revised its detectors. The final configurations included speed-volume and presence detectors, as well as combined detectors that were created by linking basic detectors with logic statements to provide higher level detection functions. Vehicle counts from the configurations are also presented in the results section.

All of the detectors were based on the video system's image processing software. The software monitored camera images for changes in the background image of the roadway. Software algorithms removed variations in the image caused by weather conditions, shadows, and day or night artifacts. When a vehicle moved through an area of the image covered by a detector, the background was obscured and the software detected a vehicle (See Figure 14 and Figure 15).

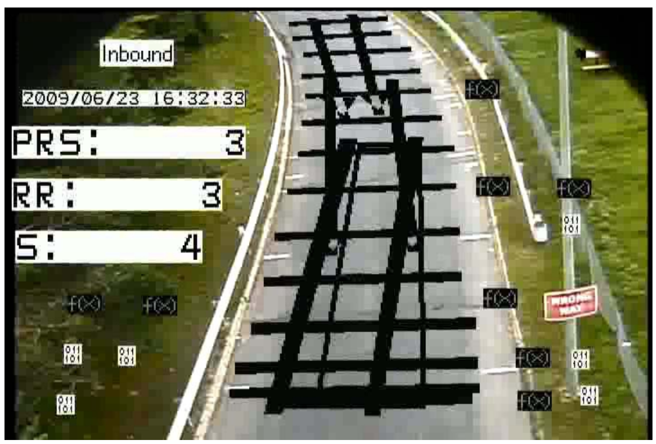

Figure 14. Final Video Detector Configurations—Inactive

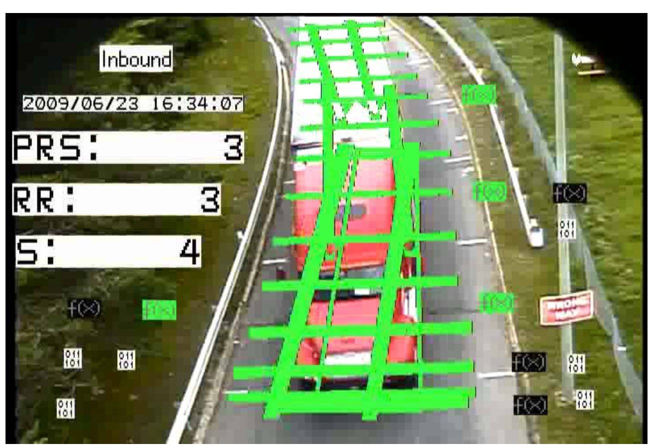

Figure 15. Final Video Detector Configurations—Active

Vehicles may stop on either the entrance or exit ramp during normal operations. During periods of high usage, the ramps may become congested creating stop-and-go traffic. Trucks also may stop on the entrance ramp during periods of high congestion in the parking area as they wait for available parking or traveling space. These situations were problematic for all detector configurations and algorithms.

SmartPark recorded entrance and exit events in log files, which were stored on the onsite computer. Authorized users had access to the data via a secure Internet connection.

The author performed physical vehicle counts of the facility occupancy. The physical counts were performed at the authors' facility utilizing Web cameras installed at the test site that provided views of the parking areas. At specified intervals, the cameras captured an image and a physical count of the vehicles in the parking area was based on the video images. The cameras were mounted on the roof of the service center building and connected to the Internet via a router and DSL. Web camera image acquisition was synchronized so that all images of all areas were acquired at the same time, thus permitting an accurate count. The Web cameras could also be used to record video for a period prior to, and after, a vehicle count. If there was a question of whether a truck obscured one or more trucks, monitoring the video could show whether trucks entered or exited the obscured locations prior to or after the vehicle count. The obscuring truck might also move during the period. The project did not advance to a point where regular parking area vehicle counts were performed. The team did verify video recording from the Web cameras and was confident a sufficient recording interval (estimated to be 30 minutes before and after the vehicle count) would ensure accurate parking area vehicle counts.

Following initial system installation, parking lot vehicle counts were checked several times daily. As system operation was verified, the vehicle counts were to be checked daily. Parking vehicle counts maintained by the SmartPark video system would not be adjusted unless they exceeded a value that caused the calculated parking availability to differ from the actual availability by more than five percent of the parking lot capacity. Since the nominal capacity of the parking lot was estimated to be 30, the requirement means the parking count would be adjusted if the difference was two or more trucks.

The vehicle count of entrance and exit events was used to determine available parking space within the facility. When the system detected a vehicle entering the facility, it would classify the vehicle-by-vehicle length and add to the count of that vehicle length type. When it detected a vehicle exiting the facility, it would subtract from the count of that vehicle length type. The number of available parking spaces at any given time was the difference between the capacity of the facility and the current count of occupied parking spaces. The capacity of the facility is a user-specified system configuration parameter.

The Charlton facility is unmarked so the capacity of the facility was determined by observing the number of vehicles parked in the facility at three points during the day when facility usage is heaviest. Using this information and consulting with the Massachusetts Turnpike (Interstate 90) Engineering Department, the authors established the facility capacity as 30 tractor-trailers. This capacity was used at the start of the test procedure. The capacity can be easily changed if necessary.

Available parking was determined by multiplying the number of vehicles of a specific length type by a parking space factor that estimates the fraction of a single tractor-trailer that is occupied by the vehicle type. Table 2 lists the vehicle types, lengths, and parking space factors. The factors are system configuration parameters and can be changed if an analysis of the parking data indicates. Observations of the Charlton facility indicate cars do not park in the truck area but tend to either use the fuel island or park in areas where trucks do not. Based on these observations, initially the parking space factor for vehicles less than 23 feet (cars, tractors) was set to zero and these vehicles were not included in the parking availability calculation. This could be changed if data analysis indicated these vehicles actually occupy truck parking spaces.

Table 2. Vehicle Types

Vehicle Type	Vehicle Length	Parking Space Factor
Car	≤ 23 feet	0
Truck	> 23 feet and ≤ 40 feet	1
Single Tractor-Trailer	> 40 feet and ≤ 70 feet	1
Double Tractor- Trailer	> 70 feet and ≤ 100 feet	1.5
Triple Tractor-Trailer	> 100 feet	2

As part of this study, the authors evaluated the quality of the data generated by the video detection system including sensitivity to weather effects, the ability to classify vehicles by length, and the determination of available parking space based on facility capacity and current occupancy by vehicle type.

2.6 TEST SITE

The Charlton Westbound Service Center, located near Exit 9 of the Massachusetts Turnpike (Interstate 90), was the test site for the Phase I program. Figure 16 illustrates the location of the service centers on the turnpike. The Charlton Service Center was an ideal location for Phase I because, according to the Massachusetts State Police and the Massachusetts Turnpike (Interstate 90) Authority, the truck parking area routinely reaches capacity. In addition, the site offered the potential in Phase II to direct trucks to another westbound service center.

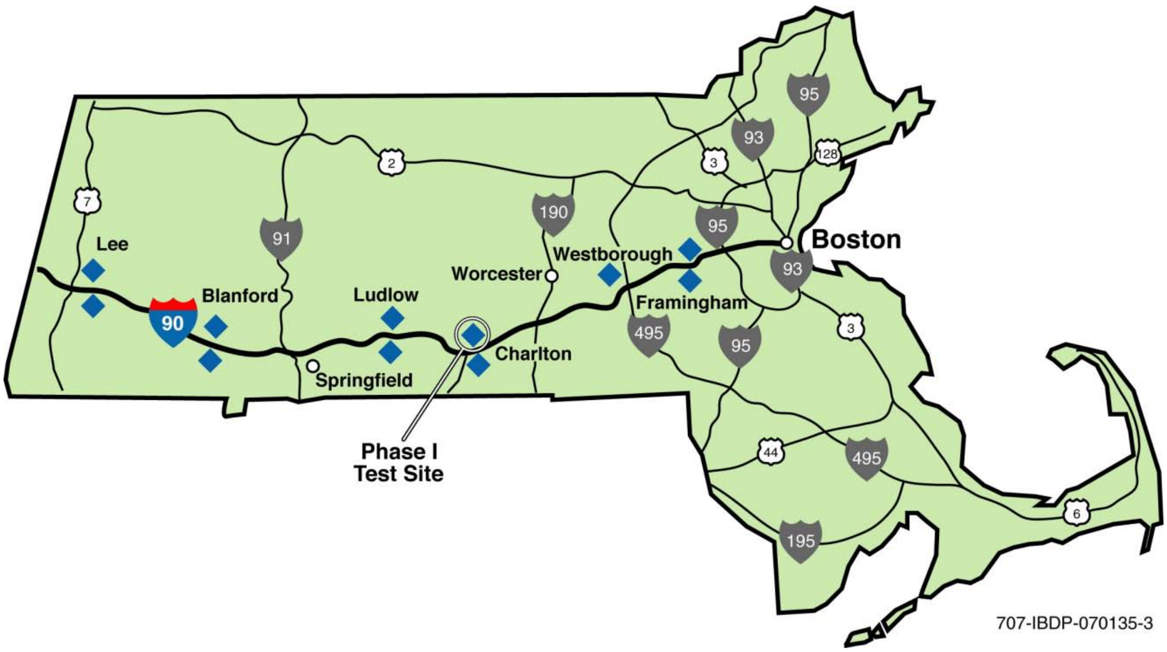

Figure 16. Location of Charlton Test Site

All service centers on the Massachusetts Turnpike (Interstate 90) have similar layouts. There are well-defined entry and exit ramps. The entrance ramp splits with cars going to the left, and trucks to the right as shown in Figure 17. The Charlton Westbound Service Center is an unmarked facility and has parking space for approximately 30 trucks (the authors worked with the Massachusetts Turnpike (Interstate 90) Engineering Department to develop this estimate).

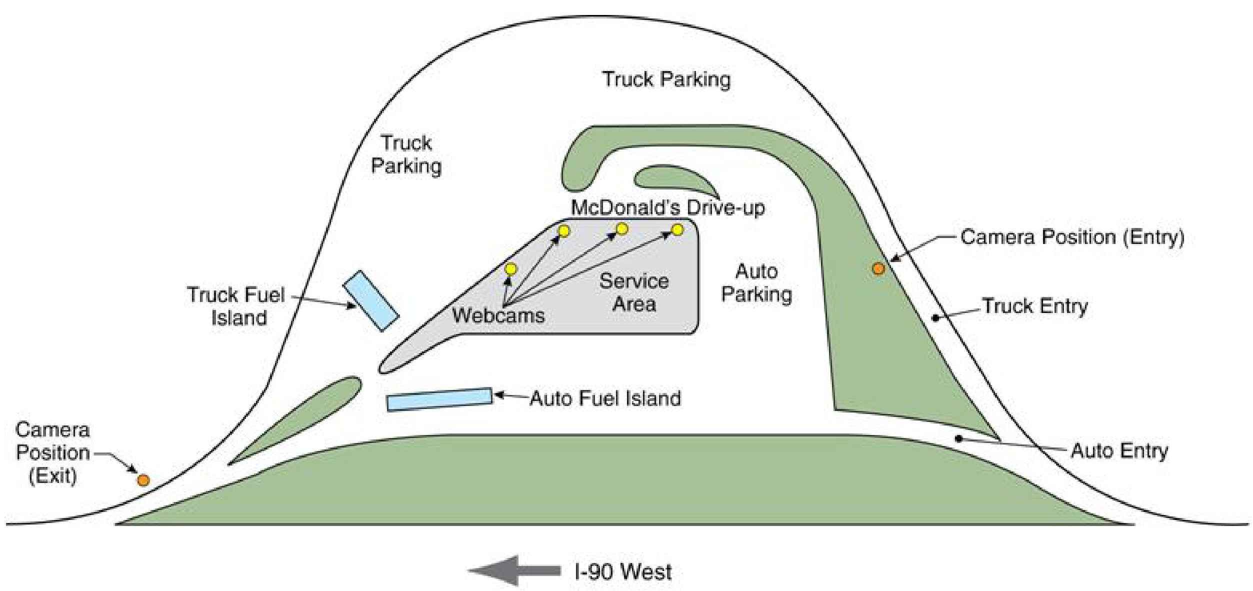

Figure 17. Layout of Charlton Service Area

The truck entrance road routes trucks to the truck parking and fueling areas at the back of the service center building. From here, trucks leave the service area via an exit road for both cars and trucks as shown in Figure 18. Occasionally, a passenger vehicle will enter via the truck route either due to error or because the driver needs diesel fuel and is not aware that there is an auto fuel island.

Figure 18. Trucks Entering Truck Parking Area at Charlton (Westbound) Service Center

A restaurant drive-through window at the rear of the service center building has an access road that routes vehicles back into the auto parking area. However, it is also possible to drive straight ahead and exit via the truck parking area. The drive-through window is used primarily by passenger vehicles, but delivery trucks for the concessionaires at the service center also drive through and park at the rear of the building to make deliveries. A cut-through between the service center building and the traffic island beyond the truck fuel island allows passenger vehicles and small delivery trucks to cross from the truck parking area to the auto area.

Figure 19 provides a composite view of the entire truck parking area as viewed via the four Web cameras on the service center roof. The Charlton facility experiences heaviest volumes 11 a.m–2 p.m. on weekdays. Truck volumes can exceed 60 vehicles per h and the facility is frequently at capacity. Truck traffic on both the inbound and outbound ramps can back up creating stop-and-go traffic. This is a particularly challenging situation for automated vehicle counting and classification. The site experiences most weather conditions including full sun, rain, fog, and snow (See

Figure 20, Figure 21, Figure 22, and Figure 23).

Figure 19. Composite View of Truck Parking Area from Four Web Cameras

Figure 20. Winter View of Truck Parking Area from Camera Facing East

Figure 21. Winter View of Truck Parking Area from Camera Facing Northeast

Figure 22. Winter View of Truck Parking Area from Camera Facing Northwest

Figure 23. Winter View of Truck Parking Area from Camera Facing West

2.7 CONCEPT OF OPERATIONS

The concept of operations for the SmartPark video system is documented in the *SmartPark Concept of Operations*[1] which includes operational scenarios that describe the operation of the system. The scenarios are described in narrative form supported by activity diagrams. The following are example scenarios.

2.7.1 Truck Enters Parking Area

In this scenario, a truck or tractor-trailer enters the parking area. The truck drives along the entrance ramp at normal speeds and passes through the field of view (FOV) of the video camera. The video camera analyzes the image, determines the vehicle length, and classifies it as either a truck or single, double, or triple tractor trailer. The camera sends a message to the onsite computer indicating a vehicle of the specific vehicle length category has entered the parking facility. The computer increments the number of vehicles of that category and records the truck entrance event in the system event log. It then recalculates the available parking as described in Section 2.7.2 (See Figure 24).

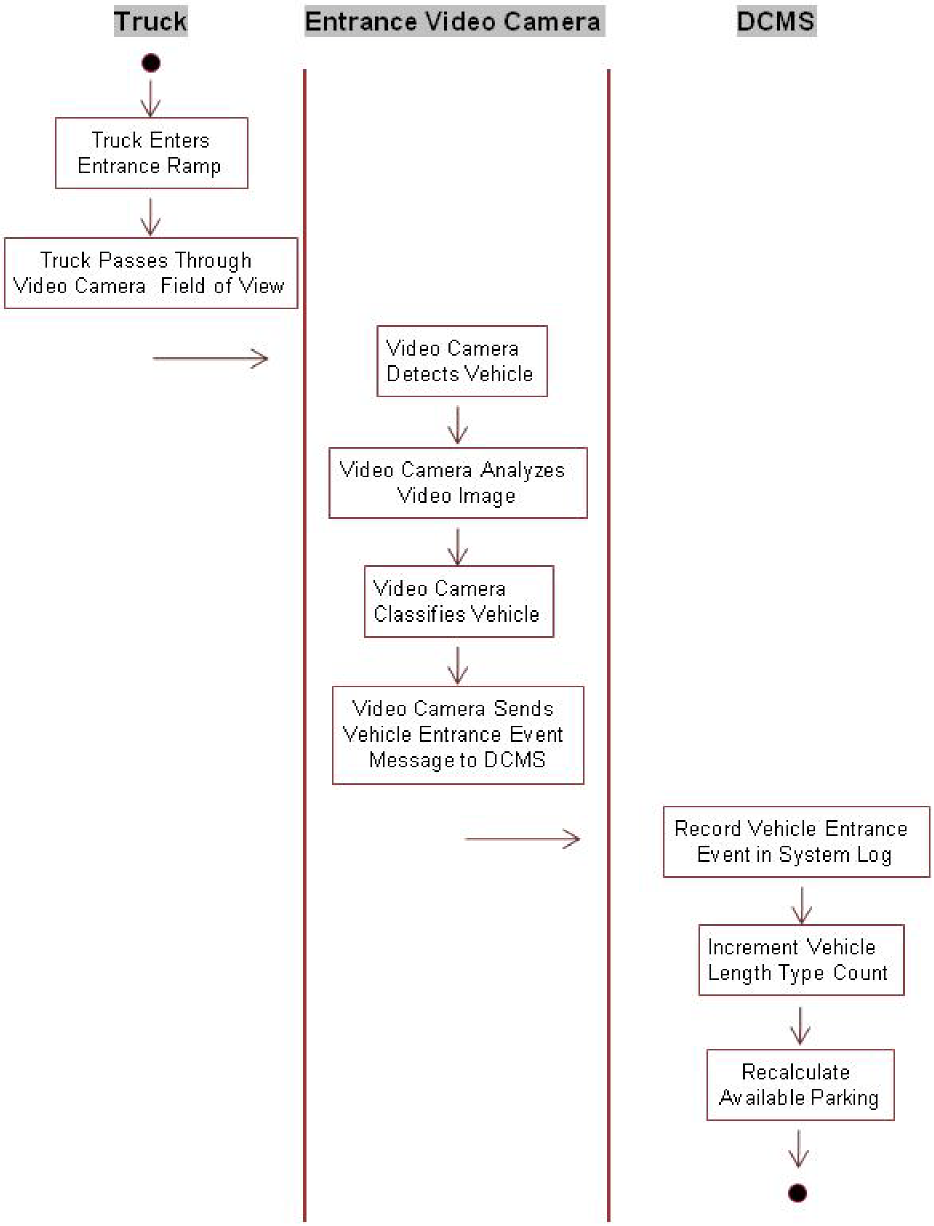

Figure 24. Activity Diagram—Truck Enters Parking Area

2.7.2 Calculation of Available Parking

This scenario describes the calculation of available parking in the parking area. The current number of vehicles in the parking area is recorded by category as shown in column 2 of Table 3. This number is multiplied by the parking space factor in column 3 resulting in the total space occupied in column 4. Column 4 is totaled to give the total parking space occupied. The number is rounded up to 22. Assuming a user-specified parking area capacity of 30, the amount of available parking would be space for eight trucks or single tractor-trailers.

The parking space factors for each vehicle length type are system configuration parameters and can be modified during the course of the field trial if analysis of the parking data indicates such an adjustment would provide a more accurate estimate of available parking.

Table 3. Example Data for Parking Availability Calculation

Vehicle Type	Number of Vehicles	Parking Space Factor	Total Space Occupied
Car	5	0	0
Truck	2	1.0	2.0
Single Tractor-Trailer	18	1.0	18.0
Double Tractor-Trailer	1	1.5	1.5
Triple Tractor-Trailer	0	2.0	0
Total			21.5

2.7.3 Truck Leaves Parking Area

In this scenario, a truck or tractor-trailer leaves the parking area. The truck drives along the exit ramp at normal speeds and passes through the FOV of the video camera. The video camera analyzes the image, determines the vehicle length, and classifies it as either a truck or single, double, or triple tractor trailer. The camera sends a message to the onsite computer indicating a vehicle of the specific vehicle length category has exited the parking facility. The computer decrements the number of vehicles of that category and records the truck exit event in the system event log. It then recalculates the available parking as described in Section 2.7.2 (see Figure 25).

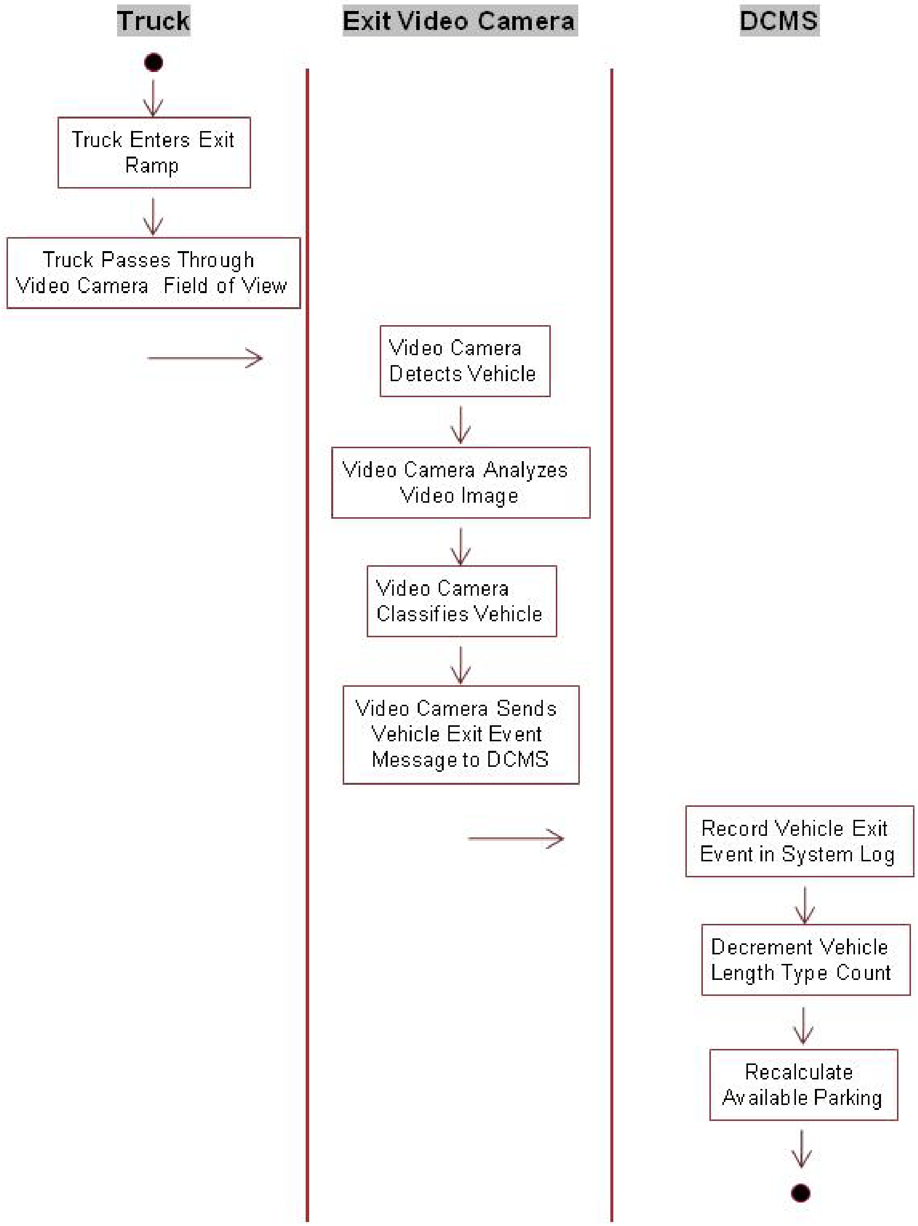

Figure 25. Activity Diagram—Truck Leaves Parking Area

2.8 SYSTEM REQUIREMENTS

The *SmartPark Performance Requirements*(2) document contains the system requirements. The *Concept of Operations*(1) document and the SmartPark video program objectives defined by FMCSA are the basis for the requirements. All requirements are traceable to the sources as demonstrated in the traceability matrix in the requirements specification. The requirements form the basis for the system design and the functional tests in the operational test plan.

The requirements are organized by type of requirement. Functional requirements describe specific functions a SmartPark video system must accomplish. Examples include:

- The system shall automatically and autonomously maintain a count of the number of vehicles in the parking area by vehicle length category.
- The system shall allow authorized users to view the count of the number of vehicles in the parking area by vehicle length category from remote locations.
- The system shall maintain counts of each type of vehicle currently in the parking area.
- The system shall allow users to display the system count of parking available in the facility.

The requirements specification also includes performance goals. These are performance targets which support the operational needs. Some of the performance goals for The SmartPark video system are:

- The system shall detect individual vehicles entering the parking area to an overall accuracy of at least 96 percent.
- The system shall classify individual vehicles entering the parking area to an overall accuracy of at least 96 percent.
- The system shall detect individual vehicles exiting the parking area to an overall accuracy of at least 96 percent.
- The system shall classify individual vehicles exiting the parking area to an overall accuracy of at least 96 percent.
- The system availability shall be at least 99 percent.

The requirements specification also includes other requirements. Interface requirements document the user and remote interfaces to the system. Data requirements identify data collected, calculated, stored, and presented by the system. Non-functional requirements include environmental and operating requirements such as:

- The system shall operate autonomously continuously.
- The system shall operate in rain, snow, and fog.
- The system shall operate between -34˚ C and 60˚ C.

The requirements document also includes system constraints. A key constraint is the system shall conform to Central Massachusetts Regional ITS Architecture. In addition, the system must detect vehicles traveling 10–40 mi/h and vehicle headways of at least two sec.

Appendix A contains the system requirements.

[This page intentionally left blank.]

3. OPERATIONAL TEST RESULTS

Installation of the SmartPark video system occurred in February 2008. Review of the system's vehicle detections through video data found the error rate higher than the required performance goal. Based on the recommendation of the vendor, the cameras were recalibrated and adjusted on three separate occasions prior to the initial tests that occurred in July 2008. Testing was suspended because the initial tests found the night performance poor. After reviewing the problem, the vendor proposed software improvements designed to correct the night problems. The vendor provided a new version of the software in May 2009. The second phase of testing occurred in June and July 2009. The following subsections provide an overview of the test plan along with the results from the initial and final tests.

3.1 TEST PLAN

The test plan consisted of two sets of tests, functional tests and operational performance tests. The design of the test plan assured the tests covered each of the requirements in the *SmartPark Performance Requirements* document. The following sections summarize the two types of tests. The *SmartPark Field Operations Test Plan* contains more detailed descriptions of the tests. A traceability matrix, which maps the performance requirements against the various tests, appears in Appendix A.

3.1.1 Test 1 Functional Tests

The functional tests covered all requirements, as described in the *SmartPark Performance Requirements*(2) document, which can be evaluated by either demonstration or inspection. All of the functional tests are pass/fail.

3.1.1.1 Test 1.1 Vehicle Detection and Classification

The purpose of this test was to verify the SmartPark video system was detecting and classifying vehicles as they entered and exited the parking area. It involved human observation and comparison with SmartPark detection and classification. The test applied to both entrance and exit events.

3.1.1.2 Test 1.2 Vehicle Count

The purpose of this test was to validate the SmartPark video system automatically and autonomously maintained a count by vehicle length of the vehicles that were in the truck parking area, and that an authorized SmartPark user could adjust the vehicle count.

3.1.1.3 Test 1.3 Event Recording

The test was designed to verify the SmartPark video system correctly recorded normal vehicle entry and exit events as well as error conditions due to inaccurate vehicle counts and camera equipment failure.

3.1.1.4 Test 1.4 Secure User Access

The purpose of the test was to verify only authorized users could access the SmartPark video system.

3.1.1.5 Test 1.5 Adherence to ISO 9000 Quality Procedures

The authors' corporate quality committee representative was to audit the project reports prescribed by ISO 9000 Quality Procedures[3] for adherence to company requirements.

3.1.1.6 Test 1.6 Operational Environment

This test has to verify the system operated under the conditions prescribed in the non-functional requirements.

3.1.1.7 Test 1.7 Constraints

This test verified conformance with the Central Massachusetts Regional ITS Architecture and the speed and vehicle headway constraints.

3.1.2 Test 2 Operational Performance Tests

The operational performance tests involved collecting appropriate data to determine the extent to which the performance of the operational the SmartPark video system met the performance goals as specified in the *SmartPark Performance Requirements* document. Analysis was used to verify the performance goals. *SmartPark Evaluation Plan* describes the methods of analysis that the authors planned for the data recorded from the four sets of operational performance tests described below.

The method to establish whether or not the SmartPark video system met the required system performance levels was statistical hypothesis testing using a *z*-score. This type of statistical analysis tests the null hypothesis that the accuracy rate is 96 percent (or the error rate is four percent), a specified SmartPark performance requirement, versus the alternative hypothesis that the accuracy rate is lower (or the error rate is higher). The relevant sample size is a function of the threshold accuracy level (e.g., 96 percent) that the hypothesis test will examine.

Vehicle detection has two outcomes, successful detection or failure to detect. Similarly, vehicle length classification has two outcomes, accurate classification or inaccurate classification. Both are binomial processes. The *z*-score for a binomial process is calculated from Figure 26:

$$z = \frac{\hat{p} - p}{\sqrt{\dfrac{pq}{n}}}$$

Figure 26. Equation to calculate the *z* score for a binomial process

where p = target accuracy rate

$q = 1\text{-}p$

$\hat{p}$ = observed accuracy rate

n = number of observations

Hypothesis testing of binomial data with the z-score requires that $np > 10$ and $nq > 10$. Therefore, testing the null hypothesis that the SmartPark video system accuracy rate is 96 percent requires a minimum sample size of 251. This is a one-tailed test since it evaluates the hypothesis that the accuracy is not less than 96 percent. Using $\alpha = 0.05$, if the computed z-score for a test is 1.645 or less, and then the conclusion is the system accuracy is at least 96 percent An $\alpha = 0.05$ means that if the test is repeated many times, in 5 percent of the cases in which the accuracy rate is at least 96 percent, the test will conclude the accuracy rate is lower. This is also referred to as a type 1 error.

3.1.2.1 Test 2.1 Vehicle Detection and Classification Accuracy

This test compares the SmartPark video system vehicle detection and classification with ground truth data from a video recording of the entrance and exit events of the parking area. The recording period should be long enough to capture the minimum sample size necessary for the statistical test as described above. Alternatively, two or more tests may be combined to achieve an adequate sample size. Discrepancies may indicate a failure to detect and classify a vehicle, misclassification of a vehicle, or detection of a vehicle when none exists. This test used video recordings of digital video from cameras. A human observer reviewed the video to establish ground truth values. To establish the accuracy of the video recorded by the system, a one-time test with two human observers validated the video recorded by the camera was identical to that recorded by the roof camera at the east end of the service center building. The observers viewed both video streams and identified 159 vehicles as of the same type on both video recordings. A similar validation of the outbound cameras was not possible, because no roof camera offered an adequate view of the outbound roadway.

3.1.2.2 Test 2.2 Availability and Reliability

There are two primary measures of system and subsystem availability: availability, and average downtime or mean time to repair (MTTR). Availability is the ratio of the time the system was properly working divided by the time the system was operational (time for routine maintenance, if any, is not part of the operational time). Reliability refers to the probability of a system or subsystem being in operation during a specified length of time. Computation of a reliability statistic for a component or system requires data from more than the limited number of units in the field operational test. As a result, reliability was measured as the number of failures during the field operational test.

3.1.2.3 Test 2.3 Accuracy of Vehicle Count and Parking Availability

The purpose of this test was to determine the accuracy of the SmartPark video system count of vehicles in the facility and the resulting prediction of parking availability. Because parking availability is a function of both the number of vehicles in the facility and the facility's nominal capacity, the test must consider the accuracy of both factors.

3.1.2.4 Test 2.4 Accuracy of Parking Availability Notification

The purpose of this test was to determine the accuracy of the parking availability notification. While this FOT does not involve notification, it is possible to determine that the vehicle counts maintained by SmartPark video system would result in a false indication of parking availability.

Two conditions are of interest are notification of parking availability when none exists and notification of the unavailability of parking when there is space available.

3.1.3 Other Considerations

In addition to determining the extent to which the relevant performance goals were achieved, analysis of the test data addressed the following questions:

- Was any specific vehicle classification more problematic?
- How did weather conditions affect vehicle detection and classification?
- Is there a relationship between traffic volume and detection accuracy?
- Does detection or classification accuracy differ between the entrance and exit points? If so, is it possible to determine the source of the difference?

While the overall goal of the field operational test was to evaluate the ability of the SmartPark video system to reliably and accurately indicate the availability of parking, it was important also to identify any operational issues that arose during the test and that affect overall system performance. Similarly, any sources of error that were revealed during the test are also of interest. Factors of interest, in addition to the items described above, include:

- If entrance vs. exit accuracy differs, is it due to road geometry? Orientation of the camera?
- Was there a particular vehicle configuration that proved difficult to detect or classify?
- Were there any unanticipated vandalism or equipment security issues?
- Were all tests completed as planned? What events, if any, prevented conducting the tests according to plan?
- What events, if any, caused inaccuracies in the application of the parking factors?

3.2 TEST PROCEDURE

For the performance tests, the system configuration allowed testing to be conducted remotely. No onsite activity was required for test setup, test performance and data collection, or analysis of test data. The tester signed into the Charlton system and initiated recording of video data from each camera. If the test also required parking lot images, a batch file for each roof camera was created to record images at selected times. Once created, the system operated unattended for the duration of the test. During the test, the system recorded both video and detector data on the Charlton computer. At the conclusion of the test, the tester downloaded the video and detector data to the authors' server. All data analysis occurred.

3.3 INITIAL TESTS

This subsection describes the results of initial testing in July 2008. All day data was collected at midday which is the busiest time of day for the Charlton Service Center. Detailed data for the performance tests appears in Appendix B.

3.3.1 Functional Tests

Initial review and testing of the system led the authors to conclude the software was not accurately classifying the length of vehicles and the night vehicle detections were characterized by multiple detections of individual vehicles. Based on these results, the authors worked with the vendor to resolve the length detection accuracy issues with the system. After extensive consultations, it was concluded that the accuracy could not be improved with the existing software. Instead, the authors developed another detection and classification algorithm (see Section 2.5) using detection data from the cameras. The authors' approach reduced the vehicle length categories to three by combining tractor-trailer, double and triple, into one tractor-trailer category. While this change would not allow the use of the parking space factors, it was necessary because the new algorithm was not accurate in detecting the three types of trucks. Ultimately, this change may affect the accuracy of the parking availability calculation.

Functional tests were conducted in July 2008 using the authors' new algorithm. All functional tests were completed except the environmental test. Tests took place in day, night, and rain. Other weather conditions did not occur; temperatures did not reach the required extremes. This was considered acceptable because the other conditions were expected to be encountered over the course of the operational test. All functional tests were passed successfully except the night vehicle detection and classification and the vehicle count. Table 4 summarizes the results of the functional tests performed with the author detection and length classification algorithm. Night detection and vehicle count continued to be problems.

Table 4. Summary of Initial Functional Tests

Test	Pass/Fail	Results
1.1 Vehicle Detection and Classification	Day—P Night—F	The software reliably classifying vehicles by length at both entrance and exit. System significantly over-counted at night.
1.2 Vehicle Count	F	Without accurate vehicle detections, vehicle count could not be accurate.
1.3 Event Recording	P	When the system software detected a vehicle entering or exiting, it properly logged the event.
1.4 Secure User Access	P	Only users with an authorized username and password could access the system.
1.5 Adherence to ISO 9000 Quality Procedures	P	The authors' Quality Management System (QMS) representative confirmed that all equipment purchases were done in accordance with the ISO 9000 QMS procedures. All project files were maintained in accordance with QMS requirements.
1.6 Operational Environment	P—partial	• The SmartPark video system operated continuously from March 1, 2008–July 24. • During initial testing, the system did not encounter the full range of temperatures and weather conditions in the performance requirements. The SmartPark video system operated in rain. • The SmartPark video system operated in natural and artificial lighting conditions, but accuracy at night did not meet the requirements.

3.3.2 Performance Tests

If vehicle detections and length classifications are not accurate, then the vehicle parking count will not be accurate and useful. For this reason, the only performance test conducted was the one for vehicle detection and length classification. Test 2.1 (see Table 5) summarizes the day results of the tests with the inbound camera and Table 6 summarizes the results for the outbound camera. The results of visual review of night video from the evening of July 22 indicated a high number of false detections. Headlights appeared to cause detection prior to the appearance of the vehicle in the detection zone. The results are summarized in Table 7.

Table 5. Summary of Initial Vehicle Detection and Classification Tests—Inbound Day

Date	Ground truth	# Vehicles Detected	Accuracy	False Detections	Missed Detections	# Multiple Counts	# Vehicles Correctly Detected and Classified	Accuracy
July 3, 2008	159	158	99.4%	1	2	0	152	95.6%
July 21, 2008	211	206	97.6%	0	5	0	200	94.8%
July 22, 2008	141	139	98.6%	0	2	0	136	96.5%
July 24, 2008	292	290	99.3%	3	5	0	252	86.3%

Table 6. Summary of Initial Vehicle Detection and Classification Tests—Outbound Day

Date	Ground Truth	# Vehicles Detected	Accuracy	# False Detections	# Missed Detections	# Multiple Counts	# Vehicles Correctly Detected and Classified	Accuracy
July 3, 2008	205	203	99.0%	1	3	0	194	94.6%
July 21, 2008	253	255	100.8%*	2	0	0	238	94.1%
July 22, 2008	156	157	100.6%*	1	1	1	142	91.0%
July 24, 2008	394	386	98.0%	3	11	0	317	80.5%

*Values exceed 100 percent because number of vehicles detected exceeds ground truth. These over-detections are errors.

Table 7. Night Vehicle Detection, July 22, 2008

Camera	Ground Truth	# Vehicles Detected	Accuracy	# False Detections	# Missed Detections	# Multiple Counts	# Vehicles Correctly Detected and Classified	Accuracy
Inbound	38	55	144.7%*	17	0	0	21	55.3%
Outbound	36	54	150.0%*	18	0	0	10	27.8%

*Values exceed 100 percent because number of vehicles detected exceeds ground truth. These over-detections are errors.

The data for July 2, 21, and 22 were combined to produce an adequate sample size for hypothesis testing. All three days had predominantly sunny or partially sunny weather therefore, combining the days is justified. July 24 had rain so the data could not be combined with the other three sets of test data with different weather conditions. Table 8 contains the results of the hypothesis tests regarding vehicle detection and vehicle length classification.

Table 8. Initial Hypothesis Test Results

Camera	*n*	Vehicle Detection *p* [95% confidence interval]	*z*	Detection and Length Classification *p* [95% confidence interval]	*z*
In—July 3, 21, 22	511	98.4% [96.9, 99.3]	-2.808	95.5% [93.3, 97.1]	.578
In—July 24	292	99.3% [97.5, 99.9]	-2.891	86.3% [81.8, 90.0]	8.457
Out—July 3, 21, 22	614	100.2% [n/a]*	-5.264	93.5% [91.2, 95.3]	3.180
Out—July 24	394	98.0% [96.0, 99.1]	-1.995	80.5% [76.2, 84.3]	15.744

*Confidence interval for binomial variable could not be calculated for values over 100 percent. The confidence interval is an interval estimate of the parameter of interest, in this case, the proportion correct. It is a measure of the reliability of the estimate. A 95 percent confidence interval implies that if the test were repeated many times, the true value would be within these limits 95 percent of the time.

The researchers tested different length recording periods. That is the reason for the differing numbers of vehicles in each test. Also, traffic patterns differ by day and until the video is viewed and analyzed, the vehicle count is unknown.

The accuracy from the initial tests on both the inbound and outbound cameras (100.8 percent–97.6 percent) demonstrated the system met the system requirement for accuracy of at least 96 percent during the daytime. The data for total vehicles detected (and hence accuracy) must be interpreted with caution because the total counts include some false detections; that is, SmartPark video system detected a vehicle when none was present. There were a total of four false detections across all of the inbound tests and seven on the outbound tests. The total detection counts also include cases where vehicles were counted more than once. One multiple detection occurred outbound on July 22.

The hypothesis tests for vehicle detection found the inbound camera detection rate met the performance requirement of 96 percent accuracy. The data for the outbound camera also demonstrated the detection rate met the 96 percent accuracy, but because of false detections and over-counting, the combined tests for July 3, 21, and 22 on the outbound camera are not meaningful.

The hypothesis tests for vehicle length classification found the only instance where the length classification accuracy met the 96 percent accuracy requirement was the inbound camera on July 2, 21, 22. Rain on July 24 may have caused the poor performance of the detections on that day. Overall, the tests indicated the inbound camera appeared to perform more accurately in terms of both vehicle detection and length classification.

Review of the video and detection data identified several problematic situations. When a high volume of vehicles enters the truck parking area, vehicles may stop on the entrance roadway.

Stopped vehicles appear as one long vehicle to the image-processing algorithm. This situation accounted for some of the missed vehicles. Similarly, the software interprets a car following closely behind a truck as one long vehicle. The vendor cautions slow moving vehicles (under 10 mi/h) may also result in over counting of vehicles.

The system senses the ambient light level and converts to black and white image analysis under conditions of reduced light. For purposes of testing, night was present when the camera went into this mode. As the night data indicate, the system significantly over-counted vehicles at night. Review of the night video and vehicle detection data indicated the system was detecting headlights separately from the vehicle. This appeared to be the cause of the over-counting. For those vehicles that were accurately detected, length classification accuracy did not meet the requirements.

3.4 FINAL TESTS

In May 2009, the vendor provided the beta version of its improved software. Final testing began once the new software was installed and tested. Detailed data for these tests appears in Appendix C. During review of the new software, the authors discovered the outbound camera had developed a leak allowing moisture to accumulate behind the lens. Additional moisture accumulated over time because of heavy rainfall in the area (compare Figure 27 and Figure 28). The result was that the camera image could not be accurately analyzed. The lead time required to obtain and install a replacement camera ruled out this option within the project performance period, therefore final tests were conducted with only the inbound camera.

The final tests evaluated the authors' detector configuration and length detection algorithm along with three detector configurations designed by the vendor. The three configurations used a speed detector, a series of presence detectors, and a combination of speed and presence detectors. Because of the moisture problem with the outbound camera, results presented below are for the inbound camera only. The availability of only the inbound camera prevented conduct of the performance tests dealing with the accuracy of the vehicle count and parking availability (Tests 2.3 and 2.4).

Figure 27. View through Outbound Camera, June 2008

Figure 28. View through Outbound Camera, June 2009

3.4.1 Functional Tests

After the new software was installed, the functional tests were repeated. Table 9 summarizes the results. The final functional test results were similar to those of the initial functional tests.

Table 9. Summary of Final Functional Tests

Test	Pass/Fail	Results
1.1 Vehicle Detection and Classification	Day—P Night—F	The software reliably classifying vehicles by length at both entrance and exit. System over-counted at night.
1.2 Vehicle Count	F	Without accurate vehicle detections, vehicle count could not be accurate.
1.3 Event Recording	P	When the system software detected a vehicle entering or exiting, it properly logged the event.
1.4 Secure User Access	P	Only users with an authorized username and password could access the system.
1.5 Adherence to ISO 9000 Quality Procedures	P	The authors' Quality Management System (QMS) representative confirmed that all equipment purchases were done in accordance with ISO 9000 QMS procedures. All project files were maintained in accordance with QMS requirements.
1.6 Operational Environment	P—partial	• The SmartPark video system operated continuously over entire test period, March 1, 2008–July 31, 2009. There were three operational failures which are discussed under Test 2.2. • During final testing, the system did not encounter the full range of temperatures and weather conditions in the performance requirements. Operated in rain. The SmartPark video system continued to record data throughout the winter months, but no testing was done at that time. Temperatures ranged from approximately -15°C to 35°C between March 1, 2008 and July 31, 2009. • The SmartPark video system operated in natural and artificial lighting conditions, but accuracy at night did not meet the performance requirement.

3.4.2 Performance Tests

The final performance tests focused first on evaluating the performance of the three detector configurations designed by the vendor (Test 2.1), and then on evaluating the authors' new detector configuration and length algorithm. The final performance tests included system availability and reliability (Test 2.2). Tests 2.3 and 2.4 could not occur because of the failure of the outbound camera.

3.4.2.1 Test 2.1 Vehicle Detection and Classification Accuracy

Table 10 summarizes the results of the tests for vehicle detection with the vendor's detector configuration. These data indicate the speed detector over-detected vehicles both during the day and at night. The detection accuracy for the presence detector and the combined speed/presence detector configurations showed marked improvement over the initial tests, but both sets of detectors failed to meet the 96 percent performance requirement. The June 19 test showed the speed detector performing at an acceptable level. The poor performance of the speed detector configuration at night was due to multiple counts. The presence detector and combined configurations tended to fail to detect vehicles. The tests also measured the number of vehicles detected; but length detection was not evaluated. (The authors chose to check for accurate vehicle detection before deciding whether or not to check length classification. Since vehicle detections were not accurate, the length classification test, which requires significant observer time, was not performed.) The only satisfactory performance with regard to accurate vehicle detections occurred with the speed detector on June 19.

Table 10. Summary of Final Vehicle Detection and Classification Tests—Inbound, Vendor Detector Configurations

Detector Configuration	Ground Truth	# Vehicles Detected	Accuracy	# False Detections	# Missed Detections	# Multiple Counts**
June 19, 2009 Day						
Speed	268	267	99.6%	0	2	1
Combined	268	224	83.6%	0	44	0
Presence	268	199	74.3%	0	69	0
May 29, 2009 Night						
Speed	107	150	140.2%	0	0	35
Combined	107	94	87.9%	0	10	0
Presence	107	97	90.7%	0	13	0
June 23, 2009 Night						
Speed	147	216	146.9%*	1	0	56
Combined	147	134	91.2%	0	13	0
Presence	147	130	88.4%	0	17	0

*Values exceed 100 percent because number of vehicles detected exceeds ground truth. The over-detections are errors.
**Individual vehicles counted two or more times.

Because the above set of tests found the accuracy of the detector configurations below the desired performance level, subsequent tests examined the authors' detectors and length classification algorithm along with the vendor's detector configurations (see Table 11). The length detection accuracy of the configurations was not evaluated because of the unacceptable detection performance.

Table 11. Summary of Final Vehicle Detection and Classification Tests—Inbound, Vendor Detector Configurations and the Authors' Algorithm

Detector Configuration	Ground Truth # of Vehicles Counted	# Vehicles Detected	Accuracy	# False Detections	# Missed Detections	# Multiple Counts†	# Vehicles Correctly Detected and Classified	Accuracy
July 14, 2009 Day								
Speed	284	309	108.8%*	Not tallied	Not tallied	Not tallied	Not tallied	Not tallied
Combined	284	271	95.4%	Not tallied	Not tallied	Not tallied	Not tallied	Not tallied
Presence	284	244	85.9%	Not tallied	Not tallied	Not tallied	Not tallied	Not tallied
Author	284	281	98.9%	6	9	0	267	94.0%
July 15, 2009 Day								
Speed	149	162	108.7%*	Not tallied	Not tallied	Not tallied	Not tallied	Not tallied
Combined	149	138	92.6%	Not tallied	Not tallied	Not tallied	Not tallied	Not tallied
Presence	149	132	88.6%	Not tallied	Not tallied	Not tallied	Not tallied	Not tallied
Author	149	142	95.3%	1	11	3	130	87.2%
July 8, 2009 Night								
Speed	156	197	126.3%*	0	5	33	Not tallied	
Combined	156	138	88.5%	0	22	4		
Presence	156	123	78.8%	0	37	4		
Author	156	155	99.4%	0	1	0	155	99.4%
July 13, 2009 Night								
Speed	112	169	150.9%*	Not tallied	Not tallied	Not tallied	Not tallied	Not tallied
Combined	112	106	94.6%	Not tallied	Not tallied	Not tallied	Not tallied	Not tallied
Presence	112	96	85.7%	Not tallied	Not tallied	Not tallied	Not tallied	Not tallied
Author	112	123	109.8%*	0	5	15	104	92.9%

*Values exceed 100 percent because number of vehicles detected exceeds ground truth. The over-detections are errors.

† Individual vehicles counted two or more times.

During the day, the authors' method experienced 7 false detections, missed a total of 20 vehicles, and counted 3 vehicles more than once with a ground truth total of 433. At night, on July 13, out of 268 vehicles, the method had no false detections, but failed to detect 6 vehicles and counted 15 vehicles more than once. In three of the four tests the vehicle detection accuracies of the authors' method met the 96 percent performance requirement. Only the July 8 night test met the performance requirement for length classification accuracy.

Table 12 and Table 13 contain the results of the hypothesis tests for, respectively, the day tests and the night tests. The individual day tests were combined as were the night tests so that there was an adequate population (*n*) to assure statistical validity. The confidence interval could not be calculated in cases where over-detection of vehicles occurred. The day *z*-scores (see Table 12) for the combined detector configuration and the authors' configuration indicate the system detection accuracy during the day would be at least 96 percent. This is not true for the speed and presence detectors. This conclusion for the combined detector is based on a *z*-score that was barely below the threshold value of 1.645 and as such, barely established conformance with the performance requirement. The hypothesis test results for the night test data show that the authors' length classification achieved the desired performance level. The authors did not evaluate the length classification accuracy of the vendor detectors because of poor detection accuracy.

Table 12. Final Hypothesis Test Results, Day

Detector Configuration	*n*	Vehicle Detection *p* [95% confidence interval]	*z*	Detection and Length Classification *p* [95% confidence interval]	*z*
Speed	433	108.8% [n/a]*	-13.567	Not tallied	Not tallied
Combined	433	94.5% [91.9, 96.4]	1.638	Not tallied	Not tallied
Presence	433	86.8% [83.3, 89.9]	9.731	Not tallied	Not tallied
Author	433	97.7% [95.8, 98.9]	-1.795	91.7% [88.7, 94.1]	4.581

*Confidence interval for binomial variable could not be calculated for values greater than 100 percent.

Table 13. Final Hypothesis Test Results, Night

Detector Configuration	*n*	Vehicle Detection *p* [95% confidence interval]	*z*	Detection and Length Classification *p* [95% confidence interval]	*z*
Speed	268	136.6% [n/a]*	-33.890	Not tallied	Not tallied
Combined	268	91.0% [87.0, 94.2]	4.140	Not tallied	Not tallied
Presence	268	81.7% [76.6, 86.2]	11.933	Not tallied	Not tallied
Author	268	103.7% [n/a]*	-6.459	96.6% [93.7, 98.5]	-0.535

*Confidence interval for binomial variable could not be calculated for values greater than 100 percent.

3.4.2.2 Test 2.2 Availability and Reliability

Between March 2008 and July 2009, there were three instances when the SmartPark video system was not available three times. During the operational test, the system was down for approximately 24 hr in each case giving an overall availability of 99.4 percent. On two occasions, the computer in Charlton required a manual restart onsite. The authors were not able to determine the reason for these outages once the problem was detected. In routine operations, the outages would have been detected and corrected within several hours. Normally, if there is a power interruption, the computer restarts. A remote power controller would allow for computer restart without a visit to the site.

Although the computer was down during these incidents, the cameras continued to record and store entrance and exit events. Once the computer was restarted, the events were downloaded to the computer without loss of data. However, after any incident requiring a restart, it is advisable to view the parking facility and reset the vehicle parking count.

The third outage involved a loss of communication with the outbound camera. This problem was resolved by a manual reset of the power system on the pole of the outbound camera within 24 h of detection of the failure. Once powered down, the only way to reengage the power source is through manual intervention so correcting this problem required a trip to Charlton. This outage occurred in December 2008. A possible explanation is that inadequate sunlight led to the batteries having inadequate power for the camera and Ethernet radio. Under normal operations, this type of failure would be quickly detected and corrected. Manual reset of the parking facility count is advisable following this type of outage and restart.

With regard to reliability, the outbound camera developed a moisture leak approximately 14 months after it was installed.

3.4.3 Other Considerations

The experiences of this operational test identified a number of factors that contributed to the accuracy of the vehicle detection and length classification. In addition to those factors discussed, along with the presentation of the numerical results, the following are important considerations:

- *Vehicle length classification*—The camera is mounted at an angle to the roadway. If a low vehicle, such as a flat bed truck or car is behind a long truck or tractor trailer, the image processing software may fail to see the low vehicle. This is a limitation of image analysis. Mounting the camera further from the roadway will reduce this problem, but structural considerations limit the height of the pole and arm holding the camera.
- *Weather*—During initial testing, rain appeared to affect detector performance with the authors' algorithm. Rain on the night of July 8, 2009, did not appear to affect the test results. In fact, nighttime detections on July 8 with rain were better than those for the night of July 13 when there was no rain. Concluding that rain improved performance requires further testing. Unfortunately, there was not an opportunity to test detector performance in snow.
- *Traffic volume and detection accuracy*—At peak periods, the Charlton Service Center may have 60 or more vehicles per h entering the facility. The speed and spacing of the

vehicles, not necessarily the volume, affected the accuracy of the system. If vehicles are too close together, the system will see them as one long vehicle and hence undercount. During periods of high volume, traffic can back up on the ramp and cause vehicles to stop in the detector field of view. If the vehicle is stopped for more than 1 minute, the camera may add it to the image background and turn off the detector. When a truck moves, the detector can fire again depending on the type of detector. This situation can cause either a double vehicle count, if the detector simply covers an area or a missed count, if the detector is tripped by a vehicle entering and then crossing an area. The authors' algorithm is relatively immune to this problem since it uses multiple trip line detectors and a timing algorithm. If a truck stops for a few seconds, the primary effect is to increase the vehicle length, causing misclassification. The authors' algorithm attempted to address these issues by tracking the leading and trailing edges of the vehicle. This improved, but did not eliminate the problem.

- *Differences between inbound and outbound accuracy*—Several differences between the inbound and outbound locations may have contributed to the differences in accuracy:
  - The existing road geometry and service center layout constrained placement of the cameras. On the inbound roadway, it was possible to position the camera so that there was a view straight down the entrance roadway. The outbound roadway was more constrained. The camera had to be positioned to eliminate the nighttime light bloom from the fuel island, but the length and configuration of the roadway was such that the camera had to be angled further down toward the roadway than the vendor normally would recommend. In addition, the pole to mount the camera could not be positioned at the originally chosen location due to underground piping and excavation problems during installation.
  - Trucks frequently park on the island at the side of the exit roadway. Their movements sometimes caused the system to detect their parking as vehicles exiting the area.
  - The lighting near the inbound camera is different than the fueling area and exit roadway. This may have contributed to the differences in camera performance between the two locations.
- *Unique vehicle characteristics*—The initial tests identified specific vehicle characteristics that appeared to cause problems for the vehicle detection algorithm. These included silver tank trucks, flatbed trucks, and tractor-trailer configurations where the tractor and trailer were of different colors. The beta version of the software used in the final tests appeared to correct these problems.
- *Site considerations*—There were no instances of unauthorized tampering with the equipment in Charlton. The authors explained the project to the Massachusetts Turnpike (Interstate 90) staff at the Service Center information desk in the event that someone inquired, but this did not happen. The utility room where the computer was located proved to be a secure location.

4. DISCUSSION OF OPERATIONAL TEST RESULTS

Based on the final tests with the inbound camera, the authors suggest that the SmartPark video system met the performance requirement for vehicle detection during the day. One nighttime test showed excellent results, but the other did not meet the performance goal due to over-detection of vehicles. The authors' detection and length classification algorithm met the performance requirement at night while day performance was slightly below the desired level. The system operated continuously except for three instances that required a manual restart. A moisture leak on the outbound camera prevented conduct of the tests concerning the parking availability count. Table 14 provides a summary of the results of the final performance tests.

The operational test identified many operational considerations that should be included in any future truck parking management tests. These include the following:

- On a number of occasions, a car entered the truck parking area then turned around and exited via the entrance roadway.
- Although the Charlton facility is not marked, trucks park in locations that are not intended as parking areas. These include the grass strip between the truck parking area and the car parking area (near the entrance) and the grass strip to the left of the exit roadway.
- Trucks stop at the end of the truck parking area roadway before pulling into traffic.
- Two uncontrolled access points to the truck parking area could lead to inaccuracies in the facility occupancy count. One is from a restaurant's drive-through window at the rear of the service center building, and the other is a cut-through between the truck fueling area and the passenger vehicle fueling area. Cars enter the restaurant's drive-through and rather than making the 180-degree turn and going back through the car parking area, many cars exit through the truck parking area (there is a large sign directing vehicles back to the car parking area). The access to the truck parking area exists so that delivery vehicles servicing the concessionaires can make deliveries. The delivery vehicles do, in fact, exit via the truck side. Occasionally, small trucks cross over from the truck fueling area to the car fueling area.

In addition to the situations already discussed in Section 3, the image-processing algorithm did not properly handle a number of situations, including:

- The shadow of a large bird on a sunny day triggered the detectors.
- A person standing on the entrance roadway triggered the detectors.
- The flashing blue lights on a State police car triggered the detectors at night.

While these are relatively infrequent occurrences, they do cause false detections for the system which, in turn, could cause the vehicle counts to become inaccurate. In contrast, the authors' algorithm combined the data from multiple presence detectors and was not affected by either the bird's shadow or the person in the roadway. The flashing blue lights caused multiple detections with the vendor's speed detector on the night of June 23, 2009. The authors' detector algorithm was not part of that test so the effect of the flashing lights on the authors' detector algorithm is unknown.

Table 14 provides a summary of performance tests and results.

Table 14. Summary of Performance Tests

Performance Goal No.	Performance Requirement	Test No.	Variables	Criterion	Results
PG1	The system shall detect individual vehicles entering the parking area to an overall accuracy of better than 96%.	2.1	vehicle count ground truth	vehicle count/ground truth ≥ 96%	Day—97.7%—pass Night—103.7%—fail
PG2	The system shall classify individual vehicles entering the parking area to an overall accuracy of better than 96%.	2.1	vehicle count length classification ground truth	correct classifications/ ground truth ≥ 96%	Day—91.7%— fail Night–96.6% – pass
PG3	The system shall detect individual vehicles exiting the parking area to an overall accuracy of better than 96%.	2.1	vehicle count ground truth	vehicle count/ground truth ≥ 96%	Could not complete test due to outbound camera failure.
PG4	The system shall classify individual vehicles exiting the parking area to an overall accuracy of better than 96%.	2.1	vehicle count length classification ground truth	correct classifications/ ground truth ≥ 96%	Could not complete test due to outbound camera failure.
PG5	The system availability shall be at least 99%.	2.2	total system operation time elapsed time for each system outage	Up time/total time ≥ 99%	Pass—99.4%
PG6	The average downtime per system failure (MTTR) shall be less than 4 hr.	2.2	elapsed time for each system outage	average outage < 4 hr	Fail—average outage was 24 hr due to lack of constant monitoring and need to visit site.
PG7	The minimum time between required resets of vehicle counts shall be one week.	2.3			Test not conducted due to failure of outbound cameras and lack of exit counts.
PG8	The deviation between system-determined occupancy and actual occupancy between count resets shall not exceed 5% of the parking area capacity.	2.3			Test not conducted due to failure of outbound cameras and lack of exit counts.
PG9	When the lot is full, the system will falsely indicate that space is available not more than 2% of the time.	2.4			Test not conducted due to failure of outbound cameras and lack of exit counts.
PG10	When space is available, the system will falsely indicate that the lot is full not more than 2% of the time.	2.4			Test not conducted due to failure of outbound cameras and lack of exit counts.

[This page intentionally left blank.]

5. CONCLUSIONS AND RECOMMENDATIONS

The primary conclusion of this FOT is that a video vehicle detection system designed for traffic monitoring applications has potential for monitoring trucks entering and leaving a truck parking area, but the detection accuracy of the test system did not meet this requirements for the SmartPark video system application. The software and detector configurations used in this operational test did not achieve the desired 96 percent vehicle detection accuracy. The authors' approach, which uses a presence-detector configuration based on system capabilities and the authors' developed algorithm, performed better with regard to both vehicle detection and length classification, and achieved the performance goal in most, but not all tests. This approach shows promise, but improvements in the image processing algorithms of the system are required to improve the performance of the authors' method. Based on discussions with the vendor, the authors believe these improvements are possible and should be pursued.

The FOT experience provided validation of the system configuration. In particular, the test illustrated that it is possible to configure and operate a traffic monitoring system with solar power. The FOT also demonstrated the feasibility of wireless transmission of video images and data via Ethernet radios, which are capable of data transmission by line of sight to a central computer.

The authors' system included secure remote access to the test site. The authors were able to make changes to the detector configurations, upgrade software, run tests, capture still images, and download video and data from tests—all without visiting the site. The only limitation of this was that it was not possible to view video in real-time, but a higher bandwidth data line would provide this capability. These results indicate that installation and operation of this system within a traffic operations center is practical and feasible.

[This page intentionally left blank.]

APPENDIX A—SMARTPARK REQUIREMENTS

This appendix lists the requirements for the Phase I SmartPark video system and contains the traceability matrix that maps the performance requirements to the various functional and performance tests.

Functional Requirements

FR1 The system shall automatically and autonomously detect individual vehicles entering the parking area within 5 seconds of vehicle entry.

FR2 The system shall automatically and autonomously classify all vehicles detected entering the parking area by length using the following categories:

- ≤ 23 feet: Car
- > 23 feet and ≤ 40 feet: Single Unit
- > 40 feet and ≤ 70 feet: Tractor-trailer
- > 70 feet and ≤100 feet: Double
- > 100 feet: Triple

FR3 The system shall automatically and autonomously detect individual vehicles exiting the parking area within 5 seconds of vehicle exit.

FR4 The system shall automatically and autonomously classify all vehicles detected exiting the parking area using the following categories:

- ≤ 23 feet: Car
- > 23 feet and ≤ 40 feet: Single Unit
- > 40 feet and ≤ 70 feet: Tractor-trailer
- > 70 feet and ≤100 feet: Double
- > 100 feet: Triple

FR5 The system shall automatically and autonomously maintain a count of the number of vehicles in the parking area by vehicle length category.

FR6 The system shall allow authorized users to view the count of the number of vehicles in the parking area by vehicle length category from remote locations.

FR7 The system shall provide a means for authorized users to remotely view the parking area to determine the current number of vehicles in the parking area by vehicle length category.

FR8 The system shall allow authorized users to reset the number of vehicles in the parking area by vehicle length category.

FR9 The system shall maintain a log of vehicle entrance and exit events.

FR10 The system shall maintain a log of all automatically detected system errors.

FR11 The system shall maintain a log of all manual adjustments to the vehicle counts.

FR12 The system shall allow authorized users to create and maintain a list of authorized users.

FR13 The system shall maintain counts of each type of vehicle currently in the parking area.

FR14 The system shall allow users to display the system count of parking available in the facility.

FR15 The system shall record when the number of vehicles in the parking area exceeds the parking area capacity.

FR16 The system shall record when an exit event occurs when the system indicates that no vehicles are in lot.

FR17 The system shall allow authorized users to remotely view and download all system event and error logs.

Performance Goals

PG1 The system shall detect individual vehicles entering the parking area to an overall accuracy of at least 96 percent.

PG2 The system shall classify individual vehicles entering the parking area to an overall accuracy of at least 96 percent.

PG3 The system shall detect individual vehicles exiting the parking area to an overall accuracy of at least 96 percent.

PG4 The system shall classify individual vehicles exiting the parking area to an overall accuracy of at least 96 percent.

PG5 The system availability shall be at least 99 percent.

PG6 The average downtime per system failure (mean time to repair) shall be less than 4 h.

PG7 The minimum time between required resets of vehicle counts shall be one week.

PG8 The deviation between system-determined occupancy and actual occupancy between count resets shall not exceed 5 percent of the parking area capacity.

PG9 When the lot is full, the system will falsely indicate that space is available not more than 2 percent of the time.

PG10 When space is available, the system will falsely indicate that the lot is full not more than 2 percent of the time.

Interface Requirements

IR1 The user interface to the system data shall be via a secure Web site.

IR2 The user interface to the views of the parking area shall be via secure Web access.

Data Requirements

DR1 The system shall record the following data for each vehicle detected entering the parking area:

- Date
- Time
- Event type (Vehicle entrance)
- Vehicle length category

DR2 The system shall record the following data for each vehicle detected exiting the parking area:

- Date
- Time
- Event type (Vehicle exit)
- Vehicle length category

DR3 The system shall record the following data when an authorized user resets the count of vehicles in the parking area for a vehicle category:

- Date
- Time
- Event type (Count reset)
- User name
- Vehicle length category
- Previous count
- New count

DR4 The system shall record the following data when a vehicle is detected entering the parking area and the system vehicle count indicates that the lot is at or exceeds lot capacity:

Date
Time
Event type (Lot occupancy exceeds capacity)
Number of vehicles in the parking area for each vehicle category

DR5 The system shall record the following data when a vehicle is detected exiting the parking area and the system vehicle indicates that the lot is empty:

Date
Time
Event type (Vehicle exit detected when lot is empty)
Vehicle length category

Non-Functional Requirements

NR1 The system shall operate autonomously 24 hr per day, 7 days per week.
NR2 The system shall operate in rain, snow, and fog.
NR3 The system shall operate between -34 degrees C and 60 degrees C.
NR4 The system shall operate during wind speeds from 0 to 40 mi/h.
NR5 The system shall operate in natural and artificial lighting conditions.

Enabling Requirements

ER1 The system shall be designed, developed, and installed following Foster-Miller's ISO-9000 quality procedures.

Constraints

C1 The system shall conform to Central Massachusetts Regional ITS Architecture.
C2 The system shall detect vehicles traveling between 10 and 40 mi/h.
C3 The system shall detect vehicles separated by a minimum of 2 s.

Table 15. Traceability Matrix for Tests

Requirement	1.1	1.2	1.3	1.4	1.5	1.6	1.7	2.1	2.2	2.3	2.4
FR1	X										
FR2	X										
FR3	X										
FR4	X										
FR5		X									
FR6		X									
FR7		X									
FR8		X									
FR9			X								
FR10			X								
FR11			X								
FR12				X							
FR13		X									
FR14		X									
FR15			X								

Requirement	1.1	1.2	1.3	1.4	1.5	1.6	1.7	2.1	2.2	2.3	2.4
FR16			X								
FR17				X							
PG1								X			
PG2								X			
PG3								X			
PG4								X			
PG5									X		
PG6									X		
PG7										X	
PG8										X	
PG9											X
PG10											X
IR1		X		X							
IR2		X		X							
DR1	X										
DR2	X										
DR3		X	X								
DR4			X								
DR5			X								
NR1						X					
NR2						X					
NR3						X					
NR4						X					
NR5						X					
ER1					X						
CR1							X				
CR2							X				
CR3							X				

APPENDIX B—DATA FROM INITIAL PERFORMANCE TESTS

The following definitions apply to the tables in this appendix:

detected—number of vehicles reported by the detector system. If the table includes detections by type of vehicle (Cars, Trucks, Tractor-Trailers), “Detected” will equal the sum of the detections by type.

false detection—artifacts detected by the system but not in the ground truth data.

ground truth—number of vehicles observed on ground truth video.

lower/upper CI—95 percent confidence interval for number of vehicles detected.

misclassification—number of vehicles incorrectly classified by length. Note: Number of misclassifications will not equal the sum of the differences between FM Detector and Actual because FM Detector includes false detections and multiple counts.

multiple count sum—total number of repeated detections of vehicles. Note: If all multiple count occurrences were double counts then multiple count sums will equal number of multiple counts. If vehicle was counted three times, then it will be included as “2” in the multiple count sum.

number of missed vehicles—number of vehicles in ground truth data, but not detected by the system.

number of multiple counts—number of vehicles detected more than once by the system.

p—number of vehicles detected divided by ground truth.

vehicles correctly detected and classified—number of vehicles that were accurately detected and properly classified by length.

z—value of z-statistic.

07/03/2008 Inbound Day Summary

	Total Vehicles Detected									Vehicles Correctly Detected and Classified				
	False Detections	# of Missed Vehicles	# of Multiple Counts	Multiple Count Sum	Detected	p	Lower CI	Upper CI	z	Detected	p	Lower CI	Upper CI	z
Speed (S) Detector	Not Tallied				Not Tallied					Not Tallied				
Combined (PRS) Detector														
Presence (RR) Detector														
FM Detector	1	2	0	0	158	0.994	0.965	1.000	-2.169	152	0.956	0.911	0.982	0.259

Ground Truth (N)	159

	Cars	Trucks	Tractor-Trailers	# of Misclassifications
FM Detector	12	46	100	5
Actual	13	42	104	N/A

Weather Conditions: Clear then Partly Cloudy, 9 mi. Visibility

Comments:

07/21/2008 Inbound Day Summary

	Total Vehicles Detected									Vehicles Correctly Detected and Classified				
	False Detections	# of Missed Vehicles	# of Multiple Counts	Multiple Count Sum	Detected	p	Lower CI	Upper CI	z	Detected	p	Lower CI	Upper CI	z
Speed (S) Detector	Not Tallied				Not Tallied					Not Tallied				
Combined (PRS) Detector														
Presence (RR) Detector														
FM Detector	0	5	0	0	206	0.976	0.946	0.992	-1.209	200	0.948	0.909	0.974	0.899

Ground Truth (N)	211

	Cars	Trucks	Tractor-Trailers	# of Misclassifications
FM Detector	13	46	147	6
Actual	10	43	160	N/A

Weather Conditions: Cloudy, 6 mi. Visibility

Comments: Traffic slowed on ramp causing numerous misclassifications and missed vehicles.

07/22/2008 Inbound Day Summary

	Total Vehicles Detected									Vehicles Correctly Detected and Classified				
	False Detections	# of Missed Vehicles	# of Multiple Counts	Multiple Count Sum	Detected	p	Lower CI	Upper CI	z	Detected	p	Lower CI	Upper CI	z
Speed (S) Detector	Not Tallied				Not Tallied					Not Tallied				
Combined (PRS) Detector														
Presence (RR) Detector														
FM Detector	0	2	0	0	139	0.986	0.950	0.998	-1.564	136	0.965	0.919	0.988	-0.275

Ground Truth (N)	141

	Cars	Trucks	Tractor-Trailers	# of Misclassifications
FM Detector	4	35	100	3
Actual	5	37	99	N/A

Weather Conditions: Overcast, 7 mi. Visibility

Comments:

07/24/2008 Inbound Day Summary

	Total Vehicles Detected									Vehicles Correctly Detected and Classified				
	False Detections	# of Missed Vehicles	# of Multiple Counts	Multiple Count Sum	Detected	p	Lower CI	Upper CI	z	Detected	p	Lower CI	Upper CI	z
Speed (S) Detector	Not Tallied				Not Tallied					Not Tallied				
Combined (PRS) Detector														
Presence (RR) Detector														
FM Detector	3	5	0	0	290	0.993	0.975	0.999	-2.891	252	0.863	0.818	0.900	8.457

Ground Truth (N)	292

	Cars	Trucks	Tractor-Trailers	# of Misclassifications
FM Detector	21	93	176	35
Actual	19	62	211	N/A

Weather Conditions: Overcast and Light Rain (.02 in.), 2 mi. Visibility

Comments:

07/03/2008 Outbound Day Summary

	Total Vehicles Detected									Vehicles Correctly Detected and Classified				
	False Detections	# of Missed Vehicles	# of Multiple Counts	Multiple Count Sum	Detected	p	Lower CI	Upper CI	z	Detected	p	Lower CI	Upper CI	z
Speed (S) Detector	Not Tallied				Not Tallied					Not Tallied				
Combined (PRS) Detector														
Presence (RR) Detector														
FM Detector	1	3	0	0	203	0.990	0.965	0.999	-2.210	194	0.946	0.906	0.973	0.998

Ground Truth (N)	205

	Cars	Trucks	Tractor-Trailers	# of Misclassifications
FM Detector	69	34	100	8
Actual	67	34	104	N/A

Weather Conditions: Clear then Partly Cloudy, 9 mi. Visibility

Comments:

07/21/2008 Outbound Day Summary

	Total Vehicles Detected									Vehicles Correctly Detected and Classified				
	False Detections	# of Missed Vehicles	# of Multiple Counts	Multiple Count Sum	Detected	p	Lower CI	Upper CI	z	Detected	p	Lower CI	Upper CI	z
Speed (S) Detector	Not Tallied				Not Tallied					Not Tallied				
Combined (PRS) Detector														
Presence (RR) Detector														
FM Detector	2	0	0	0	255	1.008	N/A		-3.888	238	0.941	0.904	0.966	1.566
Ground Truth (N)					253									

	Cars	Trucks	Tractor-Trailers	# of Misclassifications
FM Detector	57	33	165	15
Actual	53	23	177	N/A

Weather Conditions: Cloudy, 6 mi. Visibility

Comments: Car reversing down ramp counted as tractor-trailer. Black trailer confused detector. One truck took turn wide and was able to drive around some detectors and was misclassified.

07/22/2008 Outbound Day Summary

	Total Vehicles Detected									Vehicles Correctly Detected and Classified				
	False Detections	# of Missed Vehicles	# of Multiple Counts	Multiple Count Sum	Detected	p	Lower CI	Upper CI	z	Detected	p	Lower CI	Upper CI	z
Speed (S) Detector	Not Tallied				Not Tallied					Not Tallied				
Combined (PRS) Detector														
Presence (RR) Detector														
FM Detector	1	1	1	1	157	1.006	N/A		-2.958	142	0.910	0.854	0.950	3.171

Ground Truth (N)	156

	Cars	Trucks	Tractor-Trailers	# of Misclassifications
FM Detector	24	44	89	13
Actual	21	34	101	N/A

Weather Conditions: Overcast, 7 mi. Visibility

Comments:

07/24/2008 Outbound Day Summary

	Total Vehicles Detected									Vehicles Correctly Detected and Classified				
	False Detections	# of Missed Vehicles	# of Multiple Counts	Multiple Count Sum	Detected	p	Lower CI	Upper CI	z	Detected	p	Lower CI	Upper CI	z
Speed (S) Detector	Not Tallied				Not Tallied					Not Tallied				
Combined (PRS) Detector														
Presence (RR) Detector														
FM Detector	3	11	0	0	386	0.980	0.960	0.991	-1.995	317	0.805	0.762	0.843	15.744

Ground Truth (N)	394

	Cars	Trucks	Tractor-Trailers	# of Misclassifications
FM Detector	113	116	157	66
Actual	113	33	248	N/A

Weather Conditions: Overcast and Light Rain (.02 in.), 2 mi. Visibility
Comments:

07/22/2008 - 07/23/2008 Inbound Night Summary

	Total Vehicles Detected									Vehicles Correctly Detected and Classified				
	False Detections	# of Missed Vehicles	# of Multiple Counts	Multiple Count Sum	Detected	p	Lower CI	Upper CI	z	Detected	p	Lower CI	Upper CI	z
Speed (S) Detector	Not Tallied				Not Tallied					Not Tallied				
Combined (PRS) Detector														
Presence (RR) Detector														
FM Detector	17	0	0	0	55	1.447	N/A		-15.331	21	0.553	0.383	0.714	12.815

Ground Truth (N)	38

	Cars	Trucks	Tractor-Trailers	# of Misclassifications
FM Detector	23	17	15	17
Actual	2	4	32	N/A

Weather Conditions: Rain and Thunderstorms (0.95 in.), 7 mi. Visibility

Comments:

07/22/2008 - 07/23/2008 Outbound Night Summary

	Total Vehicles Detected									Vehicles Correctly Detected and Classified				
	False Detections	# of Missed Vehicles	# of Multiple Counts	Multiple Count Sum	Detected	p	Lower CI	Upper CI	z	Detected	p	Lower CI	Upper CI	z
Speed (S) Detector	Not Tallied				Not Tallied					Not Tallied				
Combined (PRS) Detector														
Presence (RR) Detector														
FM Detector	18	0	0	0	54	1.500	N/A		-16.534	10	0.278	0.142	0.452	20.889

Ground Truth (N)	36

	Cars	Trucks	Tractor-Trailers	# of Misclassifications
FM Detector	38	10	6	26
Actual	6	3	27	N/A

Weather Conditions: Rain and Thunderstorms (0.95 in.), 7 mi. Visibility

Comments:

07/03/2008, 07/21/2008, 07/22/2008 Inbound Day Summary

	Total Vehicles Detected									Vehicles Correctly Detected and Classified				
	False Detections	# of Missed Vehicles	# of Multiple Counts	Multiple Count Sum	Detected	p	Lower CI	Upper CI	z	Detected	p	Lower CI	Upper CI	z
Speed (S) Detector	Not Tallied				Not Tallied					Not Tallied				
Combined (PRS) Detector														
Presence (RR) Detector														
FM Detector	1	9	0	0	503	0.984	0.969	0.993	-2.808	488	0.955	0.933	0.971	0.578

Ground Truth (N)	511

	Cars	Trucks	Tractor-Trailers	# of Misclassifications
FM Detector	29	127	347	14
Actual	28	122	363	N/A

Weather Conditions: N/A
Comments:

07/03/2008, 07/21/2008, 07/22/2008 Outbound Day Summary

	Total Vehicles Detected									Vehicles Correctly Detected and Classified				
	False Detections	# of Missed Vehicles	# of Multiple Counts	Multiple Count Sum	Detected	p	Lower CI	Upper CI	z	Detected	p	Lower CI	Upper CI	z
Speed (S) Detector	Not Tallied				Not Tallied					Not Tallied				
Combined (PRS) Detector														
Presence (RR) Detector														
FM Detector	4	4	1	1	615	1.002	N/A		-5.264	574	0.935	0.912	0.953	3.180

Ground Truth (N)	614

	Cars	Trucks	Tractor-Trailers	# of Misclassifications
FM Detector	171	111	354	36
Actual	120	91	382	N/A

Weather Conditions: N/A
Comments:

[This page intentionally left blank.]

APPENDIX C—DATA FROM FINAL PERFORMANCE TESTS

The following definitions apply to the tables in this appendix:

***detected*—**number of vehicles reported by the detector system. If the table includes detections by type of vehicle (Cars, Trucks, Tractor-Trailers), "Detected" will equal the sum of the detections by type.

***false detection*—**artifacts detected by the system but not in the ground truth data.

***ground truth*—**number of vehicles observed on ground truth video.

***lower/upper CI*—**95 percent confidence interval for number of vehicles detected.

***misclassification*—**number of vehicles incorrectly classified by length. Note: Number of misclassifications will not equal the sum of the differences between FM Detector and Actual because FM Detector includes false detections and multiple counts.

***multiple count sum*—**total number of repeated detections of vehicles. Note: If all multiple count occurrences were double counts then multiple count sums would equal number of multiple counts. If vehicle was counted three times, then it will be included as "2" in the multiple count sum.

***number of missed vehicle*—**number of vehicles in ground truth data but not detected by the system.

***number of multiple counts*—**number of vehicles detected more than once by the system.

***p*—**number of vehicles detected divided by ground truth.

***vehicles correctly detected*—**number of vehicles that were accurately detected.

***vehicles correctly detected and classified*—** number of vehicles that were accurately detected and properly classified by length.

***z*—**value of Z-statistic.

06/19/2009 Inbound Day Summary

	Total Vehicles Detected									Vehicles Correctly Detected and Classified				
	False Detection	# of Missed Vehicles	# of Multiple Counts	Multiple Count Sum	Detected	p	Lower CI	Upper CI	Z	Detected	p	Lower CI	Upper CI	Z
Speed (S) Detector	0	2	1	1	267	0.996	0.979	1.000	-3.030	Not Tallied				
Combined (PRS) Detector	0	44	0	0	224	0.836	0.786	0.878	10.374					
Presence (RR) Detector	0	69	0	0	199	0.743	0.686	0.794	18.167					
FM Detector	Not Tallied				Not Tallied					Not Tallied				

Ground Truth	268

	Cars	Trucks	Tractor-Trailers	# of Misclassifications
FM Detector	Not Tallied			Not Tallied
Actual	Not Tallied			N/A

Weather Conditions: Fog, Overcast with Light Rain, (0.21 in.), 6 mi. Visibility

Comments:

05/29/2009 - 05/30/2009 Inbound Night Summary

	Total Vehicles Detected									Vehicles Correctly Detected and Classified				
	False Detection	# of Missed Vehicles	# of Multiple Counts	Multiple Count Sum	Detected	p	Lower CI	Upper CI	Z	Detected	p	Lower CI	Upper CI	Z
Speed (S) Detector	0	0	35	78	150	1.402	N/A		-23.325	Not Tallied				
Combined (PRS) Detector	0	10	0	0	94	0.879	0.801	0.934	4.302					
Presence (RR) Detector	0	13	0	0	97	0.907	0.835	0.954	2.822					
FM Detector	Not Tallied				Not Tallied					Not Tallied				

Ground Truth (N)				107

	Cars	Trucks	Tractor-Trailers	# of Misclassifications
FM Detector	Not Tallied			Not Tallied
Actual	Not Tallied			N/A

Weather Conditions: Dark, Clear Night

Comments:

06/23/2009 - 06/24/2009 Inbound Night Summary

	Total Vehicles Detected									Vehicles Correctly Detected and Classified				
	False Detection	# of Missed Vehicles	# of Multiple Counts	Multiple Count Sum	Detected	p	Lower CI	Upper CI	Z	Detected	p	Lower CI	Upper CI	Z
Speed (S) Detector	1	0	56	68	216	1.469	N/A		-31.517	Not Tallied				
Combined (PRS) Detector	0	13	0	0	134	0.912	0.854	0.952	2.997					
Presence (RR) Detector	0	17	0	0	130	0.884	0.821	0.931	4.680					
FM Detector	Not Tallied				Not Tallied					Not Tallied				
Ground Truth					147									

	Cars	Trucks	Tractor-Trailers	# of Misclassifications
FM Detector	Not Tallied			Not Tallied
Actual	Not Tallied			N/A

Weather Conditions: Overcast and Light Rain, (0.01 in.), 9 mi. Visibility

Comments: Police Car enters and exits through inbound ramp numerous times, creating many erroneous counts.

07/14/2009 Inbound Day Summary

	Total Vehicles Detected									Vehicles Correctly Detected and Classified				
	False Detection	# of Missed Vehicles	# of Multiple Counts	Multiple Count Sum	Detected	p	Lower CI	Upper CI	Z	Detected	p	Lower CI	Upper CI	Z
Speed (S) Detector	Not Tallied				309	1.088	N/A		-11.010	Not Tallied				
Combined (PRS) Detector					271	0.954	0.923	0.975	0.497					
Presence (RR) Detector					244	0.859	0.813	0.897	8.673					
FM Method	6	9	0	0	281	0.989	0.969	0.998	-2.532	267	0.940	0.906	0.965	1.708

Ground Truth	284

	Cars	Trucks	Tractor-Trailers	# of Misclassifications
FM Detector	8	37	236	8
Actual	10	33	241	N/A

Weather Conditions: Clear in morning, Overcast afternoon to night, 10 mi. Visibility

Comments:

07/15/2009 Inbound Day Summary

	Total Vehicles Detected									Vehicles Correctly Detected and Classified				
	False Detections	# of Missed Vehicles	# of Multiple Counts	Multiple Count Sum	Detected	p	Lower CI	Upper CI	z	Detected	p	Lower CI	Upper CI	z
Speed (S) Detector	Not Tallied				162	1.087	N/A		-7.926	Not Tallied				
Combined (PRS) Detector					138	0.926	0.872	0.963	2.107					
Presence (RR) Detector					132	0.886	0.824	0.932	4.615					
FM Detector	1	11	3	3	142	0.953	0.906	0.981	0.435	130	0.872	0.808	0.921	5.452

Ground Truth (N)	149

	Cars	Trucks	Tractor-Trailers	# of Misclassifications
FM Detector	7	17	118	8
Actual	2	14	133	N/A

Weather Conditions: Clear and Sunny, 10 mi. Visibility

Comments: The bright light sometimes washed out the trailers and resulted in the multiple counts and misclassifications.

07/08/2009-07/09/2009 Inbound Night Summary

	Total Vehicles Detected									Vehicles Correctly Detected and Classified				
	False Detection	# of Missed Vehicles	# of Multiple Counts	Multiple Count Sum	Detected	p	Lower CI	Upper CI	Z	Detected	p	Lower CI	Upper CI	Z
Speed (S) Detector	0	5	33	79	197	1.263	N/A		-19.301	Not Tallied				
Combined (PRS) Detector	0	22	4	8	138	0.885	0.824	0.930	4.805					
Presence (RR) Detector	0	37	4	8	123	0.788	0.716	0.850	10.933					
FM Detector	0	1	0	0	155	0.994	0.965	1.000	-2.141	155	0.994	0.965	1.000	-2.141

Ground Truth (N)	156

	Cars	Trucks	Tractor-Trailers	# of Misclassifications
FM Detector	5	14	136	0
Ground Truth	6	14	136	N/A

Weather Conditions: Overcast with Light Rain (0.07 in.), 8 mi. Visibility
Comments:

07/13/2009 - 07/14/2009 Inbound Night Summary

	Total Vehicles Detected									Vehicles Correctly Detected and Classified				
	False Detection	# of Missed Vehicles	# of Multiple Counts	Multiple Count Sum	Detected	p	Lower CI	Upper CI	Z	Detected	p	Lower CI	Upper CI	Z
Speed (S) Detector	Not Tallied				169	1.509	N/A		-29.646	Not Tallied				
Combined (PRS) Detector					106	0.946	0.887	0.980	0.733					
Presence (RR) Detector					96	0.857	0.778	0.916	5.555					
FM Detector	0	5	15	16	123	1.098	N/A		-7.464	104	0.929	0.864	0.969	1.697

Ground Truth (N)	112

	Cars	Trucks	Tractor-Trailers	# of Misclassifications
FM Detector	11	5	107	3
Actual	4	4	104	N/A

Weather Conditions: Clear to Overcast Night, Dark, 10 mi. Visibility

Comments:

07/14/2009, 07/15/2009 Inbound Day Summary

	Total Vehicles Detected									Vehicles Correctly Detected and Classified				
	False Detections	# of Missed Vehicles	# of Multiple Counts	Multiple Count Sum	Detected	p	Lower CI	Upper CI	Z	Detected	p	Lower CI	Upper CI	Z
Speed (S) Detector	Not Tallied				471	1.088	N/A		-13.567	Not Tallied				
Combined (PRS) Detector					409	0.945	0.919	0.964	1.638					
Presence (RR) Detector					376	0.868	0.833	0.899	9.731					
FM Detector	7	20	3	3	423	0.977	0.958	0.989	-1.795	397	0.917	0.887	0.941	4.581
Ground Truth (N)					433									

	Cars	Trucks	Tractor-Trailers	# of Misclassifications
FM Detector	15	54	354	16
Actual	12	47	374	N/A

Weather Conditions: N/A

Comments:

07/08/2009, 07/13/2009 Inbound Night Summary

	Total Vehicles Detected									Vehicles Correctly Detected and Classified				
	False Detections	# of Missed Vehicles	# of Multiple Counts	Multiple Count Sum	Detected	p	Lower CI	Upper CI	Z	Detected	p	Lower CI	Upper CI	Z
Speed (S) Detector	Not Tallied				366	1.366	N/A		-33.890	Not Tallied				
Combined (PRS) Detector					244	0.910	0.870	0.942	4.140					
Presence (RR) Detector					219	0.817	0.766	0.862	11.933					
FM Detector	0	6	15	16	278	1.037	N/A		-6.459	259	0.966	0.937	0.985	-0.536

Ground Truth (N)	268

	Cars	Trucks	Tractor-Trailers	# of Misclassifications
FM Detector	16	19	243	3
Actual	10	18	240	N/A

Weather Conditions: N/A
Comments:

REFERENCES

1. *SmartPark Concept of Operations*, DGOV080019.COO rev 2, August 9, 2007.
2. *SmartPark Performance Requirements*, DGOV080019.PRD Rev 2, August 9, 2007.
3. ISO. (2005) Quality management systems—Fundamentals and vocabulary (ISO 9000). Geneva, Switzerland; International Organization for Standardization.
4. *SmartPark Field Operations Test Plan*, DGOV080019.FTP Rev 2, May 7, 2008.
5. *SmartPark Evaluation Plan,* DGOV080019.EVP Rev 1, August 3, 2007.
6. IBI Group. (2005). *Regional ITS Architecture for Central Massachusetts Final Report.* Accessed online on February 23, 2010: http://www.eot.state.ma.us/regionalitsarchitecture/centralmass/web/files/projectdocs/Central_Implementation_Plan.pdf