Final Report

Contract No. BDV29-977-30

Feasibility of Using Video Image Detectors for Ramp Signal Operations and Performance Monitoring

Prepared for:

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METRIC CONVERSION CHART

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
in	inches	25.400	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.610	kilometers	km
mm	millimeters	0.039	inches	in
m	meters	3.280	feet	ft
m	meters	1.090	yards	yd
km	kilometers	0.621	miles	mi
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
		AREA		
in^2	square inches	645.200	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.590	square kilometers	km^2
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.470	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
		VOLUME		
fl oz	fluid ounces	29.570	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
NOTE: volumes greater than 1,000 L shall be shown in m^3.				

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Mr. Javier Rodriguez, P.E., FDOT District 6, and Ms. Elizabeth Birriel, P.E., PTOE, formerly of FDOT Central Office, served as the Project Managers for this project.

16. Abstract

District 6 Florida Department of Transportation (FDOT) has been using both inductive loops and Sensys Networks sensors at its 22 ramp signals on I-95 in Miami-Dade County, Florida. These detectors are used to detect vehicle volumes and occupancy, but do not collect traffic measures such as queue length and waiting time, which are desired for performance monitoring of ramp signals. This project investigated the feasibility of using a video detection system for not only ramp signal operations but also performance monitoring. The project also developed a Web-based system for visualizing performance data to assist in the performance monitoring and analysis.

A three-step study was conducted to attempt to identify a feasible video detection system: (1) identify and select three existing video detection systems for field evaluation at an actual ramp signal location; (2) conduct a field evaluation of the selected systems to determine their detection capabilities and accuracies; and (3) identify a final system based on the results from the field evaluation and other considerations including compatibility with the *SunGuide* software, and deployment and maintenance requirements and associated costs. Three video detection systems from FLIR, GRIDSMART, and ITERIS, respectively, were field tested. It was found that the system from FLIR produced the most positive results. The FLIR system was further evaluated for its ease of integration with the *SunGuide* software and its deployment and maintenance requirements and costs. A pilot test was subsequently conducted by FDOT (outside the scope of this project) to ensure that the FLIR system could be integrated with the *SunGuide* system and could replace the current ramp signal loop detectors for ramp signal operations.

After the pilot test provided positive results, the project proceeded to develop a Web-based system for visualizing *SunGuide* detector data for the purpose of performance monitoring and analysis. The system is able to dynamically aggregate and display detector data on a chart. The system can also display the nearby traffic incidents that occurred within the selected time periods and days. As the detector data structures in the *SunGuide* database are standardized across all detectors throughout the state, the system is applicable to all detectors in all FDOT districts.

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We are thankful to the participants in our field tests. We specifically would like to thank the following individuals for participating in the field tests and/or providing product information:

- Ms. Connie Braithwaite, Econolite
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- Mr. Pete Ganci, Control Technologies
- Mr. John Gaskins, Transportation Control Systems, Inc.
- Mr. Bryan Kaeser, Control Technologies
- Mr. Irv Rosenblum, Citilog, Inc.
- Mr. Jeremy Short, ITERIS
- Mr. Stokes Wallace, ITERIS

EXECUTIVE SUMMARY

Project Objectives

District 6 Florida Department of Transportation (FDOT) has been using a mix of inductive loops and Sensys Networks sensors at its 22 ramp signals on I-95 in Miami-Dade County, Florida. These detectors can detect both vehicle passages and presence, but are not designed to collect traffic measures such as queue length and delay (or travel time), which are needed for monitoring the performance of ramp signals. This project investigated the feasibility of using a video detection system in lieu of the current detectors for both ramp signal operations and performance monitoring. The project also developed a Web-based system for visualizing performance data to assist in the tasks of performance monitoring. As the detector data structures in the *SunGuide* database are standardized across all detectors throughout the state, the system is applicable to all detectors in all FDOT districts.

Identification of Video Detection Systems for Field Accuracy Tests

The very first task of the project involved the identification of the existing video detection systems for field accuracy tests. A survey involving a set of 18 questions was posted to five potential vendors. The questions were aimed at obtaining preliminary information on the system's general capabilities to help select three potential systems to participate in the field tests. Also included are questions on licensing costs, technical support, and field evaluation requirements. However, this information was not used to select the systems for field tests. Based on a review of the vendor responses to the survey questions, the following three vendors and their products were first invited to participate in the field tests:

- Autoscope Terra Technology from Econolite
- TrafiSense from FLIR ITS
- GridSmart System from GRIDSMART, Inc.

Development of Field Test Plan

A detailed field test plan was developed and shared with the three invited vendors. The test plan provided details on the tests, including the project background, test objective, responsible agencies and contacts, target test data, test location and test period, data evaluation method, review of test results by participants, travel support for participants, and publication requirements. After reviewing the test plan, one vendor (Econolite) decided to not participate in the test. The vendor indicated that they had a new product that was to be released soon, but was not ready for this field test. After consultation with the FDOT project managers, a new invitation was extended to ITERIS and was accepted.

Conduct of Field Tests and Evaluation of Test Results

Three field tests were conducted, one for each of the three participating vendors on the following dates:

- March 2, 2017 (Thursday): GRIDSMART Technologies
- March 6, 2017 (Monday): ITERIS
- March 8, 2017 (Wednesday): FLIR ITS

After the field tests were completed, GRIDSMART and ITERIS provided only their vehicle count data for evaluation. FLIR provided the most complete data, which included vehicle counts, vehicle occupancies, and average and maximum vehicle queue lengths. The overall detection accuracy test results based on the Mean Absolute Percentage Error (MAPE) with 5-minute data interval are summarized in the table below:

Performance Measures	Vendor	MAPE		
		Day	Night	Day and Night
Vehicle Counts	GRIDSMART	10.5%	13.5%	11.6%
	ITERIS	5.1%	44.0%	19.7%
	FLIR	3.3%	4.6%	3.7%
Vehicle Occupancy (without/with detector size adjustment)	FLIR	Not used[a]		13.3% / 5.9%
Average Vehicle Queue Length (feet)	FLIR	Not used[a]		24.2% - 31.4%[b]
Maximum Vehicle Queue Length (feet)	FLIR	Not used[a]		6.2% - 8.4%[b]

[a] Reason: no noticeable difference in the results between daytime and nighttime periods.
[b] For different scenario settings.

The following conclusions were made from the above test results:

- The FLIR video detection system gave the most accurate vehicle counts among the three systems tested, achieving a low overall MAPE of 3.7%.
- The FLIR system detected vehicle occupancy data that closely matched the loop detector data from the *SunGuide* database. With adjustments for the difference in detector size, the system achieved a low MAPE of 5.9%.
- The FLIR system was able to measure average vehicle queue lengths that matched well with those estimated from manual measurement.
- The FLIR system similarly provided good estimates of the maximum vehicle queue lengths.
- The FLIR system performed equally well under both daytime and nighttime conditions.
- The FLIR system demonstrated that it could combine data from multiple cameras, in this application, for vehicle queues that are longer than what one camera can cover.

System Evaluation and Recommendation

After the field tests, the systems were to be further evaluated for selection criteria beyond their field detection accuracy. Given the one-sided results from the field tests, only the FLIR system was included this evaluation. The evaluation provided information on the ramp signal application needs and the FLIR system's capabilities to detect and estimate traffic measures, methods for integrating with the *SunGuide* software, preliminary estimation of system deployment costs, and maintenance requirements and associated costs.

Development of Data Visualization System

A Web-based system was developed for visualizing *SunGuide* detector data for the purpose of performance monitoring. The system is able to dynamically aggregate and display detector data on a chart. The system can also display the ramp signal period (for ramp signal detectors) and nearby traffic incidents that occurred within the selected time periods and days. The system makes use of the following *SunGuide* data sets: (1) performance measures including those from the detectors and the ramp queues (when the data become available), (2) ramp signal operations status, (3) traffic incidents, and (4) ITS device locations. As noted previously, the system is generally applicable to all FDOT districts, as the *SunGuide* database structure is standardized across all detectors and the entire state.

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LIST OF ACRONYMS AND ABBREVIATIONS

API	Application Programming Interface
APL	Approved Product List
FIU	Florida International University
FDOT	Florida Department of Transportation
JPEG	Joint Photographic Experts Group
MAPE	Mean Absolute Percentage Error
MOT	Maintenance of Traffic
PDF	Portable Document Format
RMS	Ramp Metering Signal
SwRI	Southwest Research Institute
TIFF	Tagged Image File Format
TMC	Traffic Management Center
TRIS	Transportation Research Information

CHAPTER 1
INTRODUCTION

1.1. Project Background

District 6 Florida Department of Transportation (FDOT) has been using a mix of inductive loops and Sensys Networks sensors at its 22 ramp signals on I-95 in Miami-Dade County. These detectors can detect both vehicle passages and presence, but are not designed to collect traffic measures such as queue length and delay (or travel time), which are important input needed for monitoring the performance of ramp signals. Even for detecting vehicle counts, these detectors are not ideal as they are not designed for “stop and go” ramp queue conditions. Also, during roadway construction, these detectors are disabled, thus taking the ramp signals out with them.

A potential alternative to these existing detectors is video image detectors, which combine video and computer vision technologies to provide the ability to detect vehicles as well as estimate traffic measures. These detectors may also provide cost savings because a single camera can track a wider area that must currently be covered by multiple detectors. In addition, video detection will allow ramp signal operations to continue during construction projects because they can be easily relocated to align with temporary conditions. Many off-the-shelf video image detection systems are available in the market today. These products vary in performance, features, costs, maintenance requirements, and ease of implementation.

1.2. Project Objectives and Key Tasks

The main project objectives of this project were (1) investigate the feasibility of using a video detection system to collect performance data, such as queue length and wait time, in addition to vehicle volume and vehicle occupancy that are currently being collected using traditional inductive loops and sensors and (2) develop a Web-based system for visualizing performance data from detectors for performance monitoring and analysis.

The key project tasks included:

1. Survey existing video detection systems and select three for field tests at an actual ramp signal location.
2. Develop a detailed test plan to evaluate the accuracies and capabilities of video detection systems under ramp signal conditions.
3. Conduct field tests and evaluate the test results.
4. Recommend an existing video detection system for potential deployment based on the test results and other considerations, including system costs, maintenance requirements, and ease of integration with the *SunGuide* software.
5. Develop the software specifications for a Web-based system for visualizing detector data for performance monitoring and analysis, and implement the Web-based system based on the specification.

1.3. Report Organization

The rest of this report is organized as follows. Chapter 2 describes the process of identifying and selecting potential video detection systems for field test evaluation. Chapter 3 presents the development of a detailed field test plan and invitation of vendors for participation in field tests. Chapter 4 documents the conduct of the field tests, the acquisition of ground-truth data for evaluation, and the field test results. Chapter 5 describes further evaluation of systems beyond field detection accuracy, including their potential ease of integration with the *SunGuide* software, deployment costs, and maintenance requirements and their associated costs. The final chapter describes a Web-based system designed for visualizing detector data for the purpose of performance monitoring.

CHAPTER 2
SELECTION OF VIDEO DETECTION SYSTEMS FOR FIELD TESTS

This chapter describes the first task of the project, which was to identify the existing video detection systems in the market and select three of them for field tests in order to evaluate their field data detection accuracies and capabilities.

2.1. Identification of Existing Video Detection Systems

Searches on the Internet and the Transportation Research Information Services (TRIS) database using a variety of keywords were first conducted to identify the existing video image detection systems available in the market. Table 2-1 lists the potential systems identified. To avoid logistic constraints, the list includes only systems from North America. Further, as a research project, the list is inclusive of products that are not on FDOT's Approved Product List (APL). Initial contacts with the identified vendors were made through emails and phone calls. The research team identified the key contact persons, explained the intent of the project, and obtained their general product information.

Table 2-1. Existing Video Image Detection Systems

Product	Vendor	Headquarters	On APL?	Responded?
XCam-ng	Citilog, Inc.	Bala Cynwyd, Pennsylvania	No	Yes
Autoscope Terra Technologies	Econolite	St. Paul, Minnesota	Yes	Yes
TrafiSense	FLIR ITS	Wilsonville, Oregon	Yes	Yes
GridSmart	GRIDSMART Technologies, Inc. (formerly Aldis)	Knoxville, Tennessee	Yes	Yes
RZ-4 AWDR	ITERIS, Inc	Santa Ana, California	Yes	Yes
Scout Video Collection Unit	Miovision Technologies, Inc.	Kitchener, Ontario, Canada	No	No

2.2. Selection of Existing Systems for Field Tests

The selection of systems for field tests was based on the results from a survey involving a set of 18 questions. The survey form was prepared and sent to the vendors for their response. The questions were aimed at obtaining information on the system's general capabilities to help select three systems the systems for field tests. Also included in the survey were questions on licensing costs, technical support, and field evaluation requirements. However, this information was not used to identify systems for field evaluation. As indicated in Table 2-1, responses were received by five of the six vendors invited for the survey.

As part of the selection process, the research team was to also review existing studies that could help provide additional independent information for identifying systems for field evaluation. Searches on the Internet and the TRIS database using a variety of keywords yielded a significant number of publications on vehicle detection and related data analytics. However, a majority of these publications were found to focus on only the development and improvement of methods and algorithms for vehicle detection, which were not the focus of this project. On the other hand, the searches did identify a total of 10 study reports that focus on field evaluations of vehicle detection technologies. These studies are listed in Appendix A. A summary taken directly from the respective study report is also included. These studies provide some useful information for the later tasks of these projects in terms of the evaluation approach used in study and the presentation and analysis of results. However, these studies do not help in the selection of products for field evaluation in this project. Except for a Minnesota study (i.e., publication no. 3 in Attachment A), which focuses on ramp queue, all other studies were found to be for applications at signalized intersections and freeway mainlines. It is also noted that the Minnesota study evaluated microwave radar detectors and Sensys Network sensors instead of video image detectors. It is also noted that a majority of these studies are relatively old and cover products/models that are either no longer in the market or were superseded by newer products.

As independent (from vendors) information from existing studies, as summarized above, was not found to be useful for the purpose of this particular task, the research team relied on the responses gathered from the survey questions posted to the vendors. It is also noted that the ease of integration of the systems with the *SunGuide* software was not included in the survey, as it was not expected that the vendors would be familiar with the *SunGuide* software.

The vendor responses to each question together with discussion are presented in Appendix B. Based on review of the responses, the research team recommended to the FDOT that the following three vendors/products be invited for field tests:

- Autoscope Terra Technology from Econolite
- TrafiSense from FLIR ITS
- GridSmart System from GRIDSMART, Inc.

CHAPTER 3
DEVELOPMENT OF FIELD TEST PLAN

This chapter describes the second key task of the project, which was to develop a plan to field test three selected video detection systems on a ramp signal location. The test plan provided the details on the tests, including the project background, test objective, responsible agencies and contacts, target test data, test location and test period, data evaluation method, review of test results by participants, travel support for participants, and publication requirements.

3.1. Identification of Field Test Location

An important effort in the development of the field test plan was to identify a suitable ramp signal location for the tests. There were 22 ramp signals on I-95 in Miami-Dade County, including 10 in the northbound direction and 12 in the southbound direction. Due to directional traffic, the southbound ramp signals were turned on only during the AM peak and the northbound ramp signals were turned on only during the PM peak hours. In order to include nighttime conditions, only the PM northbound ramp signals could be considered. Among the 10 northbound ramp signals, 7 were regularly turned on. The remaining three were turned on only when needed.

Table 3-1 gives the location, ramp length, flow rate, queue capacity, and average queue for the 7 ramp signals (RMS #1 to #7) based on the 2016 data. For this test, it was desired to use a ramp that had a sufficient length to allow for the video detection systems to detect long queues. It was also desired to have the queue experience varying lengths, instead of one that spilled to the arterial street most of the time. Based on the queue length and the average queue (in relative to queue capacity) information in Table 3-1, it was determined that RMS #4 and RMS #5 meet both conditions the best. The queue percentage distributions for RMS #4 and RMS #5, as shown in Figures 3-1 and 3-2, respectively, further show that they experienced variable average queue lengths.

Table 3-1. Ramp Length and Queue Length Variation

RMS Number	Cross Street Location	Ramp Length (feet)	Flow Rate (vehicles/hour)	Queue Capacity (# of vehicles)	Average Queue (# of vehicles)
1	NW 62nd St	700	485	28	28
2	NW 69th St	200	219	8	4
3	NW 81st St	525	544	21	21
4	NW 95th St	650	386	26	10
5	NW 103rd St	550	567	22	10
6	NW 125th St	575	629	23	23
7	NW 135th St	600	1020	24	24

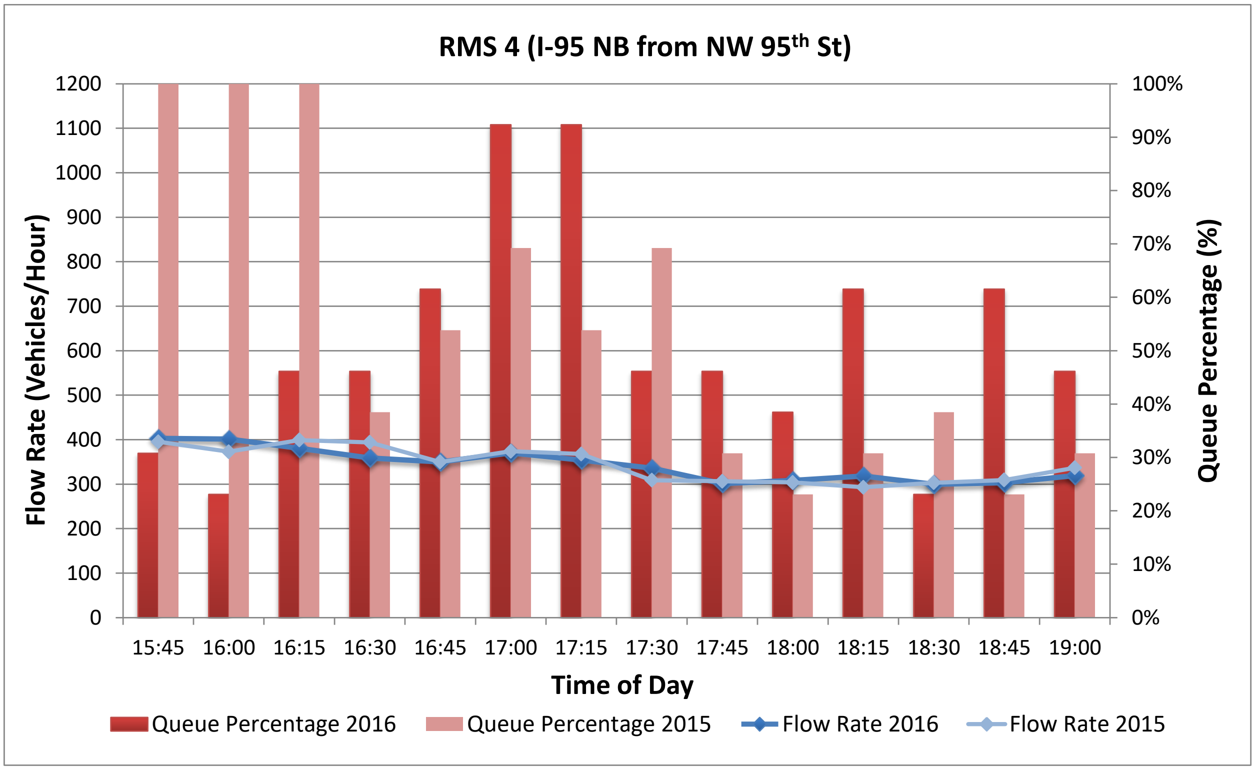


Figure 3-1. 2015 and 2016 Flow Rates and Queue Percentages at RMS #4

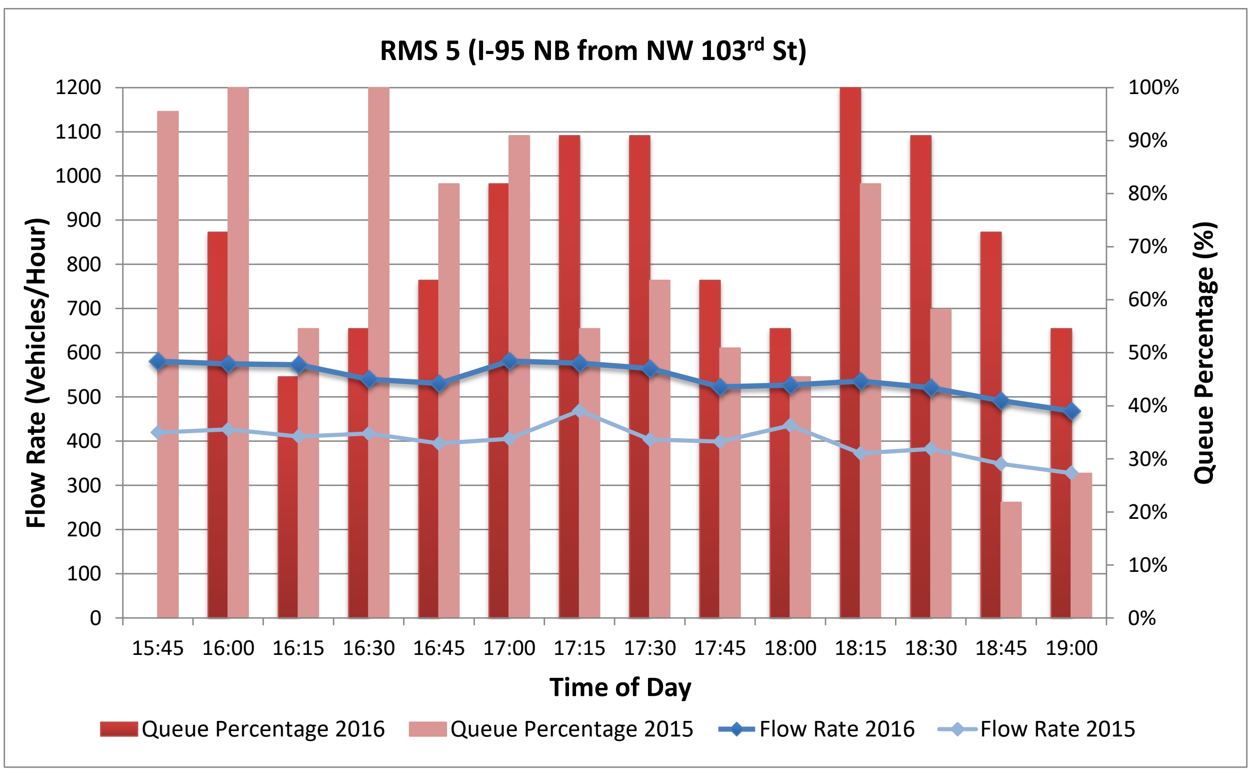


Figure 3-2. 2015 and 2016 Flow Rates and Queue Percentages at RMS #5

The two ramp signal locations were further evaluated based on the availability of existing poles potentially suitable for video camera installation. Table 3-2 gives the existing pole types and locations at all 7 ramp signal locations. It was found that RMS #4, with a camera pole location, provided both the needed pole height and the proper location for a side-fire camera installation. Figure 3-3 shows the view from the existing camera. Figure 3-4 further shows that the ramp provides ample working area for the test system setup with a bucket truck. The location also had a light pole about 140 ft downstream of the stop line that could also be used, although there was not as much working area available (see Figure 3-5). In short, the ramp signal location at the NW 95th Street (RMS #4) was selected for this test considering its ramp length, queue length distribution, and availability of existing poles and working area for test system setup.

Table 3-2. Existing Poles, Pole Types, and Pole Locations

RMS Number	Cross Street Location	Upstream of Ramp Signal		Downstream of Ramp Signal	
		Pole Location from Ramp Signal	Pole Type	Pole Location from Ramp Signal	Pole Type
1	NW 62nd St	50 ft, left	Light Pole	150 ft, Right	Light Pole
2	NW 69th St	90 ft, Left	Camera Pole	60 ft, Right	Light Pole
3	NW 81st St	10 ft, Left	Light Pole	300 ft, Right	Light Pole
4	NW 95th St	240 ft, Left	Camera Pole	140 ft, Right	Light Pole
5	NW 103rd St	90 ft, Right	Light Pole	60 ft, Right	Light Pole
6	NW 125th St	5 ft, Right	Light Pole	140 ft, Right	Utility Pole
7	NW 135th St	70 ft, Left	Light Pole	90 ft, Right	Light Pole

Figure 3-3. Camera View from an Existing Camera at RMS #4

Figure 3-4. Ample Space Available for Camera Setup on a Camera Pole at RMS #4

Figure 3-5. Potential Use of an Existing Light Pole at RMS #4 for Camera Installation

3.2. Scheduling of Field Tests

Feedback from vendors indicated that they preferred to conduct their tests individually on separate days. Accordingly, the following three test dates were proposed: February 28 (Tuesday), March 2 (Thursday), and March 6 (Monday), 2017. An alternative day schedule allowed for a second day for testing in case there was a rain or incident delay. To ensure that the tests would include a time period with sufficient nighttime conditions, it was deemed important that they be completed before the Daylight Savings Time, which began on March 12, 2017. The test dates provided a four-day buffer to accommodate potential delays that may occur.

3.3. Development and Sharing of Field Test Plan

The plan was developed and shared with the three selected vendor participants. The participant invitation letter and the complete field test plan are given in Appendices C and D, respectively. The field test plan was reviewed and approved by the FDOT project managers before it was shared with the participating vendors. The plan specified the following key conditions and requirements for the field tests:

- *Test Location*: The field test was to be conducted on the on-ramp from the NW 95th Street onto Interstate 95 in Miami-Dade County. The on-ramp location was selected based on the mainline traffic direction it serves (i.e., northbound with ramp signals operating in the PM period in order to include nighttime conditions), the available ramp length, the queue length characteristics, and the availability of existing poles and working area for test system installation.

- *Test Period*: The test was to be conducted on one afternoon, from 2:30 pm to 8:00 pm, during which the ramp signal will be in operation. A bucket truck that could reach up to a minimum of 40 feet was to be provided from 11:00 am throughout the day of the test for system installation and removal.

- *Test Data*: At the end of the test, each vendor was to provide the following test data sets for evaluation:

  - Complete video recordings from 2:30 pm to 8:00 pm
  - Stop line traffic volume at 5-minute intervals
  - Stop line traffic volume at 15-minute intervals
  - Stop line vehicle occupancy (%) at 20-second intervals
  - Maximum queue length (in feet or number of vehicles) within 5-minute intervals
  - Average queue length (in feet or number of vehicles) at 5-minute intervals
  - If a system was able to track vehicle travel time, the vendor would also provide the average travel time for vehicles to travel from the beginning of the camera's field of view to the stop line at 5-minute intervals, or any other alternative measure(s) that would allow assessment of the average wait time of vehicles in the queue.

  It was noted that other time intervals for maximum and average queue lengths may also be used, if necessary. It was also noted that the ground-truth data for comparison would be extracted from the videos provided based on the time intervals used and how the average queue length is sampled within the time interval.

- *Evaluation Method*: The accuracy of the test data provided would be evaluated using ground-truth data collected manually from videos from the test systems. The accuracy of stop-line occupancy collected by each video detection system would be evaluated using the loop detector data extracted from the *SunGuide* database at FDOT District 6 ITS Office. In other words, the evaluation of the vehicle occupancy data would be limited to assessing how close the data were to those from the loop detector. While the test occupancy data would be provided in 20-second intervals, the evaluation could be performed based on longer intervals, such as 1 and 5 minutes, to minimize potential impact from small differences in clock time synchronization between the loop detector and the test system. All test data would be compared with the ground-truth data using the Mean Absolute Percentage Error (MAPE) error measurement, defined as follows:

$$MAPE = \frac{100}{n}\sum_{i=1}^{n}\left|\frac{Ground\ Truth\ Data\ \ for\ ith\ Interval - Video\ Data\ \ for\ ith\ Interval}{Ground\ Truth\ Data\ \ for\ ith\ Interval}\right|$$

where n is the number of time intervals.

CHAPTER 4
CONDUCT OF FIELD TESTS AND EVALUATION OF TEST RESULTS

This chapter documents the third key task of this project, which was to conduct the field tests of three participating video detection systems and to evaluate their test results.

4.1. Invitation of Vendors

The field test plan, as given in Appendix D, was first shared with the following three vendors, along with an invitation to participate:

- Autoscope Terra Technology from Econolite
- TrafiSense from FLIR ITS
- GridSmart System from GRIDSMART, Inc.

After reviewing the test plan, Econolite decided to not participate in the test. The vendor indicated that they had new product that was to be released soon, but was not ready for testing. After consultation with the FDOT project managers, a new invitation was extended to ITERIS and was accepted. The three vendors agreed to conduct the field tests on the following dates:

- March 2, 2017 (Thursday): GRIDSMART Technologies
- March 6, 2017 (Monday): ITERIS
- March 8, 2017 (Wednesday): FLIR ITS

Prior to the field tests, the research team responded to several questions and requests from the vendors. They are summarized below, with the research team's responses given in parentheses.

- The location was not the best location (the research team explained the reasons behind the selection of the location and addressed related concerns).
- There was a frontage road that could affect the queue length (the research team explained that the frontage road would have no effect on the test because its distance from the ramp signal stop line of about 400 feet was longer than any one camera was likely to be able to cover).
- One of the suggested existing poles had partial tree occlusion (the team indicated that a bucket truck would be made available and can be positioned at any location that would not interfere with the ramp traffic).
- Availability of power source (the research team indicated that a bucket truck to be made available for the test would provide power through a DC-AC voltage inverter).
- A special request by FLIR ITS to set up a second camera (the research team made clear that the test was limited to just one camera for all vendors)
- A follow-up request by FLIR ITS to set up a second camera for demonstration purpose (the research team accommodated the request, with the condition that data from the second camera would not be evaluated in order to honor the agreed upon test plan).

4.2. Preparation for Field Tests

The efforts involved in preparing for the three separate field tests included the following:

- Searched for a suitable, reliable bucket truck that could provide a bucket height of at least 40 feet and was within the project budget.
- Purchased a 12 VDC to 110 VAC inverter and a long power extension cord to allow the bucket truck to serve as a power source for the video detection systems.
- Purchased a set of traffic cones to serve as location markers for quick queue length measurement and for maintenance of traffic (MOT).
- Researched, purchased, and tested a video camera and its accessories (external battery and storage card) that could provide a wide-angle and view of vehicle queue, allow long-hour recording, and record time stamps that include seconds. The video camera served to ensure that the research team had a set of backup videos.
- Worked with the *SunGuide* TMC to synchronize the loop detector clock with the *SunGuide* software clock.
- Synchronized the backup video camera clock with the *SunGuide* clock.
- Coordinated with the *SunGuide* TMC to have the ramp signal start at 2:00 pm and end at 8:00 pm.

4.3. Collection of Ground-Truth Data

To ease the collection of ground-truth queue data, the research team set up orange traffic cones along the ramp with a spacing of 20 feet, for up to a distance of 260 feet from the ramp signal stop line (see Figure 4-1). The traffic cones allow the observer to quickly estimate vehicle queue lengths from the videos. The research team also set up a backup camera to collect video data of the vehicle queue from a side-fire position. The ground-truth data for vehicle counts, queue length, and maximum queue were manually counted from the video files provided by the test participants.

Figure 4-1. Traffic Cones Serving as Markers for Quick Distance Measurement

4.4. Field Test of GRIDSMART System and Test Results

4.4.1. GRIDSMART System Field Test

The field test system setup for the GRIDSMART system began at around 11:00 am on March 2, 2017. The vendor was represented by Mr. John Gaskins of Transportation Control Systems, Inc. in Tampa. Mr. Gaskins decided to set up his camera on a light pole next to the ramp signal stop line. The camera setup provided a near overhead view of the vehicle queue. Figure 4-2 shows Mr. Gaskins using a bucket truck to install his camera on the light pole. The install included an extension pole, as shown in Figure 4-3, to increase the camera height to about 40 feet above the ground. After the initial install, it was found that the camera view was partially blocked by some tree branches. The branches were removed by the bucket truck driver who was equipped with the tool to do the job. Figure 4-4 shows a screenshot of GRIDSMART's unique fisheye video camera view of the on-ramp, which is clear of tree occlusions.

Figure 4-2. Installing GRIDSMART Camera on Light Pole

Figure 4-3. Adding Extension Structure to Increase Camera Height

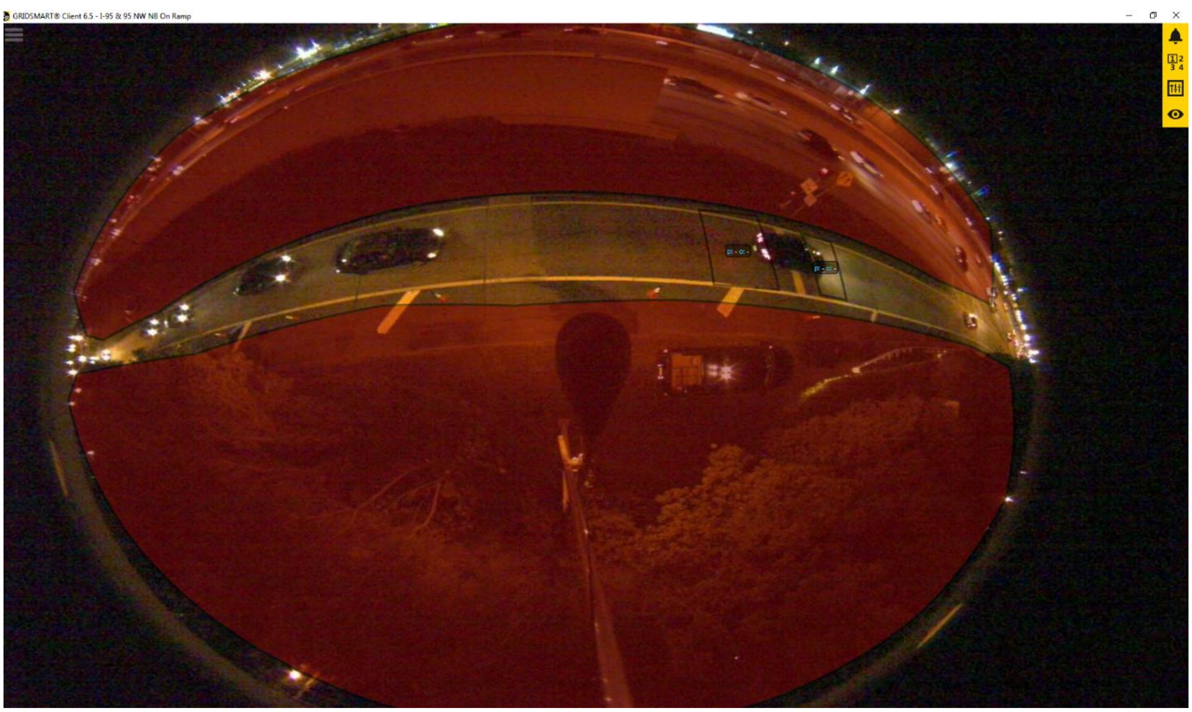


Figure 4-4. Screenshot of GRIDSMART Video Detection Camera View

During the system setup, Mr. Gaskins encountered several technical problems with his host computer system. After the problems were resolved, the video system clock time was synchronized with the backup video camera clock, which was pre-synchronized with the *SunGuide* clock. After the system was fully setup to collect data at around 2:30 pm, some light rain started to fall and became somewhat heavy over the 3:00-4:00 pm hour. The weather was good after the rain, and the test lasted through 8:00 pm as scheduled. At the end of the test, the vendor provided 5-minute vehicle counts and the recorded video files. Despite specified in the test plan, no data for vehicle occupancy, queue, or delay were provided.

4.4.2. GRIDSMART Vehicle Count Results

Figure 4-5 compares the 5-minute GRIDSMART counts with the manual counts. The following observations can be made from the comparisons:

- Using 18:30 as a cut-off time separating the day and night conditions, the GRIDSMART system counted more accurately under the daytime than nighttime conditions.
- Other than during the 20 minutes period from 17:25 to 17:45, the GRIDSMART counts match the manual counts very well both in trend and in magnitude.
- Under the nighttime conditions, the GRIDSMART system tended to undercount vehicles.

Table 4-1 provides a summary of Mean Absolute Percentage Error (MAPE) performance for vehicle counts for daytime, nighttime, and total test duration for the GRIDSMART system. The vehicle count error during nighttime is about 3% higher compared to those from daytime, with an overall MAPE of 11.6%.

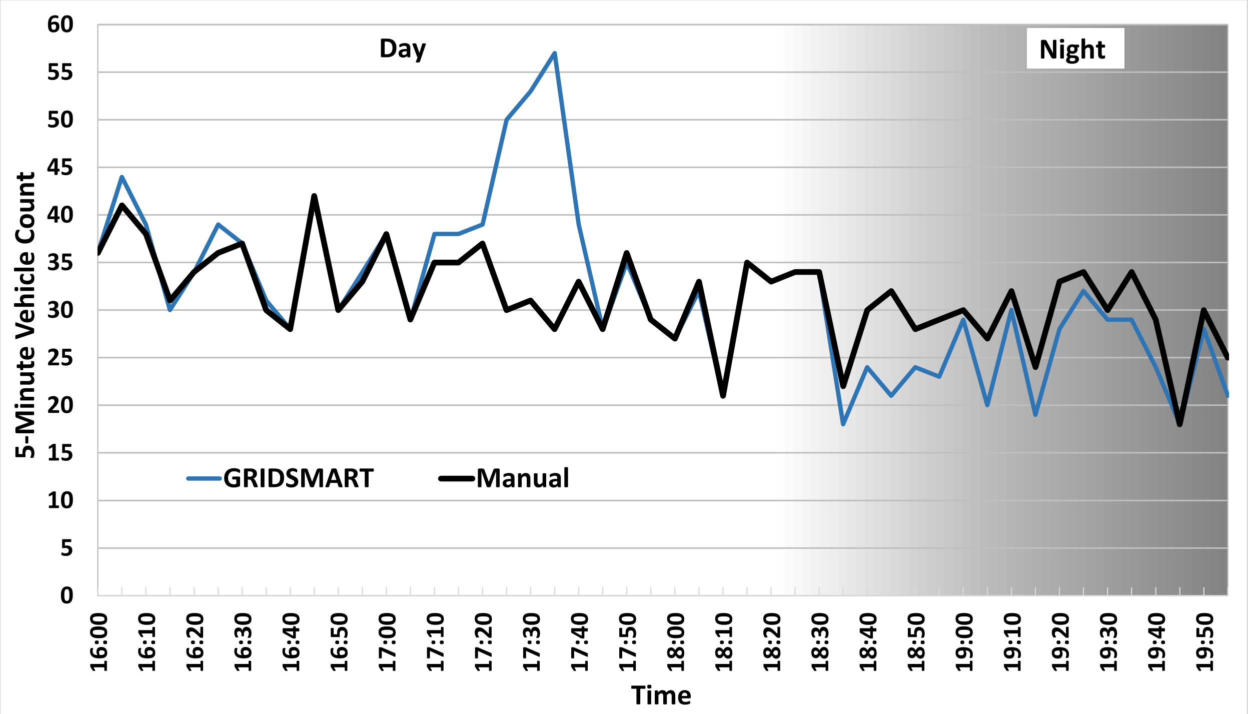


Figure 4-5. GRIDSMART vs. Manually Counted Ground-Truth for 5-Minute Vehicle Counts

Table 4-1. MAPE Statistics for GRIDSMART Vehicle Counts

	Day (16:00 – 18:30)	Night (18:30 – 20:00)	Total (16:00 – 20:00)
MAPE	10.5%	13.5%	11.6%

4.5. Field Test of ITERIS System and Test Results

4.5.1. ITERIS System Field Test

The field test for the ITERIS system began at around 11:00 am on March 6, 2017. The vendor was represented by Mr. Stokes Wallace and Mr. Jeremy Short from its Orlando office. The ITERIS team decided to install the camera on the bucket of the bucket truck, as shown in Figure 4-6. Figure 4-7 shows that the bucket truck was positioned at the ramp gore area, with the bucket extended to the middle of the ramp, allowing for a straight overhead view of the queue on the ramp. The height of the camera was about 30 feet above the ground. Figure 4-8 shows a screenshot of the on-ramp view from the ITERIS video camera detection system.

The ITERIS video detection system was fully installed with the clocks synchronized, ready to collect data at around 1:00 pm. However, the ramp signal on that day experienced some technical problem and did not turn on at the scheduled 2:00 pm. The *SunGuide* Transportation Management Center (TMC) was contacted and a technician was finally dispatched to the ramp to have the problem fixed by around 4:00 pm. The ramp signal then continued to operate through 8:00 pm as scheduled. As a result, only about four hours of test data with active ramp signals are available from this test. At the end of the test, the vendor provided 5-minute vehicle counts and the recorded video files. Despite specified in the test plan, data for vehicle occupancy, queue, or delay were not provided.

Figure 4-6. ITERIS Camera Installed on Bucket

Figure 4-7. ITERIS Overhead Camera Installation over Ramp Lane

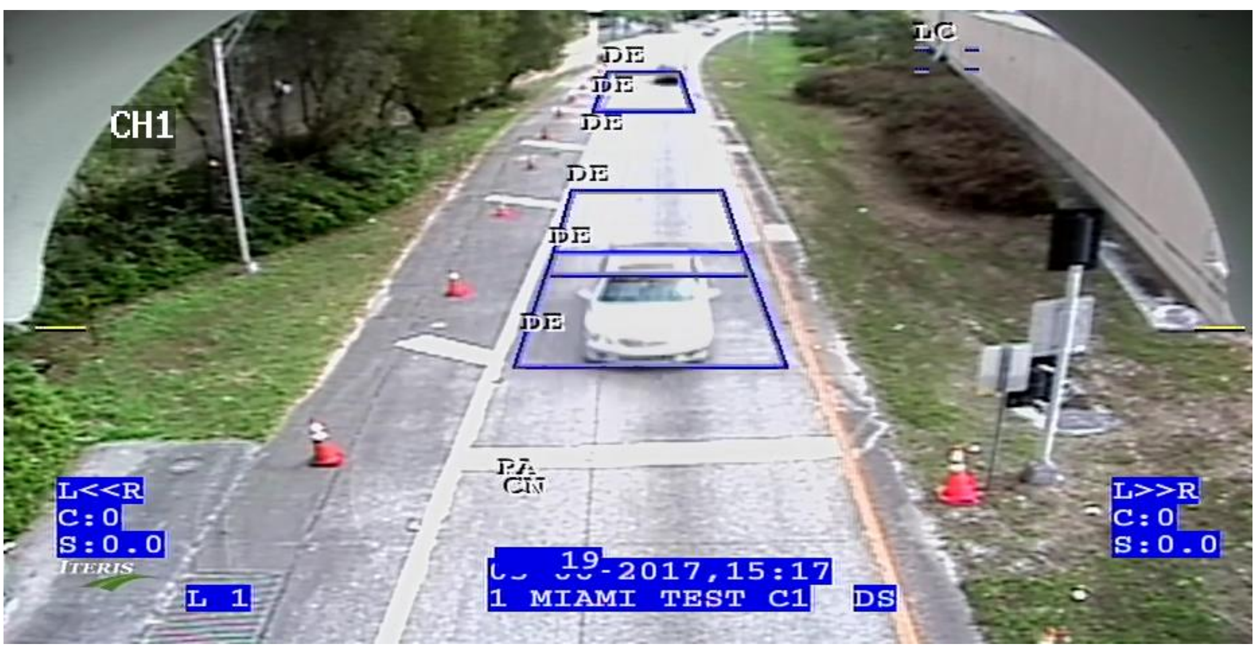


Figure 4-8. Screenshot of ITERIS Video Detection Camera View

4.5.2. ITERIS Vehicle Count Results

Figure 4-9 compares the 5-minute ITERIS counts with the manual counts. The following observations can be made from the comparisons:

- Using 18:30 as a cut-off time separating the day and night conditions, the ITERIS system counted significantly less accurately during nighttime conditions compared to daytime conditions.

- Under the daytime conditions, the ITERIS vehicle counts match the manual counts very well both in trend and in magnitude.

- Under the nighttime conditions, the ITERIS system significantly over-counted vehicles. However, its general trend matches with the trend from the manual vehicle counts.

Table 4-2 gives a summary of the MAPE performance for vehicle counts during daytime, nighttime, and total test duration for the ITERIS system. The results show that the MAPE is almost 40% higher during nighttime than daytime, yielding an overall MAPE of 19.7%.

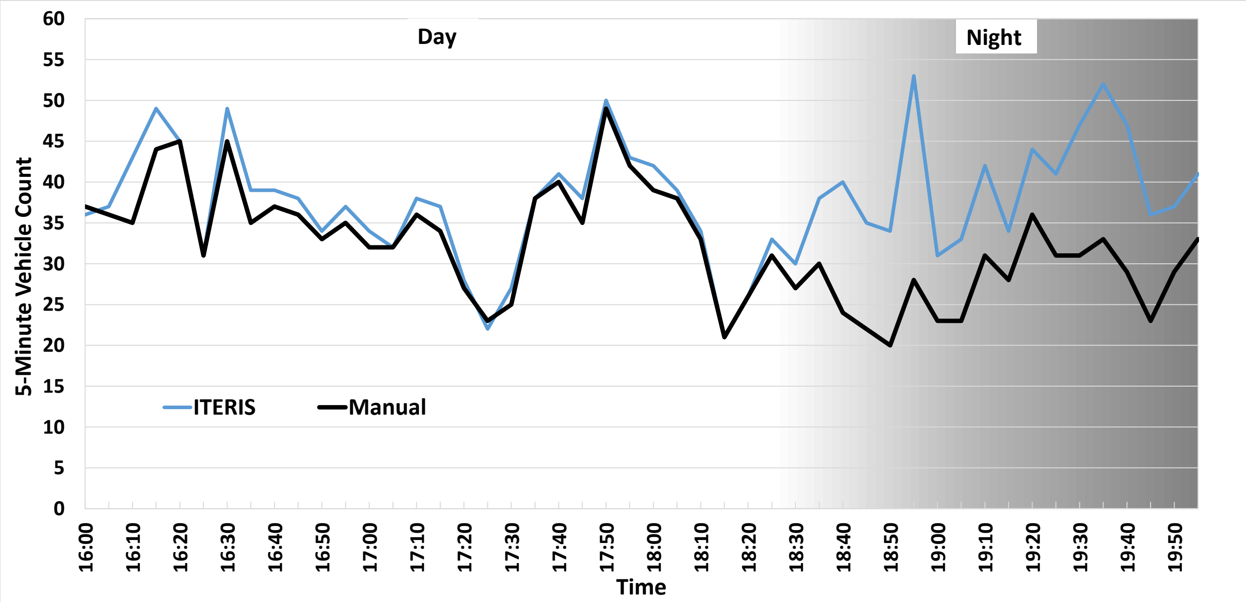


Figure 4-9. ITERIS vs. Manually Counted Ground-Truth for 5-Minute Vehicle Counts

Table 4-2. MAPE Statistics for ITERIS 5-Minute Vehicle Counts

	Day (16:00 – 18:30)	Night (18:30 – 20:00)	All (16:00 – 20:00)
MAPE	5.1%	44.0%	19.7%

4.6. Field Test of FLIR System and Test Results

4.6.1. FLIR System Field Test

The field test for the FLIR system began at around 9:30 am on March 8, 2017. The vendor requested an early start to provide additional time for the setup of a second camera. The FLIR team consisted of Mr. Pete Ganci and Mr. Bryan Kaeser of Control Technologies in Sanford, Florida, and Mr. Robin Collaert who flew in from Belgium. The FLIR team decided to also install its camera on the bucket of the bucket truck (see Figure 4-10) provided by the research team. Similar to the ITERIS system setup, the FLIR system also positioned the bucket truck at the gore area. However, unlike ITERIS, the FLIR setup had the bucket straight up and without extending it to the middle of the ramp lane (see Figure 4-11). Figure 4-12 shows a screenshot of the FLIR video detection camera view for detecting vehicle occupancies (presence zone 11, stop line) and counts (presence zones 12, after stop line). Similarly, Figure 4-13 shows a screenshot of the FLIR video detection camera view for detecting vehicle queue with multiple presence zones.

Figure 4-10. FLIR Camera Installed on Bucket

Figure 4-11. FLIR Camera Setup on Gore Area

Figure 4-12. FLIR Video Camera Detection Zones for Vehicle Counts and Occupancies

Figure 4-13. FLIR Video Camera Detection Zones for Queue Lengths

The second FLIR camera was installed on the existing camera pole. For this installation, the FLIR team hired its own bucket truck service. Figure 4-14 shows the second camera being installed to the pole from a side-fire position. The FLIR system was fully set up and the system clocks synchronized by around 12:00 pm. Similar to the other two tests, the research team also set up: (1) traffic cones along the ramp for quick queue length measurement, and (2) a video camera to collect backup video data. The test ended at 8:00 pm as scheduled. The FLIR team provided both video and detection data at the end of the test.

Figure 4-14. Installing Second FLIR Camera on FDOT Camera Pole

At the end of the test, the vendor provided the research team with 20-second data for vehicle counts and vehicle occupancies. The data for average and maximum queue lengths were provided two days after the test. The extra time was needed to process the queue information based on different queue gap settings. Because of short cycles, a ramp-metered queue is often moving. The moving queue is characterized by vehicle gaps in the queue, with approaching vehicles joining the moving queue. The vendor provided queue data for seven different gap settings.

4.6.2. FLIR Vehicle Count Results

Figure 4-15 compares the 5-minute FLIR counts with the manual counts. The figure shows that the FLIR vehicle counts closely match those of the manual counts in both trend and magnitude. Table 4-3 summarizes the MAPE performance for vehicle counts during daytime, nighttime, and both daytime and nighttime combined for the FLIR system. The results show that there is only a slight difference in the MAPE performance between daytime (3.3%) and nighttime (4.6%) for vehicle counts, yielding an overall MAPE of 3.7%.

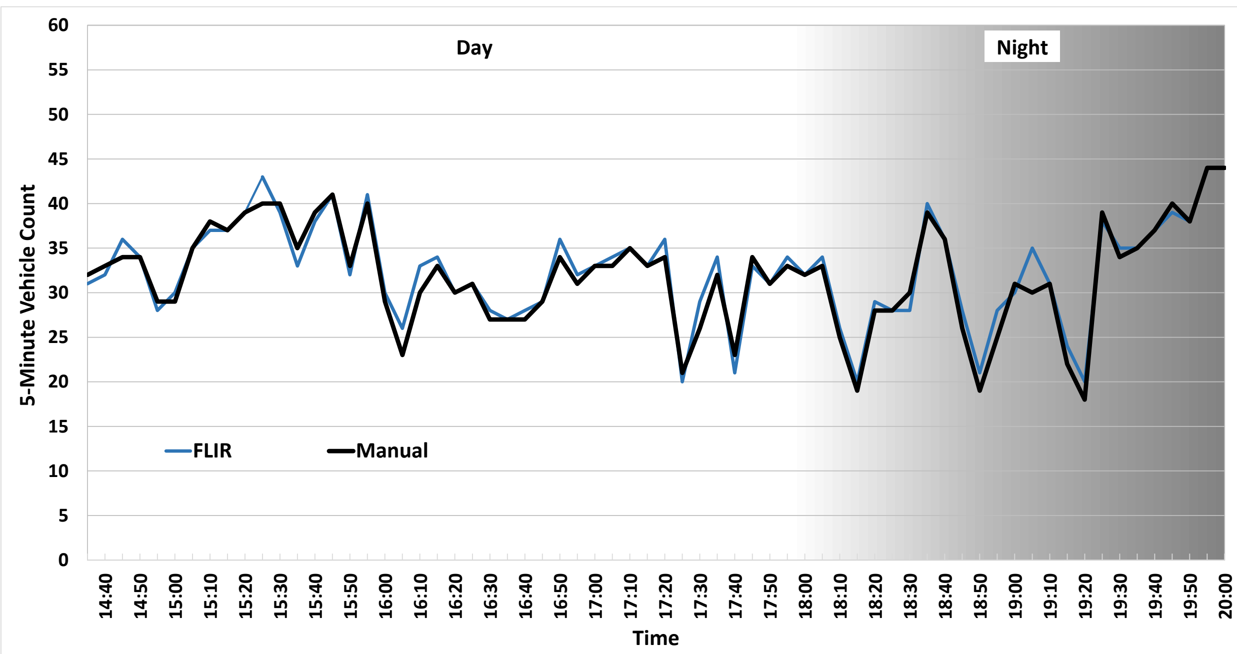


Figure 4-15. FLIR vs. Manually Counted Ground-Truth for 5-Minute Vehicle Counts

Table 4-3. MAPE Statistics for FLIR 5-Minute Vehicle Counts

	Day (14:00 – 18:30)	Night (18:30 – 20:00)	All (14:00 – 20:00)
MAPE	3.3%	4.6%	3.7%

4.6.3. FLIR Vehicle Occupancy Results

The raw data for stop line vehicle occupancies from FLIR and the *SunGuide* database are both given in 20-second intervals. For this evaluation, the raw data were aggregated into 5-minute intervals using simple averaging. Because vehicle occupancy data depends on the detector size, for comparison purposes, the occupancy data were adjusted to account for the difference in detector size. In general, the larger the detector size, the higher the vehicle occupancy. The overall vehicle occupancy from the FLIR video detection system was found to be about 15% lower than the loop detector counterparts. Accordingly, the FLIR occupancy data were multiplied by a factor 1.15.

Figure 4-16 compares the 5-minute FLIR occupancy data, both with (blue) and without (orange) adjusting for the detector size, with the loop detector occupancy data from the *SunGuide* database. The comparisons show that the adjusted occupancy data from FLIR consistently match those from the loop detector over the entire test period, and there is no noticeable difference between the daytime and nighttime periods. Table 4-4 gives the corresponding MAPE performance of these comparisons. As the table shows, the MAPE based on the raw occupancy data was 13.3%. With the adjustment for detector size difference, the MAPE was improved to 5.9%.

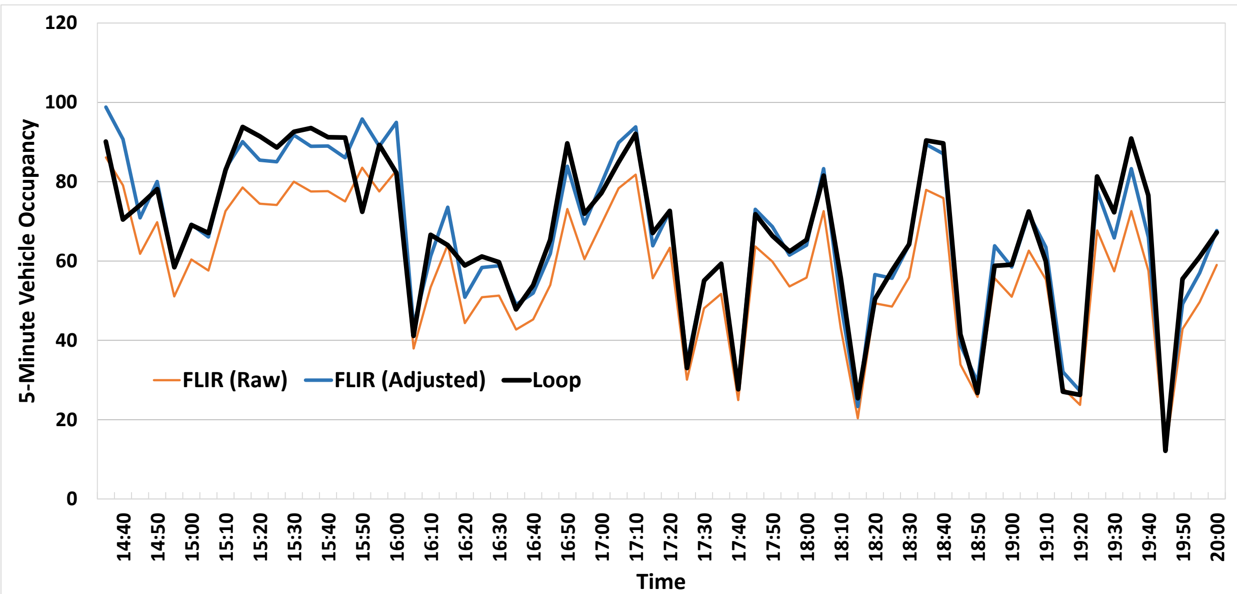


Figure 4-16. FLIR vs. Loop Detector Ground-Truth for 5-Minute Vehicle Occupancies

Table 4-4. MAPE Statistics for FLIR Vehicle Occupancies

	Raw Occupancy Data	Occupancy Data Adjusted for Detector Size
MAPE	13.3%	5.9%

4.6.4. FLIR Average and Maximum Vehicle Queue Length Results

The raw data for vehicle queue length from FLIR are given in 10-second intervals. As stated earlier, because of the moving ramp queue associated with ramp signaling, the end of a queue is not often clear cut. Table 4-5 lists the seven scenarios that FLIR defined based on the gap size and the percentage of activated zones (i.e., zones that detected a vehicle presence). Both the average and maximum queue lengths are provided by FLIR for each scenario.

Table 4-5. FLIR Scenario Settings for Determining Queue Lengths

No.	Scenario	Gap Setting	ON % Setting
1	0-100	0	100
2	1-50	1	50
3	1-75	1	75
4	1-90	1	90
5	2-50	2	50
6	2-65	2	65
7	2-80	2	80

In defining the scenarios, the following definitions apply:

- Length = the distance from begin of queue to end of queue, measured from the stop bar, and determined by zone activation, gap setting, and zone % setting.
- Gap = non-activated zone between activated zones.
- Gap Setting = the maximum number of consecutive non-activated zones that are allowed to form a queue.
- On % = percentage of activated zones.
- On % Setting = the minimum percentage of activated zones in the total queue that is needed to form that queue (note: multiple adjacent gaps count as one zone).

To extract the ground-truth queue lengths, the research team first saved a video screen in a JPEG file every 10 seconds. The queue length was then determined from each JPEG file by identifying the end of queue and measuring its distance from the stop line. The end of a queue was determined based on the size and location of the last vehicle gap in the traffic stream. A vehicle gap is any vehicle spacing measured more than two vehicle lengths, or about 40 feet. A vehicle gap defines the end of a queue if it has two or fewer vehicles behind it. In other words, if there are more than two vehicles following a gap, the gap is treated as being created by a tardy vehicle in the queue, thus, does not represent the end of the queue. In more complex cases for which such rules could not be used to determine the end of a queue, the observer played the corresponding video to observe the vehicle dynamics to make the best judgment possible.

As the test is limited to a maximum queue length of 200 feet, all queue lengths exceeding 200 feet were marked as "over 200 feet", without a specific queue length. As noted earlier, FLIR used two cameras working together to detect a queue length. The first camera was set to detect up to 200 feet, and the second camera could further detect an additional 160 feet, for a maximum detectable queue length of 360 feet. Also as noted, data from the second camera in this test was permitted for demonstration only and would not be used in this evaluation. Accordingly, all FLIR queue lengths exceeding 200 feet were also treated as "over 200 feet".

In this evaluation, the 10-second data were aggregated into 5-minute intervals based on simple averaging. All 10-second interval data marked as "over 200 feet", either from the FLIR or manual ground-truth measurements, were excluded from the averages. The same applies to the determination of the maximum queue length in each 5-minute interval.

Figures 4-17 through 4-23 compare the FLIR and ground-truth average queue lengths based on 5-minute intervals for the seven scenarios defined in Table 4-5. In these figures, the gaps in the trend lines indicate that every 10-second interval within a 5-minute interval was found to have at least one queue length exceeding 200 feet. The figures show that, in general, the FLIR and ground-truth data are similar in both trend and magnitude, that there are only minor differences among the seven scenarios. Figures 4-24 through 4-30 compare the maximum queue lengths for the same seven scenarios. Table 4-6 gives the MAPE performance statistics of FLIR for each scenario for both average and maximum queue lengths. As the numbers indicate, there are no significant differences among the scenarios.

Table 4-6. MAPE Statistics for FLIR Average and Maximum Vehicle Queue Lengths

	Scenarios						
	0-100	**1-50**	**1-75**	**1-90**	**2-50**	**2-65**	**2-80**
MAPE for Average Queue Length	24.2%	27.2%	25.6%	24.2%	31.4%	30.1%	25.8%
MAPE for Maximum Queue Length	8.4%	6.8%	6.8%	7.6%	6.2%	6.2%	6.4%

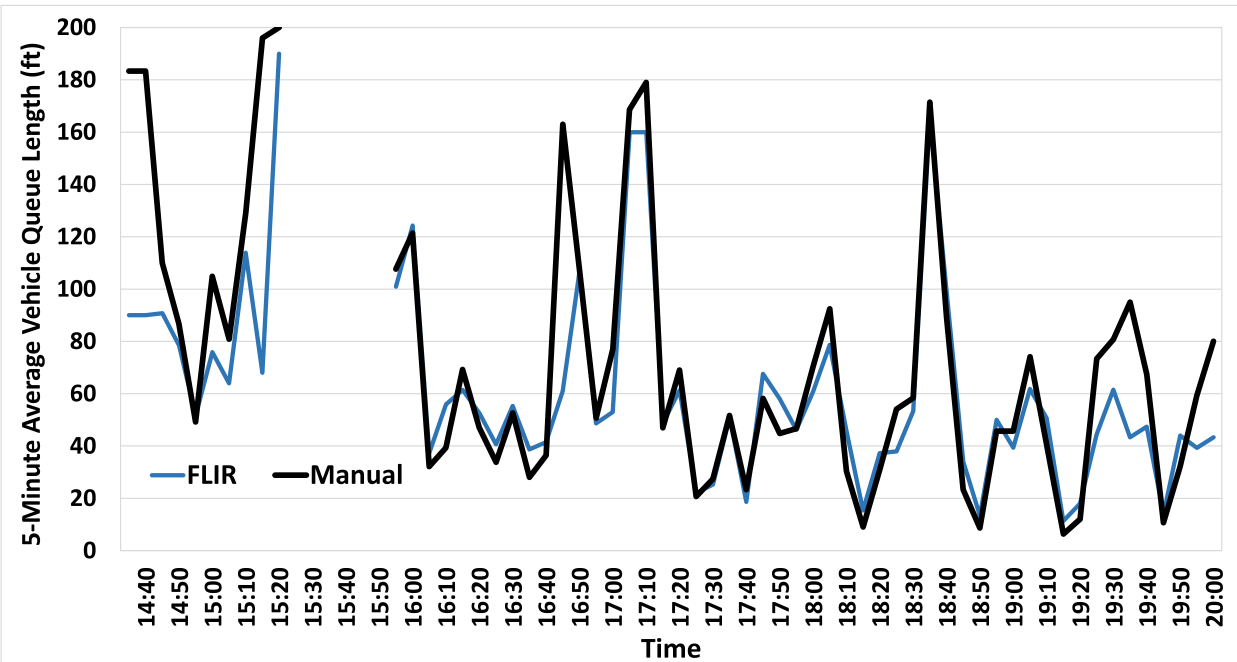


Figure 4-17. FLIR vs. Ground-Truth for 5-Minute Average Queue Length for Scenario (0-100)

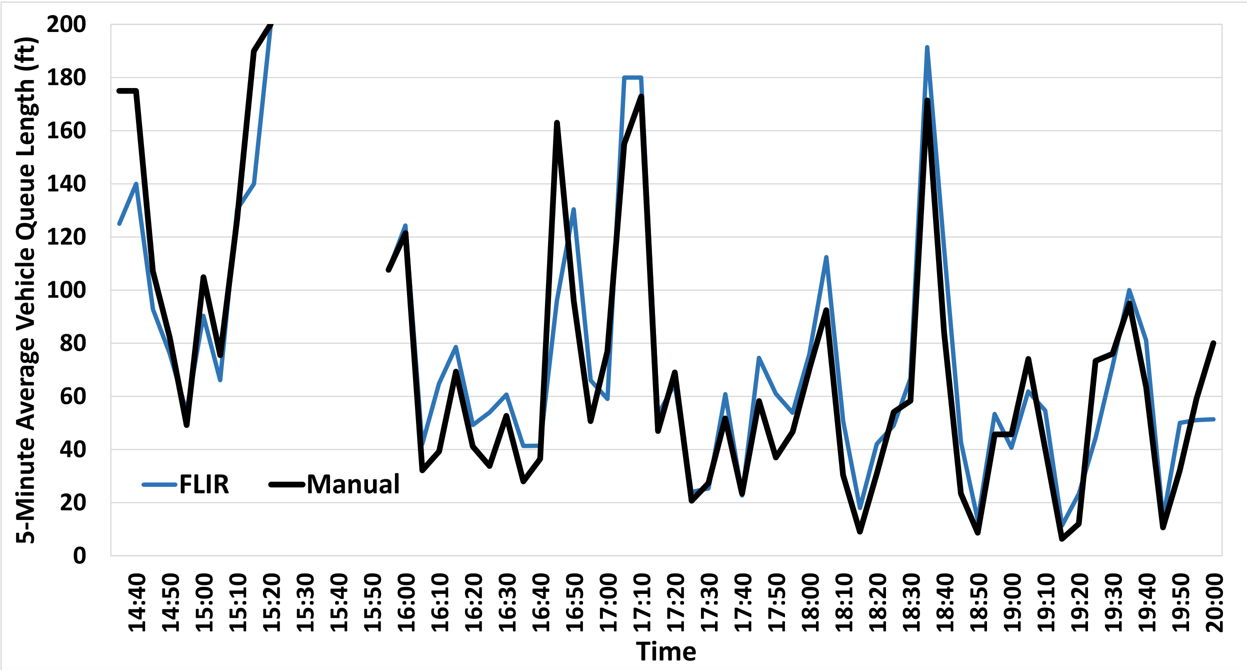


Figure 4-18. FLIR vs. Ground-Truth 5-Minute Average Queue Length for Scenario (1-50)

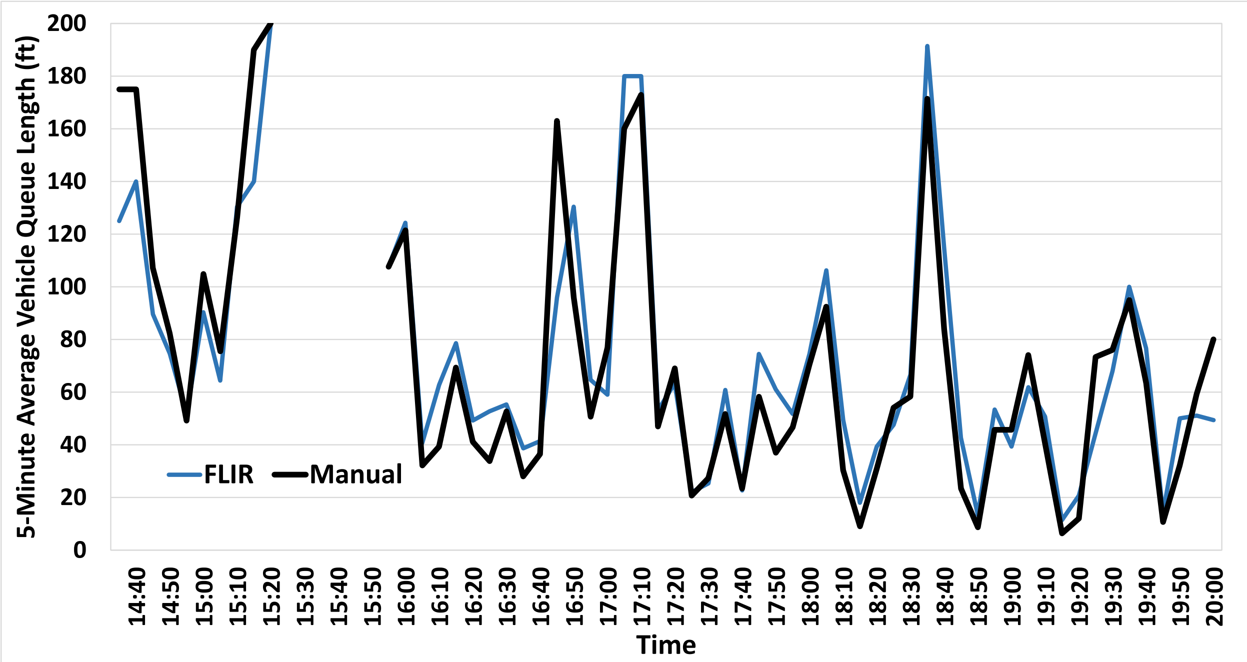


Figure 4-19. FLIR vs. Ground-Truth for 5-Minute Average Queue Length for Scenario (1-75)

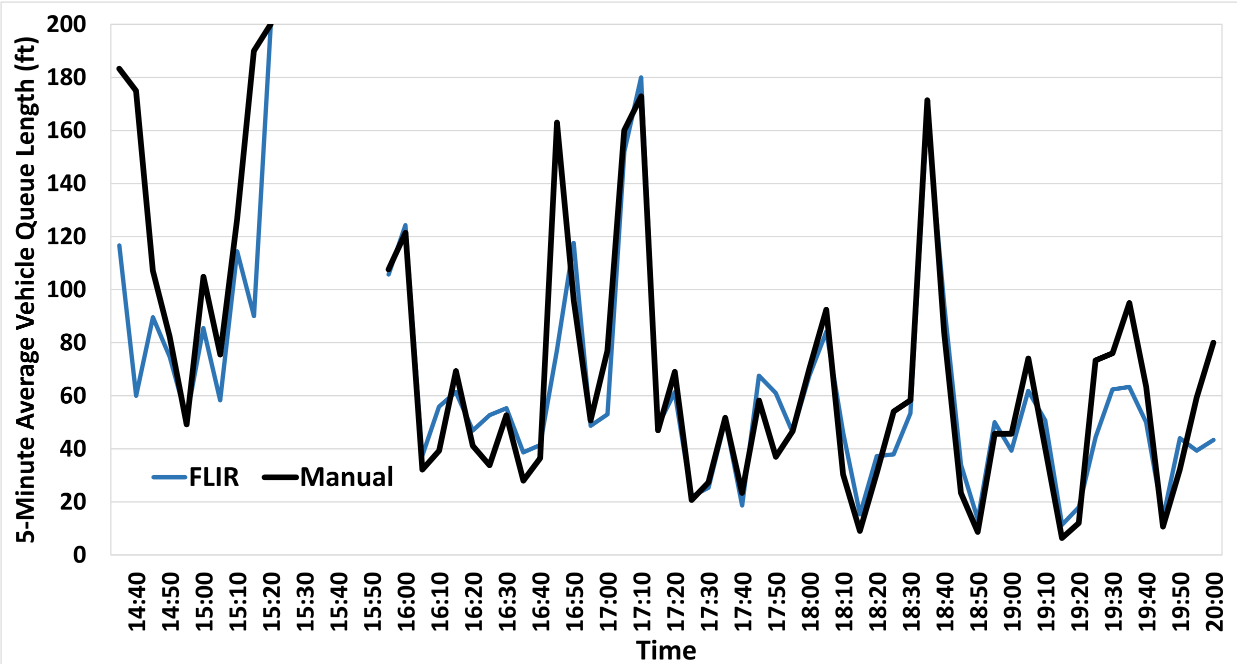


Figure 4-20. FLIR vs. Ground-Truth for 5-Minute Average Queue Length for Scenario (1-90)

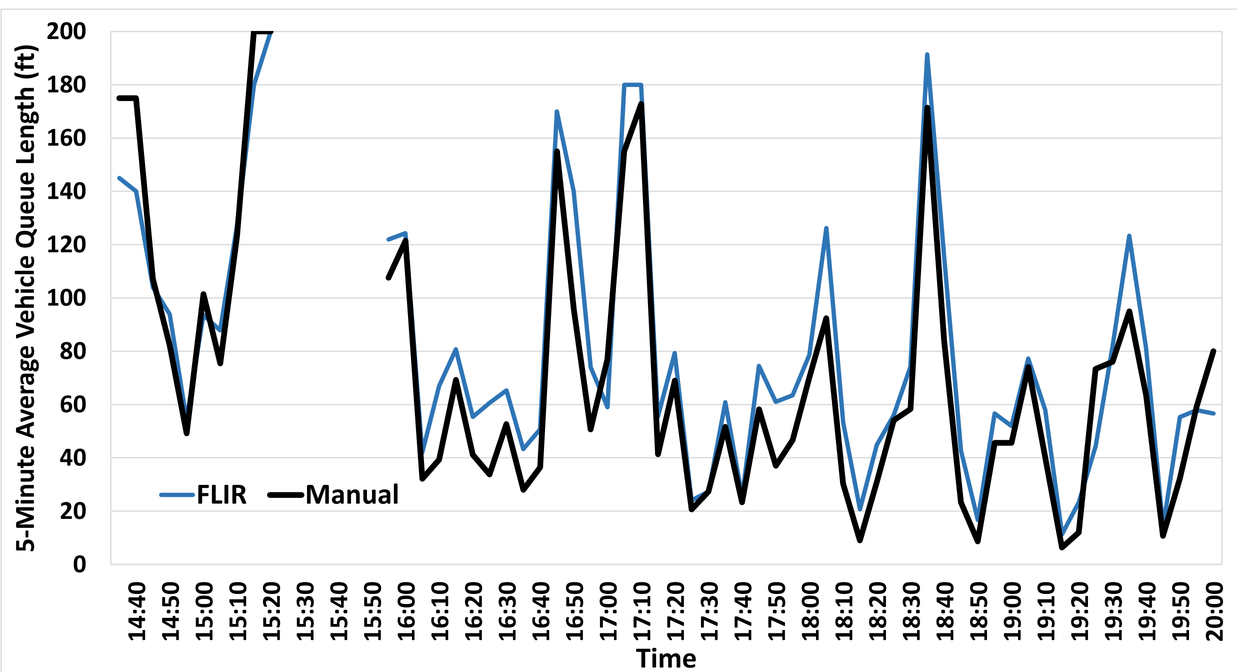


Figure 4-21. FLIR vs. Ground-Truth for 5-Minute Average Queue Length for Scenario (2-50)

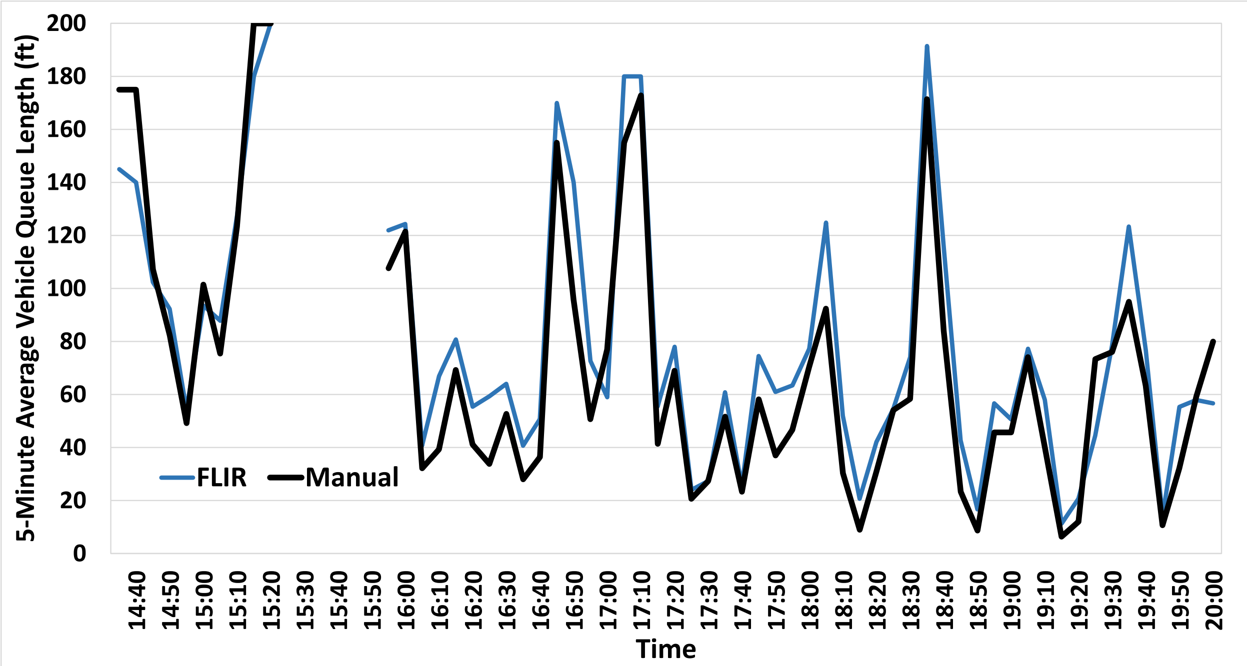


Figure 4-22. FLIR vs. Ground-Truth for 5-Minute Average Queue Length for Scenario (2-65)

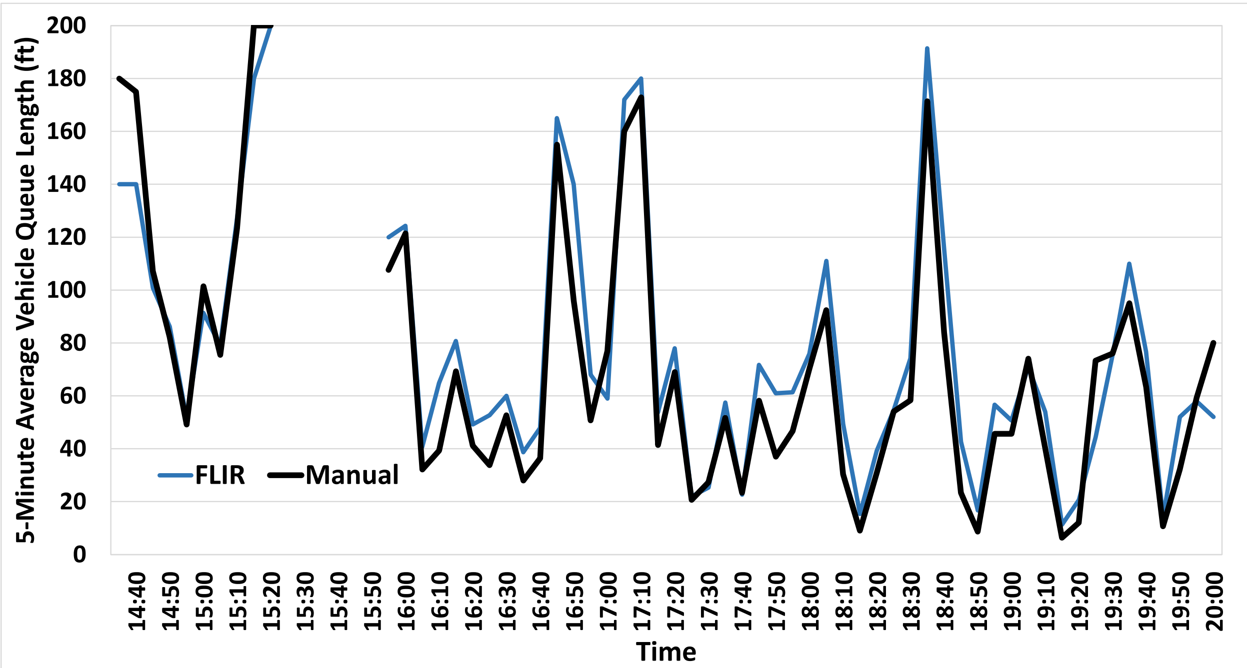


Figure 4-23. FLIR vs. Ground-Truth for 5-Minute Average Queue Length for Scenario (2-80)

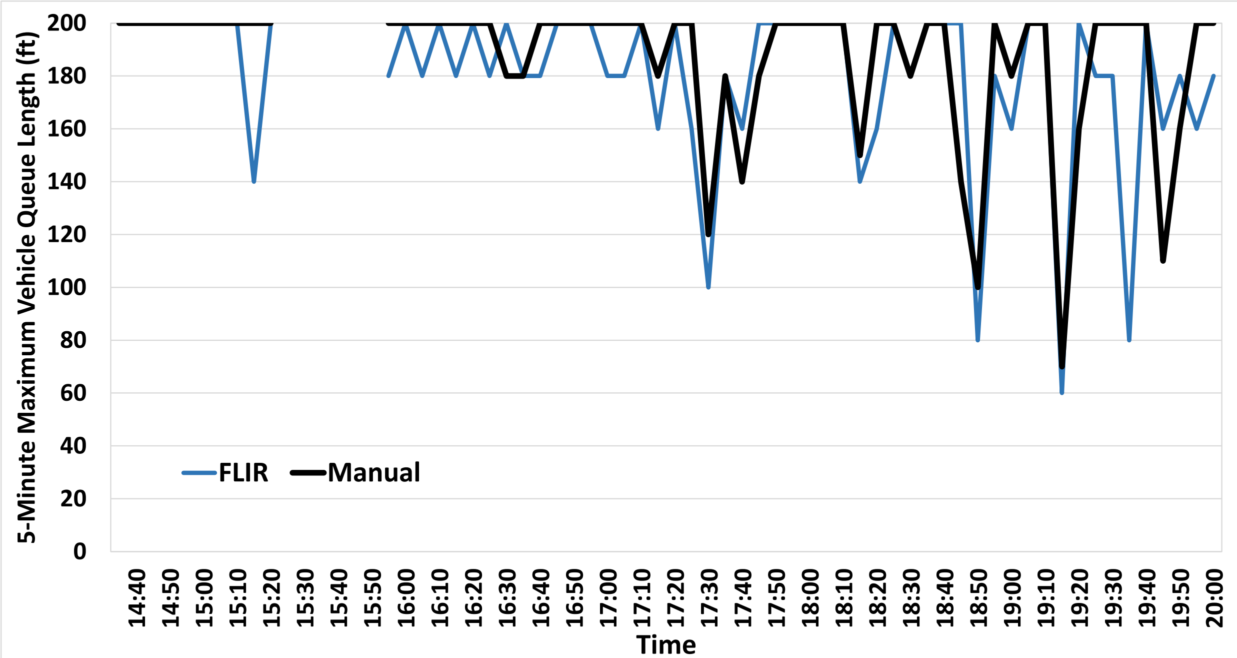


Figure 4-24. FLIR vs. Ground-Truth for 5-Minute Maximum Queue Length for Scenario (0-100)

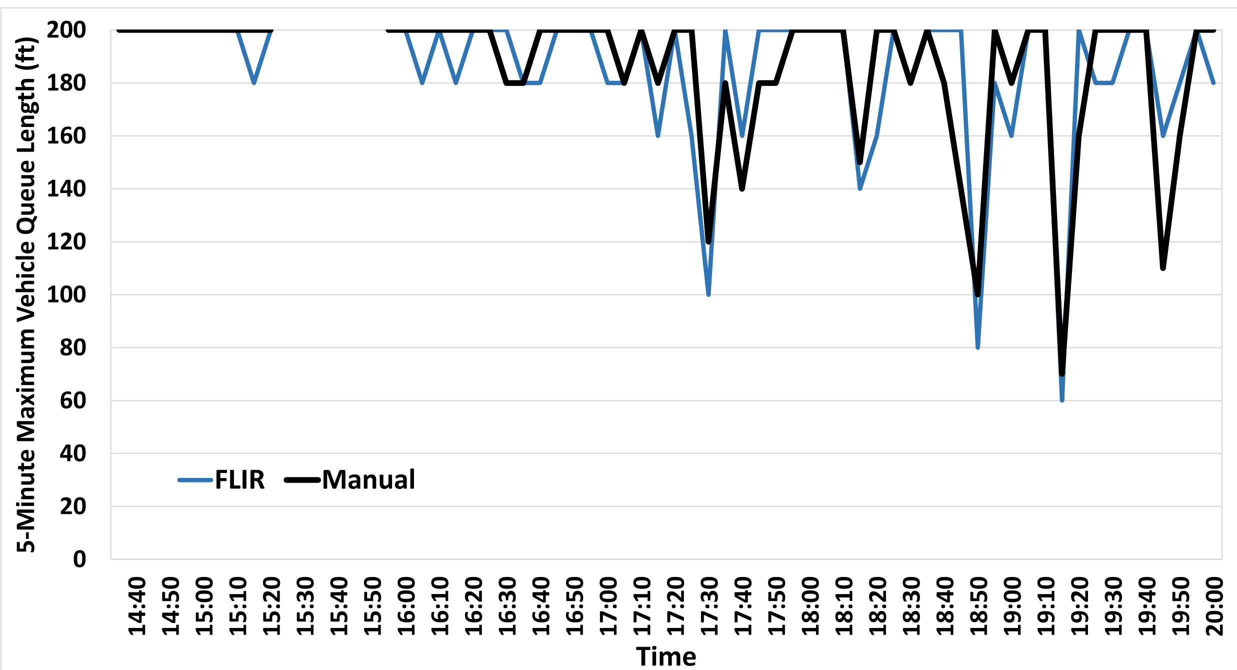


Figure 4-25. FLIR vs. Ground-Truth for 5-Minute Maximum Queue Length for Scenario (1-50)

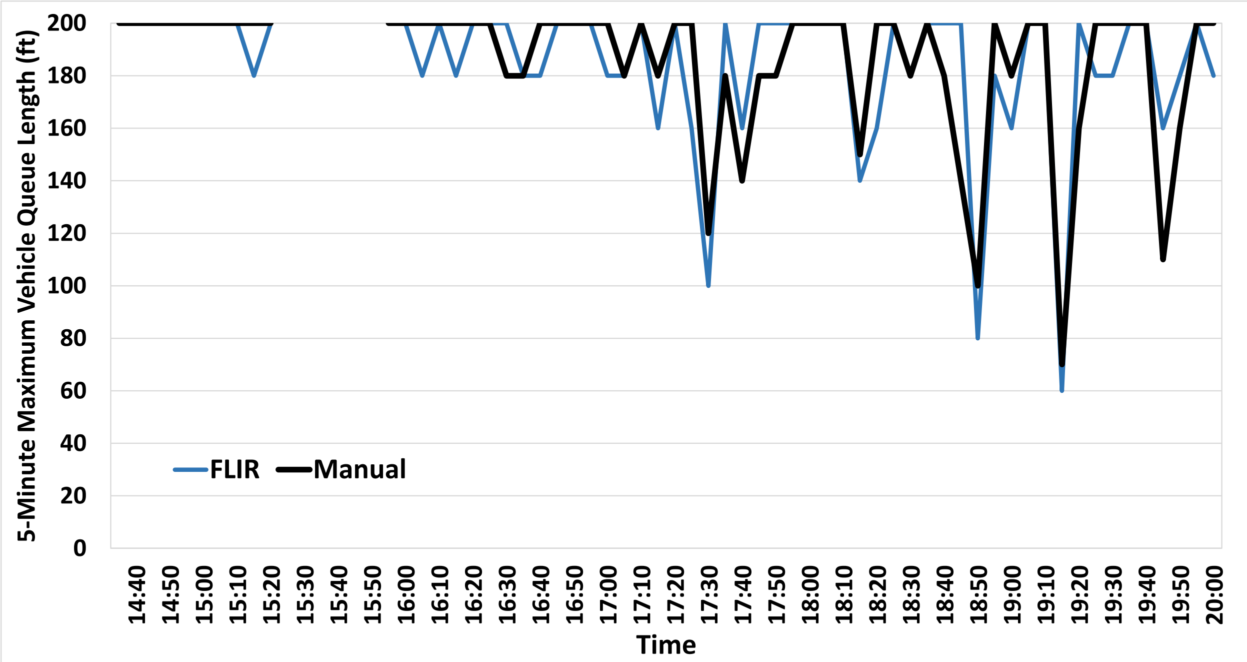


Figure 4-26. FLIR vs. Ground-Truth for 5-Minute Maximum Queue Length for Scenario (1-75)

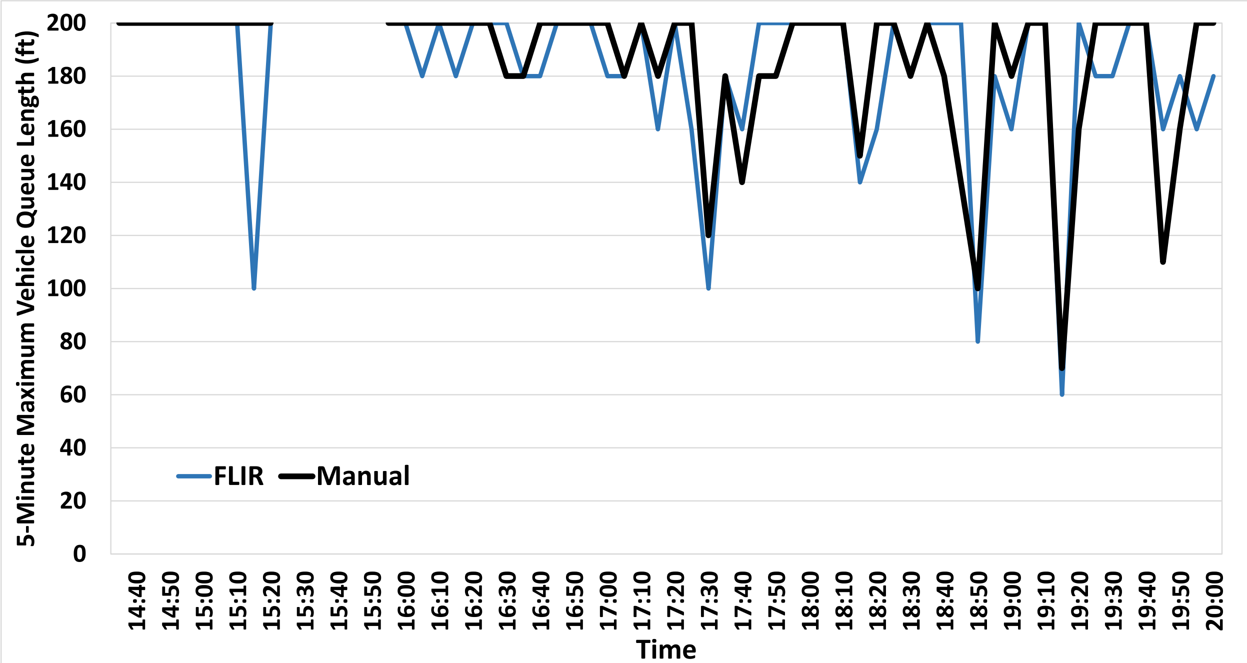


Figure 4-27. FLIR vs. Ground-Truth for 5-Minute Maximum Queue Length for Scenario (1-90)

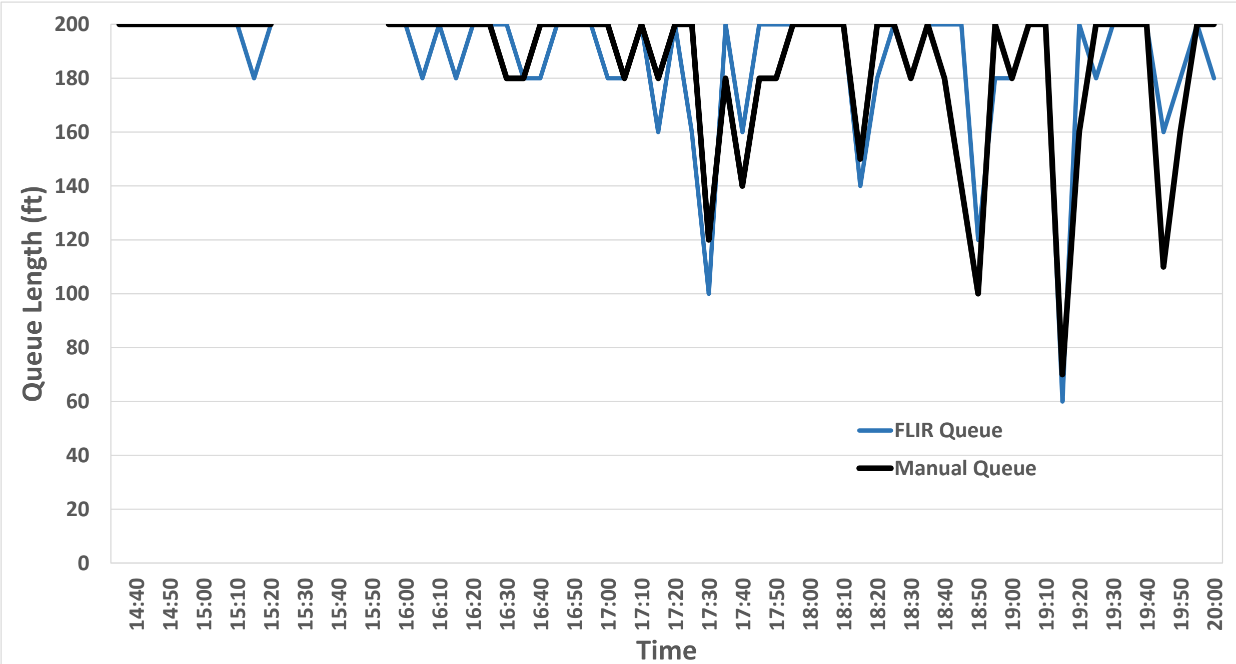


Figure 4-28. FLIR vs. Ground-Truth for 5-Minute Maximum Queue Length for Scenario (2-50)

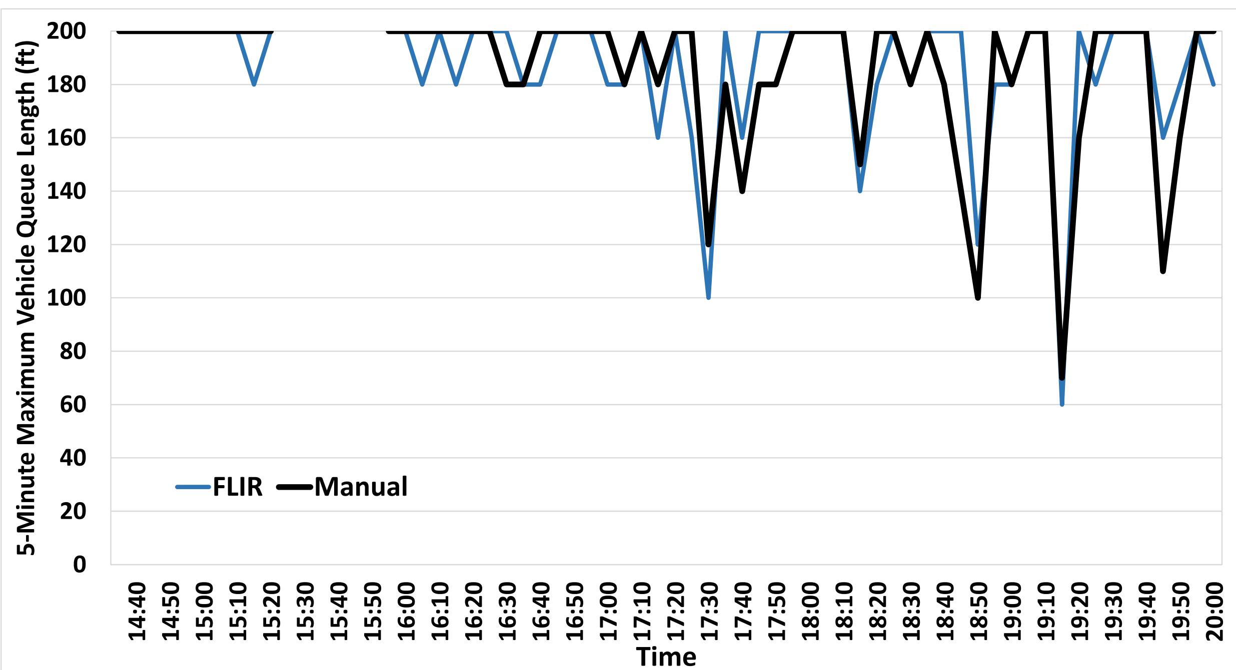


Figure 4-29. FLIR vs. Ground-Truth for 5-Minute Maximum Queue Length for Scenario (2-65)

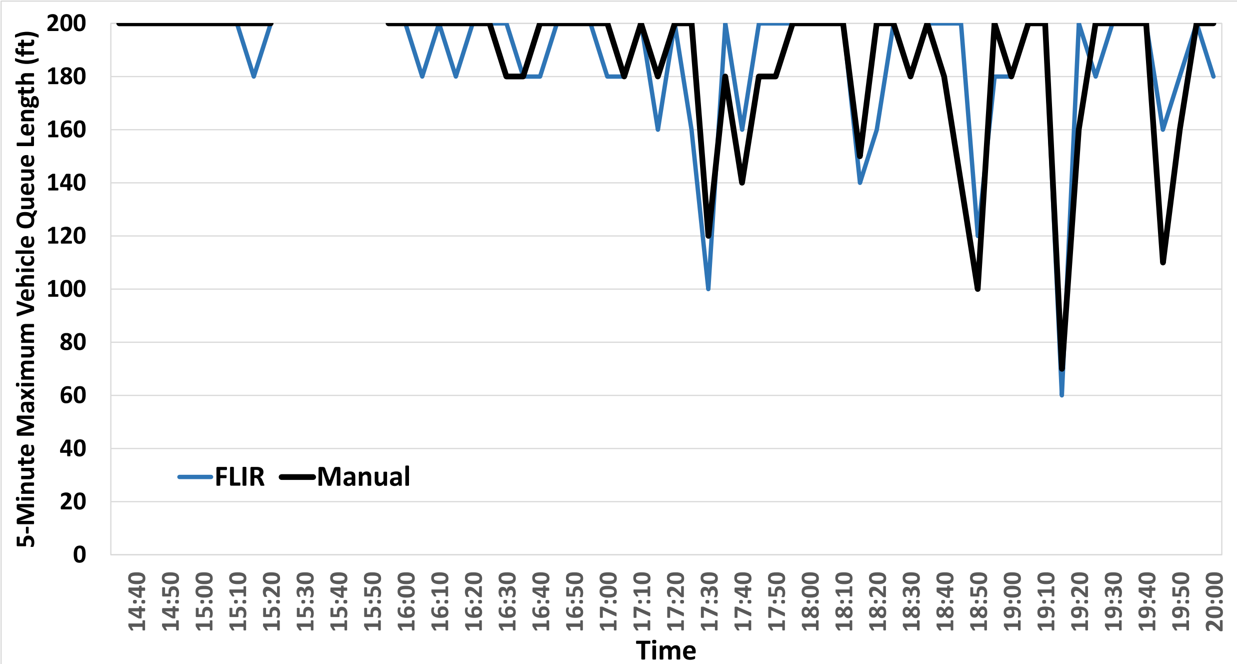


Figure 4-30. FLIR vs. Ground-Truth for 5-Minute Maximum Queue Length for Scenario (2-80)

4.7. Summary of Test Results

The field tests of all three commercial video detection systems were successfully completed as planned. However, GRIDSMART and ITERIS provided only video and vehicle count data for this evaluation. FLIR provided the most complete data, which included vehicle counts, vehicle occupancies, and average and maximum vehicle queue lengths. Table 4-7 summarizes the results based on the Mean Absolute Percentage Error (MAPE) performance measurement on 5-minute interval data. The following conclusions can be made from the results:

- The FLIR video detection system gave the most accurate vehicle counts among the three systems tested, achieving a low overall MAPE of 3.7%.
- The FLIR system detected vehicle occupancy data that closely matched the loop detector data from the *SunGuide* database. With adjustments for the difference in detector size, the system achieved a low MAPE of 5.9%.
- The FLIR system was able to measure average vehicle queue lengths that match well with those estimated from manual measurement. This is more clearly evidenced from trend lines presented in Figures 4-17 through 4-23. Although the MAPE statistics are higher compared to those for the other performance measures, it is considered good considering the uncertainties associated with moving ramp queues.
- The FLIR system similarly provided good estimates of the maximum vehicle queue lengths.
- The FLIR system performed equally well under both daytime and nighttime conditions.
- The FLIR system demonstrated that it could combine data from multiple cameras, in this application, for vehicle queues that are longer than what one camera can cover.

Table 4-7. Summary of Overall Results

Performance Measures	Vendor	MAPE		
		Day	Night	Day and Night
Vehicle Counts	GRIDSMART	10.5%	13.5%	11.6%
	ITERIS	5.1%	44.0%	19.7%
	FLIR	3.3%	4.6%	3.7%
Vehicle Occupancy (without/with detector size adjustment)	FLIR	Not used[a]		13.3% / 5.9%
Average Vehicle Queue Length (feet)	FLIR	Not used[a]		24.2% - 31.4%[b]
Maximum Vehicle Queue Length (feet)	FLIR	Not used[a]		6.2% - 8.4%[b]

[a] Reason: no noticeable difference in the results between daytime and nighttime periods.

[b] For different scenario settings.

CHAPTER 5
SYSYEM EVALUATION AND RECOMENDATION

This chapter describes the fourth key task of this project, which was to continue the feasibility study to include evaluation of the three systems for their ease of integration with the *SunGuide* software, deployment costs, and maintenance requirements and their associated costs. Only the FLIR system was included in this evaluation as it was the only system provided positive field test results.

5.1. Ramp Signal Application Needs

The ramp signal system on I-95 in FDOT District 6 (D6) applies the fuzzy-logic ramp signaling algorithm. Figure 1 shows the general detector configuration that is used to provide real-time traffic data feeds to implement the algorithm. As shown in the figure, the set of detectors includes two on the on-ramp and two on the freeway mainline. The algorithm makes use of the vehicle occupancy data from all four detectors. In addition, the queue detector at the stopline also detects vehicle presence. For the two mainline detectors, the algorithm can also make use of their speed data. However, D6 uses only data from the downstream detector because it implements the fuzzy-logic plugin used in Seattle, Washington, which does not use the data from the upstream local detector.

Although vehicle volumes are not used in the ramp signal control, they are collected by all the D6 detectors for other applications. Further, there is a third detector on the ramp that is located right after the stopline. Both vehicle occupancy and volume data are collected from this detector. Note that the detector is not shown in Figure 5-1 because it is not used for ramp signal control.

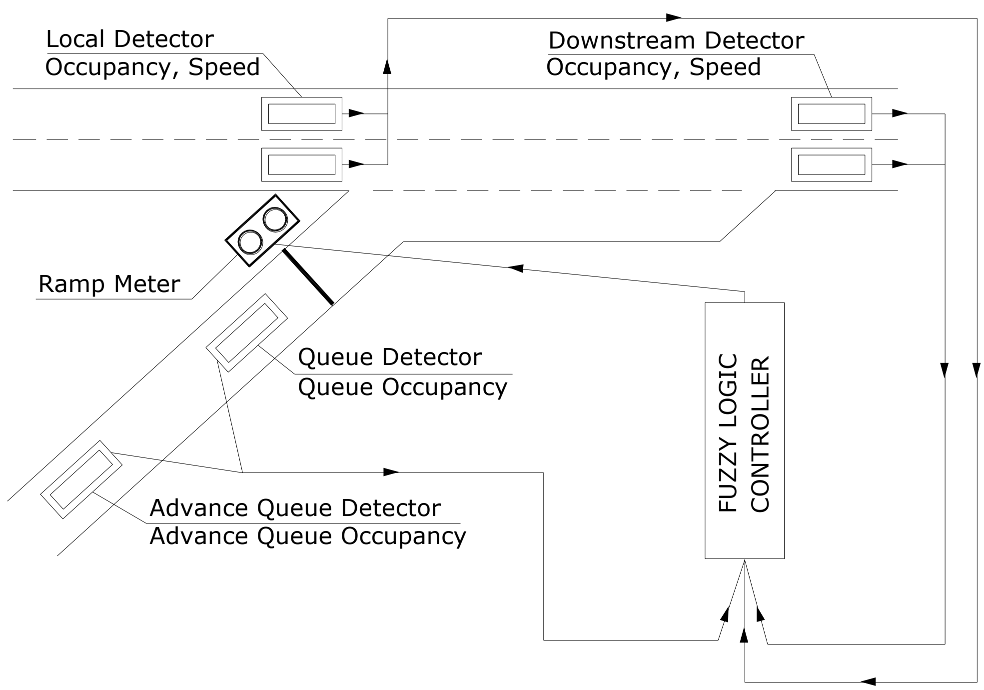


Figure 5-1. General Detector Configuration for Fuzzy Logic Ramp Signaling Algorithm

The above discussion indicates that the existing detectors collect all the traffic data needed for ramp signal control, but they do not collect the traffic data needed for ramp signal performance monitoring. The traffic measures used to monitor ramp signal performance include mainly queue lengths and waiting times. Currently, each year, only 1-3 days of queue length and waiting time data are collected manually in the field at each ramp signal location. The use of an automated video detection system would allow for continuous flow of data for ramp signal performance monitoring throughout the year.

While this project was born out of a desire to monitor ramp signal performance, a video detection system should ideally be able to also provide the data used in controlling the ramp signals. This would help to add benefits and better justify the investment. For ramp signal control, it is required that the video detection system be integrated with the *SunGuide* software to provide real-time data feeds, including vehicle presence, occupancy, and mainline speed.

For ramp signal performance monitoring, the video detection system can operate independently from the *SunGuide* software, and the data do not have to be processed and transmitted in real time. The system is only required to provide accurate estimates of average and maximum queue lengths (up to the maximum ramp length) and the average waiting time or delay.

5.2. Detection and Estimation of Traffic Measures

The field test conducted as part of this project included vehicle volumes, occupancies, and queue lengths (both average and maximum). The test was limited to only the on-ramp detectors and did not include the downstream detector on the freeway mainline. As documented in the previous chapter, the test results show that the FLIR system produced very accurate estimates of all of the traffic measures evaluated. The test did not include average waiting times because none of the systems was designed to collect such data at the time of the test. However, average waiting times can be estimated from queue lengths and vehicle counts, which the FLIR system has shown to be capable of collecting. FLIR has further confirmed to the research team that it would implement a function to estimate average waiting times from queue lengths and vehicle counts.

Unlike the data used for ramp signal control, which come only from individual video detectors, the estimation of queue lengths requires the combined data from multiple video detectors. As such, the data must be transmitted to a central system for data integration prior to queue estimation. This central system for FLIR is FLUX. FLUX can be installed on a Windows server at the TMC. It can be configured to receive data from its video detectors through FDOT's fiber communication backbone. The system will be used to integrate data from multiple video detectors to estimate average queue lengths, maximum queue lengths, and average waiting times. All FLUX data can be saved to a local server for historical analysis. Access to the FLUX interface can be through either a Web browser for remote access or a regular workstation screen at the TMC.

5.3. Integration with *SunGuide* Software

The detection and processing of data for performance monitoring are independent of the *SunGuide* software, thus requiring no *SunGuide* integration. However, for ramp signal control, the video detection system must be integrated with the *SunGuide* software, which controls the ramp signal system. In essence, the *SunGuide* software would need to be modified to take the field traffic data from the video detectors instead of from the current loop/Sensys Networks detectors. Programmers from FLIR and SwRI could work together to implement this change.

The FLIR system including FLUX was designed with open architecture, making it easy for integration with other systems. It provides two options for the *SunGuide* software to obtain the data feeds from its video detectors. One is for the *SunGuide* software to pull data from the video detectors via its REST APIs using HTTP requests. A second option is for the *SunGuide* software to subscribe to data events via its subscription APIs using WebSocket to push data from the video detectors. This option would allow the video detectors to push the data whenever available and was expected to be more suitable for this ramp signal application.

5.4. System Deployment Costs

Table 5-1 lists the one-time costs for key components in deploying the FLIR system on just the ramps. It is assumed that D6 will continue to use the existing downstream detectors on the freeway mainline. Depending on the length of a ramp, which currently ranges from 200 to 1,200 feet for those on I-95, a total of two to five video detectors may be needed at each ramp. A minimum of two detectors are needed to cover the stopline and ramp entrance detections. Each of these detectors could cover up to 200 feet. Thus, for ramps longer than 400 feet, additional detector(s) would be needed, each covering up to 300 feet from a side-fire position.

FLIR offered a hardware warranty period of three years, but could be extended to a maximum five years at a fee of 7% of the basic product price per extra year. A 5% hardware spare was recommended to make sure there would be sufficient hardware over a 10-year period (assuming a 10-year hardware mean time between failures).

Table 5-1. One-Time FLIR System Deployment Costs

Item	Purpose	Units	Unit Price
TrafiSense BPL 345	FLIR's Video detector	Minimum 2 per ramp	$2,800
TI x-Stream EDGE BPL	Provide Broadband over Power Lines (BPL) interface to video detectors.	1 per ramp	$600
FLUX License*	FLIR's central control software system	1	$4,000
Queue Length and Waiting Time Plugin on FLUX	Detect average and maximum queue length and average waiting time.	1 per video detector	$300
IMUX (optional)	Provide live video streaming for real-time video monitoring.	1 per video detector	$120
LineCount License (optional)	For video detector locations that may require more accurate vehicle counts	1 per video detector	$500

* Handle up to 200 video detectors.

Other deployment cost items that were not quantified include:

- System installation including initial configuration, fine-tuning, and verification (2-3 days per ramp, at $125 per hour per person including per diem and travel costs).
- Programming service for integration with the *SunGuide* software.

- New support structures including poles, pole bases, conduit, pull boxes, cables, etc. Note that because ramp traffic is generally one-lane, side-fire video cameras can be positioned relatively low, thus only smaller poles are needed.

5.5. Maintenance Requirements and Costs

The required hardware maintenance services of the FLIR system included:

- Camera cleaning: A regular service of once a year can be scheduled. The system has the ability to detect and send an alarm to signal a need for camera cleaning when the images are degraded to a certain level due to dust and other rare cases of spiders living in front of the lens, etc.
- System check: it was recommended that the system configuration setting be checked once a year to make sure that all detection zones are still on the same position.

It was estimated that these services would take a maximum of two days a year, at $125 per hour per person including per diem and travel costs. FLIR could also provide training so that these services could be performed in-house.

For software maintenance, FLIR offered a maintenance contract at $5,000 a year to keep all software up to date.

In terms of calibration, the system would only need to be calibrated once during initial system configuration and would not need to be recalibrated afterwards.

5.6. Remarks

The next task of this project was to develop a software specification for the development of a Web-based data visualization system for ramp signal performance monitoring. The task was put on hold temporarily as FDOT decided to conduct a pilot project (outside the scope of this project) to ensure that the FLIR system could be integrated with the *SunGuide* system and it could replace the current ramp signal loop detectors for ramp signal operations. For this pilot project, the vendor would work directly with the *SunGuide* system developer (Southwest Research Institute) directly and would include two one-month phases. The first phase would have both the existing loop-based system and FLIRs video-based detection system working in parallel in actual operations for one month. If the data from both systems were found to be comparable, the pilot project would move to the second one-month phase, which would have FLIR’s video detection system working by itself in actual operations. Based on the results from the pilot project, FDOT would then make a final determination on the feasibility of using video detection system to replace the existing loop detection system for ramp signal operations. After the pilot project was completed with positive results, DOT decided to move ahead with the development of the Web-based data visualization system, which is described in the next chapter.

CHAPTER 6
DEVELOPMENT OF THE SUNGUIDE DATA VISUALIZATION SYSYEM

This chapter describes the last key task of the project, which was to develop a Web-based performance data visualization system based on a software specification and development plan that was approved by FDOT. The system, named the *SunGuide Data Viewer*, provides a user-friendly interface for visualizing *SunGuide* detector data for the purpose of performance monitoring. As the *SunGuide* database structure is standardized across all detectors and the entire state, the system is applicable to all detectors in all FDOT districts.

6.1. System Capabilities

The *SunGuide Data Viewer* is designed to dynamically aggregate and display detector data on a chart based on a selected data interval (e.g., five-minute), within a selected time period, and over one or more selected days. The system can also display the ramp signal period (for ramp signal detectors) and nearby traffic incidents that occurred within the selected time periods and days. To achieve these capabilities, the system makes use of the following *SunGuide* data sets: (1) performance measures including those from the detectors and the ramp queues (when the data become available), (2) ramp signal operations status, (3) traffic incidents, and (4) ITS device locations. Designed to be user-friendly, the system provides an interface that allows the user to easily make user selections and instantaneously update the data display with every user selection. The system also allows the data and the charts to be exported for external use, such as for posting on the *sunguide.info* website.

6.2. System Platforms

The system is designed as a Web-based desktop application and is compatible with all commonly used Web browsers, including Internet Explorer, Edge, Chrome, Firefox, and Safari. Developed using C# with Microsoft SQL Server, the system runs on the Microsoft Windows Server operating system with .NET Framework 3.5. In addition, the system makes use of the *Google Maps* APIs for its mapping functions and the *Google Charts* for charting. To comply with FDOT's Application Development Documentation and Guidelines, the system is developed in N-Tier architecture and all file and data paths were "soft" coded and stored in the system configuration file.

6.3. System Login and User Types

Figure 6-1 shows the login page of the system. The login credentials include a username and a password. The username is defaulted to the user's email. The page also includes a *Forgot your password* link that allows a password to be sent to the user's email. The system includes two user types, i.e., system administrator and general user. The only difference between the two user types is that a system administrator has the additional function of managing the user accounts (see Section 6.5). When logging into the system, the system will automatically recognize the user type and provide the access privilege accordingly.

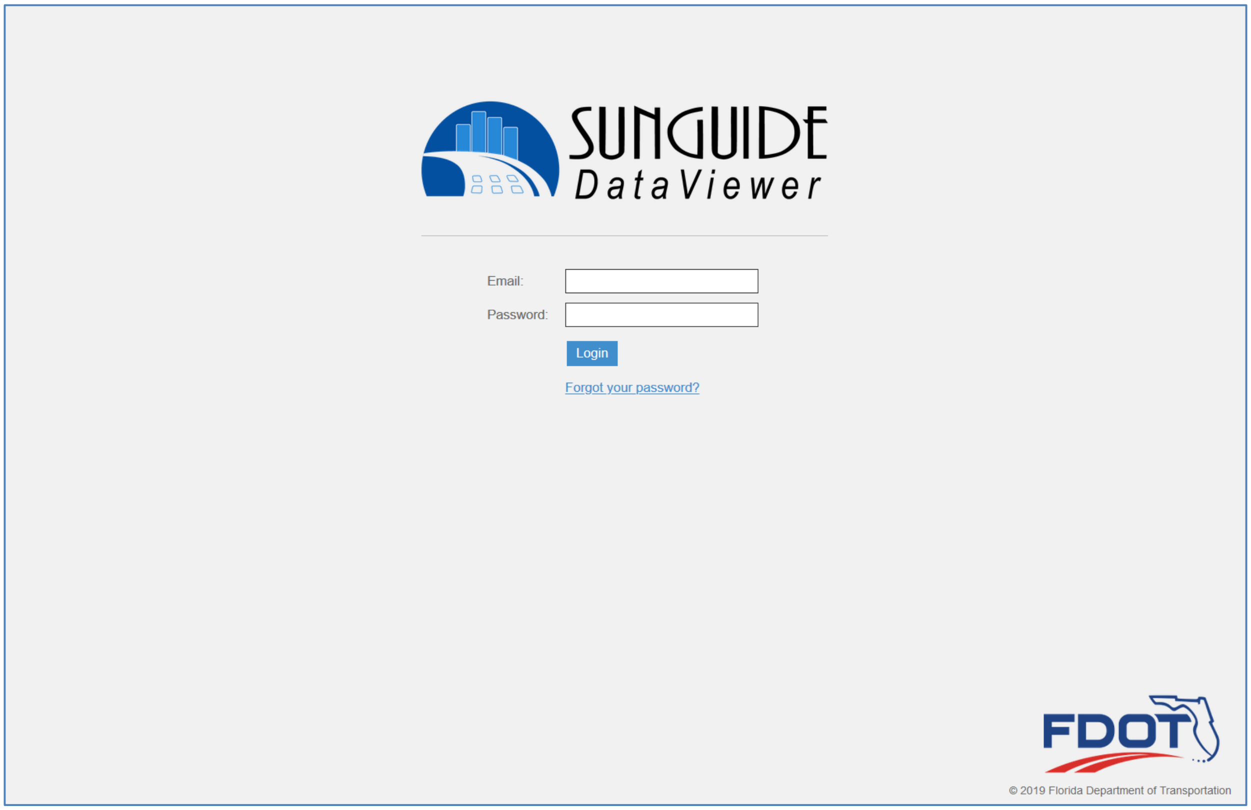


Figure 6-1. System Login Page

6.4. System Main Page

Figure 6-2 shows the main page that is displayed when the user first logs into the system. The page includes two areas, i.e., a banner area on top which is always displayed, and a display interface area below the banner.

The banner area displays the system logo, the FDOT logo, and a set of six action links that allows the user to access the different functional areas of the system, as follows:

1. The *Users* link allows the user to display and manage the user accounts. The link appears only when the user type is *System Administrator*. (See Section 6.5 for further details)

2. The *Chart* link allows the user to display the detector and incident data. It is the default display area when the user first enters the system. (See Section 6.6 for further details)

3. The *Settings* link allows the user to customize the data display settings. (See Section 6.7 for further details)

4. The *Export* link allows the user to export: (a) a chart to a JPG, PNG, TIFF, Excel, or PDF file; and (b) the chart data and the incident data to an Excel file. (See Section 6.8 for further details)

5. The *"User's name"* link always displays the user's name. It allows the user to view and edit the user account information, including the password.

6. The *Logout* link allows the user to log out from the system and exit to the *Login* page,

The first four functional areas are further detailed below.

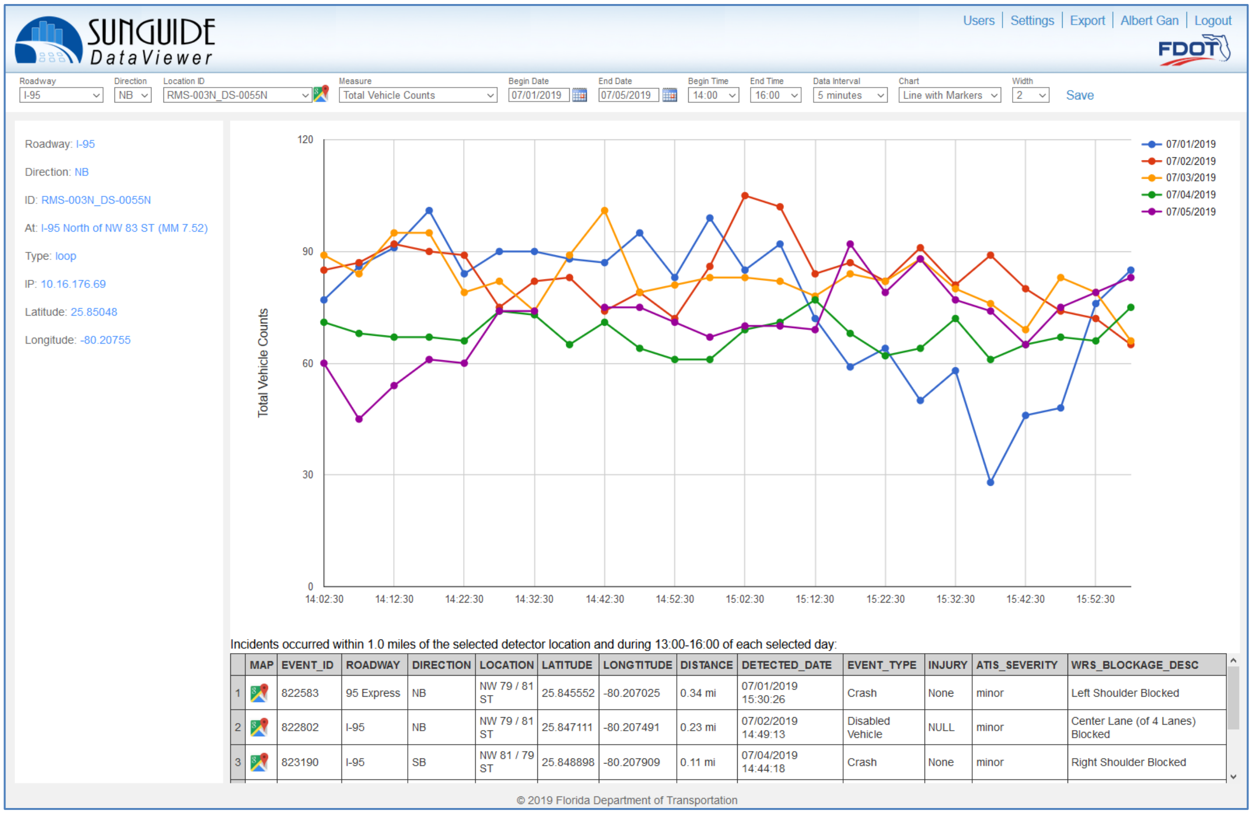


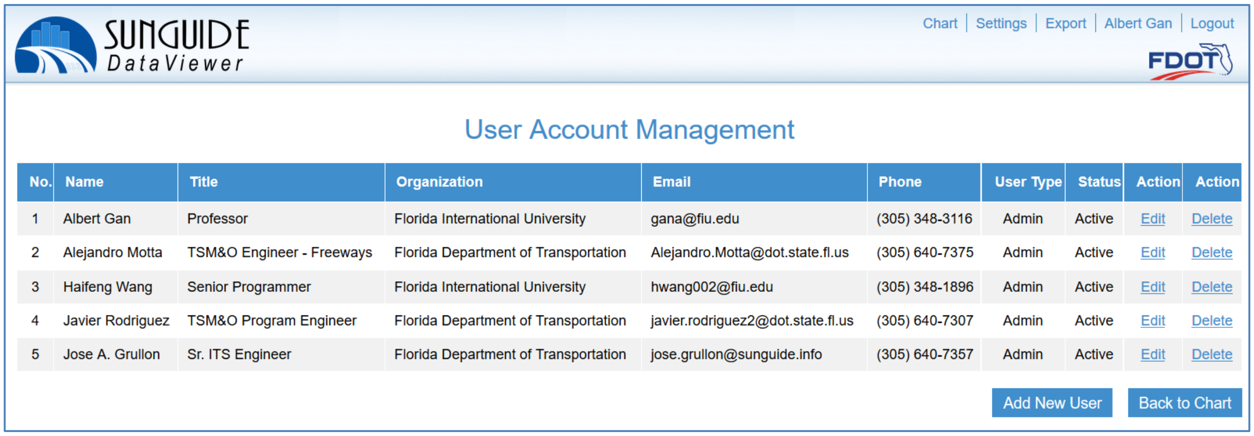
Figure 6-2. System Main Page

6.5. User Account Management Functional Area

Figure 6-3 shows an example of the display area for *User Account Management*. The area is displayed after clicking the *Users* link. As noted previously, the link appears only if the user type is *system administrator*. The display area allows a system administrator to add, edit, or delete a user account. It lists all existing user accounts, which are identified by the user's name, title, organization, email address, and phone number. A system administrator can create a new user account by first clicking the *Add New User* button and then filling out the user account information. As shown in Figure 6-3, the account information also includes a temporarily assigned password. When a new user account is created, an email is automatically sent to the user's email address. The email informs the new user of his/her account creation and reminds the user to update his/her password in the system.

6.6. Data Visualization Functional Area

As shown in Figure 6-2, the *Data Visualization* functional area located below the banner is divided into four panes: the *Query* pane on top, the *Location Information* pane to the left, the *Chart* pane right below the *Query* pane, and the *Incident* pane at the bottom. Each of these panes is described below in further details.



No.	Name	Title	Organization	Email	Phone	User Type	Status	Action	Action
1	Albert Gan	Professor	Florida International University	gana@fiu.edu	(305) 348-3116	Admin	Active	Edit	Delete
2	Alejandro Motta	TSM&O Engineer - Freeways	Florida Department of Transportation	Alejandro.Motta@dot.state.fl.us	(305) 640-7375	Admin	Active	Edit	Delete
3	Haifeng Wang	Senior Programmer	Florida International University	hwang002@fiu.edu	(305) 348-1896	Admin	Active	Edit	Delete
4	Javier Rodriguez	TSM&O Program Engineer	Florida Department of Transportation	javier.rodriguez2@dot.state.fl.us	(305) 640-7307	Admin	Active	Edit	Delete
5	Jose A. Grullon	Sr. ITS Engineer	Florida Department of Transportation	jose.grullon@sunguide.info	(305) 640-7357	Admin	Active	Edit	Delete

Figure 6-3. User Account Management Display Area

6.6.1. Query Pane

The *Query* pane allows the user to select specific data to be plotted. Specifically, it allows the user to:

1. Select a detector location from dropdown lists or the *Google Maps*. To allow the user to quickly identify and select a detector location, the locations selected from the dropdown lists are filtered by roadway (e.g., I-95) and direction (e.g., SB). To select a location using the *Google Maps*, the user first clicks the *Google Maps* icon next to the Location ID dropdown list, which opens a screen as shown in Figure 6-4. Each detector location is represented with a triangular icon that points in the travel direction. The selected detector location is highlighted with a red standard *Google Maps* icon. The user can click or re-click a detector icon to select or deselect it. Regardless of whether a detector location is selected from dropdown lists or *Google Maps*, the selection is consistently shown on both the *Query* pane and the map. The user can click the “X” button on the map close it and return to the chart display.

2. Select a performance measure, which can be: (a) total vehicle counts, average vehicle speed, and average vehicle occupancy; and (b) average queue length, maximum queue length, and average waiting time (when the data are available).

3. Select the begin and end data dates, which can be a range of one or more days.

4. Select the begin and end data hours, which can be a time period within each selected day.

5. Select the data interval, which may be 20-second, 1-minute, 5-minute, 10-minute, 15-minute, 30-minute, hourly, and daily. Based on the selected data interval, the system will dynamically perform the data aggregation accordingly, and will display the results on a chart instantaneously. In the case that the user selections result in more data points than can be plotted, the system will automatically select the next feasible data interval and a warning message will appear below the chart to inform the user of the change in the data interval used.

6. Select the chart type (column, bar, or line). For line charts, the user can further select the line width and whether to show the line markers. All charts are two-dimensional, with the x-axis plotting the data intervals and the y-axis plotting the performance measure. When multiple days are selected, the chart will plot the data for each day with a separate bar or line. One exception is when the selected data interval is “daily”, in which case, the chart will plot the daily totals or averages for the selected time period. Figure 6-5 shows such an example.

The user may click the *Save* link next to the last dropdown list to save all the selections. The selections will be automatically set the next time the user logs into the system.

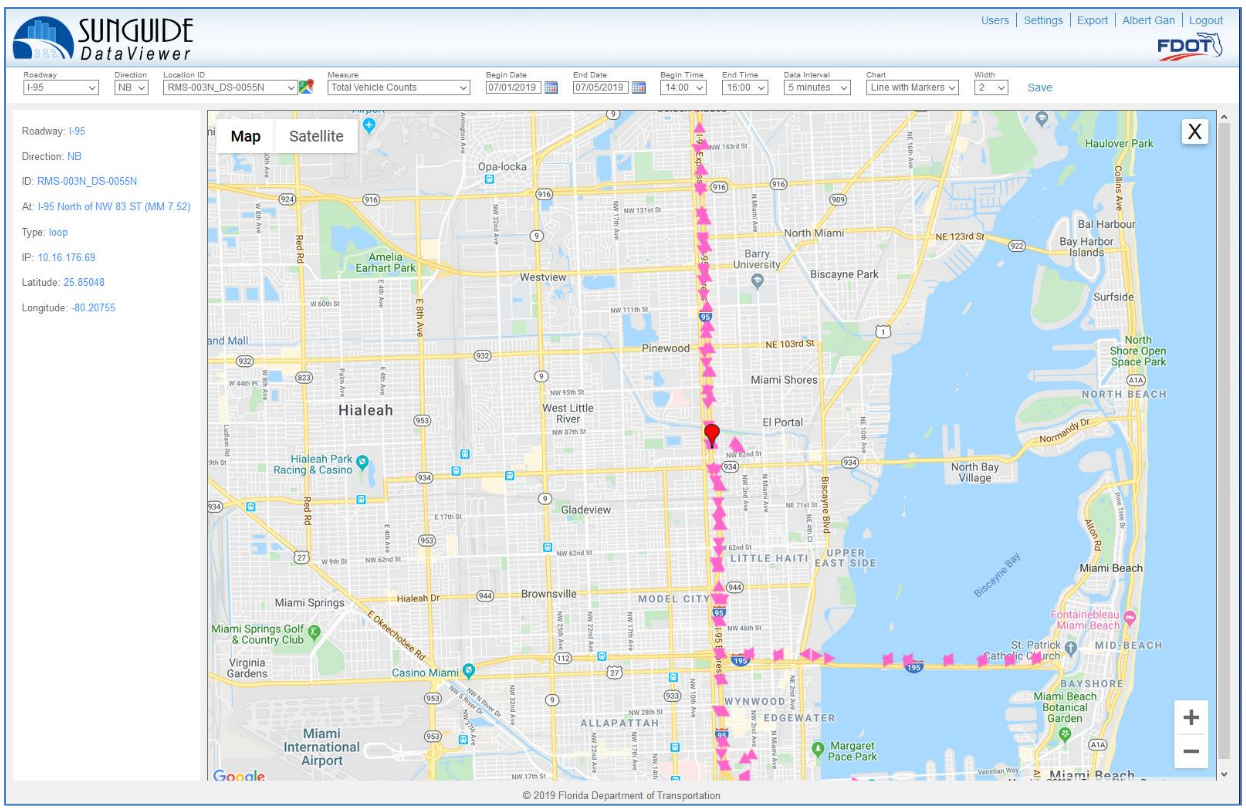


Figure 6-4. Location Selection Via Google Maps

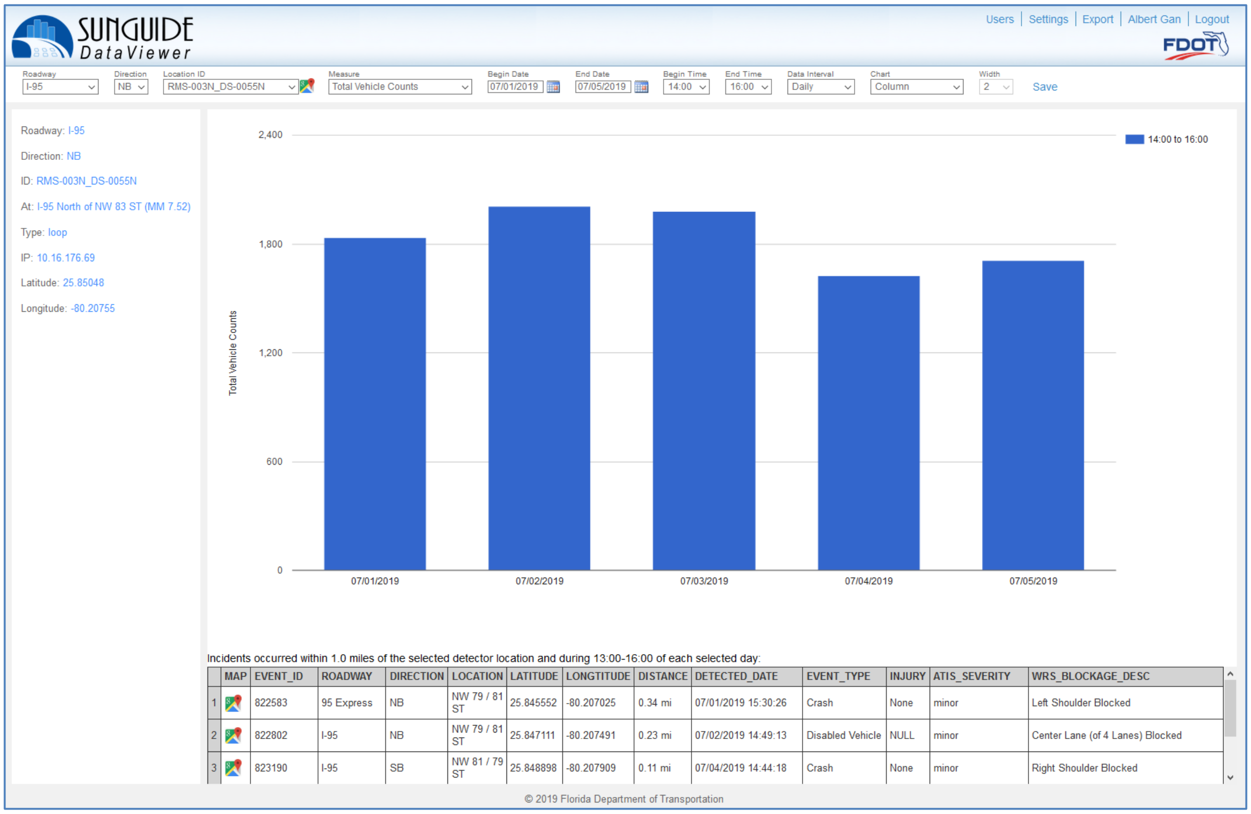


Figure 6-5. Sample Plot of Total Vehicle Counts Each Day (during 14:00-16:00)

6.6.2. Location Information Pane

The *Location Information* pane displays the detector location attribute data and the ramp signal status (when a ramp signal location is selected). As shown in Figure 6-5, the location attributes include roadway ID, travel direction, detector ID, detector location description, detector type, detector IP address, and detector latitude/ longitude coordinate.

6.6.3. Chart Pane

The *Chart* pane displays the chart based on the user selections on the *Query* pane. The same area is also used to display the *Google Maps* for selecting detector locations via the map (see Figure 6-4). The chart is automatically refreshed as soon as the user makes a new selection. The chart is designed to be size-responsive, i.e., it will automatically re-size to take up the available space in the *Chart* pane. This can be particularly useful for users who use multiple monitors, as it allows a chart with many data points to spread across multiple monitors.

6.6.4. Incident Pane

The *Incident* pane displays all incidents that occurred: (1) within a certain distance of a selected detector location, and (2) up to a certain number of hours prior to the selected begin time period of each day. The incident information allows the user to determine how the detector data being displayed on the chart may have been affected by incidents. The user can click the *Google Maps* icon of each incident record to plot the incident locations on the *Google Maps*. As shown in Figure 6-6, the map shows the selected detector location with a red triangular icon, the selected incident (i.e., of which the *Google Maps* icon was clicked) with a red balloon icon, and each of the other incidents with a green balloon icon.

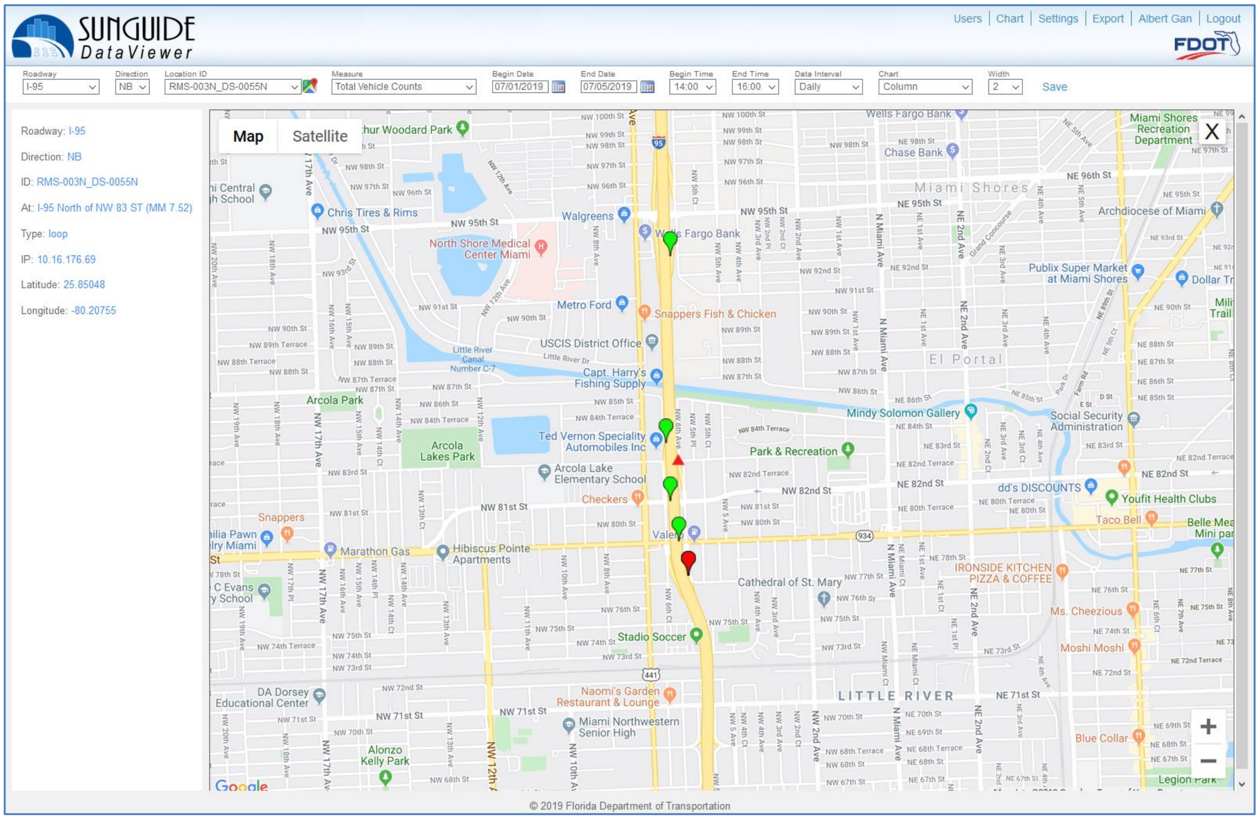


Figure 6-6. *Google Maps* Display of Incident Locations

6.7. User Settings Functional Area

The *User Settings* functional area is opened by clicking the *Settings* link in the banner. As shown in Figure 6-7, this functional area allows the user to customize four user-preferred settings for the *Data Visualization* functional area, as follows:

1. The user can check specific performance measures to be listed on the *Measures* dropdown list.

2. For each performance measures, the user can choose to indicate the minimum percentage of missing 20-second data allowed for data aggregation to take place. For example, for five-minute data interval, indicating a minimum of 0% in the dropdown list for a performance measure will require that all original 20-second data be present for the data aggregation to take place. Similarly, a minimum of 50% will require that at least half of the original 20-second data be present (i.e., if the location has three detectors, at least 23 of the total 45 original 20-second data are required to have a value). A data interval for which

the aggregate value is not calculated will show up as a gap on the chart.

3. The user can specify the maximum distance from the detector location within which a traffic incident is considered to have a potential impact on the detector/ramp data, thus to be listed in the *Incident* pane (see Section 6.6.4).

4. For those incidents located within the minimum distance as defined above, the user can further specify to include only those that occurred a certain number of hours prior to the data begin time of each day. Accordingly, if one hour is specified and the selected time period is 14:00 to 16:00, it will include incidents that occurred during 13:00-16:00.

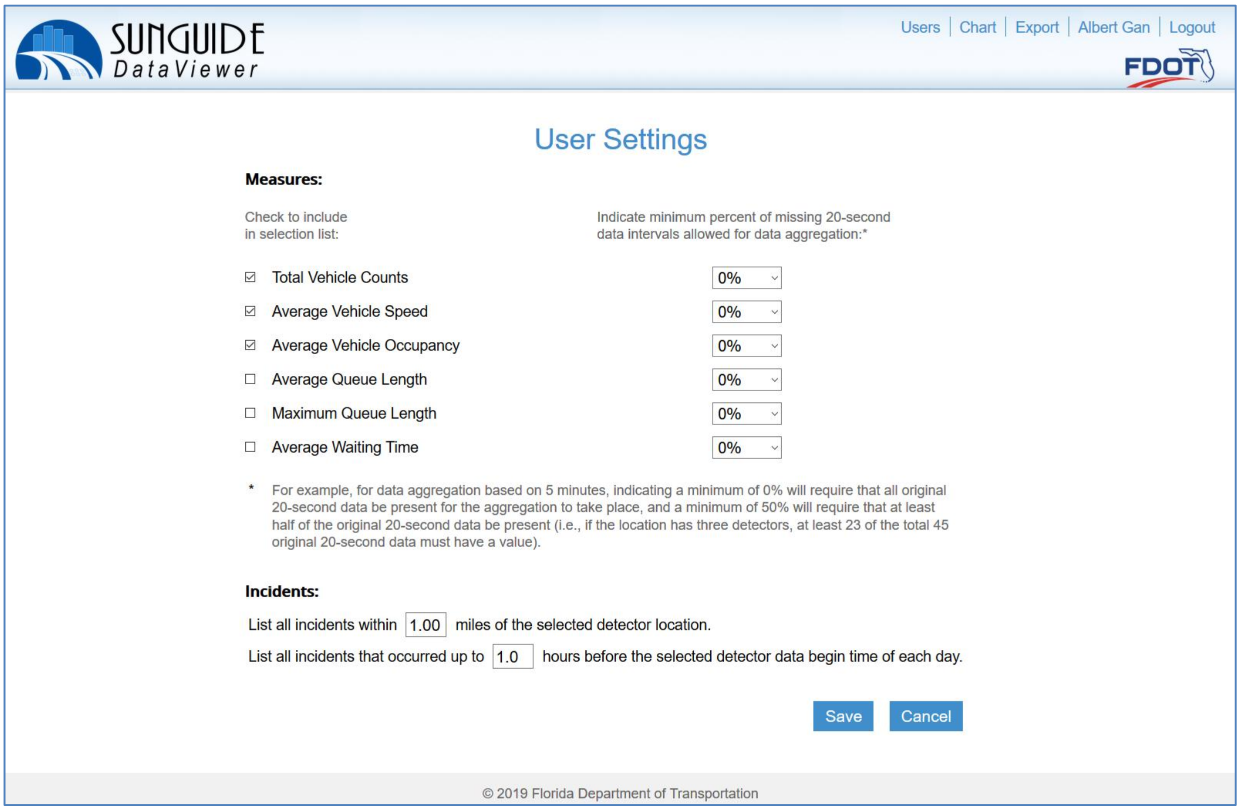


Figure 6-7. User Settings Functional Area

6.8. Data Export Functional Area

The *Data Export* functional area is opened by clicking the *Export* link in the banner. As shown in Figure 6-8, this functional area allows the user to select the type of data (i.e., chart, chart data, or incident data) to save to an external file in a selected file format. A chart can be saved as a JPEG, PNG, TIFF, or PDF file, and a chart data set or a set of incident records can only be saved to an Excel file. Once the data type and file format are selected, the user can click the *Save* button to prompt a dialog box for the user to enter a name for the external file to save the data to.

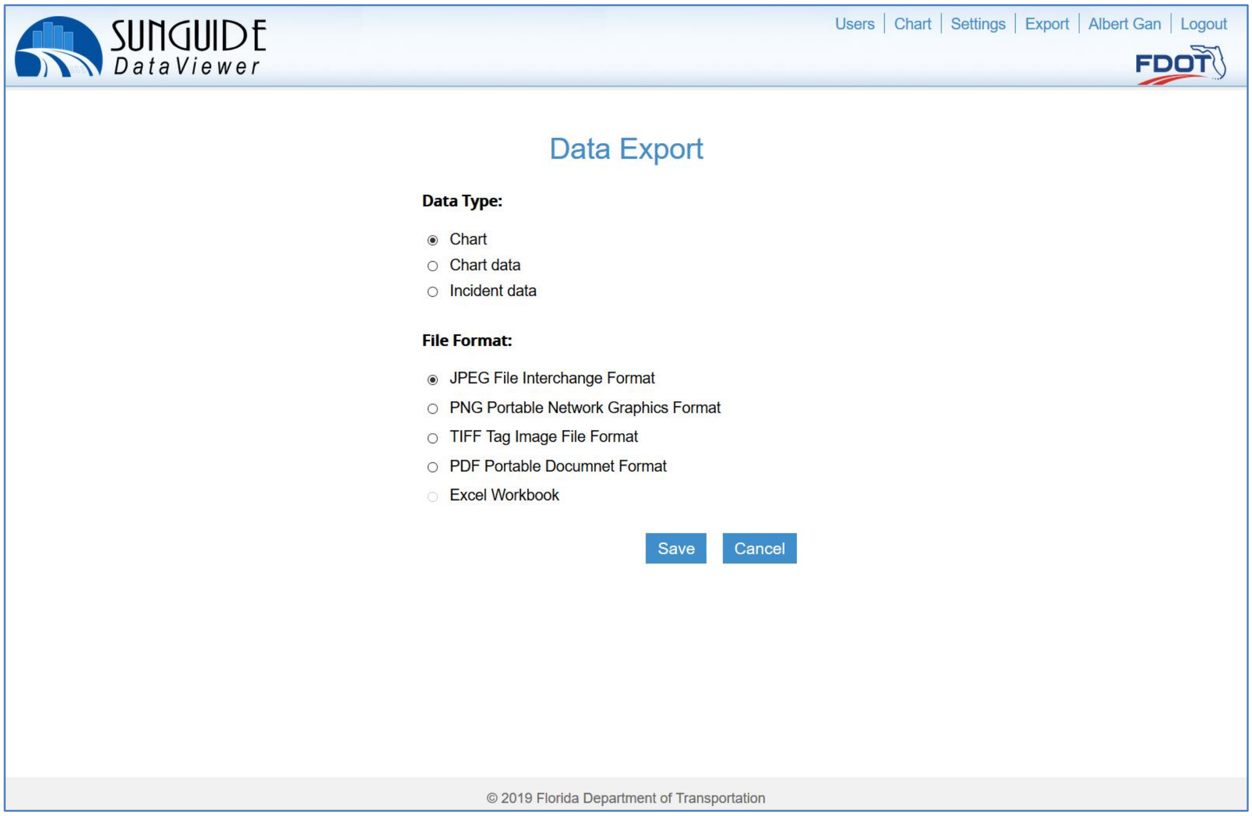


Figure 6-8. Export Functional Area

CHAPTER 7
SUMMARY AND CONCLUSIONS

District 6 Florida Department of Transportation (FDOT) has been using a mix of inductive loops and Sensys Networks sensors at its 22 ramp signals on I-95 in Miami-Dade County, Florida. These detectors can detect both vehicle passages and presence, but are not designed to collect traffic measures such as queue length and delay (or travel time), which are needed for monitoring the performance of ramp signals. This project investigated the feasibility of using a video detection system in lieu of the current detectors for both ramp signal operations and performance monitoring. The project also developed a Web-based system for visualizing performance data to assist in the tasks of performance monitoring. As the detector data structures in the *SunGuide* database are standardized across all detectors throughout the state, the system is applicable to all detectors in all FDOT districts.

The very first task of the project involved the identification of the existing video detection systems for field accuracy tests. A survey involving a set of 18 questions was posted to five potential vendors. The questions were aimed at obtaining preliminary information on the general capabilities of each vendor's system to help select three potential systems to participate in the field tests. Also included were questions on licensing costs, technical support, and field evaluation requirements. However, this information was not used to select the systems for field tests. Based on a review of the vendor responses to the survey questions, the following three vendors with their products were first invited to participate in the field tests:

- Autoscope Terra Technology from Econolite
- TrafiSense from FLIR ITS
- GridSmart System from GRIDSMART, Inc.

A detailed field test plan was developed and shared with the three invited vendors. The test plan provided details on the tests, including the project background, test objective, responsible agencies and contacts, target test data, test location and test period, data evaluation method, review of test results by participants, travel support for participants, and publication requirements. After reviewing the test plan, one vendor (Econolite) decided to not participate in the test. The vendor indicated that they had a new product that was to be released soon, but was not ready for this field test. After consultation with the FDOT project managers, a new invitation was extended to ITERIS and was accepted.

Three field tests were conducted, one for each of the three participating vendors on the following dates:

- March 2, 2017 (Thursday): GRIDSMART Technologies
- March 6, 2017 (Monday): ITERIS
- March 8, 2017 (Wednesday): FLIR ITS

After the field tests were completed, GRIDSMART and ITERIS provided only their vehicle count data for evaluation. FLIR provided the most complete data, which included vehicle counts, vehicle occupancies, and average and maximum vehicle queue lengths. The overall detection accuracy test results based on the Mean Absolute Percentage Error (MAPE) with 5-minute data interval are summarized in Table 7-1 (reproduced from Table 4-7).

Table 7-1. Summary of Overall Results

Performance Measures	Vendor	MAPE		
		Day	Night	Day and Night
Vehicle Counts	GRIDSMART	10.5%	13.5%	11.6%
	ITERIS	5.1%	44.0%	19.7%
	FLIR	3.3%	4.6%	3.7%
Vehicle Occupancy (without/with detector size adjustment)	FLIR	Not used[a]		13.3% / 5.9%
Average Vehicle Queue Length (feet)	FLIR	Not used[a]		24.2% - 31.4%[b]
Maximum Vehicle Queue Length (feet)	FLIR	Not used[a]		6.2% - 8.4%[b]

[a] Reason: no noticeable difference in the results between daytime and nighttime periods.
[b] For different scenario settings.

The following conclusions were made from the above test results:

- The FLIR video detection system gave the most accurate vehicle counts among the three systems tested, achieving a low overall MAPE of 3.7%.
- The FLIR system detected vehicle occupancy data that closely matched the loop detector data from the *SunGuide* database. With adjustments for the difference in detector size, the system achieved a low MAPE of 5.9%.
- The FLIR system was able to measure average vehicle queue lengths that match well with those estimated from manual measurement.
- The FLIR system similarly provided good estimates of the maximum vehicle queue lengths.
- The FLIR system performed equally well under both daytime and nighttime conditions.
- The FLIR system demonstrated that it could combine data from multiple cameras, in this application, for vehicle queues that are longer than what one camera can cover.

System Evaluation and Recommendation

After the field tests, the systems were to be further evaluated for selection criteria beyond their field detection accuracy. Given the one-sided results from the field tests, only the FLIR system was included this evaluation. The evaluation provided information on the ramp signal application needs and the FLIR system's capabilities to detect and estimate traffic measures, methods for integrating with the *SunGuide* software, preliminary estimation of system deployment costs, and maintenance requirements and associated costs.

Development of Data Visualization System

A Web-based system was developed for visualizing *SunGuide* detector data for the purpose of performance monitoring. The system is able to dynamically aggregate and display detector data on a chart. The system can also display the ramp signal period (for ramp signal detectors) and nearby traffic incidents that occurred within the selected time periods and days. The system makes use of the following *SunGuide* data sets: (1) performance measures including those from the detectors and the ramp queues (when the data become available), (2) ramp signal operations status, (3) traffic incidents, and (4) ITS device locations. As noted previously, the system is generally applicable to all FDOT districts, as the *SunGuide* database structure is standardized across all detectors and the entire state.

APPENDIX A:
EXISTING STUDIES

1. Traffic Counting Using Existing Video Detection Cameras
Final Report prepared by Sherif Ishak, Julius Codjoe, Saleh Mousa, Sydney Jenkins, Jennifer Bonnette, Department of Civil and Environmental Engineering, Louisiana State University, for the Louisiana Department of Transportation and Development, November 2015.

Abstract:
The purpose of this study is to evaluate the video detection technologies currently adopted by the city of Baton Rouge and DOTD. The main objective is to review the performance of Econolite Autoscope cameras in terms of their ability to detect data, ease of use, accessibility to data, security issues and cost. The final goal of this project is to investigate the effectiveness of this video detection technology in traffic data collection at signalized intersections in Baton Rouge and to judge the reliability of integrating the traffic count data from the Autoscopes into a database that could be used to supplement traffic count information at any time. In order to accomplish these tasks, a sample of intersections was selected for analysis from an inventory detailing each site's traffic volume, lighting conditions, turning movements, camera mounting type, technology used, and geometric characteristics. Volume counts from the video detection technology (camera counts) were statistically compared against ground truth data (manual counts) by means of Multiple Logistic Regression and t-tests. Using this data, the capabilities of the existing video detection system was assessed to determine the quality of the data collected under various settings. The results of this research indicate that the performance of the Solo Terra Autoscopes was not consistent across the sample. Of the 20 intersections sampled, eight locations (40%) proved to show significant statistical differences between the camera and manual counts. The results of the regression analysis showed only lane configuration, time of day, and actual traffic volumes were statistically affecting the performance of the Autoscopes. According to supplemental t-test analysis on the time of day, the least accurate counts were recorded during the morning and afternoon peak hours and late at night. When testing based on traffic volume, the camera performance worsened as the traffic volume increased; when considering lane configuration, there were statistical differences for the through lanes, right lanes, and shared right/through lanes. Due to the fact that 60% of the sampled intersections (the remaining 12 out of the 20) provided reliable performance under high traffic volumes and during the same study period and weather conditions, the research team attributed the poor performance of some of the cameras to poor calibration and maintenance of the system. It was concluded that the recalibration of the Econolite Autoscopes can significantly enhance the performance of the video detection system, and can therefore be considered a reliable means for traffic counting.

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2. Improving Stop Line Detection Using Video Imaging Detectors
Technical Report prepared by Dan Middleton, Ryan Longmire, Hassan Charara, Darcy Bullock, and Jim Bonneson, Texas Transportation Institute, the Texas A&M University System, for the Research and Technology Implementation Office, the Texas Department of Transportation, August 2009

Abstract:
The Texas Department of Transportation and other state departments of transportation as well as cities nationwide are using video detection successfully at signalized intersections. However, operational issues with video imaging vehicle detection systems (VIVDS) products occur at some locations. The resulting issues vary but have included:

- camera contrast loss resulting in max-recall operation,
- failure to detect vehicles leading to excessive delay and red-light violations, and
- degraded detection accuracy during nighttime hours.

This research resulted in the development of a formalized VIVDS test protocol and a set of performance measures that agencies can incorporate in future purchase orders and use to uniformly evaluate VIVDS products. It also resulted in the development of a VIVDS video library and conceptual plans for a field laboratory for future projects to deploy a range of VIVDS products at an operational signalized intersection. Researchers evaluated alternative VIVDS stop line detection designs and developed methods for enhancing the operation of VIVDS through adjustments in controller settings for day versus night versus transition periods, zone placement, and camera placement.

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3. **Ramp Queue Detection**
Final Report Prepared by SRF Consulting Group, Inc. for the Minnesota Department of Transportation, January 30, 2009.

Executive Summary:
A 2001 Minnesota Department of Transportation (Mn/DOT) study of ramp meter operations showed that freeway performance must be balanced with commuters' tolerance for waiting at ramp meters. Following this study, Mn/DOT added automated monitoring of wait times at meters so that metering rates can be adjusted as needed by the Regional Transportation Management Center (RTMC). The automated system limits wait times at local ramps to four minutes, while system-to-system ramps are limited to two minutes.

Finding a way to consistently and accurately monitor ramp queues in real time has proven to be a challenge. Current methods use entrance/exit counting loop detectors to generate an estimate of queue length. However, loops do not function optimally when ramp geometry does not restrict vehicles to a defined path.

This project explored alternative methods for detecting queues on freeway onramps with geometries that are not conducive to using loops. A common issue at these ramps is that they are wide enough to allow vehicles to track outside the areas where loops are placed. This can lead to double-counting if a large vehicle travels over both loops, or undercounting if the vehicle drives outside the loops. Because the existing loop detectors are inaccurate, the ramp control system must use a conservative metering rate to assure that the queue does not back up onto the local streets or allow vehicles to wait longer than the legislated two- or four-minute maximum wait times.

This project evaluated four innovative detection systems to better determine queue lengths. The first two systems do this by counting vehicles:

- *Sensys Count Array:* This system consists of a series of five in-pavement sensors placed in a line laterally across the lanes. As vehicles pass over the sensor array, they activate one or more sensors. These activations are then post-processed to determine the number of vehicles that entered the ramp.

- *Wavetronix SmartSensor HD:* A side-fire microwave radar sensor was mounted on a pole adjacent to the ramp and oriented towards the center of the set of lanes. This device detects vehicles travelling on the ramp regardless of their position within the lanes.

The other two systems are designed to directly detect the length of the queue. With the queue length known, a count can be derived, which can be applied to adjust the metering rate:

- *Sensys Queue Length Array:* Six in-pavement sensors were placed every 50 feet in alternating lanes, starting 50 feet upstream of the ramp meter and extending the entire length of the ramp. The queue length is measured by analyzing the number of detectors with slow-moving or stopped vehicles over them.

- *Wavetronix SmartSensor Advance:* This forward-firing sensor was mounted on a pole near the entrance of the ramp. It was aimed towards the ramp meters so that it would cover as much of the ramp as possible. As vehicles drove down the ramp, the sensor tracked them to determine their distance and speed. Based on those parameters, it determined when vehicles were queued and reported the length of the queue.

All four systems were found to perform accurately and to be implementable on most ramps. However, two systems are recommended because they are viable for a wider variety of ramp types. These two systems are also relatively easy to install, configure, integrate and maintain, but take different approaches to measuring the queue. The Wavetronix SmartSensor HD could be easily integrated as a loop replacement in locations where a count method is acceptable and/or preferred. For sites where queue length is a better parameter to monitor, the Sensys Queue Length Array is recommended.

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4. **Video Vehicle Detector Verification System (V2DVS) Operators Manual**
Project Final Report Prepared by Arthur MacCarley, Electrical and Computer Engineering Department, California Polytechnic State University, for the Division of Research and Innovation, the California Department of Transportation, Revision 9, March 21, 2012.

Abstract:
The accurate detection of the presence, speed and/or length of vehicles on roadways is recognized as critical for effective roadway congestion management and safety. Vehicle presence sensors are commonly used for traffic volume measurement and control of signalized intersections and ramp meters. In addition, vehicle speed, either measured directly from a

"speed trap" or estimated based on vehicle length, and classification from length are important for automated incident detection and the characterization and prediction of traffic demand.

The market has recently seen an increasing number of out-of-pavement and wireless in-pavement detection systems. These systems are easier to install and maintain than conventional inductive loop detectors, but there is evidence from pilot installations, however anecdotal, that they have different detection characteristics and can yield different results. Due to situations including lane-changing, high ground clearance, trailers and occlusion, detectors will occasionally fail to detect, falsely detect or multiply detect individual vehicles. These errors tend to cancel each other when detection data is aggregated into bins, as in common practice. Non-aggregated (i.e., individual vehicle) data is needed on how these detectors perform in different situations in order to optimally specify equipment for certain detection requirements and environments. There was previously no way to compile individual detection data or quantify detection errors without manually comparing each individual detection event record to video ground-truth, which is a labor-intensive process that is practically impossible for large datasets.

Selected out-of-pavement and wireless in-pavement detection systems, along with duplex inductive loop detectors, are installed on Route 405 in the city of Irvine to detect the passage of each northbound vehicle. Installed at the same site is the Video Vehicle Detector Verification System (V2DVS) that automates the collection and accuracy assessment of output data from all detectors under test.

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5. **Evaluation of Commercial Video-Based Intersection Signal Actuation Systems**
Final Project Progress Report prepared by Arthur MacCarley, Electrical Engineering Department, California Polytechnic State University, for the Division of Research and Innovation, the California Department of Transportation, December 30, 2008.

Project Summary:
Video cameras and computer image processors have come into widespread use for the detection of vehicles for signal actuation at controlled intersections. Video is considered both a cost-saving and convenient alternative to conventional stop-line inductive loop detectors. Manufacturers' specification and performance statements vary in the metrics used and data reported, and are inconsistent between available products. The lack of common test standards and procedures has made product selection and optimal deployment decisions difficult for local jurisdictions as well as Caltrans. Performance of these systems is difficult to ascertain by simple observation of signal actuation.

The project builds upon work conducted under the 1995-97 PATH-sponsored Video Traffic Detection System Evaluation, in which in consultation with an extensive advisory board including the FHWA, Caltrans, City traffic personnel and system manufacturers, a standardized approach for the evaluation of intersection detection systems was developed and applied to one such system deployed as part of a FHWA Field Operational Test.

The present evaluation updates and applies these standards and procedures to the testing and comparative evaluation of examples of video-based intersection signal actuation systems in general. Over a two-year period, standardized test methodologies and metrics of effectiveness (MOEs) were developed in consultation with current and potential users of these systems, system manufacturers, and colleagues at other institutions that had performed related evaluations. Technical background and product update reviews were completed multiple times during the nearly three year extended project period as technologies changed. Many lessons were learned during this process. The project as proposed required the volunteer cooperation of both the system manufacturers and traffic management agencies that deploy these systems. Unfortunately, no funding was available for the purchase of systems for testing or the reimbursement of costs associated with deployment work by local agencies, which was required to conform with local traffic safety concerns and labor restrictions.

While we had intended to be able to report independent comprehensive performance data based upon the test procedures developed in the course of this work, from at least a subset of the commercially available systems, this was ultimately not possible due to a lack of volunteer cooperation and test restrictions later raised by all except one system manufacturer. Product "warranty concerns" were also raised by the vendor of the systems that were already deployed at our local designated test intersections.
Regardless, the information and lessons learned over the course of this effort provide improved insight into both the advantages and limitations of this class of detectors.

The actual evaluation project remains an on-going effort by Cal Poly, regardless of funding. Sufficient hardware and protocol development effort in support of the final testing of the commercial systems has been completed, and will result in published system test data as negotiations continue and we succeed in obtaining the use of system for testing purposes from alternative sources.

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6. Evaluation of Non-Intrusive Technologies for Traffic Detection
Final report prepared by Erik Minge, Jerry Kotzenmacher, Scott Peterson, of SRF Consulting Group for the Minnesota Department of Transportation Research Services Section, September 2010.

Abstract:
The use of non-intrusive technologies for traffic detection has become a widespread alternative to conventional roadway-based detection methods. Many sensors are new to the market or represent a substantial change from earlier versions of the product.

This pooled fund study conducted field tests of the latest generation of non-intrusive traffic sensors. Sensors were evaluated in a variety of traffic and environmental conditions at two freeway test sites, with additional tests performed at both signalized and unsignalized intersections. Emphasis was placed on urban traffic conditions, such as heavy congestion, and varying weather conditions. Standardized testing criteria were followed so that the results from this project can be directly compared to results obtained by other transportation agencies.

While previous tests have evaluated sensors' volume and speed accuracy, the current generation of sensors has introduced robust classification capabilities, including both length-

based and axle-based classification methods. New technologies, such as axle detection sensors, and improved radar, contribute to this improved performance.

Overall, the sensors performed better than their counterparts in previous phases of testing for volume and speed accuracy. However, the additional classification capabilities had mixed results. The length-based sensors were generally able to report accurate vehicle lengths. The axle-based sensors provided accurate inter-axle measurements, but significant errors were found due to erroneously grouping vehicles, affecting their ability to accurately classify trucks.

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7. Alternative Vehicle Detection Technologies for Traffic Signal Systems
Technical report prepared by Dan Middleton, Hassan Charara, and Ryan Longmire, of Texas Transportation Institute, the Texas A&M University System, for the Texas Department of Transportation Research and Technology Implementation Office, February 2009.

Abstract:
Due to the well-documented problems associated with inductive loops, most jurisdictions have replaced many intersection loops with video image vehicle detection systems (VIVDS). While VIVDS have overcome some of the problems with loops such as traffic disruption and pavement degradation, they have not been as accurate as originally anticipated. The objective of this project is to conduct evaluations of alternative detector technologies for application into the state's traffic signal systems. The research will include investigating the available detectors that could replace loops or VIVDS through a literature search and agency contacts, followed by field and/or laboratory investigations of promising technologies.

Deliverables will include a research report, a project summary report, and a detector selection guide. Findings indicate that three detectors should be considered as alternatives to VIVDS for signalized intersections – one is a radar detector and the other two are magnetic detectors. The radar detector is only for dilemma zone detection and does not cover the stop line area. The other two are point detectors, so their basic function would be for loop replacements. One is an intrusive detector, requiring a short lane closure for installation and replacement. Field testing of performance for all three detectors indicated they are worth considering as inductive loop or VIVDS replacements.

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8. An Evaluation of Non-Intrusive Traffic Detectors at the NTC/NDOR Detector Test Bed
Master thesis prepared by Benjamin W. Grone to the Faculty of the Graduate College at the University of Nebraska, May, 2012.

Abstract:
Throughout the field of transportation engineering, decision makers require quality information. The information used in transportation operations, planning, and design is based, in part, on data from traffic detectors. The need for quality data has spurred innovations in data collection including the introduction of modern, commercially available, non-intrusive traffic detectors. As these new technologies become available, a need exists to understand their capabilities and limitations—especially limitations that are unique to a specific region.

This thesis examined the accuracy of four non-intrusive traffic detector technologies considered for potential data collection applications on Nebraska's highways. The technologies evaluated included the Solo Pro II video image processor (VIP), 3M Canoga Microloop 702 magnetic induction detector, Image Sensing Systems RTMS G4 microwave radar detector, and Wavetronix SmartSensor 105 microwave radar detector. These four detectors were installed at the NTC/NDOR non-intrusive detector test bed along Interstate 80 near the Giles Road interchange in Omaha, Nebraska. Data were collected in June, July, and August of 2011, and these detectors were analyzed based on the accuracy of their volume, speed, and length-based vehicle classification.

The analysis in this thesis utilizes numerous graphical and statistical methods to demonstrate the significance of errors in the data from the four evaluated detectors. The impacts of lighting, rain, traffic volume, and various levels of temporal aggregation on the detectors' accuracies were analyzed. Multiple regression analysis revealed that the volume accuracy of the Solo Pro II was affected by night lighting, as well as by the combined effect of dawn lighting and rain. The volume accuracies of the Microloop 702 and G4 were significantly affected by the combination of dusk lighting and rain, while the volume accuracy of the SmartSensor 105 was not found to be significantly affected by lighting or rain conditions. In addition to these results, this thesis analyzed the collected data in order to provide hypotheses pertaining to potential links between significant environmental factors and physical operating characteristics of the evaluated non-intrusive traffic detectors.

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9. **Detector Technology Evaluation**
Final report prepared by Peter T. Martin, Yuqi Feng, and Xiaodong Wang of the Utah Traffic Lab, University of Utah, for the Utah Department of Transportation Research Division, September 2003.

Abstract:
Inductive loop detectors are the most common technology for detecting vehicles. However, they have some disadvantages such as disruption to traffic flow during installation and maintenance, higher failure rate under particular conditions, and inflexibility. Professionals are seeking alternatives to inductive loops. Market demands and technology advancement have inspired manufacturers to develop new detector devices with improved performance and capabilities. A large quantity of detector devices with different operation theories is now available on the market. This paper reports on the present status of detector technologies and on the development trends in these technologies.

This report provides comparison matrixes based on detector technology and specific devices in this field of technology. The technology matrixes offer general information about each detector technology. The device matrixes give specific information regarding each particular detector device. Selecting an appropriate device is more important than choosing a specific technology. The matrixes need to be continuously updated to reflect changes in the detector market.

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10. Low-Cost Portable Video-Based Queue Detection for Work-Zone Safety

Final Report Prepared by Ted Morris, Jory A. Schwach, and Panos G. Michalopoulos, of the Department of Civil Engineering, University of Minnesota, for the Center for Transportation Studies, Intelligent Transportation Systems Institute, January 2011.

Abstract:

Highway work-zone safety is a major concern for government agencies, the legislature, and the traveling public. Several work zone intelligent transportation systems (WZITS) have been developed as a safety countermeasure to warn drivers of dangerous traffic conditions. Unfortunately, the effectiveness of a WZTIS is diminished if the actual traffic flow conditions do not correspond with the sensor information leading to false warnings; these confuse drivers and reduce the credibility of the system, which is often ignored. This can lead to situations where drivers crash into work-zone areas because they are unprepared to stop. The national cost of crashes due to this was estimated to be nearly $2.5 billion. Such "dangerous" traffic conditions are typically characterized by unpredictable queue formations that propagate rapidly into higher speed traffic immediately upstream from the active work zone. False positives or missed warnings could be reduced if the location of queue tails in addition to vehicle speeds in proximity to the active work zone can be accurately detected. In this study, a low-cost rapidly deployable and portable queue detection WZITS warning system is proposed. To demonstrate WZITS feasibility, a queue detection algorithm was designed and tested using widely available, field proven, machine vision hardware that can be integrated into the current portable system prototype, using video data collected in the field from the portable device. The warning trigger generated by the algorithm can then be transmitted to a remote upstream location for triggering roadside emergency warning devices (such as VMS, flashers, etc.).

APPENDIX B:
SURVEY RESPONSES AND DISCUSSION

1. Camera Placement Options

The vendors were asked to describe the available camera placement options (e.g., overhead, side fire, etc.) and their preferred placement option(s). Camera placement options can limit its use of existing support structure, and thus affect the implementation cost. For example, a system that requires camera to be mounted overhead would require new overhead structure be built, instead of making use of existing structure, such as a camera pole. In addition, overhead installation would also require lane closure for maintenance, including periodic lens cleaning. As listed in the table below, all vendors indicated that their products could work with overhead and roadside positions. Two vendors (Citilog and Iteris) preferred the overhead position. One vendor (Autoscope) proposes to use three cameras from a single pole for three different cameras to collect different data.

Product	Response
Citilog XCam-Edge-ng	Preferred placement is over the center of the lane. However, there are provisions for off center, and side fire that work well also.
Econolite Autoscope Terra Technology	Ramp metering can involve 3 cameras for freeway counts, demand/passage/count, and ramp queue objectives. Autoscope Terra Technology can position cameras for approaching, above, side, or receding views. Typically, we look at approaching views. With zoom capability, one pole ahead of the ramp stop line can support cameras for all 3 objectives – an approaching view of queue (often on a curve), an approaching view of demand/passage/count, and an approaching view of freeway counts.
FLIR ITS TrafiSense	Preferred option: mounting location with minimal optical occlusion, having a clear view on each lane. In case of 1 lane: placement next to the roadway is OK, minimum sensor height 4 m. In case of 2 lanes: placement next to the roadway is OK, minimum sensor height 8 m, but overhead mounting at 6 m height is also OK. In case of 3 lanes: overhead mounting recommended.
GridSmart System	GRIDSMART is mounted on the existing infrastructure of the intersection. Specifically, mounting on the mast arm, off of a luminaire, or off of a strain pole. The single-camera deployment allows us to pick the most optimal location in the intersection to mount the camera.
Iteris RZ-4 AWDR	Ideal placement is mast arm mounting directly in front of the approaching traffic. Also side of lane mounted, but in front of the approaching traffic. Our SmartSpan allows for span-wire mounting to achieve the best geometry for detection. Our algorithms work best with traffic moving from the top to the bottom of the screen.

2. Detection of Average Vehicle Queue Length and Maximum Detectable Queue Length

Queue length is a key measure for ramp signal performance monitoring. It is also a major potential strength of video image detectors over other types of detectors. For example, estimating queue length using traditional point detectors, such as inductive loop or Sensys Sensors, would require multiple such detectors be installed over the length of a ramp (such as every 50 feet). The queue length is then estimated based on some threshold at each loop/sensor, such as below an average speed or above a certain occupancy rate, as a way to detect the extent of a vehicle queue. This requires multiple detectors and the accuracy of the queue length estimate also depends on the spacing of the point detectors installed. Currently, FDOT D6 had students out in the field to count the number of vehicles every x minutes and then average the vehicle over a time period. The vendors were asked to describe the abilities and limitations in detecting average vehicle queue length. As listed in the table below. All vendors indicated that their products could provide average queue length estimation.

Product	Response
Citilog XCam-Edge-ng	XCAM–NG and XCAM-Edge-NG are designed specifically for average queue length detection typically limited to 3 lanes coverage.
Econolite Autoscope Terra Technology	In many designs, queue measurement is some distance behind the stop line and depends on storage before the surface street. Autoscope Terra Technology can provide an indication of stopped vehicles, presence, or rough count at this distance. Typically, we use the stopped vehicle feature to indicate backup at one or more distances from the stop line.
FLIR ITS TrafiSense	Thermal gives a similar image day and night, no influence (non-)illumination. Today, an algorithm is on-board to give an output (contact closure) and/or an event (TCP/IP, http based JSON protocol) in case a certain queue length (in meters or in feet) is reached. There is a "time on" (configurable, in seconds) and a "time off" (configurable, in seconds) to activate and deactivate the output/event. Up to 6 queue length zones can be drawn, overlap of zones is possible. Also stop presence zones in AND-relation can be used to activate and output/event in case there is a certain row of stopped vehicles present. If a queue is standing still (without any movement) for more than 5 minutes, the detection will drop.
GridSmart System	GRIDSMART tracks vehicles and determines a zone's vehicle occupancy reasonably well within 200 feet of the center of the area of detection. The occupancy count is limited by the length of the user-configure detection areas and will not include vehicles that are behind other vehicles but not in the detection zone.
Iteris RZ-4 AWDR	Our system is a detection system, but those zones can be tied to queue lengths inside of the controller; up to 300' from the stop-bar.

3. Maximum Detectable Queue Length

As an extension to the previous question, the vendors were further asked to specify the maximum queue length that their system could detect with good accuracy. This is important, as a product that could estimate only very short queues will be of limited use. Except for Autoscope, which did not provide a specific length, the other vendors indicate a range of 100 and 400 feet, depending on the camera height and horizontal field of view (HFOV) used.

Product	**Response**
Citilog XCam-Edge-ng	Generally up to 100 feet of queue is consistently accurate. However, if an optimal mounting height is available for the XCAM video sensor, up to 150 feet of queue length is detectable with acceptable performance.
Econolite Autoscope Terra Technology	For Autoscope Terra Technology, a good design guideline is the 10:1 relationship between distance away and height above the detection area. This allows a queue to be measured at one or more places in this view behind the stop line.
FLIR ITS TrafiSense	This depends on the used lens type. TrafiSense has 5 lens options: 90°, 45°, 35°, 25° or 17° horizontal field of view (HFOV). The 90° HFOV version can detect vehicle queues from 0 m (0 ft) to about 35 m (l15 ft). The 17° HFOV version can detect vehicle queues from about 30 m (100 ft) to about 120 m (400 ft). Note that optical occlusion (i.e., the height of vehicles) will influence the measured queue length, so the higher the mounting position, the better.
GridSmart System	The GRIDSMART system is a tracking-based technology and it will effectively begin to identify and begin tracking objects at 250 to 260 feet from the camera when the camera is mounted at 35 feet.
Iteris RZ-4 AWDR	300’ if mounted high enough in front of the traffic.

4. Detection of Average Vehicle Waiting Time

Average vehicle waiting time is another major measure that of special interest to FDOT D6 for ramp signal performance monitoring. Currently, D6 manually collects "travel time" by having students in the field to track the time a vehicle takes to travel from the point when it first enters a ramp until the time it leaves the ramp signal stop line. The average travel time is computed by averaging the "travel time" of a sample of vehicles over a time period.

The vendors were asked to describe their system's abilities and limitations in estimating average vehicle waiting time. The vendor responses as listed in the table below indicate that the products do not estimate waiting time directly. Most suggest ways, mostly based on occupancy, that waiting or delay time may be estimated. In general, the products appear to have difficulty with estimating waiting time, which is understandably a difficult measure to estimate with any detection system. The research team expects to be more certain and learn more about this capability of the various products through the field evaluation.

Product	**Response**
Citilog XCam-Edge-ng	XCAM-NG and XCAM-Edge-NG also provide average time of occupancy in a designated virtual loop.
Econolite Autoscope Terra Technology	Typically, LOS for demand is measured at the traffic controller. This feature was not added to the Autoscope Terra Technology detection subsystem. With stopped vehicle measures in the queue area from Autoscope Terra Technology, it would be possible for the engineer to estimate wait times from that position to the stop line for various green delay times.
FLIR ITS TrafiSense	Vehicle waiting time is done with vehicle presence zones and presence levels/events. In case the zone occupancy goes above a user configurable threshold, and output and/or event will be generated. There are 2 levels, representing medium zone occupancy (default setting 20%) and high zone occupancy (default setting 60%). No event means fluent traffic. Also stop presence zones can be used, with or without an activation delay and extend. In that case, an output and/or event can be provided in case a vehicle is standing still for a certain period of time. The output/event is dropped when vehicles are moving again for a certain period of time.
GridSmart System	The GRIDSMART system has 11 different formal data reports that are available to provide information at a moment's request. Of these reports are "Green Occupancy" and "Red Occupancy" as well as "Percent Arrivals on Green" and "Percent Arrivals on Red". These reports can be run in five minute, fifteen minute, thirty minute, or one hour long intervals. These can be run for the entire twenty-four-hour period of the day, or, condensed to a particular peak hour synopsis. The information is archived and can be re-run in any particular manner desired. In addition to this, GRIDSMART has an open API to provide an easy way to extract or retrieve any of the raw data information in real time.
Iteris RZ-4 AWDR	We are a detection system so it would be the controller that would need to do the time estimation.

5. Detection of Vehicle Counts

Vehicle counts are needed for both ramp signal operations and performance monitoring. The vendors were asked to describe their system's abilities and limitations in estimating vehicle counts. Except for XCam-Edge-ng, which suggests another product from the vendor that is designed for vehicle counting and classification, all others indicated that their products are able to do both counting and classification. It is noted that independent review of the XCAM-NG product series as introduced in the vendor website indicates that the product does collect counts.

Product	Response
Citilog X Cam-Edge-ng	XCAM-NG is not a product for vehicle counts. Our product for counts is the XCAM-TD which counts and classifies vehicles.
Econolite Autoscope Terra Technology	In ramp meter application, Autoscope Terra Technology can provide very accurate counts of vehicles passing the stop line. Since some ramp meters will have multiple lanes or carpool bypass lanes, counts can be summarized by lane or overall for various time intervals simultaneously. For freeway counts, the view from a ramp pole is not optimum for high accuracies. However, the relative change in counts is detected and may include average speed or density.
FLIR ITS TrafiSense	The presence data function gives zone count per lane per user configured time interval. The best count performance will be possible with the 90° HFOV version, shooting about 45° downwards from a high camera position, so the system can see the gaps between the vehicles.
GridSmart System	Of the GRIDSMART system's formal report types, there is a report for "Turning Movements", "Volume", and "Length Classification". The GRIDSMART system is 98% accurate with the counts. In fact, we are currently being used in the FDOT D5 project for providing turning movements and other data reports on 32 intersections.
Iteris RZ-4 AWDR	With ideal camera mounting geometry, easily into the 90 percent range.

6. Detection of Vehicle Occupancy

Vehicle occupancy is an input to the ramp signal algorithm used by FDOT D6. It may also be used as an indicator of the level of queue presence for performance monitoring. The vendors were asked to describe your system's abilities and limitations in estimating vehicle occupancy. It was somewhat difficult to discern the capabilities from the limited responses as summarized in the table below. However, it is recognized that all vendors indicate that their products could estimate occupancy. This is likely to be the case given occupancy being a common measure. This will be further confirmed as part of the field evaluation.

Product	Response
Citilog XCam-Edge-ng	XCAM-NG and XCAM-Edge-NG also provide average time of occupancy in a designated virtual loop.
Econolite Autoscope Terra Technology	Autoscope Terra Technology presence detection events provide occupancy to the traffic controller. In data collection, it produces average time occupancy and space mean occupancy over multiple selected time intervals from 1 second to 1 hour or for the cycle.
FLIR ITS TrafiSense	The presence data function gives zone occupancy per lane per user configured time interval. The best count performance will be possible with the 90° HFOV version, shooting about 45° downwards from a high camera position, so the system can see the gaps between the vehicles.
GridSmart System	The GRIDSMART system has 11 different formal data reports that are available to provide information at a moment's request. Of these reports are "Green Occupancy" and "Red Occupancy" as well as "Percent Arrivals on Green" and "Percent Arrivals on Red". These reports can be run in five minute, fifteen minute, thirty minute, or one hour long intervals. These can be run for the entire twenty-four hour period of the day, or, condensed to a particular peak hour synapsis. The information is archived and can be re-run in any particular manner desired. In addition to this, GRIDSMART's open API provides access to real-time occupancy data on a per phase or per zone basis.
Iteris RZ-4 AWDR	Again, we are a detection system so it would be the controller that would need to do the time estimation. However, we have the capabilities of doing delay zones that are only triggered after a vehicle has sat upon a detection zone for a preset amount of time (user definable in 1/10th of a second).

7. Detection of Other Additional Measures

The vendors were asked to indicate any other traffic measures besides the four major measures above that their systems are able to estimate that could also be useful for ramp signal operations. Two vendors (Econolite and FLIR ITS) indicate that their products estimate average speed, which could be useful for performance monitoring.

<table>
<tr><th>Product</th><th>Response</th></tr>
<tr><td>Citilog XCam-Edge-ng</td><td>XCam-Edge-ng computes the following data (detailed below):
1. For Advance Loops:
1 Presence Detection (binary, 1 or 0)
2 Stop Detection (binary, 1 or 0)
3 Space Occupancy (in %)
2. For Urban Queues:
1 Queue Length (meters or feet)
2 End of Queue (meters or feet)
3 Available Space (meters or feet)</td></tr>
<tr><td>Econolite Autoscope Terra Technology</td><td>Autoscope Terra Technology can output vehicle presence and speed to the traffic controller. It has comprehensive data collection capabilities that include flow rate, headway, occupancy, density, LOS by speed or capacity, speed, volume, and classification over multiple selected time intervals from 1 second to 1 hour or for the cycle. In addition, the system can collect individual vehicle speed and length.</td></tr>
<tr><td>FLIR ITS TrafiSense</td><td>TrafiSense can be used for traffic data collection.
<table>
<tr><th>Data Type</th><th>Definition</th><th>Unit</th></tr>
<tr><td>• Occupancy</td><td>Occupancy</td><td>%</td></tr>
<tr><td>• Confidence level</td><td>Indication of the accuracy of data based on Image quality</td><td>0 -10: from bad to good</td></tr>
<tr><td>• Average length</td><td>Length of the vehicles</td><td>0,1 m/3,94 in</td></tr>
<tr><td>• Headway</td><td>Time between the back of a</td><td>m</td></tr>
<tr><td>• Density</td><td>Number of vehicles over distance</td><td>Vehicle /Km</td></tr>
<tr><td>• Vehicle class</td><td>Classification of vehicles</td><td>-</td></tr>
<tr><td>• Vehicle count</td><td>Number of vehicles</td><td>-</td></tr>
<tr><td>• Speed</td><td>Vehicle speed</td><td>Km/h</td></tr>
<tr><td>• Gap time</td><td>Time between the front of a vehicle and the back of the</td><td>S(0,1 s)</td></tr>
</table>
TrafiSense can be used for detecting wrong way drivers. TrafiSense can be used for traffic monitoring, giving up to 4 level of service outputs/events in case the zone occupancy goes above a certain threshold, eventually in combination with the traffic flow speed going below certain thresholds. Typically, an alarm can be provided for dense traffic, delayed traffic, congested traffic, stop & go traffic. Levels of service defined by the flow speed and the zone occupancy, with their default settings.</td></tr>
</table>

GridSmart System	Of the 11 GRIDSMART formal report types, a perpetual collection of information can be accessed on the following report types: “Volume”, “Vehicle Classification”, “Turning Movement Counts”, “Incident”, “Raw Report”, “Seven Day Volume”, “Green Occupancy”, “Red Occupancy”, “Percent Arrivals on Green”, “Percent Arrivals on Red”, and “Speed”. In addition to these, GRIDSMART has an open API. Furthermore, GRIDSMART also features “Alerts” in which one can be notified via e-mail if the intersection exceeds a certain volume or if a “wrong-way” driving incident occurs.
Iteris RZ-4 AWDR	All of the Iteris systems, NEXT, Vantage, SmartSpan, and Vector have the ability of collecting turning movement counts, bike counts with SmartCycle, and pedestrian counts with PedTrax.

8. Flexibility in Setting Time Intervals for Data Aggregation

The vendors were asked about their system's flexibility in setting time interval for data aggregation (e.g., every 15 minutes). This is important for performance monitoring over different time intervals. All of the vendors indicated that their systems could be set to collect data for a variety of time intervals (slices), mostly up to an hour. The GridSmart system further allows time intervals to be set for a day and any specific period of a day.

Product	Response
Citilog XCam-Edge-ng	Not a problem multiple aggregates can be configured as well.
Econolite Autoscope Terra Technology	Autoscope Terra Technology can collect data over multiple selected time intervals from 1 second to 1 hour or for the cycle. Data can be collected for the approach, by lane, or by zone of detection.
FLIR ITS TrafiSense	Following time intervals can be selected: 10, 20, 30, 60, 120, 180, 300, 360, 600, 900, 1,800, 3,600 seconds. In case another time interval is needed, a modification to the firmware can be made.
GridSmart System	GRIDSMART report types can be run in intervals of five minutes, fifteen minutes, thirty minutes, and one hour. A sum or average aggregate can be chosen as well. This can be selected for a single day, or for just a particular part of a day. Furthermore, many days can be selected collectively to run a report. Data accessed via the API is available in real-time and can be accessed as frequently as once per second.
Iteris RZ-4 AWDR	That data can be recorded in intervals of 10, 20, 30 seconds, and 1, 5, 15, and 60 minutes. If the controller has the capability, it could be output in real-time.

9. Availability of Video Recording Options

The vendors were asked to describe their video recording options, including time lapse options, video formats, storage and transmission options. In general, only two products (Econolite and FLIR ITS) appear to provide some limited video recording options.

Product	**Response**
Citilog X Cam-Edge-ng	The XCAM-NG and XCAM-Edge-NG do not store any video locally within the device. Video recording options, formats, etc. may be managed by external devices or systems such as DVRs, video management systems (VMS) or media storage devices.
Econolite Autoscope Terra Technology	Autoscope Terra Technology provides snapshots or MPEG-4 compressed streaming video over an Ethernet connection. The Autoscope Software Suite provides recording of snapshots or of video onto a computer or server storage media (permanent or temporary). Other packages, such as VideoLAN VLC, can record video as a standard RTSP stream. To adapt to various network throughput limitations, the stream can be preset to use less bandwidth by setting the max framerate and video compression quality.
FLIR ITS TrafiSense	There is a small internal flash with circular buffer, making continuous recordings, this is used to make event based recordings, where an AVI-sequence can be made from a certain time interval before the event (PRE) to a certain time interval after the event (POST). For example, a video sequence can be made from 30s before a wrong way driver is detected to 45s after that detection. Via public API, a snapshot and/or a recording of a certain event can be requested. TrafiSense has dual stream capabilities, so for example a high quality full frame rate stream can be sent to a monitor, while a low quality slow frame rate stream can be sent to a recording device. The bandwidth is selectable per stream between 0.01 Mbits/s and 4.00 Mbits/s. The frame rate is selectable per stream between 1.0 frames/s and 30.0 frames/s. The codec can be MJPEG, MPEG-4 or H.264, also here selectable per stream. Transmission is done over TCP/IP connection, via xml2 protocol (Traficon internal protocol) or public API (http based protocol, JSON, with GET/POST messages, external protocol, easy to implement). A third party device is needed to store recordings. A RaspberryPi with FLIR ITS software can be used for event triggered recordings and scheduled recordings. An RTSP recorder & playback tool from FLIR is available to make live and/or scheduled recordings on a laptop/PC, locally or from a remote location. FLIR^ FLUX traffic management system with T-REC plugin can be used to make recordings too.

GridSmart System	GRIDSMART's recording options are available only if one purposely intends to record. In order to achieve this, an external hard drive would have to be installed on the GRIDSMART processor in the traffic cabinet. The amount of storage will be dependent upon the size of the hard drive. From there, the recorded video can be viewed from the GRIDSMART client (the "record" feature will allow for pausing, fast-forwarding, rewinding, and changing the image itself through the virtual PTZ).
Iteris RZ-4 AWDR	We do not record. Any video could be recorded with a third party device.

10. Availability of Output File Formats, and Storage and Transmission Options

The vendors were asked to describe their system's available output file formats, storage options, and data transmission options. All vendors indicate that their systems output XML files. Most except Citilog also output CSV files.

Product	Response
Citilog XCam-Edge-ng	XCam-Edge-ng provides dual streaming features: 1. H.264 stream for streaming (up to D1 resolution @ 30 fps, RTSP protocol) 2. MJPEG stream for streaming (up to D1 resolution @ 6 fps, Citilog XML protocol or http protocol) 3. Data Transmission is achieved via onboard XML server
Econolite Autoscope Terra Technology	Autoscope Terra Technology supports an Ethernet connection to show activity, transmit traffic data, snapshots, and video. The Autoscope Software Suite provides detailed maintenance and monitoring capabilities, including and archive operations log. Traffic data is stored in onboard memory, which can be days or weeks, or can be collected directly by one or more hosts simultaneously. Data collection files are delimited text files after uploading the compressed messages. It is also possible to interface with commands to a TCP socket or to create custom client applications.
FLIR ITS TrafiSense	Data and events: CSV-file and XML-file, via TCP/IP connection Count pulses, occupancy pulse lengths: via outputs / contact closures Images and videos: MJPEG/MPEG-4/H.264, via TCP/IP connection. Ethernet connection direct via sensor, or via interface module (RJ45 port present). Via FLUX: data, images and videos can be retrieved, monitored, stored and exported.
GridSmart System	Data can be exported as PDF, xls, csv, or HTML. Data can be stored on the client, cloud, or on USB. Data accessed using the GRIDSMART API is available in XML or JSON formats. The GRIDSMART system guarantees local storage of a year of data. Unlimited backup storage is provided as part of GRIDSMART Cloud. Data can be accessed via a standard Ethernet connection or by exporting stored data to USB Hard Drive.
Iteris RZ-4 AWDR	Data in 15 minute intervals could be stored in the processor for several months before writing over the oldest data. Data can be output into a CSV file. Also with our TS2 IM input / output module, you can output up to 64 channels of data to a controller for direct input into a Central Software program. Our EdgeConnect can stream the video and provide Ethernet connectivity for communication with the traffic control system.

11. Availability of Post-Processor

The vendors were asked to describe any data post-processors their system includes and their features and functionalities. The responses from the vendors for this question, as summarized below, are somewhat varied. It appears that Citilog and Iteris that did not understand that the question was looking for data visualization/reporting tools (which the other three vendors did).

Product	Response
Citilog XCam-Edge-ng	As outputs, the XCam-Edge-ng is generating both binary data (presence or stop detection) and numerical data (Space occupancy, queue length, queue end position, stocking space). In order to be able to interface XCam-Edge-ng to any traffic controller thanks to its digital inputs board, there is a need to convert all information coming from XCam-Edge-ng to binary data. This is done thanks to the LogicConfig software module that is embedded into Xcom-LC**.** An additional circuit board din rail mountable device which can power and control up to 6 XCAM-NG's at the same time provision of up to 16 relay outputs.
Econolite Autoscope Terra Technology	The Autoscope Software Suite automatically converts traffic data collection to a simple text file suitable for a spreadsheet program or for transacting into a database. In addition, system integration is possible with command interface to a TCP socket or by creating a custom client application.
FLIR ITS TrafiSense	Visualization of technical events, traffic events (both in event stack) and gathered data via FLUX management system.
GridSmart System	The GRIDSMART Client includes a built-in reporting tool that can generate each of the 11 different report types previously mentioned.
Iteris RZ-4 AWDR	Iteris can provide a secure, cloud-based, hosted data service that collects, analyzes, and presents vehicle, bicycle, and pedestrian data in a browser-based format. Vehicle turning movement counts, bicycle counts, and pedestrian counts are presented in various charts and graphs with download and printing capabilities for easy post-processing. UTDF (Universal Traffic Data Format) reports can be generated, as well as peak hour factor calculations for user-defined day and time periods. Simultaneous, multi-user access is provided, and all data is available 24/7/365.

12. Impacts of Environmental Conditions

The vendors were asked to describe the impacts on the accuracy of your system when operating during night and rain conditions. All vendors indicated that their systems are able to detect under night or adverse weather conditions. Design of camera angle/tilt is cited by three products as way to reduce impact from rain. The thermal-based TrafiSense product, in particular, has the advantage of not affecting by lighting conditions as the sensor detects heat instead of optical level. Note that the accuracy under the night conditions will be further confirmed for products selected for field evaluation.

Product	Response
Citilog XCam-Edge-ng	Some minimal ambient scene lighting is required. However vehicle headlights will provide adequate object lighting. Camera body tilt is important to keep rain off of the lens. The camera does have a lens shield and video fail safe i.e., when video quality falls below acceptable levels the camera will automatically go to a fail safe status (no output) until video quality returns to acceptable.
Econolite Autoscope Terra Technology	Typically, presence detection and most data collection activities are not affected by night operations or rain when sensors are deployed properly. Autoscope Terra Technology product specifications do provide estimates for accuracy in severe conditions.
FLIR ITS TrafiSense	The accuracy of thermal is not influenced by natural or artificial illumination. Rain will reduce the contrast of the image, but that will only have a very limited impact on system accuracy.
GridSmart System	The GRIDSMART Bell camera design is unique in its ability to mitigate visibility problems during rainy conditions. Since it is downward facing, water interference is limited to the edges of the image rather than the center where tracking and detection occurs. When installed within spec, GRIDSMART maintains its accuracy at night by tracking vehicle headlights.
Iteris RZ-4 AWDR	Our algorithms help our system maintain accuracy in all types of conditions, rain, dark, fog, heavy shade or shadow. Specifically, we utilize an algorithm called Lane Structure that compares video signal strength between adjacent lanes to give the best detection accuracy in nighttime, rain, shade, shadow, and dirty camera conditions. Our WDR wide dynamic range sees well in high and low light conditions.

13. Compatibility with Other Video Camera Systems

The vendors were asked about their system's compatibilities with other video cameras and if there are specific types of cameras that are required or work best with their system. The key to this question was to find out if the system requires a specific type of camera and can only work well with it. All vendors either indicate that their cameras are integrated within their systems or their video analytic software is optimized for their specific camera.

Product	**Response**
Citilog XCam-Edge-ng	Citilog detections are only available onboard Axis cameras and Citilog XCAM video sensors. Our central server MediaRoad product can analyze video streams from most brands of optical or thermal cameras.
Econolite Autoscope Terra Technology	Autoscope Terra Technology products have been deployed with cameras from other video detection companies and with some surveillance cameras. These products require a standard video coax connection with video signal conforming to RS170, RS 170A, or NTSC specifications. Econolite manufactures video cameras optimized for its Autoscope Terra Technology products.
FLIR ITS TrafiSense	A thermal video camera is already included in the TrafiSense system.
GridSmart System	The GRIDSMART system will only work with GRIDSMART cameras.
Iteris RZ-4 AWDR	We require that use of our cameras with our processors. Our family of cameras are tuned to work optimally with our algorithms.

14. Re-Calibration Requirements

The vendors were asked to describe the camera calibration requirements, including the recommended frequency (i.e., how often) for re-calibration. All vendors claim that their systems either do not require regular calibration or no re-calibration is needed. Note that the initial calibration efforts will be observed and recorded during the actual field evaluation.

Product	Response
Citilog XCam-Edge-ng	Should not require recalibration after desired level of performance is reached upon setup unless camera has moved.
Econolite Autoscope Terra Technology	Typically, a camera is setup for the application and not changed for many years. Autoscope Terra Technology products include ClearVision design elements that help reduce maintenance and prolong life. Econolite recommends that the new equipment be incorporated into an agency's standard preventive maintenance procedures. In most cases, an annual inspection from the ground or office checks for lens cleanliness and proper aim to meet the detection objectives. Econolite can provide more detailed documents on standard maintenance and troubleshooting procedures.
FLIR ITS TrafiSense	Queue length: draw a queue length zone and fill in its length during configuration Presence data: no calibration needed. Traffic data, level of service, wrong way driver detection: draw zone and fill in its length during configuration. Calibration does not need to be redone in case the system is operational and in case the system is not out of position.
GridSmart System	The GRIDSMART camera does not require any calibration, ever. Not only does it not require calibration, it does not have to be aimed or focused.
Iteris RZ-4 AWDR	If set properly upon installation, no re-calibration would be required.

15. Unique Capabilities Over Other Products

The vendors were asked to describe any unique/special capabilities/features their system has that make it superior to other systems. The table below lists their responses. One feature that stood out is from the TrafiSense product, whose thermal video recording provides additional privacy to drivers.

Product	Response
Citilog XCam-Edge-ng	XCAM is a self-contained camera which includes analytics. XCAM is hermetically sealed, weatherproof, and does not require additional enclosures, heaters, or fans. Full featured logic availability. Same piece of hardware can function as several different types of detectors with only a firmware flash. Citilog is the first to develop queue length detection in a camera. We have been doing this now for 8 years. XCAM was deployed for traffic control at the recent Winter Olympics in Sochi, Russia and at the Summer Olympics in Rio de Janeiro.
Econolite Autoscope Terra Technology	Autoscope Terra Technology products provide simple wizard or template setup. A tech support team can assist in making changes if the detection objectives change over time. Once configured, the archive Operations Log makes equipment replacement as simple as possible by loading the old log into new equipment. With reduced maintenance, especially for lens cleaning, the lifetime cost of the installation is an excellent value to the agency.
FLIR ITS TrafiSense	With thermal, you can see 24/7 what is going on in the field of view. Also recordings can be made, respecting privacy because no number plates visible, no people recognizable, no colors of vehicles visible, thermal does not look through glass, blanking zones can be drawn to make part(s) of the image permanently black. Thermal is very flexible with respect to installation, requires minimum maintenance and has many functionalities onboard. TrafiSense is quick and easy to install and configure. The system has a long MTBF, product warranty is 3 years, with the most expensive component, being the thermal core, having a 10-year factory warranty. TrafiSense can be used for permanent and temporal installations.
GridSmart System	The GRIDSMART system is such an all-encompassing system. It has been described to me before to be the "Swiss Army Knife" of traffic wants and needs. GRIDSMART provides the ease of installation, and a simple, intuitive set up. It provides impeccable detection, unmatched data collection report types (not to mention the open API), and with connectivity, it provides a virtual PTZ feature while still actuating and collecting the data. Also, we do not have any reoccurring or licensing fees. It is the lowest total cost of ownership on the market and can be purchased off of the state APL contract.

Iteris RZ-4 AWDR	Multiple form factors for different intersection configuration, i.e., mast arm, span-wire, hybrid detection; that can mix and match with one another into one complete system. SmartCycle – bike detection, differentiation, and counting is standard in all platforms. PedTrax – pedestrian tracking and counting can collect ped counts on an approach and store the count data along with the speed in feet per seconds. Standard in all systems. Our system has been designed with the Complete Streets program for multiple modes of transportation with one system.

16. Availability of Technical Support

The vendors were asked to describe the availability and associated fee technical support service. The table below lists their responses. With the exception of FLIR ITS, all vendors appear to provide reasonable technical support service based on the responses provided below. However, based on earlier contact with the vendor, the research team is aware that FLIR ITS provides good service through Control Technologies, base in Sanford, Florida.

Product	Response
Citilog XCam-Edge-ng	Remote assistance available Mon. – Fri. 8 AM to 6 PM at $125 per hour Onsite Assistance available at same hourly rate plus per diem for cost of travel & lodging.
Econolite Autoscope Terra Technology	Econolite technical support is available by phone, email, and onsite. Some information is available online at a Tech Support website for Econolite's customers. Most remote support is available on demand without charge. Specific commitments for availability, especially onsite or by VPN to systems, can be quoted for a project or agency.
FLIR ITS TrafiSense	FLIR ITS has a technical support engineer in the USA. In case needed, people from outside USA can be dispatched.
GridSmart System	There are no charges or fees for technical support for GRIDSMART. GRIDSMART has a direct phone line as well as an e-mail address for customers to reach out with questions, concerns, or problems. GRIDSMART deploys an "on call rotation" that is adjusted each week. GRIDSMART is not just in the eastern time zone, for we are in almost every single US state and 22 foreign countries. GRIDSMART also has a local distributor in Florida to provide additional technical support and on-site assistance if needed.
Iteris RZ-4 AWDR	We currently have two full time customer support personnel in Florida and 10+ others located around the country. Installation, warranty, and troubleshooting support are free of charge. In addition, we provide IMSA level training on a yearly basis; free of charge. We also have a Resource Center at https://www.iteris.com/support/sales/tools; also free of charge.

17. Licensing Fee Structure

Vendors were asked to provide system's software and hardware licensing fee structure. It was understood by the research team that obtaining precise information from the vendors for this question is difficult at this stage of the evaluation. The intent of this question was simply to get whatever information that vendors are able or willing to provide and more detailed information will be obtained from the vendors selected for evaluation.

Product	Response
Citilog XCam-Edge-ng	Citilog XCAM and SmartTraffic apps for Axis cameras are all provided with perpetual licenses.
Econolite Autoscope Terra Technology	Econolite's sales representative will provide budgetary and project quotations for software and hardware upon request.
FLIR ITS TrafiSense	The TrafiSense price typically includes hardware and firmware and is sold for a 1-time fee. Leasing/renting can be discussed. The PC software to configure the sensor, TCT (Traficon Configuration Tool), is free of charge, as well as TDT (Traficon Data Tool) to retrieve traffic data. FLUX can be installed on a server and several clients can be connected. This software package has a 1-time fee. Also a FLUX cloud solution is available. Here, a monthly fee must be paid to get access to the connected sensor information.
GridSmart System	GRIDSMART does not have any software or hardware licensing fees. Once a GRIDSMART system is purchased, ALL software releases are available with no additional fees. When software is released, a notification is sent to registered users that the new software is available for download. This includes all enhances to functionality and new data reports.
Iteris RZ-4 AWDR	Firmware upgrades, which come our fairly regularly are free as long as the generation of processors are compatible with the new firmware. Licensing fees are included with hardware costs. Our Vantage Live Data Collection and Management software fee structure has not been released at this time.

18. Field Test Requirements

The vendors were asked to list any specific needs and requirements for their participation in a one-day field test/evaluation to be conducted at a ramp signal location on I-95 in Miami-Dade County in February 2017. The information is mainly to help with the preparation of the planned field evaluation, and not used as part of the product selection. All systems show interest in participating in the evaluation. The information requested including test location, mounting support, available power, bucket truck, etc. will be addressed in the test plan being prepared.

Product	Response
Citilog XCam-Edge-ng	No special needs.
Econolite Autoscope Terra Technology	We request information about the site, poles, and detection objectives several weeks prior to the onsite date. If we can mount one or more of the Autoscope Terra Technology products, we want to plan accordingly. If the agency is providing a non-standard camera, we want to plan accordingly.
FLIR ITS TrafiSense	Google earth co-ordinates? Mounting options? Required detection distances for queue length? Required locations for counting, occupancy measurements etc.? Available power supply? Permanent remote connection for monitoring, modifying configurations, making recordings?
GridSmart System	GRIDSMART very much looks forward to the field test/evaluation of our system in February. We will supply all of the equipment that will be needed and will be there for technical support. We, however, cannot physically do the install and we do not have a bucket truck. But again, we will be right there every step of the way to provide the technical support needed to install.
Iteris RZ-4 AWDR	I have no problem doing a desktop demonstration; or if Miami-Dade staff would be willing to install a camera and processor, we could do it live in an intersection. I look forward to meeting with you.

APPENDIX C:
INVITATION LETTER

Dear Mr./Ms. ______:

On behalf of the Florida Department of Transportation (FDOT), we are pleased to invite your company to participate in a field test of your video image detection system. The test is to be conducted at a ramp signal location on I-95 in Miami-Dade County. The attached field test plan provides additional details on the test.

We would like to have the field test be conducted on February 28, 2017. If the date and the test plan are agreeable to you, please sign at the end of the attached test plan document and return it to me by February 10, 2017 in its entirety.

We thank you in advance for your participation in this test. If you have any questions or suggestions, please do not hesitate to let me know. Thank you.

Sincerely,

Albert Gan, Ph.D.
Professor
Department of Civil and Environmental Engineering
Florida International University

APPENDIX D:
FIELD TEST PLAN

This document describes the field test plan for evaluating three commercial video image detection systems at a ramp signal location on I-95 in Miami-Dade County, Florida. It covers the project background and test purpose, the organizing agencies and contacts, the test location and test period, the test data, the data evaluation method, the support for participant travel, and the requirements for publication of test results and conclusions.

Project Background and Test Purpose

Florida Department of Transportation (FDOT) District 6 currently uses inductive loops and Sensys Networks sensors at its 22 ramp signals on I-95 in Miami-Dade County, Florida. These detectors are used to detect vehicle passages and presence, but do not collect traffic measures such as queue length and waiting time, which are desired for performance monitoring of ramp signals. The FDOT Research Center has tasked Florida International University (FIU) to investigate the feasibility of using a video image detection system in place of the existing detectors to both detect vehicles and collect performance monitoring data, including traffic volume, occupancy, queue length, and waiting time (or a variation of it). The project has recently completed a general survey of existing video detection systems and is inviting three potential systems to participate in a field test at an actual ramp signal location. The main purpose of this field test is to assess the ability of each participating system in accurately detecting the aforementioned data. Depending on the test results and other considerations, one of the tested systems may be recommended for deployment.

Responsible Agencies and Contacts

Dr. Albert Gan is the FIU project manager, and Mr. Javier Rodriguez and Ms. Elizabeth Birriel are the FDOT project managers for this project. Their contact information is listed below:

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Test Location

The test location is located on I-95 in Miami-Dade County, on the on-ramp at NW 95th Street. The location was chosen for this test after considering the ramp length, traffic volume, queue length, availability of a suitable existing pole, and availability of space for test system setup. Its Google map location is https://www.google.com/maps/@25.8630628,-80.2084485,18z. The latest field inspection of the ramp location shows no noticeable changes in the field conditions when compared to those shown in the latest Google's Street View (dated August 2016). As can be seen in the Google Street View, the ramp location has an existing camera pole that is about 240 feet away from the ramp signal stop line. The picture below shows a field of view from the existing camera. Participants are encouraged to use a wide field of view to capture as much of the ramp queuing area as possible.

The ramp location also has another light pole about 140 feet downstream of the stop line (see the figure below) for potential system installation, although there will not be as much working area available.

While the test location has been selected to make sure that there are existing pole(s) with sufficient working area for system installation, participants are free to select any other locations that work best with their systems – with the condition that the setup will not affect or interfere with the normal traffic operations at the ramp. Participants may also bring their own poles or mount the system on a bucket truck crane (see the next section on bucket truck availability).

Test Period

The data collection period will be from 2:30 pm to 8:00 pm, a period during which the ramp signal will be in operation. A bucket truck that can reach up to a minimum of 40 feet will be available from 11:00 am the day of the test for both system installation and uninstallation. The truck can also provide electrical power for the test system in the field. In the event that an unexpected condition, such as a rain or traffic incident, that may significantly reduce the amount of data available for evaluation, the test will be rescheduled for the following day.

Test Data

At the end of the test, participants will provide the following test data sets to a FIU representative in the field on a flash drive or an external drive (to be provided by FIU):

1. Complete video records from 2:30 pm to 8:00 pm.
2. Stop line traffic volume at 5-minute intervals.
3. Stop line traffic volume at 15-minute intervals.
4. Stop line vehicle occupancy (%) at 20-second intervals.
5. Maximum queue length (in feet or number of vehicles) within 5-minute intervals.
6. Average queue length (in feet or number of vehicles) at 5-minute intervals.

7. If system is able to track vehicle travel time, provide average travel time for vehicles to travel from the beginning of the visible video area to the stop line at 5-minute intervals, or any other alternative measure(s) that allows assessment of the average time vehicles waiting in the queue.

Note that other time intervals for maximum and average queue lengths may be used, if necessary. The ground truth data for comparison will be extracted from the videos provided (item #1 above) based on the time intervals used and how the average queue length is sampled within the time interval.

Data Evaluation

The accuracy of the test data provided will be evaluated using ground truth data extracted manually from videos from the test systems. The accuracy of stop-line occupancy collected by each video detection system will be evaluated using the loop detector data extracted from the *SunGuide* database at FDOT District 6 ITS Office. In other words, the evaluation of the vehicle occupancy data will be limited to assessing how close the data are to those from the loop detector. While the test occupancy data will be provided in 20-second interval, the evaluation may be performed based on longer intervals, such as 1 and 5 minutes, to minimize potential impact from small differences in clock time synchronization (between the loop detector and the test system). All test data will be compared with the ground truth data using the Mean Absolute Percentage Error (MAPE) measurement.

Review of Test Results by Participants

The test results and conclusions will be shared with all participants, who will have one month to review and provide comments. The ground truth data used in the evaluation will be made available to participants on request.

Publication of Test Results

As part of the contract requirements with the FDOT Research Center, FIU is required to submit a final report that documents the entire project in detail, including the test process, the results, and the conclusions from this test. Participant comments on the report can be considered for inclusion in the final report as attachments if requested.

Travel Support

The following travel support will be provided for participant travel to Miami for up to two persons:

- Transportation (airfare, rental car, gas and toll): up to $1,000 total per vendor.
- Lodging/hotel: up to 2 nights @ maximum $150 per night per person + 13% tax.
- Class C meals: up to 3 days @ $36 per day per person.

Receipts are required for all reimbursements.

Acceptance Acknowledgement

By signing below, the signee, on behalf of his/her company, agrees to participate under the terms and conditions specified in this test plan.

Signature: ___________________________ Date: _____________

Name: ______________________________

Title: _______________________________

Company: ___________________________