Final Report

Contract No. BDV29-977-33

Effectiveness of Stationary Police Vehicles with Blue Lights in Freeway Work Zones

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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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16. Abstract

Work zone safety affects both drivers and construction workers. Two main safety measures for reducing work zone crashes and their severity have been to reduce the vehicle speeds in work zones and to increase the separation between the vehicles and the workers. This project attempted to assess the effectiveness of deploying stationary police vehicles with flashing blue warning lights in freeway work zones. The effectiveness was evaluated based on (1) reductions in average vehicle speeds, (2) reductions in vehicle speeding, and (3) changes in vehicle lane use. Vehicle speed and lane use data were collected at two freeway work zones in Florida, including a static work zone on I-4 near Daytona Beach and a dynamic work zone on I-75 near Gainesville. Data were collected for two weeks prior to the deployment of a police vehicle, two weeks during which a police vehicle with flashing lights was stationed at the work zone, and two weeks following the removal of the police vehicle.

For the static work zone on I-4 in which there was with 1-lane closure (out of three), it was found that the average speed within the work zone was reduced by 4.4 mph following the deployment of police vehicle, and by 1.4 mph following the removal of the police vehicle. The deployment of police vehicle was also found to reduce vehicle speeding by 20%. While the deployment of police vehicle with flashing lights was found to shift only a very small percentage of vehicles away from the work zone, the result was not considered reliable because it was skewed by a large percentage of vehicles that pre-positioned themselves for a downstream off-ramp exit.

For the dynamic work zone on I-75 which included both 2-lane and 2.5-lane closures (out of three), it was found that the average speed within the work zone with 2-lane closure was reduced by 3.8 mph following the deployment of police vehicle, and by 2.7 mph following the removal of police vehicle. The deployment of police vehicle was also found to reduce vehicle speeding within the work zone by about 16%. In the case with 2.5-lane closure, the average speed within the work zone was reduced by 2.8 mph following the deployment of police vehicle, and by 3.1 mph following the removal of police vehicle. The latter result was not considered reliable as it was derived based on very limited data. The deployment of police vehicle with 2.5-lane closure was found to reduce vehicle speeding by 10%.

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EXECUTIVE SUMMARY

Crashes in work zones pose risk not only to the drivers, but also to the construction workers. Two main safety measures for reducing work zone crashes and their severity have been to reduce the vehicle speeds in work zones and to increase the separation between the vehicles and the workers. One common method to help reduce vehicle speeds has been to position police vehicle(s) in the vicinity of work zones to get drivers to slow down as they enter the work zone. This project attempted to assess the effectiveness of deploying stationary police vehicles with flashing blue warning lights in freeway work zones. The effectiveness was evaluated based on (1) reductions in average vehicle speeds, (2) reductions in vehicle speeding, and (3) changes in vehicle lane use.

Vehicle speed and lane use data were collected at two freeway work zones in Florida, including a static work zone on I-4 near Daytona Beach, and a dynamic work zone on I-75 near Gainesville. Both study locations were on six-lane facilities in suburban areas. Data were collected for two weeks prior to the deployment of a police vehicle with flashing warning lights, two weeks during which a police vehicle with flashing warning lights was stationed at the work zone, and two weeks following the removal of the police vehicle.

Daytona Beach Study Location

The Daytona Beach study location was part of a major project at the outskirts of City of Daytona Beach to widen I-95 from four to six lanes. The project limits ran between north of SR 44 and north of US 92 (International Speedway Boulevard). The project also included the reconstruction of the two interchanges at I-4 and US 92. The specific work zone location selected for this study is located on I-4 eastbound approaching I-95. The speed limit was 70 mph upstream of the work zone and 65 mph within the work zone. During the entire six weeks of data collection, the work zone remained static, with the left-most lane closed at all times. Florida Highway Patrol (FHP) vehicles were used at this study location. The FHP vehicles included a small red light in the middle of two blue lights. As such, the flashing warning light used at this study location was actually "mostly blue" rather than only blue. The key results from this study location are summarized below:

1. The deployment of FHP vehicle with blue lights at the study location reduced the average speed within the work zone by about **4.4 mph**.

2. During the two-week period following the removal of the FHP vehicle with blue lights, the average speed within the work zone was reduced by **1.4 mph** when compared to the baseline data from the first two weeks.

3. The deployment of FHP vehicle with blue lights reduced vehicle speeding (i.e., >65 mph) by **20%**.

4. The deployment of FHP vehicle with blue lights at the study location shifted only a very small percentage of vehicles away from the work zone. However, this result is not considered reliable due to a large percentage of vehicles that pre-positioned themselves on the inside lane to use the left-side off-ramp to head northbound on I-95.

Gainesville Study Location

The Gainesville study location involved a fast-moving asphalt milling and resurfacing project located on I-75 at the outskirts of City of Gainesville. The project limits ran between south of SR 121 (SW Williston Rd) and south of SR 222 (NW 39 Ave). The section of the I-75 had three lanes in each direction and the total distance was 6.5 miles. The regular speed limit on the section was 70 mph and was temporarily reduced to 60 mph during construction. Over the six weeks of data collection, except for one night when only one lane was closed, all the other night closures closed either 2 lanes to pave the inside lane or the left shoulder or 2.5 lanes to pave the middle lane. Traffic within the work zone was generally congested during the early hours of the night closures and usually became uncongested only after midnight. The data used in this study included only those from the uncongested time periods when there was no queue and vehicles were able to enter the work zone with no delay. The vehicles used at this study location were from the Florida Fish and Wildlife Conservation Commission (FWC) and displayed only blue lights. The key results from this study location are summarized below:

For 2-lane closure (out of three lanes):

1. The deployment of FWC vehicle with blue lights at the study location reduced the average vehicle speed within the work zone by about **3.8 mph**. This is a slightly lower reduction compared to the 4.4 mph from the Daytona Beach study location.

2. During the period following the removal of FWC vehicle with blue lights, the average vehicle speed within the work zone was reduced by **2.7 mph** when compared to the baseline data from the first two weeks with no blue lights. However, this reduction was derived based on more limited data available for the period following the blue light deployment and is not considered reliable.

3. The deployment of FWC vehicle with blue lights reduced vehicle speeding (i.e., >60 mph) within the work zone by about **16%**.

For 2.5-lane closure (out of three lanes):

1. The deployment of FWC vehicle with blue lights at the study location reduced the average vehicle speed within the work zone by about **2.8 mph**.

2. During the period following the removal of FWC vehicle with blue lights, the average vehicle speed within the work zone was reduced by **3.1 mph** when compared to the baseline data from the first two weeks with no blue lights.

3. These results for 2.5-lane closure are not considered reliable as the baseline data from the period before the deployment of FWC vehicle with blue lights came from just one night closure.

4. The deployment of FWC vehicle blue lights reduced vehicle speeding (i.e., >60 mph) within the work zone by about **10%**.

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LIST OF ACRONYMS/ABBREVIATIONS

FDOT	Florida Department of Transportation
FHP	Florida Highway Patrol
FWC	Florida Fish and Wildlife Conservation Commission
ISS	Image Sensing Systems
MOT	Maintenance of Traffic
NB	Northbound
NCHRP	National Cooperative Highway Research Program
PTMS	Portable Traffic Monitoring Site
SB	Southbound
UF	University of Florida

CHAPTER 1
INTRODUCTION

1.1 Project Background

In 2013, Florida experienced 75 fatalities and 4,422 injuries in 7,519 work zone crashes. As investments in the nation's roadway infrastructure are expected to increase significantly in the coming years, the number of work zones is bound to increase, bringing with it the risk of work zone crashes. Crashes in work zones pose risk not only to the drivers, but also to the construction workers. Accordingly, two main safety measures for reducing work zone crashes and their severity have been to reduce the vehicle speeds in work zones and to increase the separation between the vehicles and the workers.

National Cooperative Highway Research Program (NCHRP) Synthesis 482[1] presents data and case examples regarding the effectiveness of various speed management techniques. The techniques are categorized as follows:

1. Engineering technologies (speed management devices)
2. Engineering techniques (changes in the physical or perceptual driving environment)
3. Operational techniques (using lead vehicles or field personnel to limit traffic speeds)
4. Traditional "human" enforcement techniques (police officers in cars)
5. Automated speed enforcement
6. Education and outreach
7. Combinations of the above

Among these categories, operational and traditional "human" enforcement techniques were found to provide the most and immediate speed reductions in work zones. One such technique is to use police vehicles as "pace vehicles" to lead and constrain the speed of a platoon of vehicles traveling through a work zone. The technique requires a minimum of one vehicle per lane for each platoon. The process must be repeated using additional police vehicles. As multiple police vehicles are needed, the technique could incur a high deployment cost and resource availability issues; thus, it is normally used only when there is a public safety issue involving overhead work over the travel lanes.

An alternative to pacing is to position police vehicle(s) in the vicinity of work zones to get drivers to slow down as they enter the work zone. Flashing warning lights which could include both amber and blue lights are usually displayed to capture drivers' attention and to increase the method's effectiveness. The intent of this study is to focus on the display of blue lights. A literature search did not find any existing studies that evaluated the impacts of blue lights on stationary police vehicles in work zones. In this study, it was desired to assess the effectiveness of blue lights in reducing vehicle speeds within work zones. This includes reductions in both the average speed and the percentage of vehicles speeding as a result of blue lights.

[1] Shaw, J. W., Chitturi, M. V., Bremer, W., & Noyce, D. A., *Work Zone Speed Management: A Synthesis of Highway Practice*, National Cooperative Highway Research Program 482, Transportation Research Board, Washington, D.C., 2015.

As Florida is one of the states with a Move Over Law, the use of blue lights not only may help reduce vehicle speeds, but may also cause drivers to change lane away from the active work area when such lanes are available, thus, provide additional protection for the workers. First enacted in 2002, the Florida Move Over Law (Florida Statute 316.126) stated that "drivers must vacate the lane closest to the stationary emergency vehicle, tow truck, sanitation, or utility vehicle. Drivers must slow down to a speed of 20 mph below the posted speed limit if they cannot move over safely." However, some drivers may not comply, despite this legal requirement. For those that do comply, some may move back to their original lane soon after passing the stationary police vehicle.

1.2 Project Objective

The main objective of this project is to assess the effectiveness and value gained by the use of stationary police vehicles with flashing blue warning lights in freeway work zones. The impacts are evaluated based on the following measures:

1. Reductions in average vehicle speeds.
2. Reductions in vehicle speeding.
3. Changes in vehicle lane use.

1.3 Report Organization

The rest of this report is organized as follows. Chapter 2 describes the efforts taken to plan and prepare for field data collection. They include mainly the selection of study locations, the study methods, the acquisition and testing of field data collection equipment, and the training of field crew members. Chapters 3 and 4 describe the specific field conditions, the data collection method used, the data collection period covered, and the study results from the two study locations in Daytona Beach and Gainesville, respectively. Finally, Chapter 5 summarizes the key results from this project.

CHAPTER 2
STUDY PREPARATION

This chapter describes the effort to plan and prepare for the field data collection. It covers the process of identifying and selecting work zone project locations, the design of the study periods, the acquisition and testing of data collection equipment and accessories, the placement of data collection equipment, the field logistics and monitoring, and the training of field data collection crew members.

2.1 Design of Data Collection Periods

It was determined by FDOT that the field data were to be collected for three two-week periods, for a total of six weeks, as follows:

1. Two weeks without any police vehicle at the work zone.
2. Two weeks during which a police vehicle with flashing blue lights is stationed at the work zone.
3. Two weeks following the removal of the police vehicle.

Data from the first two weeks provides the baseline data. Data from the second two weeks, with the deployment of blue lights, were to be compared with the baseline data to estimate the impacts of blue lights on vehicle speeds and lane use. Data for the last two weeks were to be used to determine the continual impacts from the blue lights deployed during the prior two weeks.

2.2 Identification of Study Locations

It was originally planned for this project to include three study locations. However, only two study locations were eventually included. The research team worked with the FDOT project managers, the FDOT district engineers, the construction project managers, and the contractors to identify potential project locations for this study. A list of ongoing projects around the state was first identified by FDOT project managers and shared with the research team. The research team identified a number of candidate projects from the list based on basic information provided in the list, such as project location, type of construction, project duration, and available number of remaining night closures. The research team contacted the project representatives by email, over the phone, and met with the representatives of several project teams to brief them on the research study and to obtain additional details on the specific projects. Through conversations with construction project managers and FDOT district engineers and also with the help of the FDOT Office of Construction, the research team was able to identify and contact additional projects not included in the initial FDOT list. Many of the projects were eventually rejected for one or more of the following reasons:

- Project did not have six weeks of continuous night closures needed for this study.
- Project was already deploying police vehicles and would skew the baseline data.
- Project had other upstream work zones that would have already reduced the speeds of the approaching traffic.
- Project team members simply chose not to participate.

Working closely with the FDOT district engineers and the Office of Construction, the research team eventually was able to identify two study locations for this study, one in Daytona Beach and a second one in Gainesville. Both of these study locations are six-lane facilities located in suburban areas.

2.3 Acquisition of Equipment and Accessories

An important decision in developing the field data collection plan was to identify the appropriate devices for collecting speed readings and vehicle counts. As the study locations involved high-speed freeway work zones, the devices would need to be non-intrusive to make sure that they would not become a safety hazard to the passing vehicles as well as affect the vehicle speeds at the study locations.

A number of non-intrusive commercial systems, such as SmartSensor from Wavetronix, and Autoscope and RTMS from Image Sensing Systems (ISS), have been used for speed measurements on freeways. However, these systems usually require major field calibration, thus were determined to be unsuitable for data collection at mobile/dynamic work zones that would require that the equipment be installed quickly. Further, as this study was to involve collecting speed data at multiple spot locations along a work zone, variation in calibration errors at different locations along a work zone would make it impossible for the speed data to be compared.

One device that was found to gain increasing popularity, especially for speed monitoring in work zones, was the iCone system. The system includes the iCone devices with radar speed detection equipment and battery power housed inside (see Figure 2-1). The battery power could last for a minimum of two weeks before it has to be recharged. The system also includes a central website to which the data are transmitted continuously via satellite. The transmitted data include the latitude and longitude of the device, its battery charge status, the date and time of the readings, and a frequency count of vehicle speed readings in 5-mph bins. Version 3.0 of the system also records individual speed readings in a built-in SD card, allowing for more precise speed calculations. In short, the main benefit of iCones for this study was that it did not require field calibration, thus, allowing the devices to be both positioned and re-positioned quickly for mobile work zone operations. In addition, as data were transmitted to a website, the devices could be easily and continuously monitored to make sure that they continued to function properly.

As stated earlier, this project was to include three study locations for which date were to be collected simultaneously. It was also planned for the project to use seven iCones at each study location. Accordingly, a total of 21 iCones were rented from an equipment rental company. Upon checking the 21 iCones received, it was found that three of the units were not of the latest version (3.0) as required by the rental contract. In addition, one unit was found to have been damaged during shipment. These units were replaced by the rental company.

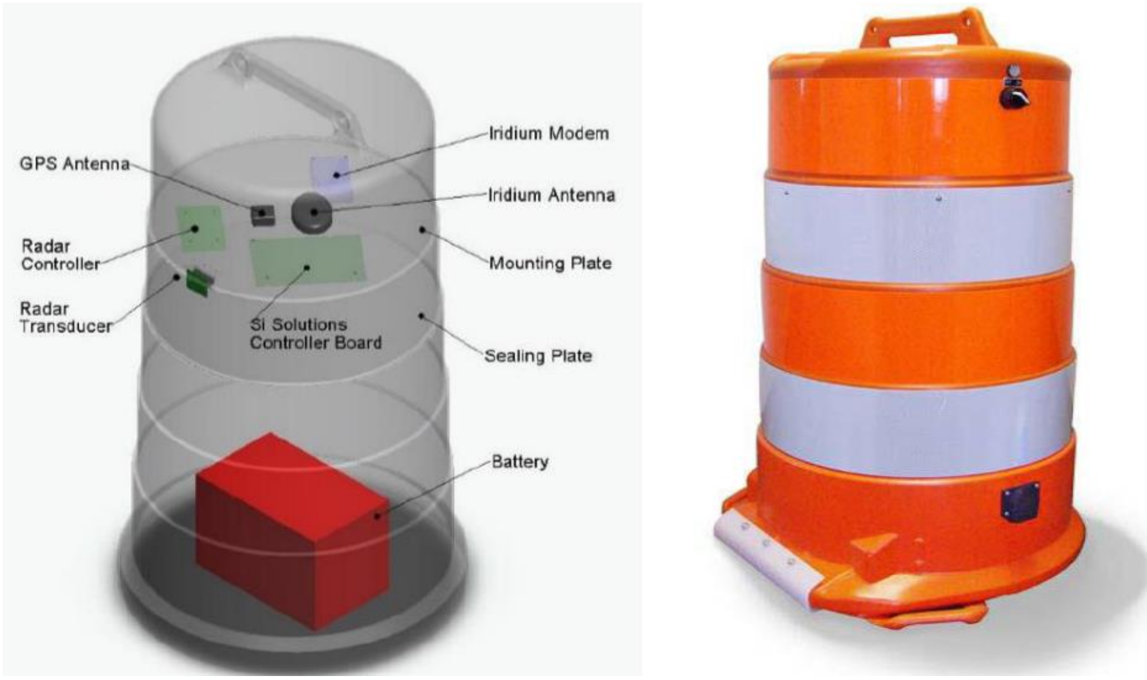


Figure 2-1. iCone Components

As the use of iCones was new to the research team, the team members spent extra time to fully investigate and become familiar with the system, including both the physical iCone units and the iCone online monitoring website. The research team continued to work with the iCone technical support to determine the desired iCone system settings for this project and to test the units to verify if the units produced and delivered the accurate and desired data.

In preparation for the field data collection, the research team also acquired other equipment and accessories needed for field data collection, including:

- Video cameras and their accessories including external batteries and SD storage cards.
- Safety accessories including LED warning beacon lights, class 3 safety vests, hard hats, safety glasses, and headlights.
- Data storages including hard-drives and flash drives.
- Others: hand trucks, measuring wheels, torch lights and batteries, extension cords, surge protectors, and USB chargers.

2.4 Testing of iCones

The iCones were tested for their data accuracy and consistency. It was originally planned for the iCone speeds to be tested against the ground-truth speeds from an existing Portable Traffic Monitoring Site (PTMS). However, the research team was unable to find a suitable PTMS location for this test. One main reason was because most of the PTMS locations were located near intersections, thus, would not provide the free-flow and/or stable speeds needed for this test. The research team subsequently decided to set up pneumatic road tubes at a desired midblock location to collect the speed data.

As shown in Figure 2-2, the setup of the test involved placing iCones side-by-side at the location with a pneumatic road tube setup. The setup was situated at a mid-block location on West Flagler Street between Woman Park Drive and SW 103rd Court (see Figure 2-3). The test was successfully completed on April 27, 2017, with speed data collected from both iCones and the road tubes from 11:00 am to 3:00 pm, for a total of four hours. During the entire test period, traffic was free-flow, and was not affected by any vehicle queue.

Figure 2-2. iCone and Road Tube Test Setup

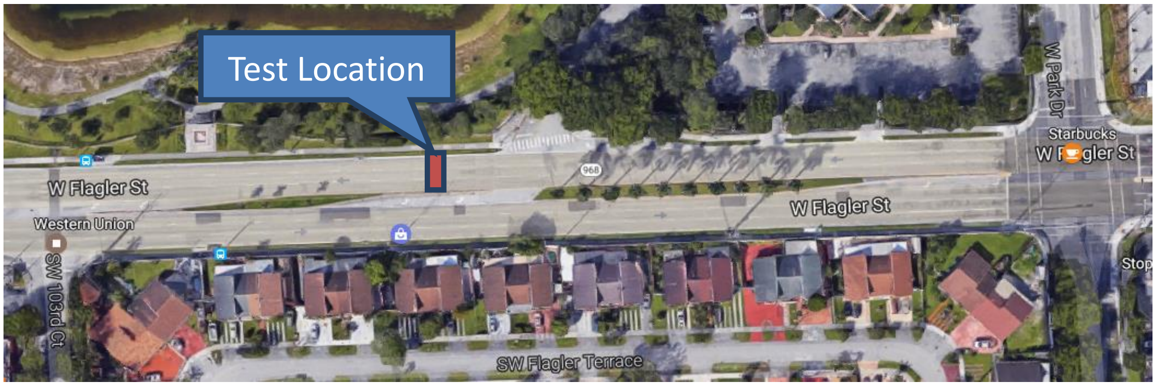


Figure 2-3. Test Site Location (Map)

Only 17 of the 21 iCones were available for this test, as four of the iCones were not in working condition at the time of the test and needed to be replaced by the rental company. Among the four iCones not available for testing, two (including one from the four replacement units as indicated above) could not be powered on for an unknown reason, and two had detached wires that the research team was unable to reconnect. The wires broke when the units were being opened to retrieve data from their SD cards.

As stated earlier, the iCone system provides two options for extracting data: through the iCone website, and through an SD card residing inside each iCone. For this test, the data were retrieved from the SD cards, which provided individual speed readings. Table 2-1 summarizes the test results comparing the differences in the overall average speeds between each of the 17 iCones tested and their road tube counterpart. The following observations can be made from Table 2-1:

1. The average speeds from all the iCones tested are consistently higher than their road tube counterpart (see also Figure 2-4). This indicates a good level of consistency.

2. Twelve of the 17 iCones have an average speed difference that comes within 1 mph, with one iCone (no. 13) slightly higher than 1 mph. This indicates a good overall level of speed accuracy and consistency among these 13 iCones.

3. The last four iCones experienced a relatively high speed difference, with the differences ranging from 1.41 mph to 2.52 mph.

4. The four iCones with higher average speed differences also detected a lower sample (< 2,000 vehicles). This indicates potential detection problems in these units that affected both the sample size and the accuracy.

Table 2-1. Test Results for 17 iCones

No.	iCone ID	iCone Vehicle Counts*	iCone Average Speed (mph)	Road Tube Average Speed (mph)	Average Speed Difference (mph)	Average Speed Difference (%)	Mean Absolute Percentage Difference (MAPD) (%)**
1	686	3,183	34.70	34.62	+0.08	+0.2	2.3
2	6C7	2,701	34.95	34.62	+0.33	+1.0	2.4
3	69E	2,618	35.00	34.62	+0.38	+1.1	2.8
4	6C4	2,932	35.03	34.62	+0.41	+1.2	2.9
5	6C9	2,514	35.20	34.62	+0.58	+1.7	2.6
6	6CB	2,416	35.22	34.62	+0.60	+1.8	2.6
7	6B1	2,387	35.40	34.62	+0.78	+2.2	2.8
8	6C6	2,454	35.48	34.62	+0.86	+2.5	3.0
9	6D7	2,498	35.56	34.62	+0.94	+2.7	3.1
10	6CA	2,630	35.60	34.62	+0.98	+2.8	3.3
11	6C8	2,549	35.60	34.62	+0.98	+2.8	3.6
12	6CD	2,333	35.60	34.62	+0.98	+2.8	3.3
13	670	2,251	35.65	34.62	+1.03	+3.0	3.6
14	66B	1,980	36.03	34.62	+1.41	+4.1	4.2
15	6CE	1,505	36.06	34.62	+1.44	+4.2	4.5
16	6CC	1,704	36.14	34.62	+1.52	+4.4	5.2
17	6C3	1,802	37.14	34.62	+2.52	+7.3	7.6

* Road tubes detected a total of 4,050 vehicles.

** $MAPD = \frac{1}{N}\sum_{i=1}^{N} \frac{|\,Road\ Tube\ Average\ Speed - iCone\ Average\ Speed\,|}{Road\ Tube\ Average\ Speed}$, N = 48 five-minute periods

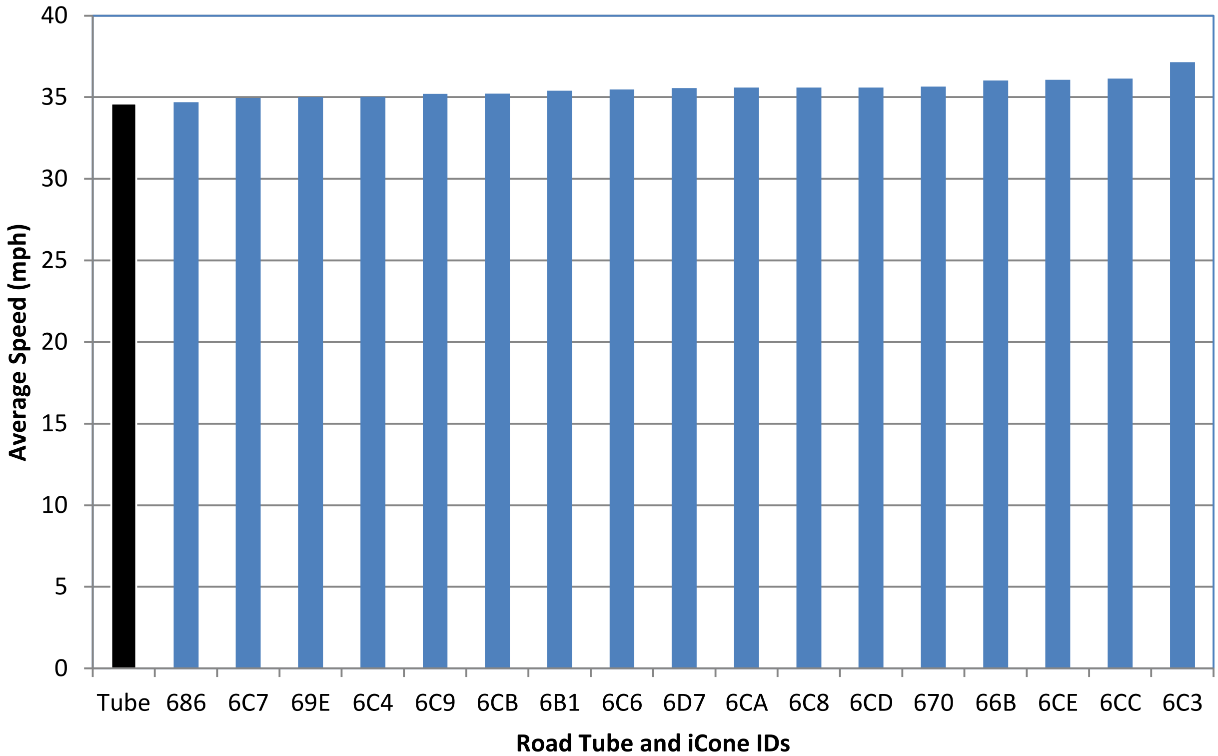


Figure 2-4. Overall Average Speeds from Road Tubes and iCones

It can be seen from Table 2-1 that the iCones detected only a fraction of the 4,050 vehicles detected by the road tubes. As a radar-based detector, iCone is designed to take a radar sweep every *x* number of seconds. The iCones in this test were set to a sweep rate of 2.5 seconds, with no delay between sweeps. According to the iCone manufacturer, iCones tend to pick up the vehicle with a higher speed when there are multiple vehicles. This may explain the consistently higher average speeds from the iCones vs. the road tubes.

Figure 2-5 shows the five-minute average speed trends for the iCones. Overall, the average speed trends for the iCones follow that of the road tubes. The data for this figure are given in Table 2-2.

Overall, the test results show that the average speeds estimated by iCones are comparable to those of pneumatic road tubes, and are sufficiently accurate and consistent (among iCones) for the application in this project, i.e., to estimate the speed differentials along a work zone.

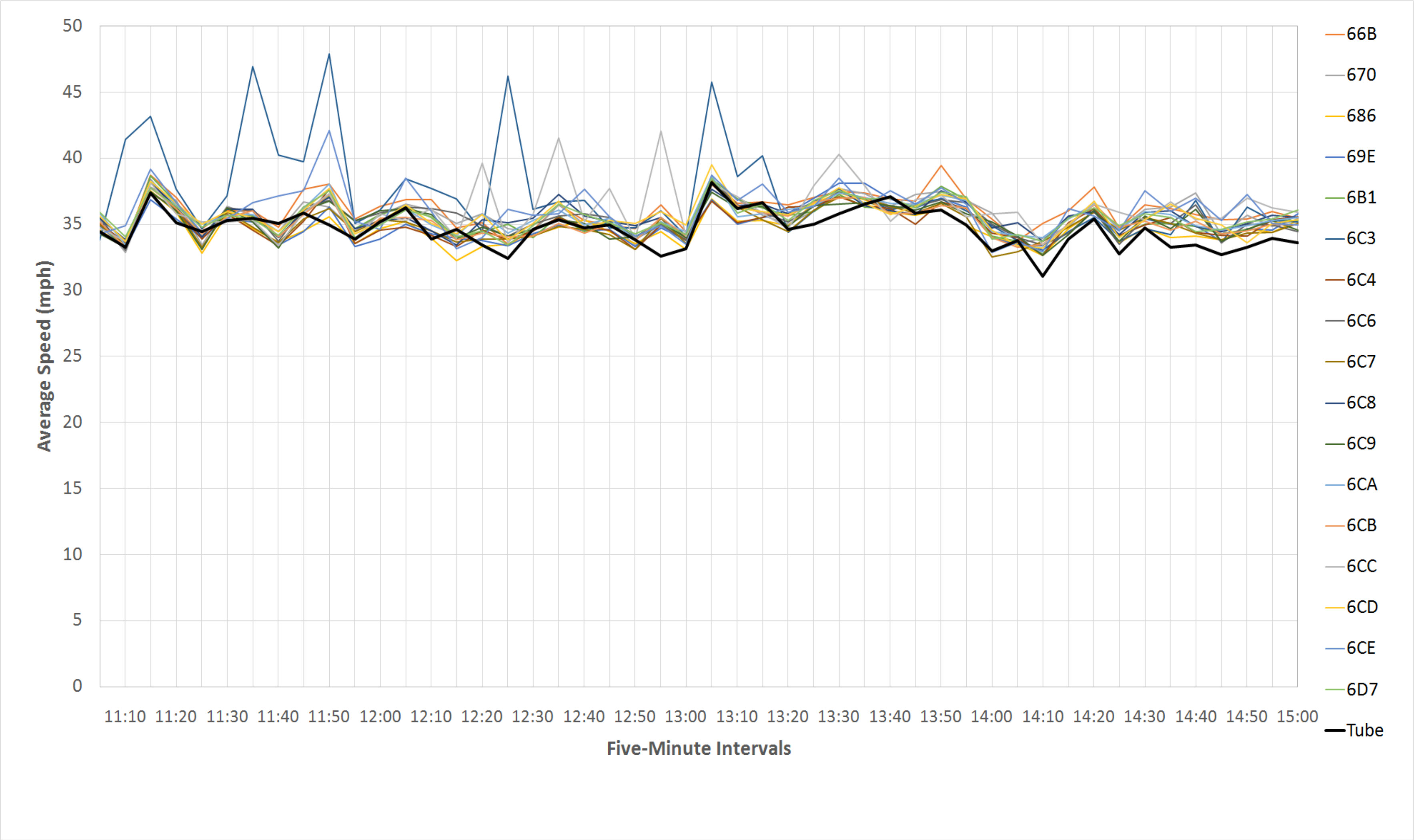


Figure 2-5. Five-Minute Average Speeds from iCones and Road Tubes

Table 2-2. Five-Minute Average Speeds from iCones and Road Tubes

Time	Tube	66B	670	686	69E	6B1	6C3	6C4	6C6	6C7	6C8	6C9	6CA	6CB	6CC	6CD	6CE	6D7
11:05	34.4	34.4	35.4	34.5	34.9	35.0	33.8	35.0	35.5	34.9	34.4	35.4	34.5	34.9	35.0	33.8	35.0	35.5
11:10	33.3	33.4	32.9	33.3	33.2	33.2	41.4	33.6	33.0	33.5	33.4	32.9	33.3	33.2	33.2	41.4	33.6	33.0
11:15	37.3	38.7	37.8	37.5	36.9	38.7	43.1	38.3	38.4	37.3	38.7	37.8	37.5	36.9	38.7	43.1	38.3	38.4
11:20	35.1	37.0	36.8	35.9	35.4	36.6	37.7	36.1	36.2	36.2	37.0	36.8	35.9	35.4	36.6	37.7	36.1	36.2
11:25	34.5	34.6	33.5	32.8	34.0	34.3	34.7	33.9	34.0	33.2	34.6	33.5	32.8	34.0	34.3	34.7	33.9	34.0
11:30	35.3	36.0	36.3	35.7	35.4	35.9	37.1	35.8	36.2	35.9	36.0	36.3	35.7	35.4	35.9	37.1	35.8	36.2
11:35	35.4	36.0	35.7	34.6	35.2	35.6	46.9	34.5	36.0	34.8	36.0	35.7	34.6	35.2	35.6	46.9	34.5	36.0
11:40	35.1	34.8	34.5	33.6	33.4	34.0	40.2	33.4	33.7	33.6	34.8	34.5	33.6	33.4	34.0	40.2	33.4	33.7
11:45	35.9	37.6	36.7	34.5	34.5	36.0	39.7	35.2	36.3	35.4	37.6	36.7	34.5	34.5	36.0	39.7	35.2	36.3
11:50	35.0	38.0	36.3	35.6	36.3	37.1	47.9	37.7	36.8	36.2	38.0	36.3	35.6	36.3	37.1	47.9	37.7	36.8
11:55	33.9	35.4	34.5	33.6	33.3	34.7	35.1	33.5	35.3	34.5	35.4	34.5	33.6	33.3	34.7	35.1	33.5	35.3
12:00	35.2	36.4	35.7	34.7	33.9	35.7	36.1	34.5	35.8	35.3	36.4	35.7	34.7	33.9	35.7	36.1	34.5	35.8
12:05	36.2	36.8	36.5	35.2	35.0	36.3	38.4	34.8	36.3	35.2	36.8	36.5	35.2	35.0	36.3	38.4	34.8	36.3
12:10	33.9	36.9	36.1	34.0	34.3	35.5	37.7	34.2	36.2	34.5	36.9	36.1	34.0	34.3	35.5	37.7	34.2	36.2
12:15	34.6	34.7	35.1	32.2	33.9	33.9	36.9	33.3	35.8	33.7	34.7	35.1	32.2	33.9	33.9	36.9	33.3	35.8
12:20	33.4	35.1	35.8	33.3	33.8	34.4	34.4	34.6	34.9	33.9	35.1	35.8	33.3	33.8	34.4	34.4	34.6	34.9
12:25	32.4	33.5	34.7	33.5	33.4	35.0	46.2	33.8	34.1	33.9	33.5	34.7	33.5	33.4	35.0	46.2	33.8	34.1
12:30	34.6	34.5	34.5	34.2	34.3	34.0	36.1	34.5	35.0	34.1	34.5	34.5	34.2	34.3	34.0	36.1	34.5	35.0
12:35	35.4	36.5	36.5	34.8	34.9	35.6	36.7	35.5	35.6	34.8	36.5	36.5	34.8	34.9	35.6	36.7	35.5	35.6
12:40	34.7	35.3	35.0	35.4	34.5	34.4	36.8	34.8	35.8	34.6	35.3	35.0	35.4	34.5	34.4	36.8	34.8	35.8
12:45	35.0	35.0	35.1	34.5	34.6	35.2	34.7	34.6	35.5	34.2	35.0	35.1	34.5	34.6	35.2	34.7	34.6	35.5
12:50	33.8	34.7	33.4	33.6	33.3	34.0	34.7	33.1	33.9	33.1	34.7	33.4	33.6	33.3	34.0	34.7	33.1	33.9
12:55	32.6	36.5	34.9	34.5	34.7	35.1	36.0	34.9	35.0	35.5	36.5	34.9	34.5	34.7	35.1	36.0	34.9	35.0
13:00	33.1	34.4	33.9	33.1	33.8	34.0	34.1	33.8	33.8	33.6	34.4	33.9	33.1	33.8	34.0	34.1	33.8	33.8
13:05	38.2	38.3	38.1	36.9	36.9	38.4	45.8	36.7	38.4	38.2	38.3	38.1	36.9	36.9	38.4	45.8	36.7	38.4
13:10	36.2	36.6	36.9	35.2	35.0	36.9	38.6	35.1	36.5	36.3	36.6	36.9	35.2	35.0	36.9	38.6	35.1	36.5
13:15	36.6	36.7	35.7	35.3	35.5	36.2	40.2	35.5	35.9	35.3	36.7	35.7	35.3	35.5	36.2	40.2	35.5	35.9

Table 2-2. Five-Minute Average Speeds from iCones and Road Tubes (continued)

Time	Tube	66B	670	686	69E	6B1	6C3	6C4	6C6	6C7	6C8	6C9	6CA	6CB	6CC	6CD	6CE	6D7
13:20	34.6	36.5	35.0	34.9	35.8	35.7	34.4	36.3	35.2	34.4	36.5	35.0	34.9	35.8	35.7	34.4	36.3	35.2
13:25	35.0	37.0	36.0	36.6	37.0	35.9	36.0	36.3	36.3	36.1	37.0	36.0	36.6	37.0	35.9	36.0	36.3	36.3
13:30	35.8	37.5	37.7	37.4	38.1	37.3	37.5	37.1	37.4	37.0	37.5	37.7	37.4	38.1	37.3	37.5	37.1	37.4
13:35	36.5	37.3	37.3	36.9	38.1	36.3	36.9	36.4	36.9	36.9	37.3	37.3	36.9	38.1	36.3	36.9	36.4	36.9
13:40	37.1	36.9	36.3	35.9	36.9	36.2	36.1	36.2	36.2	36.4	36.9	36.3	35.9	36.9	36.2	36.1	36.2	36.2
13:45	35.9	36.8	37.3	35.7	36.3	36.4	36.6	35.0	36.4	35.9	36.8	37.3	35.7	36.3	36.4	36.6	35.0	36.4
13:50	36.1	39.5	37.5	36.2	37.0	37.9	36.9	36.7	36.9	36.6	39.5	37.5	36.2	37.0	37.9	36.9	36.7	36.9
13:55	35.0	36.9	36.8	34.9	36.3	36.9	36.0	36.2	36.6	35.6	36.9	36.8	34.9	36.3	36.9	36.0	36.2	36.6
14:00	33.0	35.4	35.8	34.0	34.0	34.1	34.9	34.4	35.0	32.5	35.4	35.8	34.0	34.0	34.1	34.9	34.4	35.0
14:05	33.7	33.8	33.5	33.6	33.5	33.7	33.8	34.0	34.0	32.9	33.8	33.5	33.6	33.5	33.7	33.8	34.0	34.0
14:10	31.1	35.0	33.9	32.6	33.4	32.8	33.1	32.6	33.4	33.7	35.0	33.9	32.6	33.4	32.8	33.1	32.6	33.4
14:15	33.9	36.0	34.8	34.7	35.6	35.0	34.5	35.1	34.3	34.8	36.0	34.8	34.7	35.6	35.0	34.5	35.1	34.3
14:20	35.4	37.8	36.6	36.0	35.9	36.5	35.5	36.2	36.0	35.9	37.8	36.6	36.0	35.9	36.5	35.5	36.2	36.0
14:25	32.7	34.7	34.6	33.6	34.1	34.1	33.7	34.1	33.5	34.5	34.7	34.6	33.6	34.1	34.1	33.7	34.1	33.5
14:30	34.7	36.5	36.1	34.7	35.4	35.0	34.6	35.0	35.5	35.5	36.5	36.1	34.7	35.4	35.0	34.6	35.0	35.5
14:35	33.2	36.2	36.3	34.0	35.0	35.1	34.2	35.5	35.0	35.1	36.2	36.3	34.0	35.0	35.1	34.2	35.5	35.0
14:40	33.4	35.8	37.4	34.1	34.9	34.9	36.8	34.4	36.5	34.3	35.8	37.4	34.1	34.9	34.9	36.8	34.4	36.5
14:45	32.7	35.3	34.2	33.8	33.7	34.2	33.6	34.2	33.6	33.8	35.3	34.2	33.8	33.7	34.2	33.6	34.2	33.6
14:50	33.3	35.4	35.7	34.6	34.7	34.6	36.3	34.1	35.0	34.3	35.4	35.7	34.6	34.7	34.6	36.3	34.1	35.0
14:55	33.9	35.9	34.9	34.4	34.5	35.3	35.3	35.3	34.9	34.4	35.9	34.9	34.4	34.5	35.3	35.3	35.3	34.9
15:00	33.6	35.5	35.4	35.3	35.8	35.3	35.2	35.6	34.4	35.1	35.5	35.4	35.3	35.8	35.3	35.2	35.6	34.4

2.5 Placement of Data Collection Equipment

As stated previously, it was originally planned to collect data at three study locations simultaneously, using seven iCones at each study location. However, due to difficulties in finding suitable study locations, data were collected at only one study location at a time. As a result, more iCones could be used at each study location, and a total of eight iCones were finally used, and they were placed as follows:

1. Two iCones at some distance upstream of the stationary police vehicle.
2. One iCone at the stationary police vehicle.
3. Five additional spot locations downstream of the stationary police vehicle.

In addition, the research team was also able to always bring one additional iCone to the field as spare in case of equipment failure. As there were still more tested iCones available than were needed for one study location, the research team was also able to use the iCones that had better test results (see Subsection 2.4).

In addition to iCones, two video cameras were set up at the beginning and end of the work zone to determine: (1) the vehicle lane use at the beginning of lane closure and at the end of the work zone; (2) the exact time periods of police vehicle presence.

2.6 Field Logistics and Monitoring

A large 12-passenger van with its seats removed was used by the field crew members to deliver nine iCones and other equipment and accessories to and from the field. When out in the field, the crew members performed the following tasks:

- Set up the iCones and video cameras at the intended spot locations
- Ensured that the iCones and police vehicles were positioned at the intended locations
- Continued to monitor iCones through the night to make sure they were working properly via the iCone website
- Recorded special field conditions (e.g., rains, traffic accidents/incidents, etc.)
- Retrieved the equipment and placed it back in the van at the end of data collection each night.

The crew members also monitored the iCone batteries and recharged them when needed.

2.7 Training of Field Crew Members

To prepare the field crew members for the study, an in-house training session was first conducted to familiarize them with:

- iCone and video camera setup
- iCone status monitoring via iCone website
- Field conditions recording
- Safety equipment checklist
- Maintenance of Traffic (MOT) safety training.

In addition, the crew members met with the construction project team members at each study location to go through a safety training and briefing. Further, to familiarize the crew members with the actual equipment setup and operations in the field, a training week was added to the beginning of the six weeks of data collection at the first study location. The data collected during this training week were excluded from the data used in the analysis.

CHAPTER 3
DAYTONA BEACH STUDY LOCATION

This chapter describes in detail the field conditions, the data collection method used, the data collection period covered, and the study results from the study location in Daytona Beach, Florida.

3.1 Field Conditions

The Daytona Beach study location was part of a major project at the outskirts of City of Daytona Beach to widen I-95 from four to six lanes. The project limits were between north of SR 44 and north of US 92 (International Speedway Boulevard). The project also included the reconstruction of the two interchanges at I-4 and US 92. The specific work zone location selected in this study was located on I-4 eastbound approaching I-95. Figure 3-1 shows the general study location and Figure 3-2 shows the study project limits.

At the time of data collection, the I-4 section where the work zone was located had been widened to six lanes, with only minor sporadic construction work activities along the work zone. During the entire six weeks of data collection, the work zone remained static, with the left-most lane closed at all times. As there were no regular daily construction activities, it was suggested by the FDOT project team that, for the purpose of this study, a light plant be set up and the FIU crew vehicle be instrumented with multiple strobe lights to "emulate" daily construction activities at the study location (see Figure 3-3). The specific work zone location had two advantages: (1) there were no other upstream work zones that would have already reduced the approaching vehicle speeds, and (2) there was no prior police vehicle deployment that would have affected the baseline data.

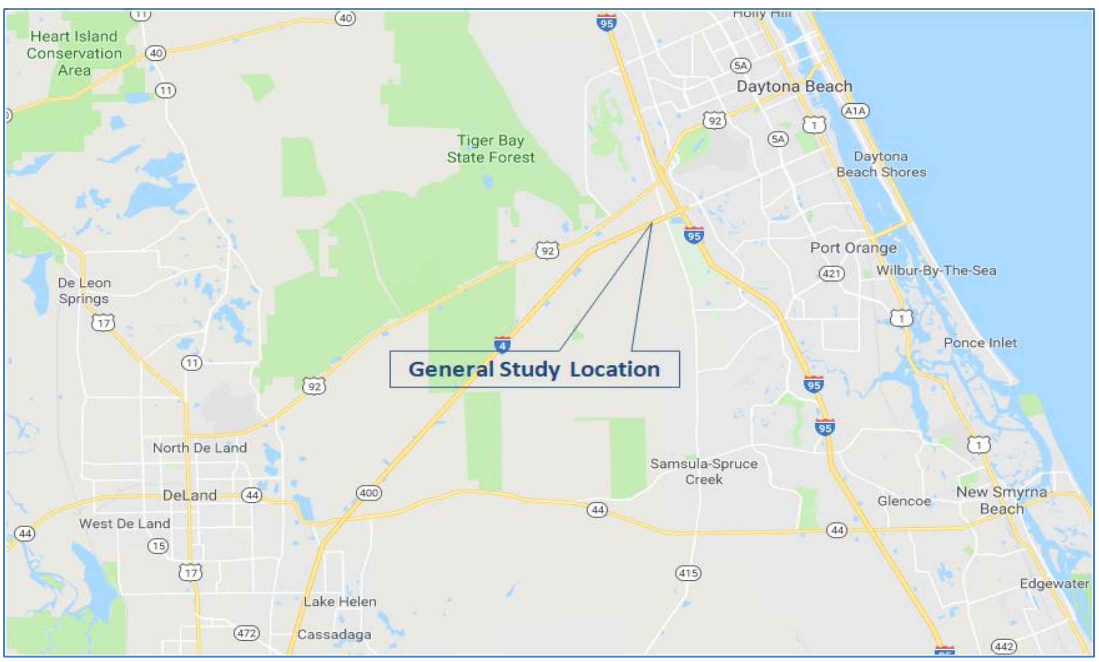


Figure 3-1. General Study Location (Map)

Figure 3-2. Project Limits (Map)

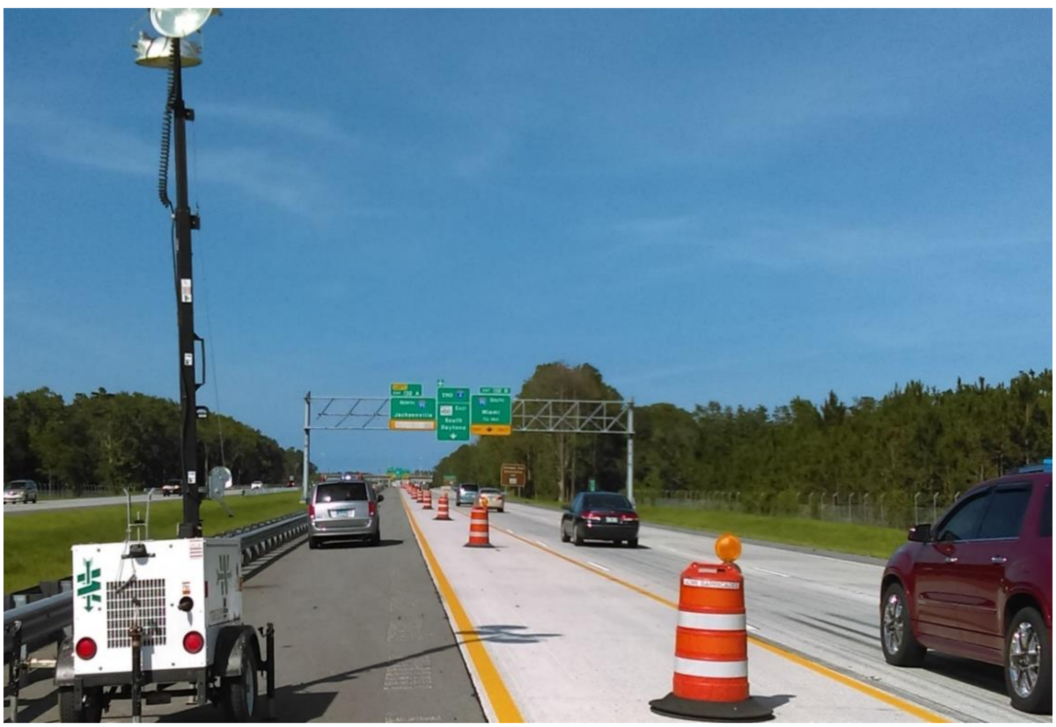


Figure 3-3. Light Plant and FIU Crew Vehicle

The study location included a taper transition followed by a full left-lane closure that extended through both the southbound and northbound ramps to I-95, as well as straight ahead to a local arterial street where I-4 ended (see Figure 3-4). The study location also included a 1.9-mile section upstream of the work zone to capture the vehicle speeds before they entered the work zone. The speed limit was 70 mph upstream of the work zone and 65 mph within the work zone. The entire study area was completely dark with no streetlights.

Figure 3-4. Directional Signs on I-4 Eastbound Approaching I-95 Interchange

3.2 Data Collection Method

The setup for data collection involved mainly the placement of data collection equipment, which included: (1) eight iCones that were used to collect spot speeds at multiple locations along the study corridor, and (2) two video cameras that were used to record videos at two locations within the work zone. The videos were to be used for manual counting of the vehicles using each of the two open lanes in order to assess the impact of police vehicle with blue lights on vehicle lane use. Figure 3-5 shows the locations of the eight iCones that were used to collect speeds across the study area.

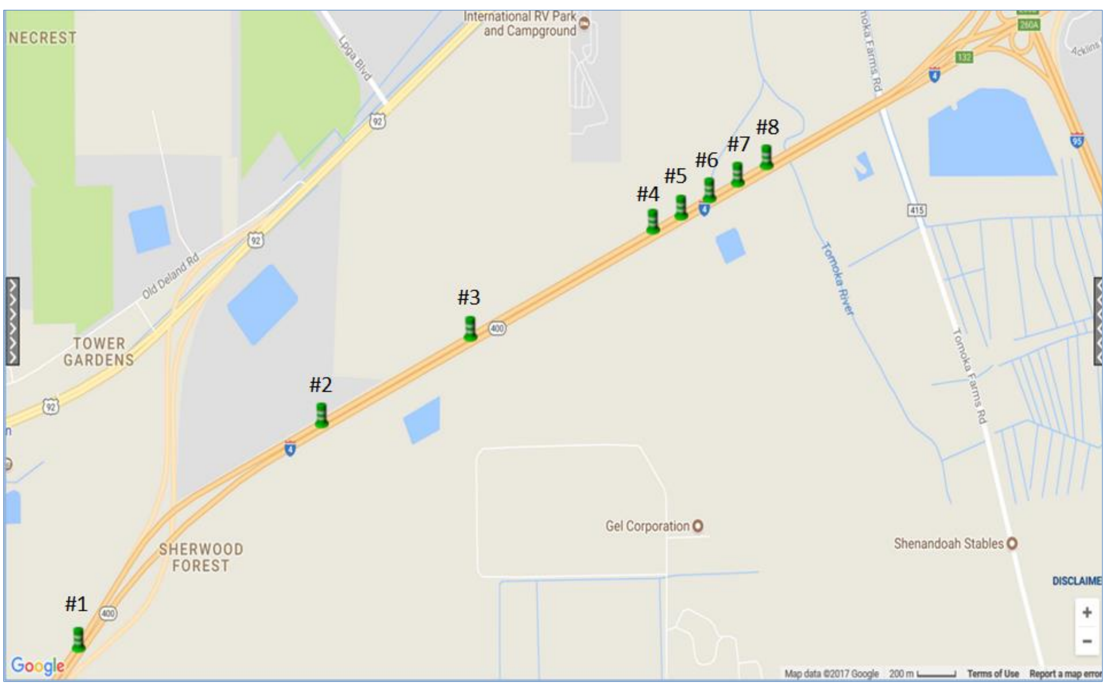


Figure 3-5. iCone Locations for Speed Data Collection

Among the eight iCones used, iCones #1 to #3 were located upstream of the work zone and iCones #4 to #8 were located within the work zone. More specifically:

- iCone #1 was located before a horizontal curve (see Figure 3-6). At this location, drivers were not able to see the police vehicle with blue lights, ensuring that their speeds would not be affected by the police vehicle. As the horizontal curve was relatively straight, its impact on the vehicle speeds was expected to be negligible.

Figure 3-6. iCone #1 Located Ahead of the Curve (and Upstream of Work Zone)

- iCone #2 was located at the "ROAD WORK 1 MILE" warning sign. At this location, drivers were able to see the police vehicle with blue lights relatively clearly (see Figure 3-7).

Figure 3-7. iCone #2 at "ROAD WORK 1 MILE" Sign

- iCone #3 was located at the "ROAD WORK ½ MILE" warning sign (see Figure 3-8). At this location, drivers were able to see the police vehicle with blue lights clearly.

Figure 3-8. iCone #3 at "ROAD WORK ½ MILE" Sign

- iCone #4 was located within the taper transition zone, which measured about 1,100 feet.

- iCone #5 was located at the beginning of the full lane closure.

- iCones #6 to #8 were additional iCones along the work zone.

- iCones #4 to #8 were spaced 500 feet from each other, for a total distance of about 0.5 miles. A larger spacing was not used as vehicles were observed to slow down as they got closer to the I-95 interchange area.

The first of the two video cameras used in this study was placed on top of iCone #5, which was located at the beginning of the full lane closure. This was also the location where the Florida Highway Patrol (FHP) vehicle was stationed. As such, this video camera also captured the stationed FHP vehicle and helped to keep a record of the exact time periods that the FHP vehicle was present. The second video camera was placed on top of the last iCone (i.e., #8) for the purpose of determining the degree to which vehicles continued to stay away from the work area.

It is important to note that the FHP vehicles used in this study location were not able to have only the blue lights on. According to the officers, the flashing lights on FHP vehicles can operate in two modes. The "day" mode has most of the lights in red and the night mode has most of the lights in blue. The "night" mode, which was used in this study, included a red light in the middle (of two blue lights) that cannot be turned off. Accordingly, the "blue lights" as referred to throughout this chapter are actually "mostly blue", rather than entirely blue. The small difference in light colors was not expected to make a difference in the driver behaviors.

3.3 Data Collection Period

The data collection started on May 22, 2017, and ended on June 30, 2017, for a total of six weeks. This period included:

1. Two weeks prior to the stationing of a FHP vehicle.
2. Two weeks during which a FHP vehicle with blue lights is stationed.
3. Two weeks following the removal of the FHP vehicle.

Data were collected from 10:00 pm through 5:00 am each day, from Monday night through Saturday morning each week. However, not all data collected were useful. Data for the following days were excluded for the reason indicated:

- Week 1, Monday, May 22, 2017: Rain
- Week 1, Tuesday, May 23, 2017: Light plant did not work
- Week 2, Monday, May 29, 2017: Holiday (Memorial Day)
- Week 3, Monday, June 5, 2017: Light plant did not work
- Week 3, Wednesday, June 7, 2017: Rain
- Week 3, Friday, June 9, 2017: FHP officer failed to show up
- Week 5, Monday, June 19, 2017: Light plant did not work
- Week 6, Tuesday, June 27, 2017: Rain

3.4 Study Results

3.4.1 Average Speeds

Table 3-1 gives the weekly average speeds for each of the eight iCone locations (i.e., #1 to #8). The table also gives the average speeds for the three evaluation periods, i.e., before, during, and after blue lights. Figures 3-9 and 3-10 plot the average speeds by week and evaluation period, respectively. The figures show that the average speeds decreased as vehicles entered the work zone and continued to decrease throughout the remaining iCone locations. The reduction was the greatest over the third and fourth weeks when a FHP vehicle with blue lights was deployed.

Table 3-1. Average Speeds at iCone Locations

Period	Weeks	Average Speed (mph)							
		iCone 1	iCone 2	iCone 3	iCone 4	iCone 5	iCone 6	iCone 7	iCone 8
Before Blue Lights	1	66.6	65.9	66.7	65.5	65.6	65.0	63.0	62.1
	2	66.0	68.0	67.4	65.4	65.3	65.4	63.7	62.8
	1 and 2	66.3	66.9	67.0	65.4	65.5	65.1	63.3	62.4
During Blue Lights	3	66.9	67.0	65.8	60.5	59.9	59.5	58.6	58.3
	4	66.9	67.1	66.6	61.4	60.9	60.6	59.8	59.3
	3 and 4	66.9	67.0	66.3	61.0	60.5	60.1	59.4	59.0
After Blue Lights	5	67.6	66.4	67.9	64.2	64.3	64.0	62.3	61.3
	6	67.9	66.0	68.4	63.7	62.2	63.2	62.1	62.6
	5 and 6	67.7	66.2	68.1	64.0	63.5	63.6	62.2	62.0

Note: FHP vehicle stationed near iCone 5.

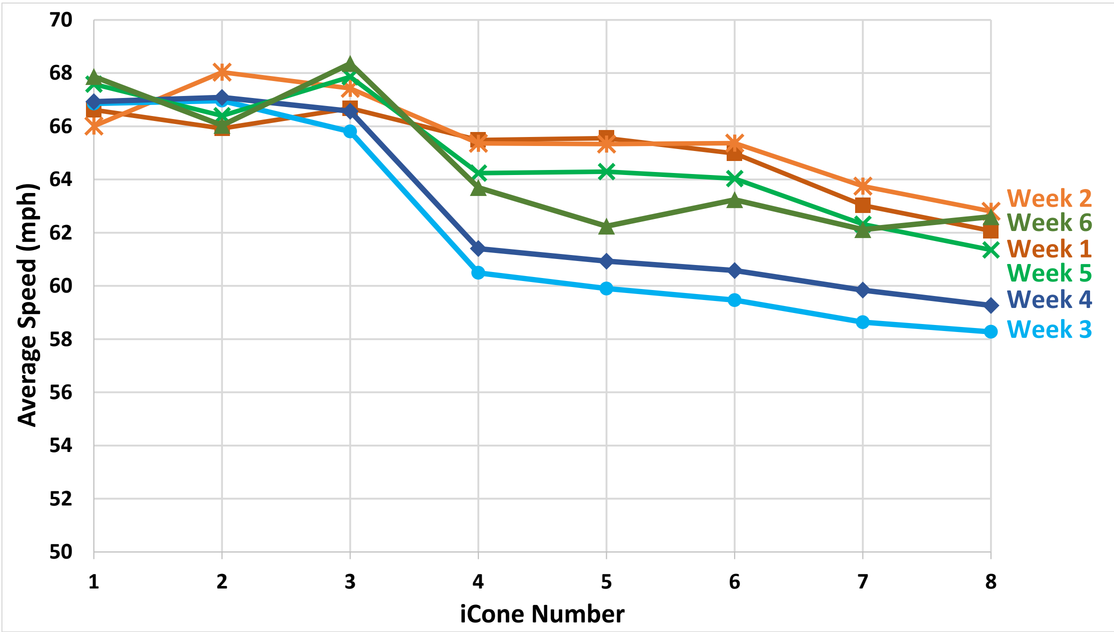


Figure 3-9. Average Speeds at iCone Locations by Week

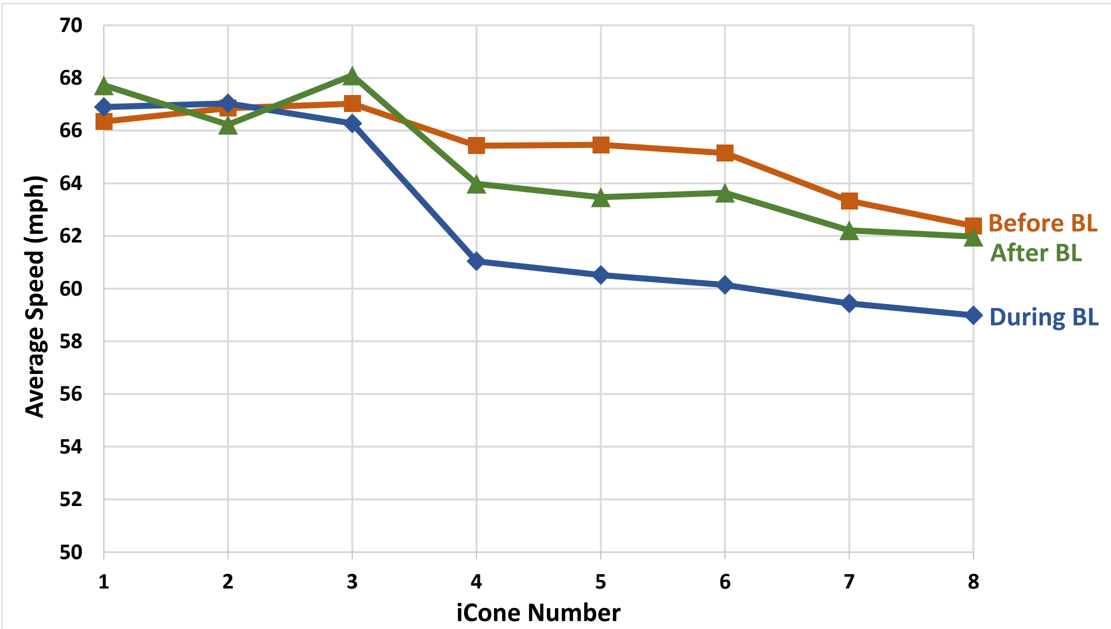


Figure 3-10. Average Speeds at iCone Locations by Evaluation Period

It is observed that the overall average speeds are relatively low for the given speed limits (i.e., 70 mph before the work zone (iCones #1 to #3) and 65 mph within the work zone (iCones #4 to #8). Several factors could contribute to the lower average speeds, including but are not limited to:

- Drivers tended to drive slower at night and at locations without streetlights.
- There was a high percentage of slower trucks at night (refer to Subsection 3.4.3).

- There was a high concentration of vehicles using the inside lane, as drivers pre-positioned themselves to use the I-95 northbound ramp to Jacksonville (also see Subsection 3.4.3).
- Laser-based iCones tended to pick up more speed readings from the larger, slower trucks than the smaller, faster passenger cars.

Since the main measure of effectiveness in this study is not based on the absolute average speeds, but the reductions in average speeds, any impact these factors may have on the results are expected to be minimal.

Table 3-2 divides the eight iCones into two groups: iCones #1 to #3, located upstream of the work zone, and iCones #4 to #8, located within the work zone. In Table 3-2, the overall average speeds are summarized for both groups for each week and each evaluation period.

Table 3-2. Overall Average Speeds Upstream and within Work Zone

Period	Weeks	Average Speed (mph)		Average Speed Difference (mph)
		Upstream of Work Zone (iCones 1-3)	Within Work Zone (iCones 4-8)	
Before Blue Lights	1	66.4	64.4	2.0
	2	67.2	64.7	2.5
	1 and 2	66.8	**64.5**	2.3
During Blue Lights	3	66.5	59.5	7.0
	4	66.8	60.4	6.4
	3 and 4	66.7	**60.1**	6.6
After Blue Lights	5	67.3	63.3	4.0
	6	67.5	62.8	4.7
	5 and 6	67.4	**63.1**	4.3

The following key observations can be made from the table:

- Before the deployment of FHP vehicle with blue lights, the average speed difference before and after vehicles entered the work zone was 2.3 mph. Following the FHP vehicle deployment, the difference increased to 6.6 mph, for a net average speed reduction of **4.3 mph** that could be attributed to blue light deployment.

- Following the removal of the FHP vehicle with blue lights, the average speed difference before and after vehicles entered the work zone was 4.3 mph, representing a smaller net average speed reduction of **2.0 mph** when compared to the baseline average speed from the first two weeks.

- Comparing the overall average speeds from the five iCones within the work zone before and during the FHP vehicle deployment, there was a net average speed reduction of **4.4 mph**, from 64.5 mph to 60.1 mph. Similarly, following the removal of the FHP vehicle with blue lights, there was a small net average speed reduction of **1.4 mph**, from 64.5 mph to 63.1 mph.

Figure 3-11 plots the overall average speeds for each evaluation period for iCones upstream of the work zone and iCones within the work zone.

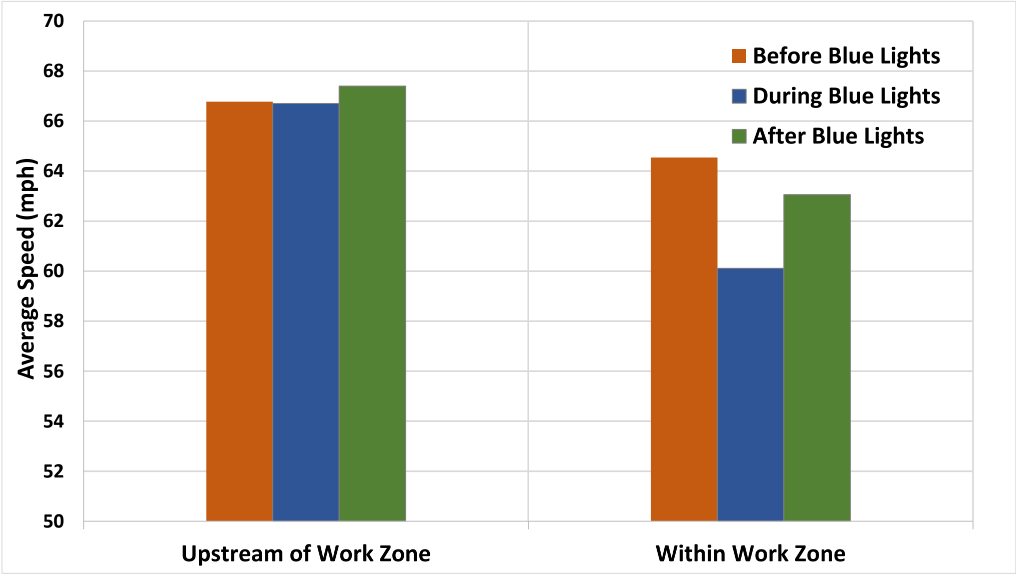


Figure 3-11. Overall Average Speeds Upstream of and within Work Zone

3.4.2 Vehicle Speeding

Figure 3-12 compares the cumulative speed distributions before and during the deployment of FHP vehicle with blue lights at iCone #5 (where the FHP vehicle was stationed). It can be seen from the figure that the deployment of FHP vehicle reduced vehicle speeding (i.e., > 65 mph) from 37% to 17%, for a net reduction of 20%.

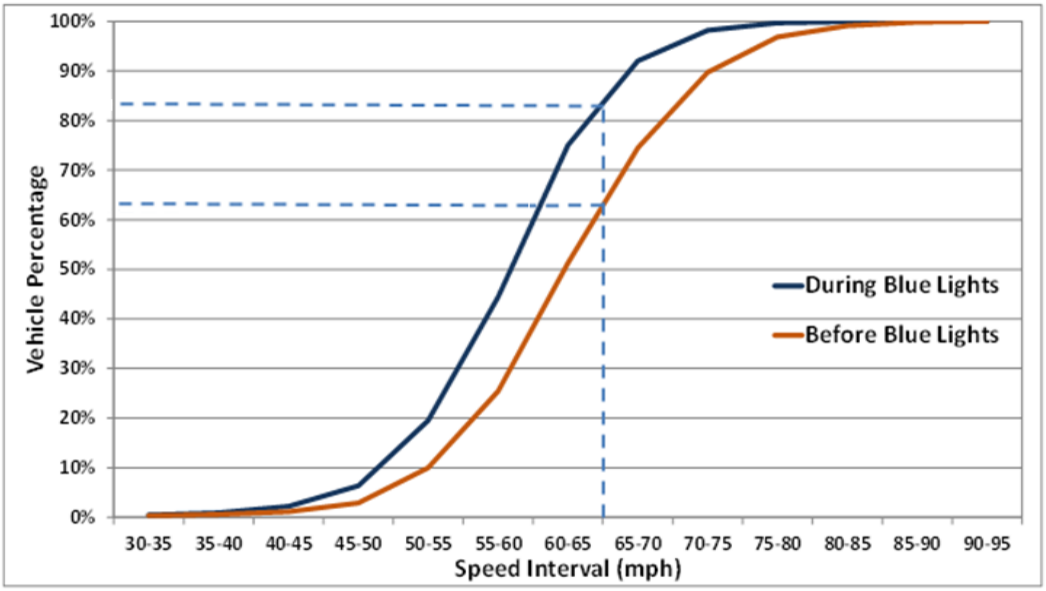


Figure 3-12. Cumulative Speed Distributions at iCone #5 before and during Blue Light Deployment

3.4.3 Vehicle Lane Use and Truck Percentage

To assess the impact of FHP vehicle with blue lights on vehicle lane use, three hours of videos taken each at iCone #5 and #8 were sampled from each study day. The hours sampled are 10:00 pm - 11:00 pm, 1:00 am - 2:00 am, and 4:00 am - 5:00 am. Vehicles on each of the two open lanes were manually counted from the videos. Trucks and passenger cars were counted separately. The overall percentage of trucks during those hours was found to be about 25%.

Table 3-3 gives the percentages of vehicles using the inside (i.e., adjacent to work zone) and outside lanes at iCone #5 and #8. As noted earlier, iCone location #5 was located where the FHP vehicle was parked during weeks 3 and 4 of the study. Figure 3-13 plots the lane use percentages during each evaluation period. It can be seen from the percentages that there was a high concentration of vehicles using the inside lane adjacent to the work zone. This was because a large majority of the vehicles were heading north on I-95 toward Jacksonville. These vehicles, as directed by multiple directional overhead signs, pre-positioned themselves as they approached the interchange.

Table 3-3. Vehicle Lane Use Percentages at Beginning of Full Lane Closure and at End of Work Zone

Period	Weeks	At iCone #5		At iCone #8	
		Inside Lane (%)	Outside Lane (%)	Inside Lane (%)	Outside Lane (%)
Before Blue Lights	1	87.1	12.9	87.9	12.1
	2	89.0	11.0	91.1	8.9
	1 and 2	88.1	11.9	89.5	10.5
During Blue Lights	3	82.7	17.3	87.1	12.9
	4	83.9	16.1	87.0	13.0
	3 and 4	83.5	16.5	87.0	13.0
After Blue Lights	5	84.0	16.0	85.6	14.4
	6	82.1	17.9	85.3	14.7
	5 and 6	83.1	16.9	85.4	14.6

As can be seen in Table 3-3, there was a small 4.5% shift in vehicles from the inside lane to the outside lane following the deployment of FHP vehicle. The shift percentage was reduced to 2.5% at iCone #8 (i.e., about 1,500 feet after passing the FHP vehicle), indicating that some vehicles shifted back to the inside lane after passing the FHP vehicle. Following the removal of the FHP vehicle, a slightly higher shift was observed at both iCone locations, which was somewhat unexpected. In any case, given the large number of pre-positioning vehicles, the study location is not ideal for assessing the impact of FHP vehicle with flashing lights on vehicle lane use.

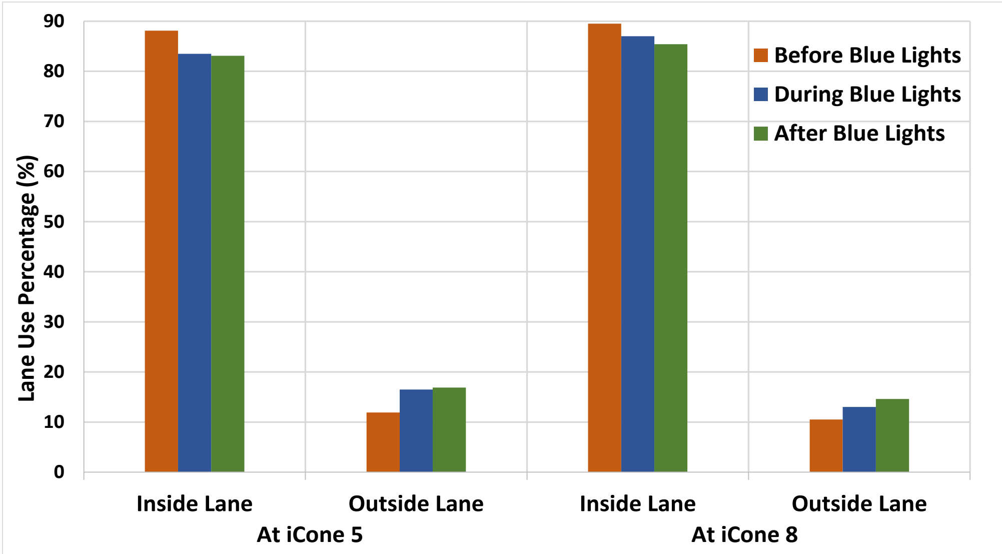


Figure 3-13. Lane Use Percentages before, during, and after Blue Light Deployment

CHAPTER 4
GAINESVILLE STUDY LOCATION

This chapter describes in detail the field conditions, the data collection method used, the data collection period covered, and the study results from the study location in Gainesville, Florida.

4.1 Field Conditions

The selected construction project was a fast-moving asphalt milling and resurfacing project located on I-75 at the outskirts of City of Gainesville (see Figure 4-1). As shown in Figure 4-2, the project limits ran between south of SR 121 (SW Williston Rd) and south of SR 222 (NW 39 Ave). The section of the I-75 had three lanes in each direction and the total distance was 6.5 miles. The section included three major interchanges that pass over the W. Newberry Road to the north, the SW Williston Road to the south, and the SW Archer Road in between. As a result of these overpasses, there were three minor crest vertical curves that were not expected to significantly affect the truck speeds. As can be seen in Figure 4-2, the section was relatively straight, thus the vehicle speeds were not affected by horizontal curves. The regular speed limit on the section was 70 mph and was temporarily reduced to 60 mph during construction (see Figure 4-3).

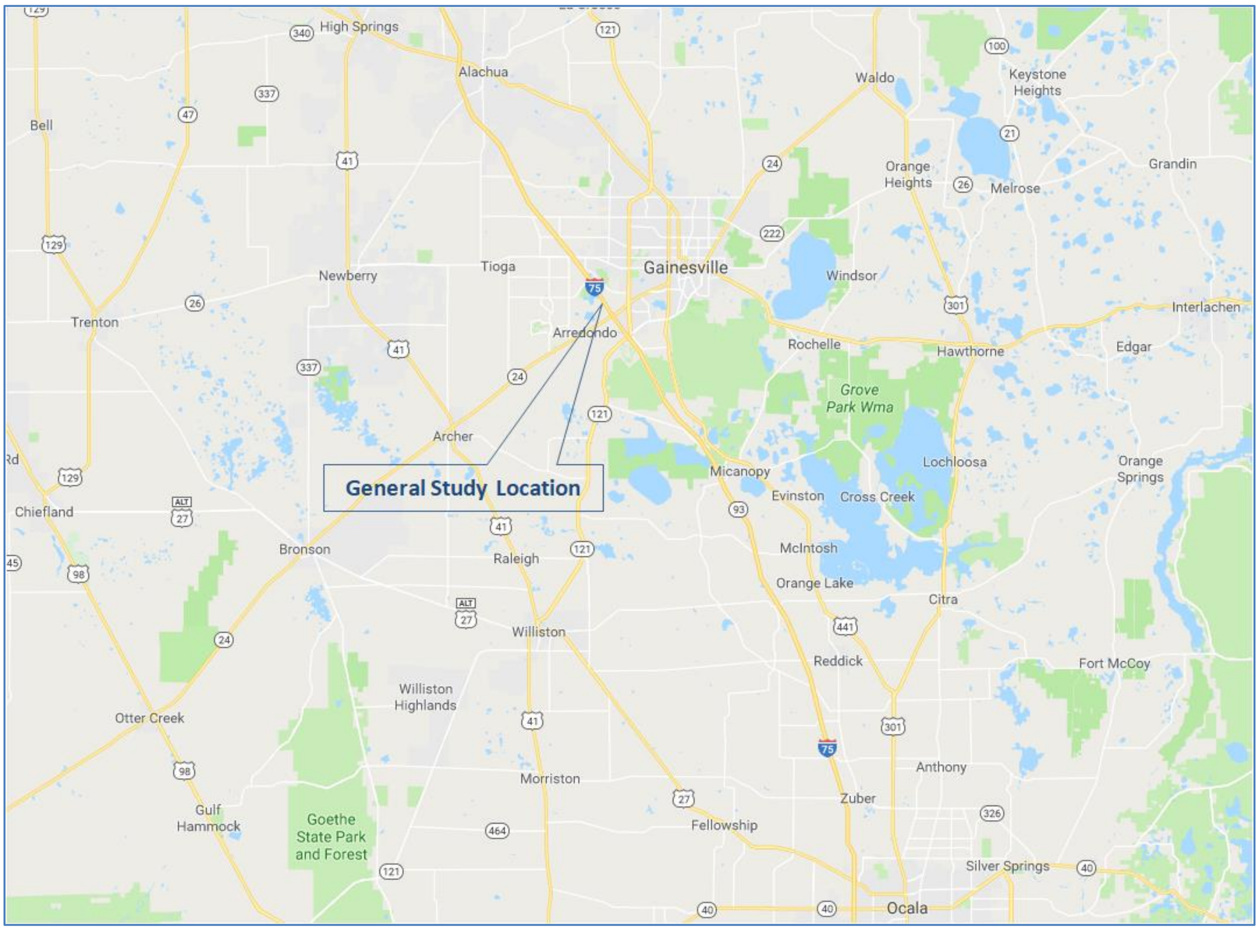


Figure 4-1. General Study Location (Map)

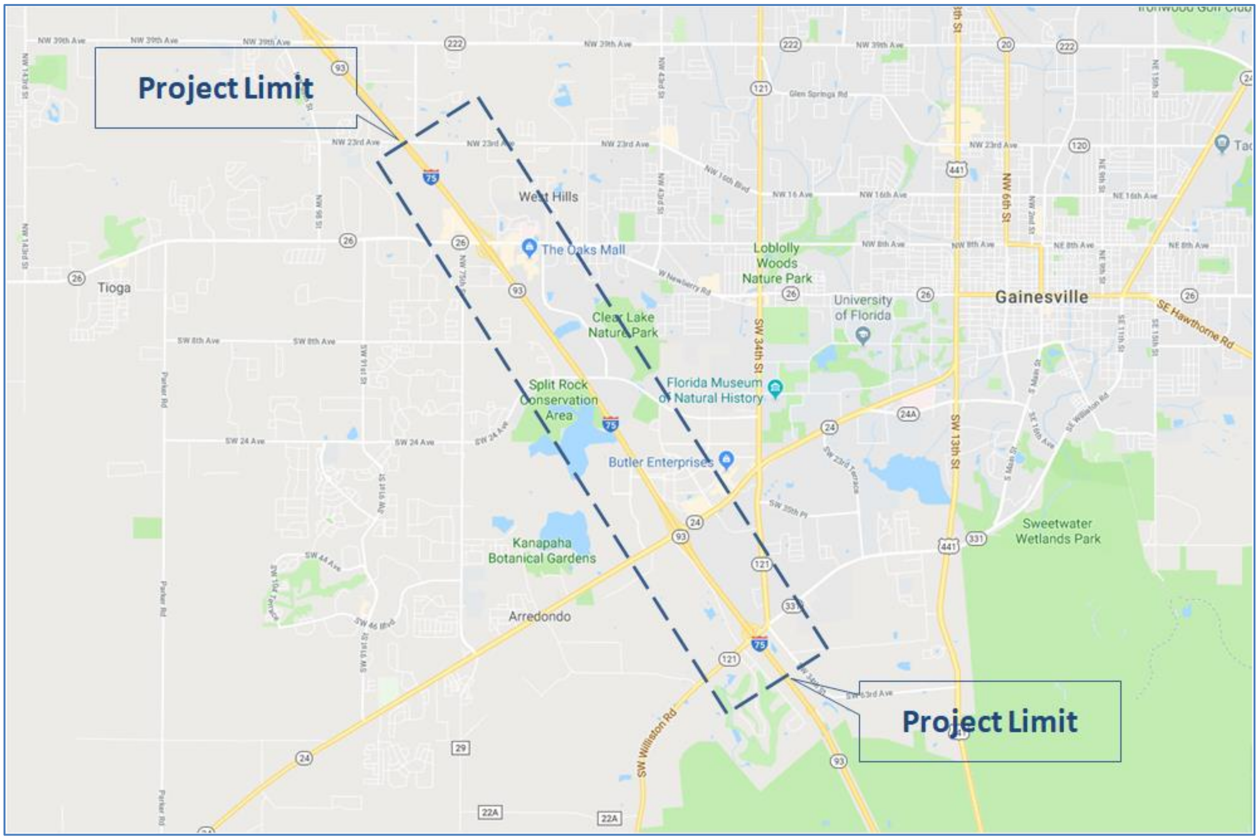


Figure 4-2. Project Limits (Map)

Figure 4-3. Reduced Work Zone Speed Limit Warning Sign

4.2 Data Collection Method

The setup for data collection involved mainly the placement of data collection equipment, which included: (1) eight iCones that were used to collect spot speeds at multiple locations along the study corridor, and (2) two video cameras that were used to record videos at two locations within the work zone.

As an example, Figure 4-4 shows the locations of the eight iCones used to collect the vehicle spot speeds on October 16, 2017. In general, the eight iCones were placed as follows:

- iCone #1 was located two miles upstream of iCone #3, which was located at the beginning of the full 1-lane closure. At this location, drivers were not able to see the blue lights, thus ensuring that their speeds would not be affected by the blue lights.

- iCone #2 was located one mile upstream of iCone #3. At this location, drivers were able to see the presence of blue lights ahead, but not clearly.

- iCone #3 was located at the beginning of the full 1-lane closure. At this location, drivers were able to clearly see the blue lights. It is noted that two tapers were used to achieve a 2-lane or 2.5-lane closure, with the first taper leading to a full 1-lane closure, and the second taper leading to a full 2-lane or 2.5-lane closure.

- iCone #4 was located at the beginning of the full 2-lane closure when paving the inside lane or the left shoulder, or 2.5-lane lane when paving the middle lane.

- iCones #5 to #8 were spaced evenly across the full 2-lane or 2.5-lane closure, with the exception of having to avoid undesirable locations, as explained further below.

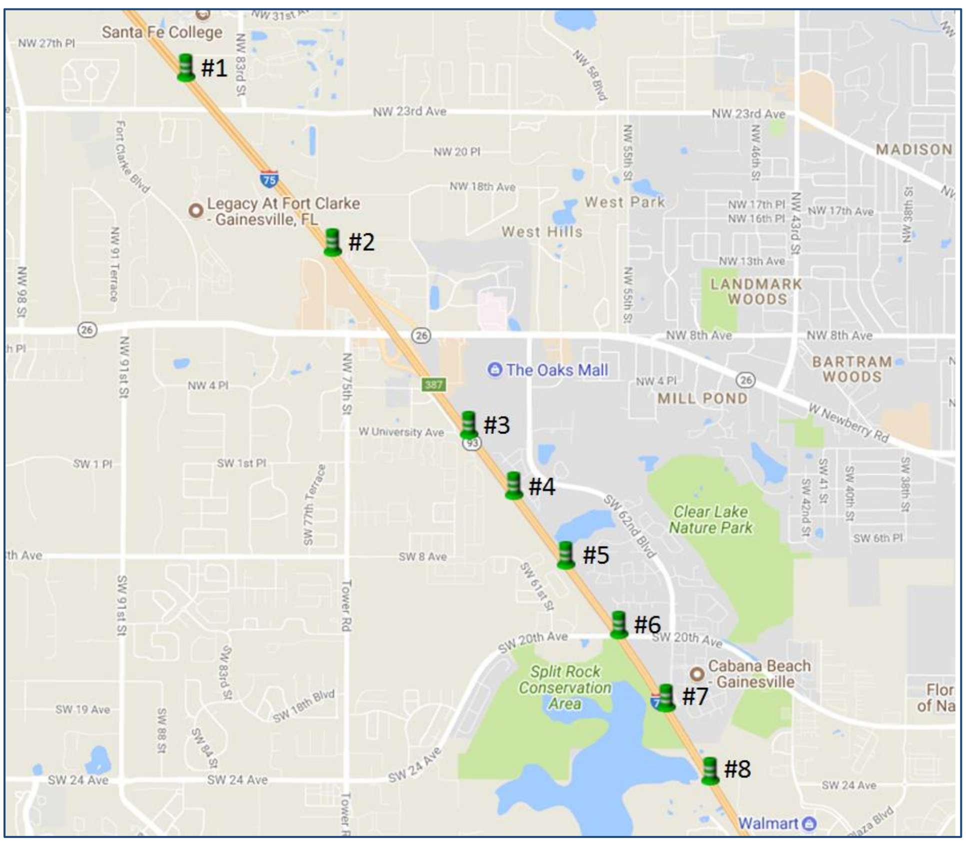


Figure 4-4. iCone Locations for Speed Data Collection

As the work zone locations varied each day, the actual locations of the iCones for each day were adjusted (i.e., moved slightly upstream or downstream) as needed, in order to avoid: (1) vertical curve slopes where the average speeds, especially of the trucks, could be affected; (2) acceleration and deceleration lanes where the average speeds could be affected by those of the merging and diverging vehicles. The actual iCone locations used for each of the night closures for which data were collected are given in Appendix A. For the entire study, all iCones were placed near the outside shoulder (see Figure 4-5 for an example) next to the open travel lane.

Figure 4-5. iCones Placed Next to the Outside Shoulder

The first of the two video cameras was set up at iCone #4 located at the beginning of the full closure (2-lane or 2.5-lane). This was also the location where the vehicles with blue lights were parked. The vehicles used in this study were from the Florida Fish and Wildlife Conservation Commission (FWC) and displayed only blue lights (see Figure 4-6). This particular video camera served four main purposes: (1) captured the parked vehicle with blue lights and helped to keep a record of the exact time periods that blue lights were present, (2) determined the congestion level in order to identify the uncongested periods for analysis, (3) determined the period when construction ended, and (4) determined the truck percentages and lane use distribution (for the one night closure with two lanes open, see Table 4-1).

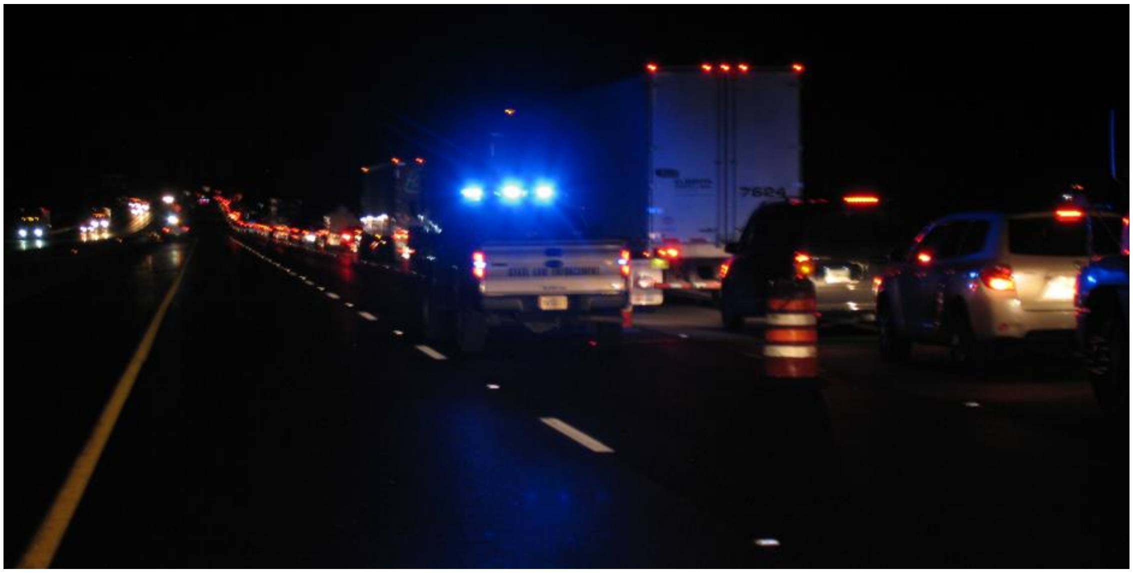


Figure 4-6. Florida Fish and Wildlife Conservation Commission (FWC) Vehicle with Blue Lights

4.3 Data Collection Period

The data collection period started on September 24, 2017, and ended on November 2, 2017, for a total of six weeks. The weekly construction days were from Sunday night to Thursday night. The construction generally started at around 9:00 pm until the work scheduled for the night was completed, typically at around 5:00 am. As the work zone was dynamic, i.e., with its location and length changing each day, the data collection equipment (i.e., iCones and video cameras) could only be set up after the work zone was set up for the night. The equipment was typically set up by 10:00 pm.

Table 4-1 summarizes the data collection conditions of each day over the entire six-week data collection period. The original plan was to include two weeks prior to the deployment of blue lights, two weeks with the deployment of blue lights, and two weeks following the removal of blue lights. Upon consultation with the FDOT project managers, this plan was modified slightly, i.e., extend the period for the blue lights for two extra days into the fifth week of the study period in order to make up for the excess number of cancelled construction days during the fourth week. As indicated in Table 4-1, a total of 10 planned study days (out of 30) of the study period had to be excluded due to a variety of reasons, including rain, cold weather, special events on the nearby University of Florida (UF) campus, problems with construction equipment and materials, and a very short work zone located in the middle of an interchange area.

Table 4-1 also lists for each data collection night, the paving direction, the approximate length of each work zone, the number of lanes that were closed, the specific lane that was paved, and the uncongested time period. With only one lane open, there was significant congestion along the study location especially during the early hours of lane closures. The uncongested time periods were identified from the video at iCone #4. An uncongested time period started when there was not a queue observed at the beginning of a full 2- or 2.5-lane closure and vehicles were able to enter the work zone with no delay.

As can be seen from Table 4-1, the nightly closures over the study period started from the south end moving north, paving just the inside lane. The construction then shifted to the southbound direction after reaching the north end of the project limits. In the southbound direction, the construction moved slower, paving either the inside lane, the middle lane, or the left shoulder during each night closure. Except for the one night closure on October 4, 2017, when only one lane was closed, all the other night closures closed either 2 lanes to pave the inside lane or the left shoulder, or 2.5 lanes to pave the middle lane.

Table 4-1. Summary of iCone Data Collection

Period	Week	Study Date	Paving Direction*	Length of Work Zone (miles)	Number of Lanes Closed	Lane Paved	Uncongested Time Period
Before Blue Lights	1	9/24/2017 Sun	NB	1.6	2	Inside Lane	22:00 - 4:13
		9/25/2017 Mon	NB	1.6	2	Inside Lane	23:43 - 5:00
		9/26/2017 Tue	NB	1.6	2	Inside Lane	23:15 - 5:00
		9/27/2017 Wed	NB	1.6	2	Inside Lane	22:37 - 5:00
		9/28/2017 Thu	SB	1.6	2	Inside Lane	00:20 - 5:00
	2	10/1/2017 Sun	Cancelled due to rain.				
		10/2/2017 Mon	Cancelled due to rain.				
		10/3/2017 Tue	SB	1.8	2.5	Middle Lane	22:00 - 4:13
		10/4/2017 Wed	SB	2.2	1	Left Shoulder	23:43 - 5:00
		10/5/2017 Thu	Cancelled due to UF Homecoming event.				
During Blue Lights	3	10/8/2017 Sun	Cancelled due to rain.				
		10/9/2017 Mon	SB	0.8	2.5	Middle Lane	22:55 - 3:28
		10/10/2017 Tue	SB	1.4	2	Inside Lane	22:20 - 3:34
		10/11/2017 Wed	SB	1.5	2	Left Shoulder	23:06 - 5:00
		10/12/2017 Thu	SB	1.6	2.5	Middle Lane	00:10 - 5:00
	4	10/15/2017 Sun	Cancelled due to milling machine failure.				
		10/16/2017 Mon	SB	1.6	2.5	Middle Lane	00:00 - 2:35
		10/17/2017 Tue	Cancelled due to missing paving materials.				
		10/18/2017 Wed	SB	1.6	2	Inside Lane	23:25 - 5:00
		10/19/2017 Thu	Cancelled due to Spencer speaker event at UF.				
	5	10/22/2017 Sun	SB	1.4	2.5	Middle Lane	2:25 - 5:00
		10/23/2017 Mon	Cancelled due to rain.				
		10/24/2017 Tue	SB	1.6	2	Left Shoulder	23:25 - 4:29
After Blue Lights	5	10/25/2017 Wed	SB	1.2	2	Inside Lane	00:10 - 4:45
		10/26/2017 Thu	Cancelled due to cold weather.				
	6	10/29/2017 Sun	SB	1.2	2	Left Shoulder	1:05 - 4:50
		10/30/2017 Mon	Not used due to very short work zone in middle of an interchange.				
		10/31/2017 Tue	SB	1.7	2.5	Middle Lane	23:45 - 4:00
		11/1/2017 Wed	SB	1.6	2.5	Middle Lane	00:05 - 4:30
		11/2/2017 Thu	SB	1.3	2	Inside Lane	23:48 - 4:40

* NB: Northbound; SB: Southbound

4.4 Study Results

4.4.1 Average Speeds

For the purpose of this study, only the uncongested time periods during which vehicle speeds were not constrained by congestion are included in the analysis. Table 4-2 gives the average speeds at each iCone location for each evaluation period (i.e., before, during, and after the deployment of blue lights) under different number of closed lanes. Figures 4-7 to 4-8 compare the average speeds among the three evaluation periods for days with 2-lane closure, days with 2.5-lane closure, and days with either 2-lane or 2.5-lane closure (i.e., combined), respectively. The figures show that, in general, the average speeds decreased as vehicles approached the work zone. Figure 4-7 shows that, for the days with 2-lane closure, the average speeds with blue lights are consistently lower within the work zone area, with the largest speed reduction occurring at iCone #4, where the vehicle with blue lights was stationed.

Table 4-2. Average Speeds at iCone Locations

Number of Closed Lanes	Evaluation Period	Average Speed (mph)							
		iCone 1	iCone 2	iCone 3	iCone 4	iCone 5	iCone 6	iCone 7	iCone 8
2	Before BL	65.9	63.4	59.8	56.4	54.8	52.3	51.0	52.9
	During BL	65.9	64.8	57.9	50.2	51.0	49.1	48.3	51.0
	After BL	66.2	61.9	58.5	54.1	50.7	50.9	50.3	48.8
2.5	Before BL	65.3	62.6	59.9	53.9	41.5	42.6	53.9	54.8
	During BL	65.1	65.9	59.6	49.5	44.2	43.2	44.9	50.6
	After BL	63.6	62.6	56.7	53.2	41.9	41.0	44.4	52.9
1	Before BL	64.9	63.6	62.3	59.3	59.9	59.3	56.7	60.9

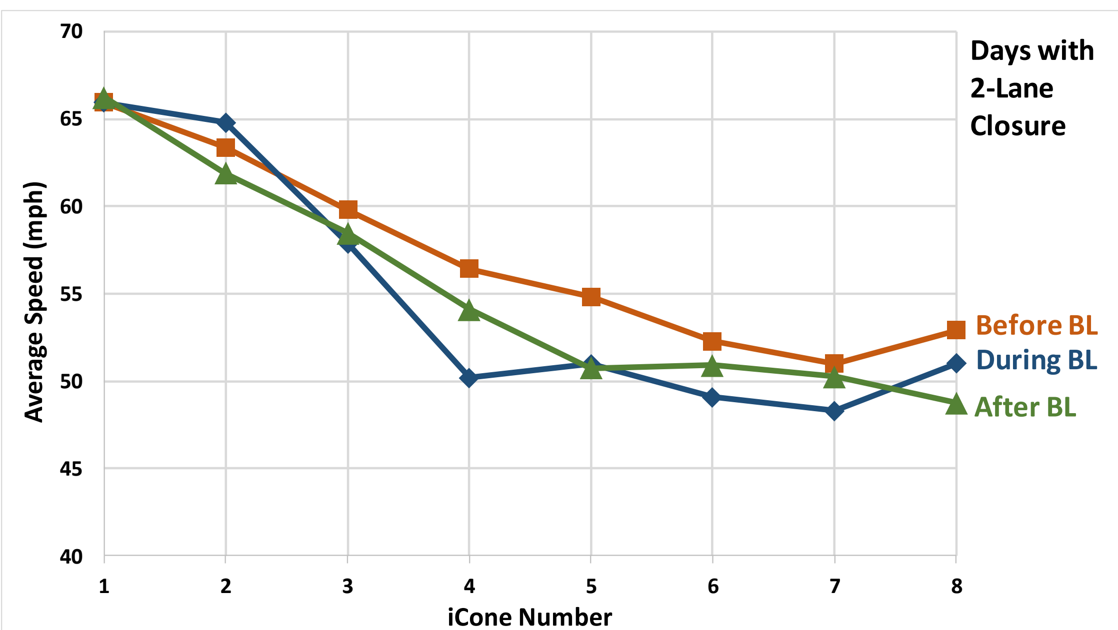


Figure 4-7. Average Speeds for Days with 2-Lane Closure

Figure 4-8 shows that, for the days with 2.5-lane closure, the average speeds dropped more drastically due to the extremely narrow travel space, with vehicles travelling partially on the right shoulder. However, the average speeds recovered as vehicles approached the end of work zone. It can also be seen that the presence of blue lights resulted in some speed reduction at iCone #4. It also contributed to more stable average speeds across the work zones.

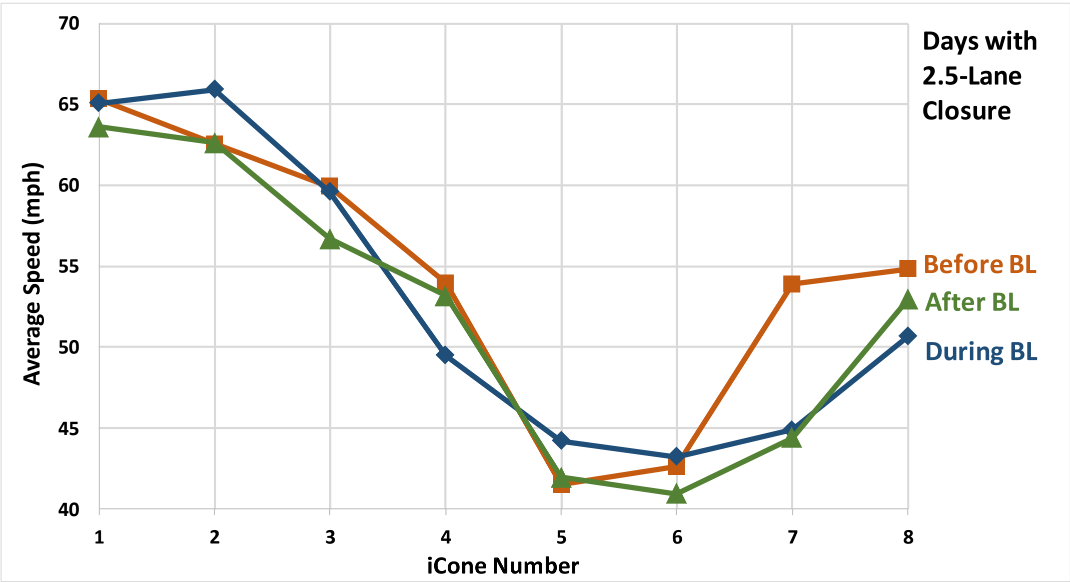


Figure 4-8. Average Speeds for Days with 2.5-Lane Closure

Figure 4-9 shows that the average speeds for the one day on October 4, 2017 when only one lane was closed and with no blue lights. It can be seen that the average speeds across the work zone with two lanes open were significantly higher than those with 2- or 2.5-lane closures, averaging at near 60 mph across the work zone, compared to near 50 mph when 2 or 2.5 lanes were closed.

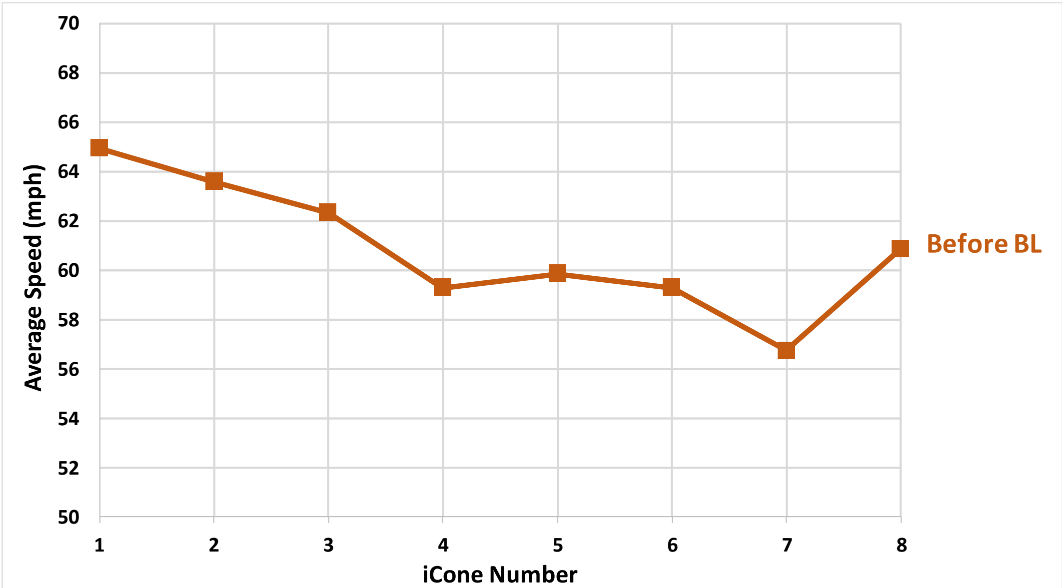


Figure 4-9. Average Speeds for a Single Day with 1-Lane Closure

Table 4-3 groups the eight iCones into those located upstream of the work zone (i.e., iCones #1 to #3) and those located within the work zone (iCones #4 to #8). The overall average speeds are summarized similarly based on the number of closed lanes and evaluation periods.

Table 4-3. Overall Average Speeds Upstream and within Work Zone

Number of Closed Lanes	Evaluation Period	Average Speed (mph)		Average Speed Difference (mph)
		Upstream of Work Zone (iCones 1-3)	Within Work Zone (iCones 4-8)	
Days with 2-Lane Closure Only	Before Blue Lights	62.8	53.7	9.1
	During Blue Lights	62.4	49.9	12.5
	After Blue Lights	61.9	51.0	10.9
Days with 2.5-Lane Closure Only	Before Blue Lights*	62.5	49.2	13.3
	During Blue Lights	63.1	46.4	16.7
	After Blue Lights	61.0	46.1	14.9

** This baseline data is based on only one night of speed data and is not considered reliable.*

The following key observations can be made from Table 4-3 for the results from the days with 2-lane closure:

- Before blue light deployment, the average speed difference before and after vehicles entering the work zone was 9.1 mph. Following the blue light deployment, the difference increased to 12.5 mph, for a net average speed reduction of **3.4 mph** that could be attributed to blue light deployment.

- Following the removal of the blue lights, the average speed difference before and after vehicles entering the work zone was 10.9 mph, representing a smaller net average speed reduction of **1.8 mph**. It should be noted that the sample size during the period after the blue light deployment is relatively small, thus this average speed reduction is considered less reliable.

- Comparing the overall average speeds from only the five iCones within the work zone before and during the blue light deployment, there was a net average speed reduction of **3.8 mph**, reducing from 53.7 mph to 49.9 mph. Similarly, following the removal of the blue lights, there was a small net average speed reduction of **2.7** mph, from 53.7 mph to 51.0 mph. Again, this speed reduction is considered to be less reliable due to the smaller sample size during the period after the blue light deployment.

In the case of 2.5-lane closure, the following results can similarly be observed. It is important to note that the results are not considered reliable as only one day of data with 2.5-lane closure was available during the period before the blue light deployment.

- Before blue light deployment, the average speed difference before and after vehicles entering the work zone was 13.3 mph. Following the blue light deployment, the difference increased to 16.7 mph, for a net average speed reduction of **3.4 mph** that could be attributed to blue light deployment.

- Following the removal of the blue lights, the average speed difference before and after vehicles entering the work zone was 14.9 mph, representing a smaller net average speed reduction of **1.6 mph**.

- Comparing the overall average speeds from only the five iCones within the work zone before and during the blue light deployment, there was a net average speed reduction of **2.8 mph**, reducing from 49.2 mph to 46.4 mph. Similarly, following the removal of the blue lights, there was a small net average speed reduction of **3.1 mph**, from 49.2 mph to 46.1 mph.

Figures 4-10 and 4-11 show the overall average speeds upstream of and within work zone for each of the three evaluation periods for 2-lane and 2.5 lane closures, respectively.

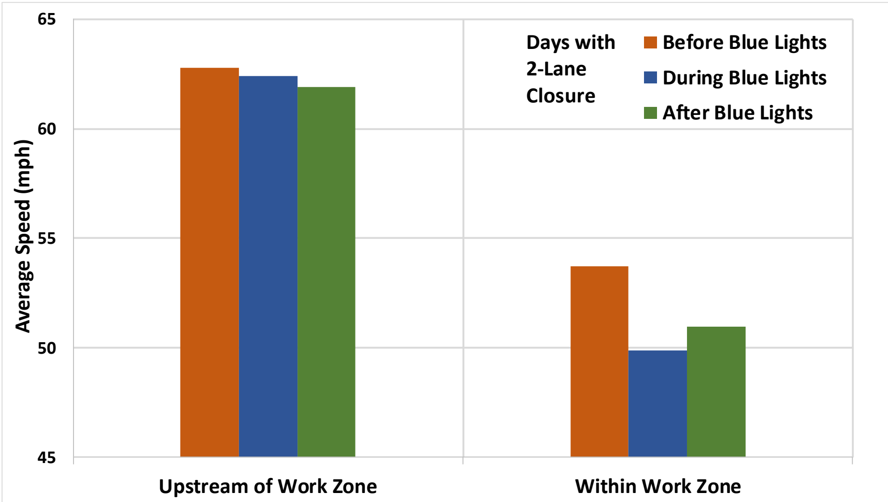


Figure 4-10. Overall Average Speeds Upstream of & within Work Zone for 2-Lane Closure

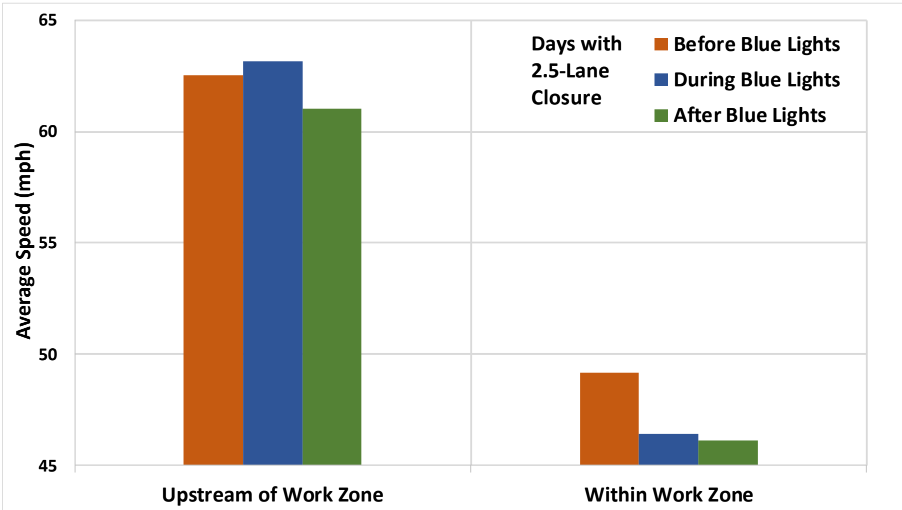


Figure 4-11. Overall Average Speeds Upstream of & within Work Zone for 2.5-Lane Closure

4.4.2 Vehicle Speeding

Figure 4-12 compares the cumulative speed distributions for the days with 2-lane closure before and during blue light deployment at iCone #4 where the vehicles with blue lights were stationed. It can be seen from the figure that the deployment of blue lights reduced vehicle speeding (i.e., >60 mph) from 21% to 5%, for a net reduction of 16%. Similarly, Figure 4-13 shows a smaller but significant reduction of about 10% in speeding (from 15% to 5%) in the case of 2.5-lane closure.

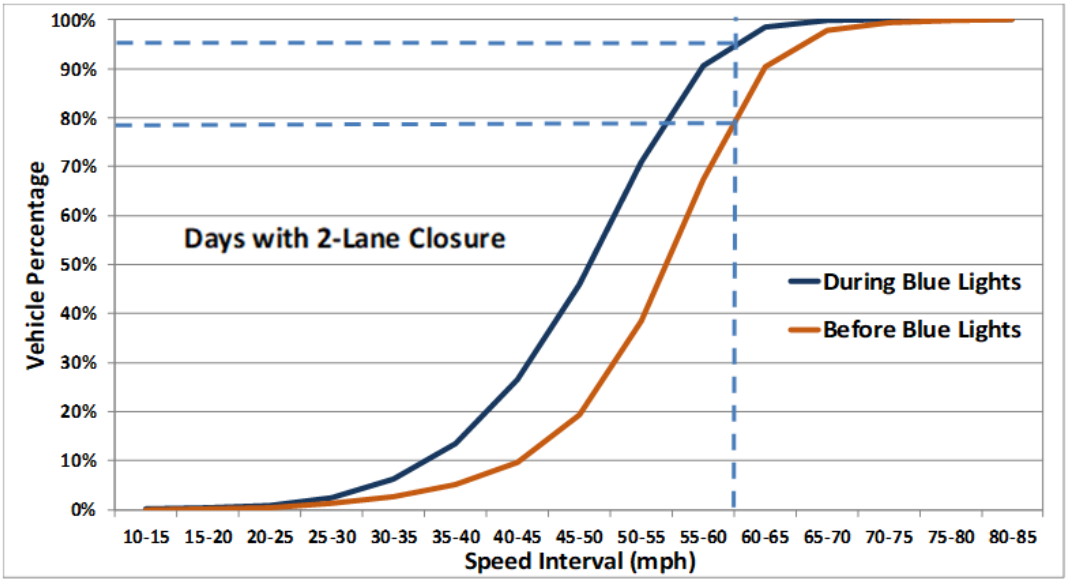


Figure 4-12. Cumulative Speed Distributions at iCone #4 before and during Blue Light Deployment for Days with 2-Lane Closure

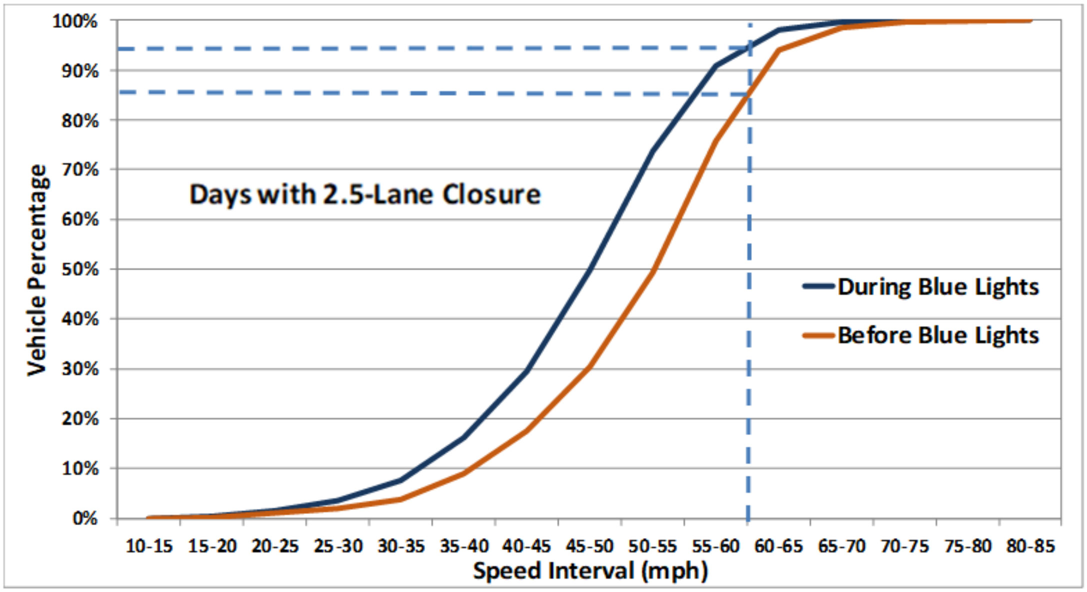


Figure 4-13. Cumulative Speed Distributions at iCone #4 before and during Blue Light Deployment for Days with 2.5-Lane Closure

4.4.3 Vehicle Lane Use and Truck Percentages

As there was only one night closure with two lanes opened at this study location, the impact of blue lights on lane use distribution cannot be evaluated. Table 4-4 gives the vehicle lane use percentages from a three-hour sample for the one day (October 4, 2017) when two lanes were open. The statistics are given for the start (iCone #4) and end (iCone #8) locations of the full 1-lane closure. The results show that, overall, about a third of the vehicles used the middle lane adjacent to the work area, with the remaining two thirds of the vehicles used the outside lane away from the work area.

Table 4-4. Vehicle Lane Use Percentages at Start and End of Full 1-Lane Closure

Time Period	At iCone #4 Vehicles (Percentage)		At iCone #8 Vehicles (Percentage)	
	Middle Lane	Outside Lane	Middle Lane	Outside Lane
10 PM - 11 PM	340 (42%)	471 (58%)	278 (35%)	526 (65%)
1 AM - 2 AM	163 (32%)	339 (68%)	129 (27%)	356 (73%)
3 AM - 4 AM	136 (30%)	311 (70%)	197 (45%)	244 (55%)
Overall	639 (36%)	1,121 (64%)	604 (35%)	1,226 (65%)

Table 4-5 gives the estimates of truck percentages at the study location based on two half-hour video count samples (i.e., 1:00-1:30 am and 3:00-3:30 am) for each day of data collection. The percentage of trucks ranged from 42% to 68%, for a high overall truck percentage of 58%.

Table 4-5. Estimates of Truck Percentages at Study Location

Study Date	# of Cars	# of Trucks	Truck Percentage
9/24/2017 Sunday	137	105	43
9/25/2017 Monday	153	205	57
9/26/2017 Tuesday	143	215	60
9/27/2017 Wednesday	99	208	68
9/28/2017 Thursday	222	279	56
10/3/2017 Tuesday	136	275	67
10/4/2017 Wednesday	203	226	53
10/10/2017 Tuesday	157	256	62
10/11/2017 Wednesday	167	290	63
10/12/2017 Thursday	210	225	52
10/16/2017 Monday	181	234	56
10/18/2017 Wednesday	188	281	60
10/22/2017 Sunday	226	220	49
10/24/2017 Tuesday	168	254	60
10/25/2017 Wednesday	164	300	65
10/29/2017 Sunday	283	208	42
10/31/2017 Tuesday	196	270	58
11/1/2017 Wednesday	171	295	63
11/2/2017 Thursday	196	260	57
Total	**3,400**	**4,606**	**58**

CHAPTER 5
SUMMARY OF KEY RESULTS

Below is a summary of the key results from each of the two locations included in this study.

5.1 Daytona Beach Study Location

The key results from the I-4 study location in Daytona Beach (1-lane closure out of three lanes) are summarized below:

1. The deployment of Florida Highway Patrol (FHP) vehicle with blue lights at the study location reduced the average speed within the work zone by about **4.4 mph**.

2. During the two-week period following the removal of FHP vehicle with blue lights, the average speed within the work zone was reduced by **1.4 mph** when compared to the baseline data from the first two weeks.

3. The deployment of FHP vehicle with blue lights reduced vehicle speeding (i.e., >65 mph) by **20%**.

4. The deployment of FHP vehicle with blue lights at the study location shifted only a very small percentage of vehicles away from the work zone. However, this result was not considered reliable due to a large percentage of vehicles that pre-positioned themselves on the inside lane to use the left-side off-ramp to head northbound on I-95.

5.2 Gainesville Study Location

The key results from the I-75 study location in Gainesville are summarized below:

For 2-lane closure (out of three lanes):

1. The deployment of Florida Fish and Wildlife Conservation Commission (FWC) vehicle with blue lights at the study location reduced the average vehicle speed within the work zone by about **3.8 mph**. This is a slightly lower reduction compared to the 4.4 mph from the Daytona Beach study location.

2. During the period following the removal of FWC vehicle with blue lights, the average vehicle speed within the work zone was reduced by **2.7 mph** when compared to the baseline data from the first two weeks with no blue lights. However, this reduction was derived based on more limited data available for the period following the blue light deployment and is not considered reliable.

3. The deployment of FWC vehicle with blue lights reduced vehicle speeding (i.e., >60 mph) within the work zone by about **16%**.

For 2.5-lane closure (out of three lanes):

1. The deployment of FWC vehicle with blue lights at the study location reduced the average vehicle speed within the work zone by about **2.8 mph**.

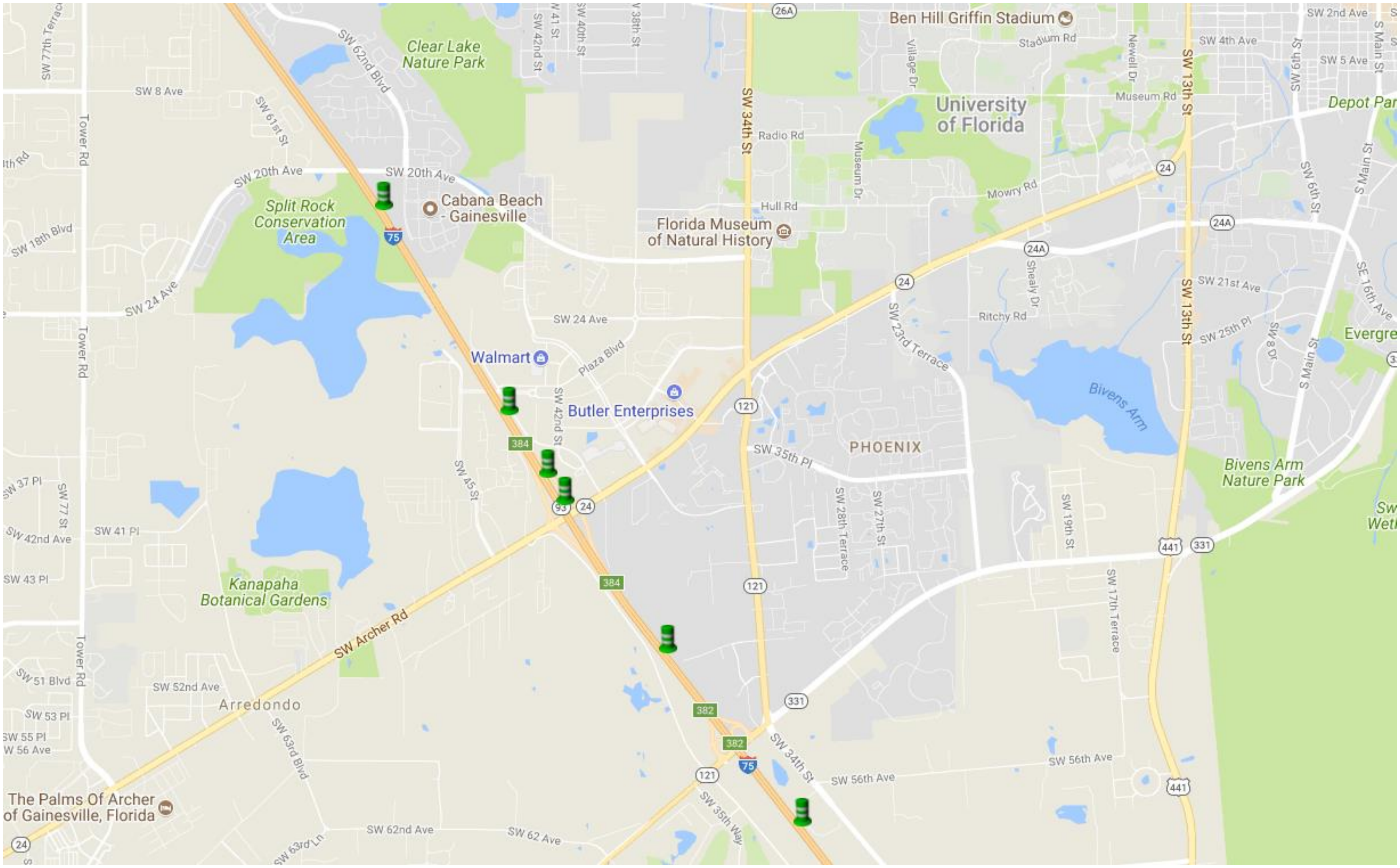
2. During the period following the removal of FWC vehicle with blue lights, the average vehicle speed within the work zone was reduced by **3.1 mph** when compared to the baseline data from the first two weeks with no blue lights.

3. These results for 2.5-lane closure are not considered reliable as the baseline data from the period before the blue light deployment came from just one night closure.

4. The deployment of FWC vehicle with blue lights reduced vehicle speeding (i.e., >60 mph) within the work zone by about **10%**.

APPENDIX A:

MAPS OF THE iCONE LOCATIONS OF EACH NIGHT CLOSURE AT THE GAINESVILLE STUDY LOCATION



Note: Missing two iCones due to a problem with GPS connection to the iCone website.

Figure A-1. Map of iCone Locations for Week 1, Sunday, 9-24-2017

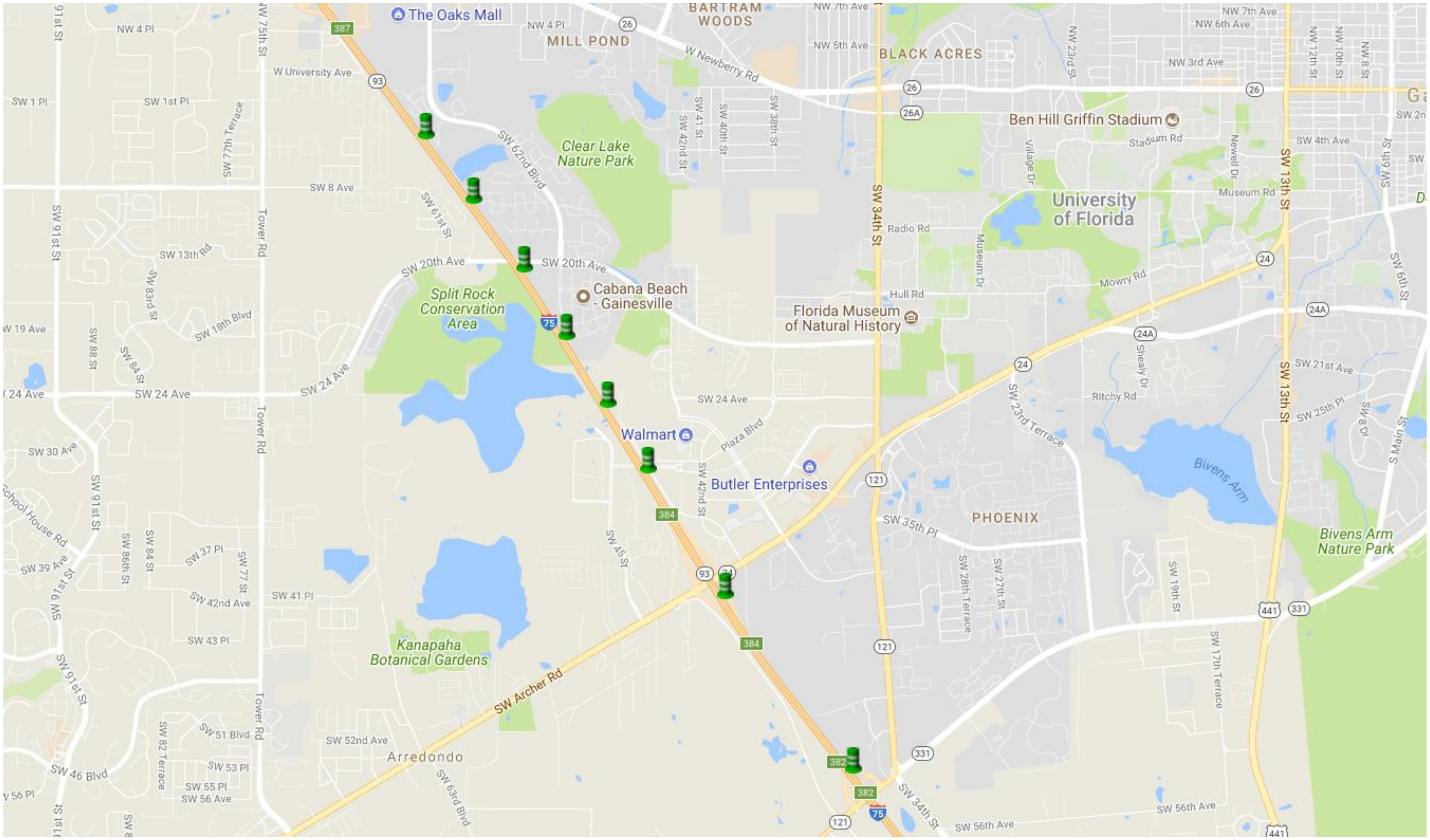


Figure A-2. Map of iCone Locations for Week 1, Monday, 9-25-2017

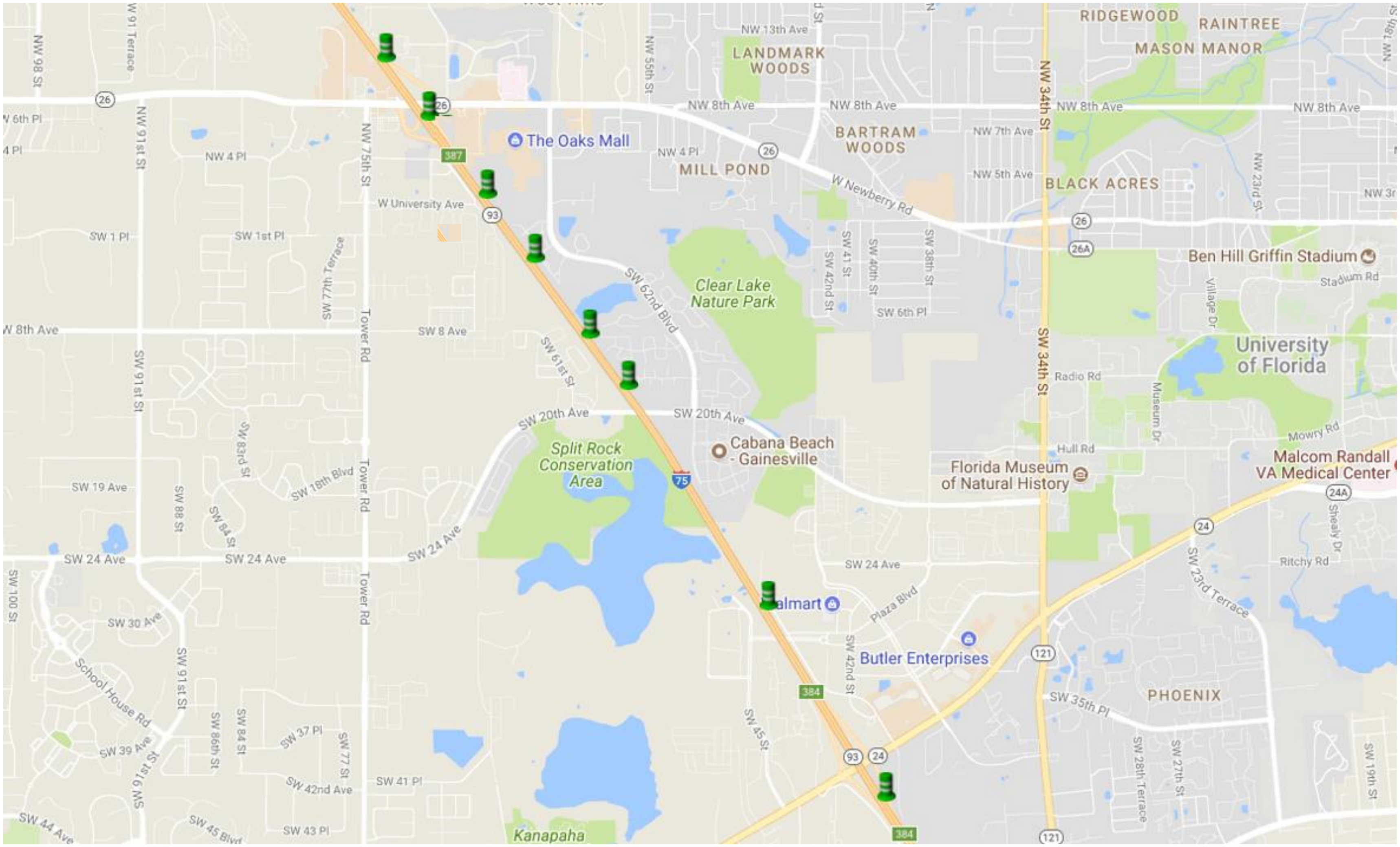


Figure A-3. Map of iCone Locations for Week 1, Tuesday, 9-26-2017

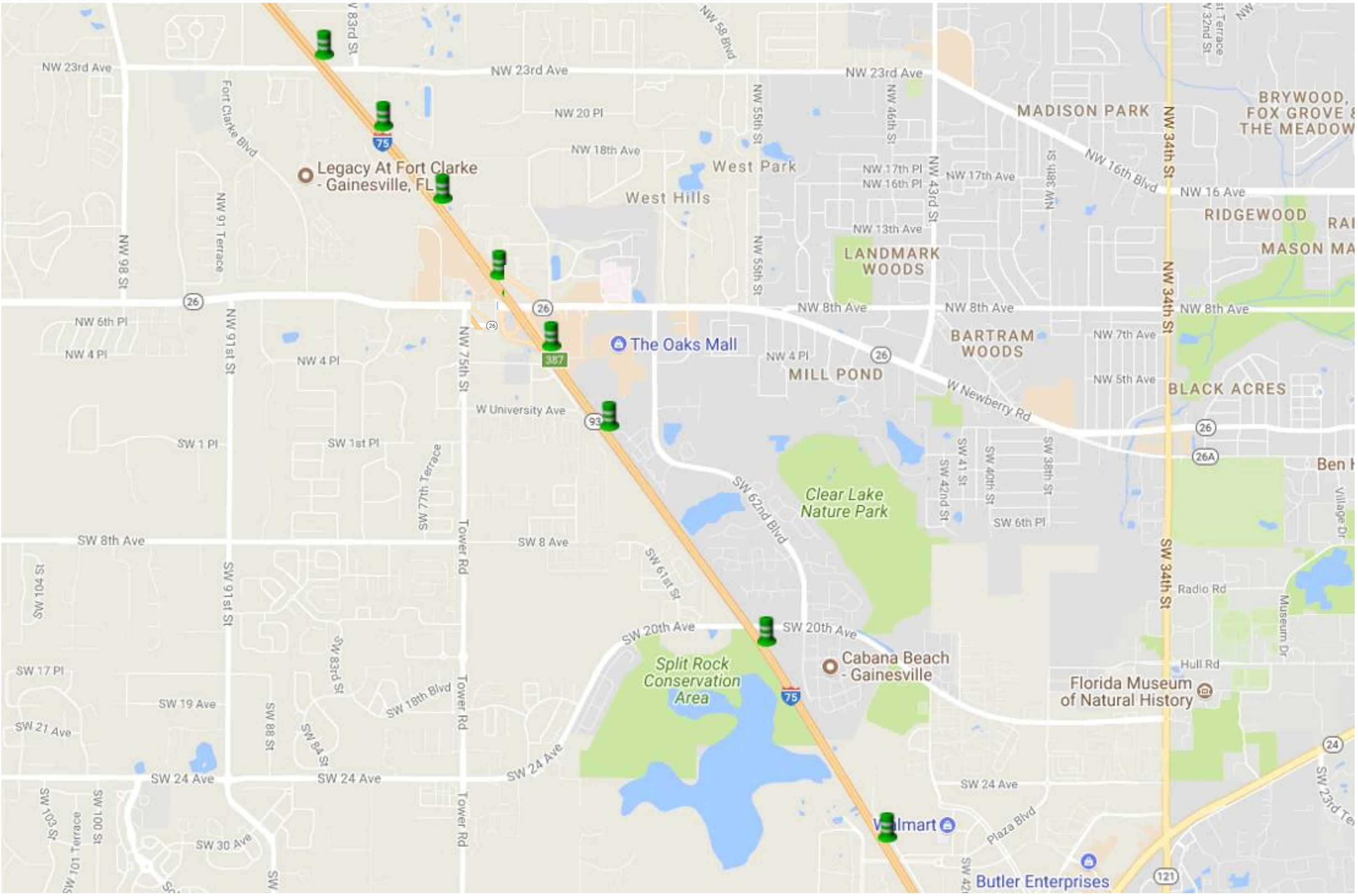


Figure A-4. Map of iCone Locations for Week 1, Wednesday, 9-27-2017

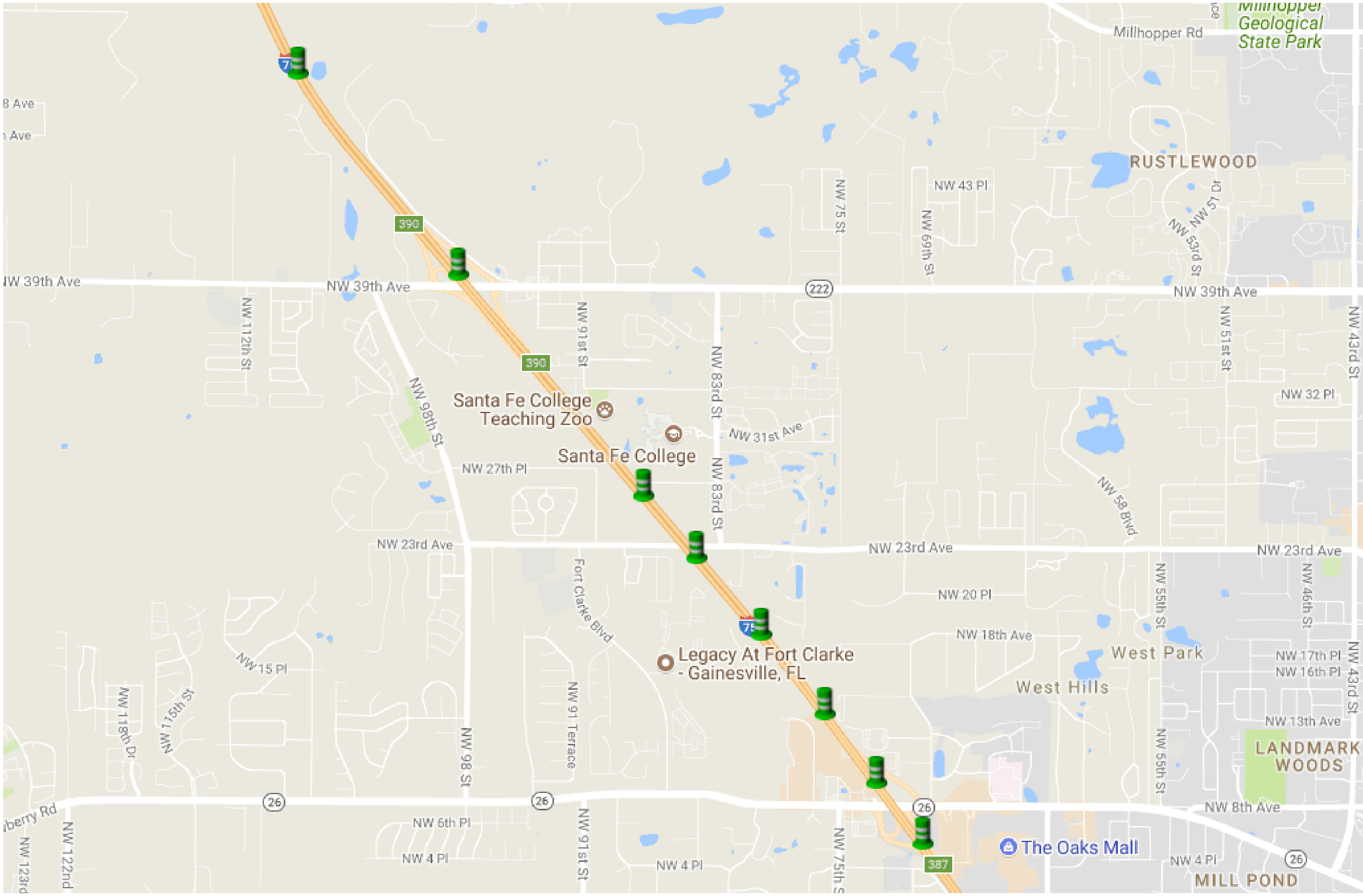


Figure A-5. Map of iCone Locations for Week 1, Thursday, 9-28-2017

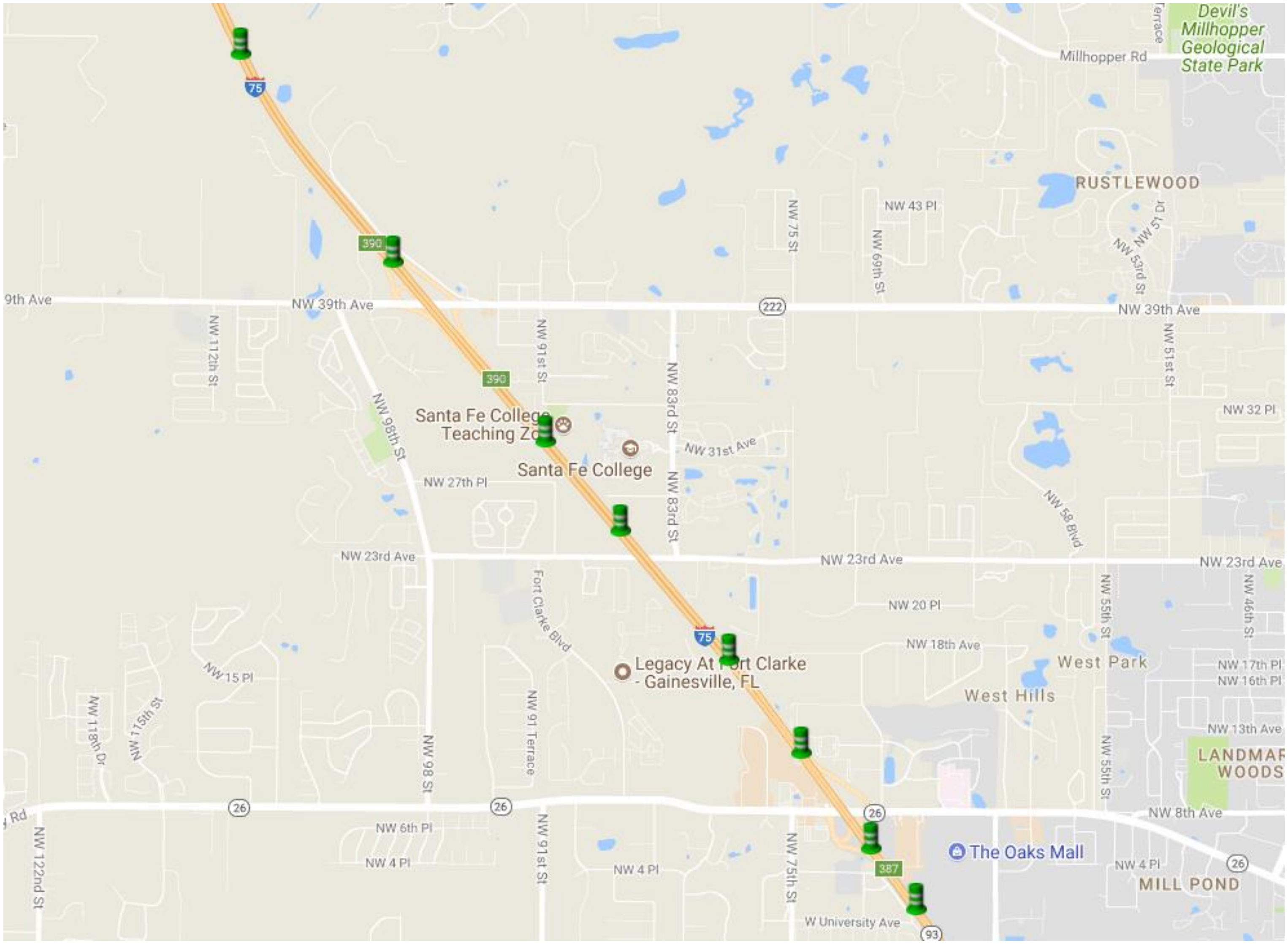


Figure A-6. Map of iCone Locations for Week 2, Tuesday, 10-03-2017

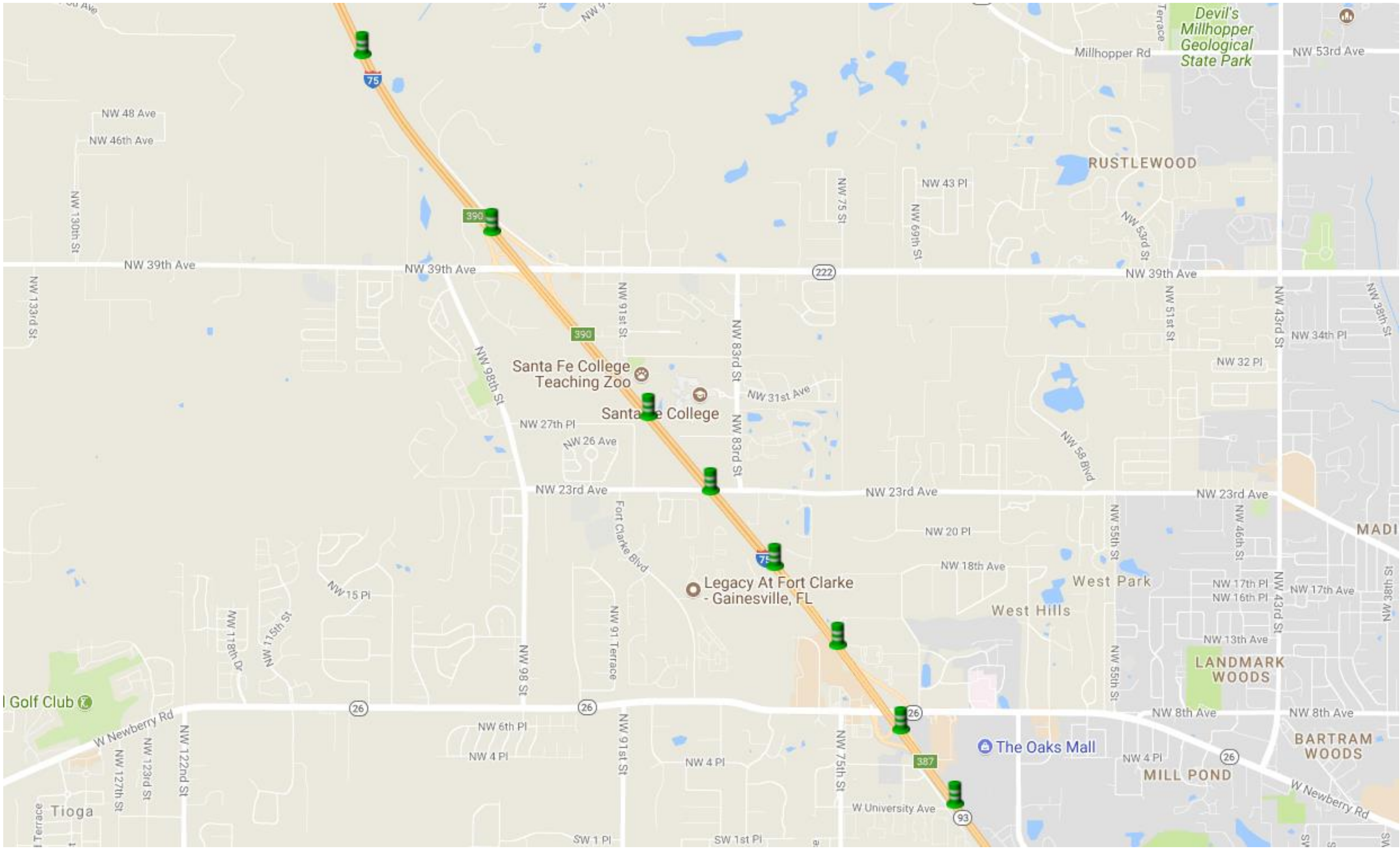


Figure A-7. Map of iCone Locations for Week 2, Wednesday, 10-04-2017

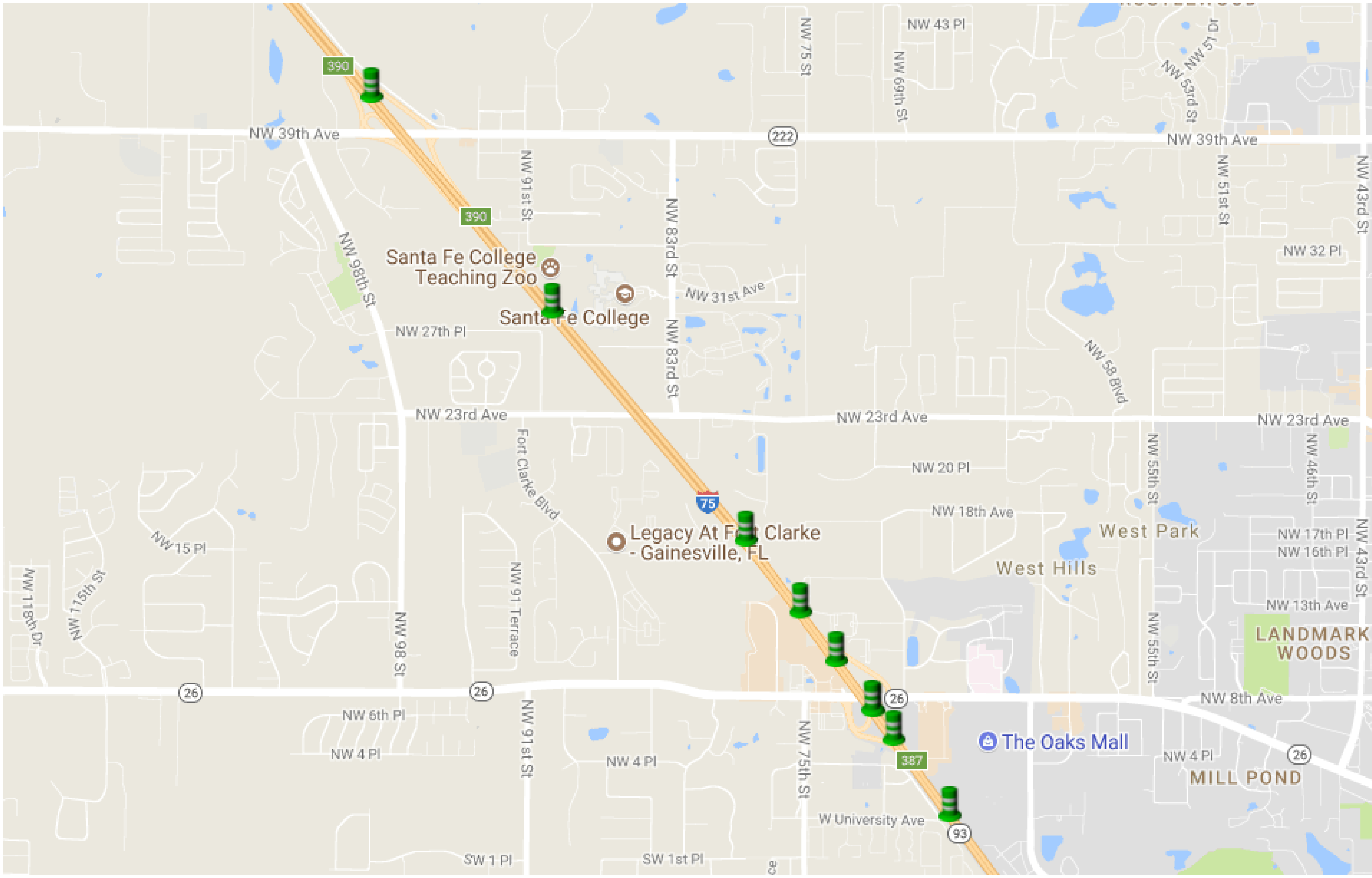


Figure A-8. Map of iCone Locations for Week 3, Monday, 10-09-2017

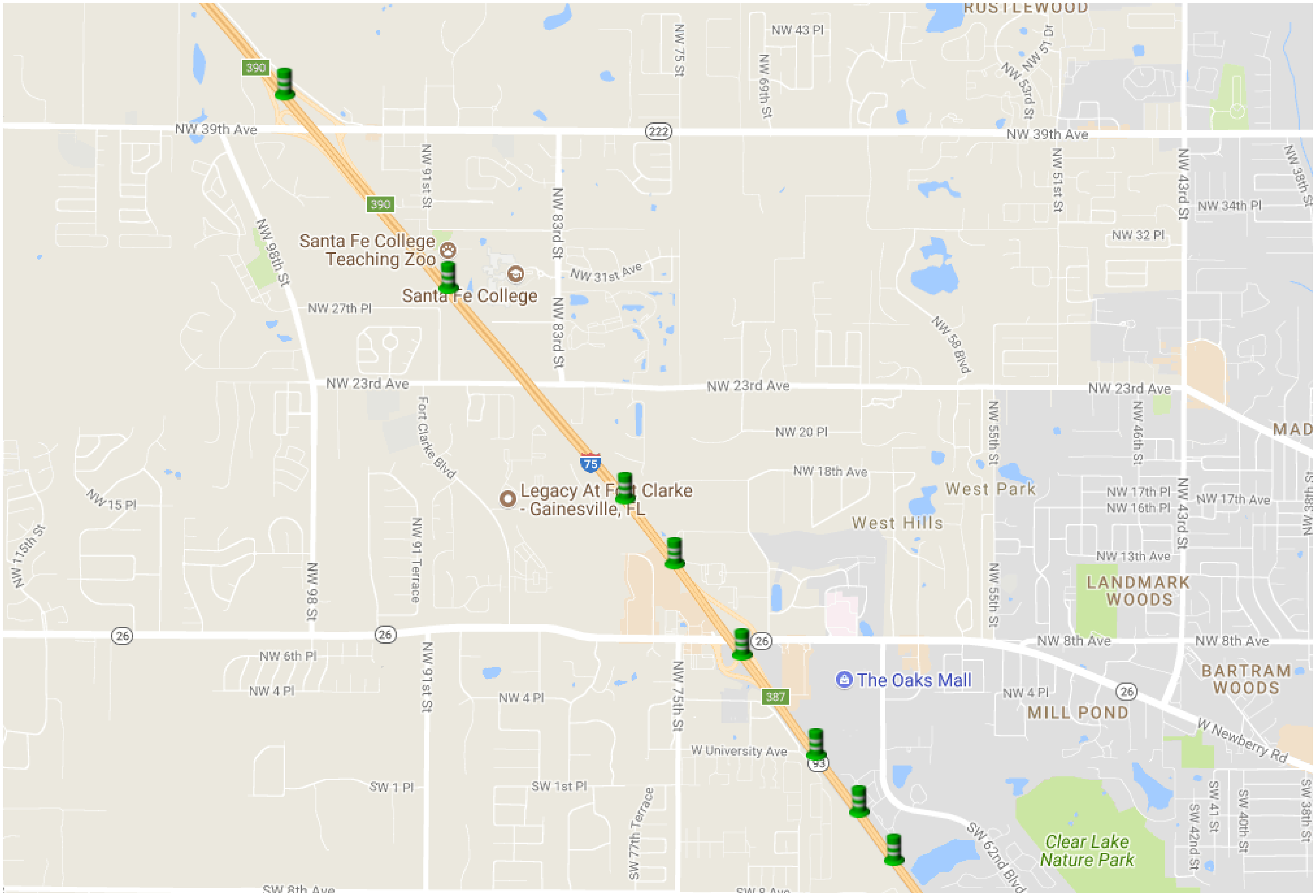


Figure A-9. Map of iCone Locations for Week 3, Tuesday, 10-10-2017

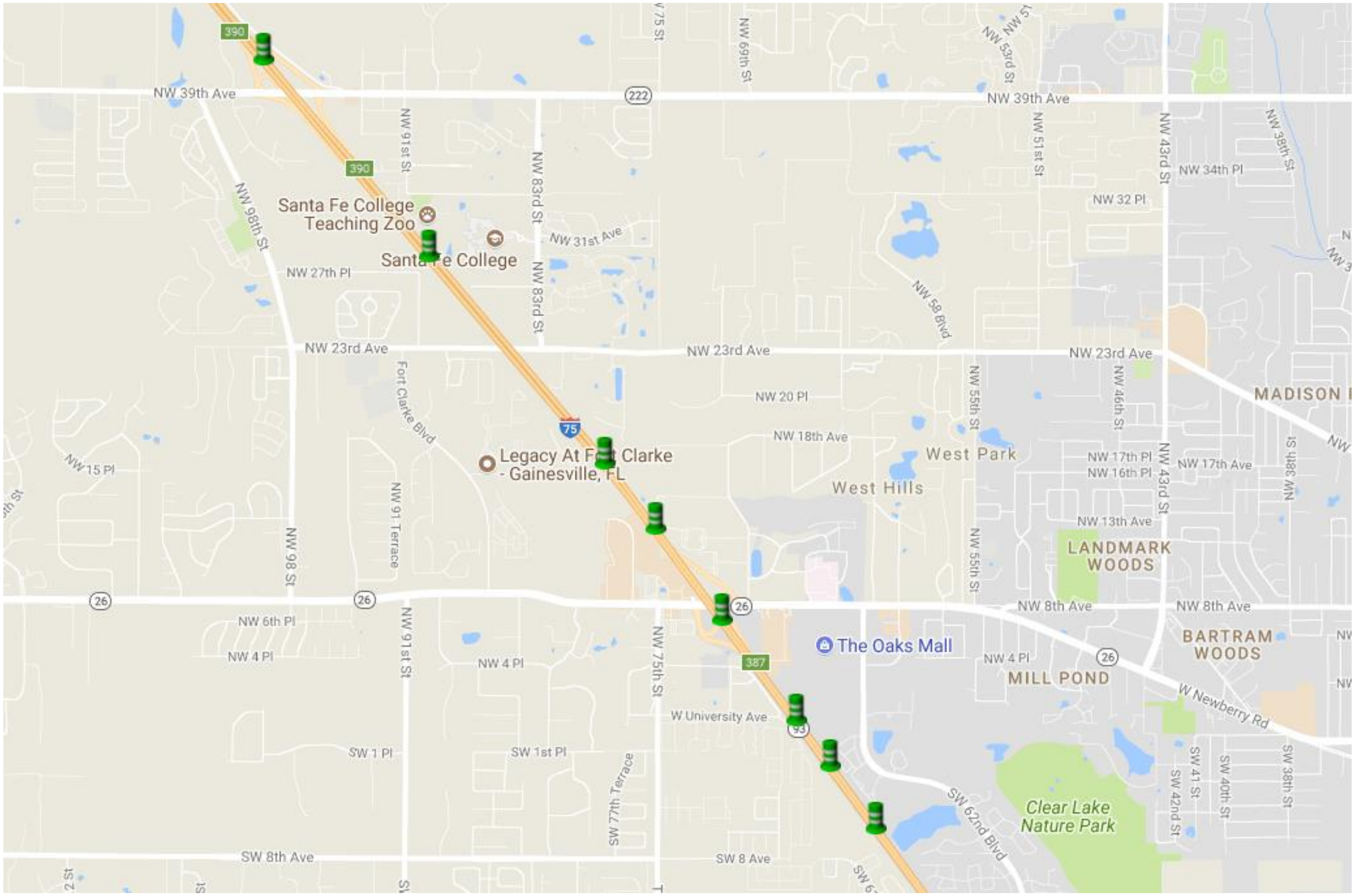


Figure A-10. Map of iCone Locations for Week 3, Wednesday, 10-11-2017

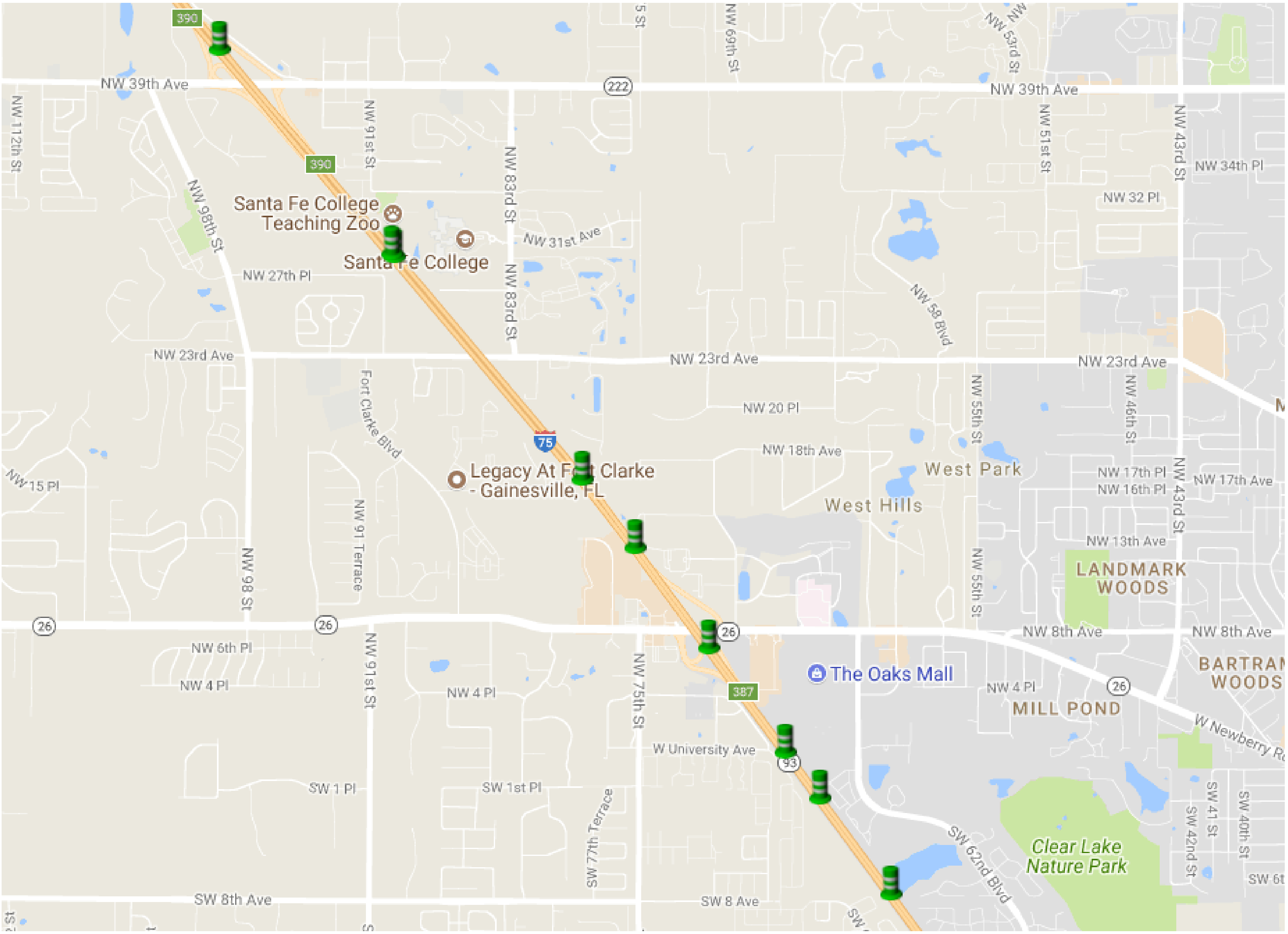


Figure A-11. Map of iCone Locations for Week 3, Thursday, 10-12-2017

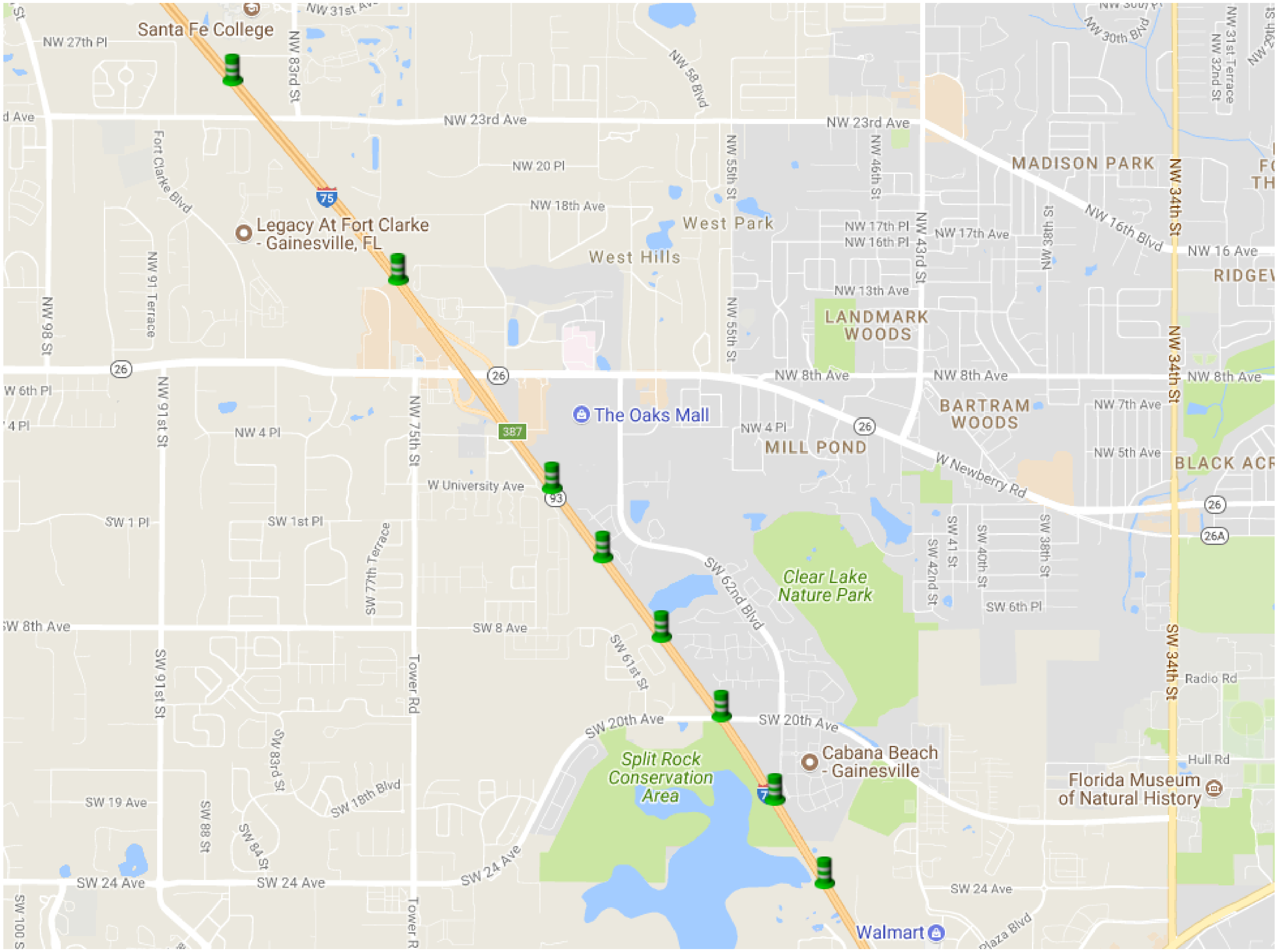


Figure A-12. Map of iCone Locations for Week 4, Monday, 10-16-2017

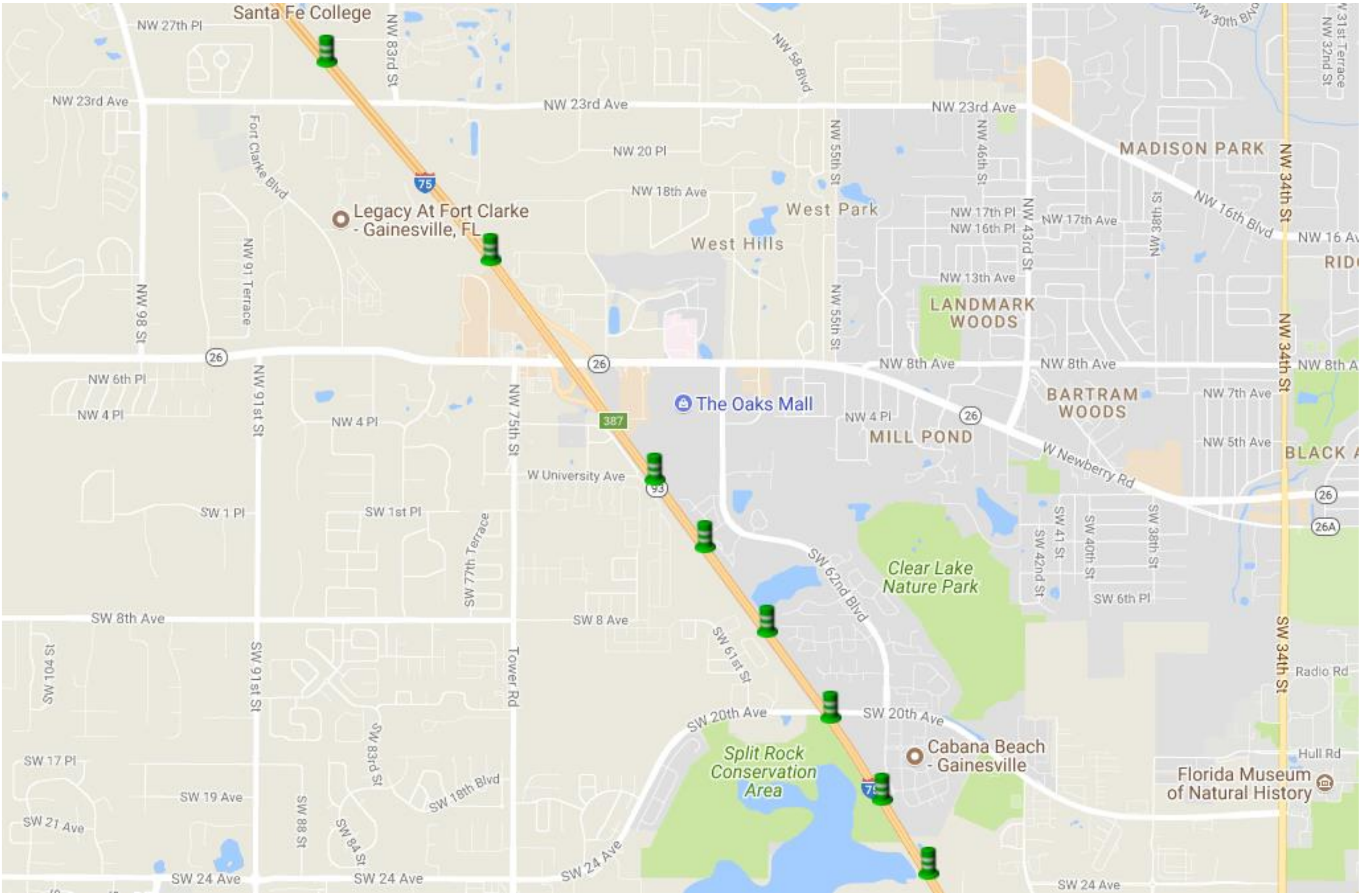


Figure A-13. Map of iCone Locations for Week 4, Wednesday, 10-18-2017

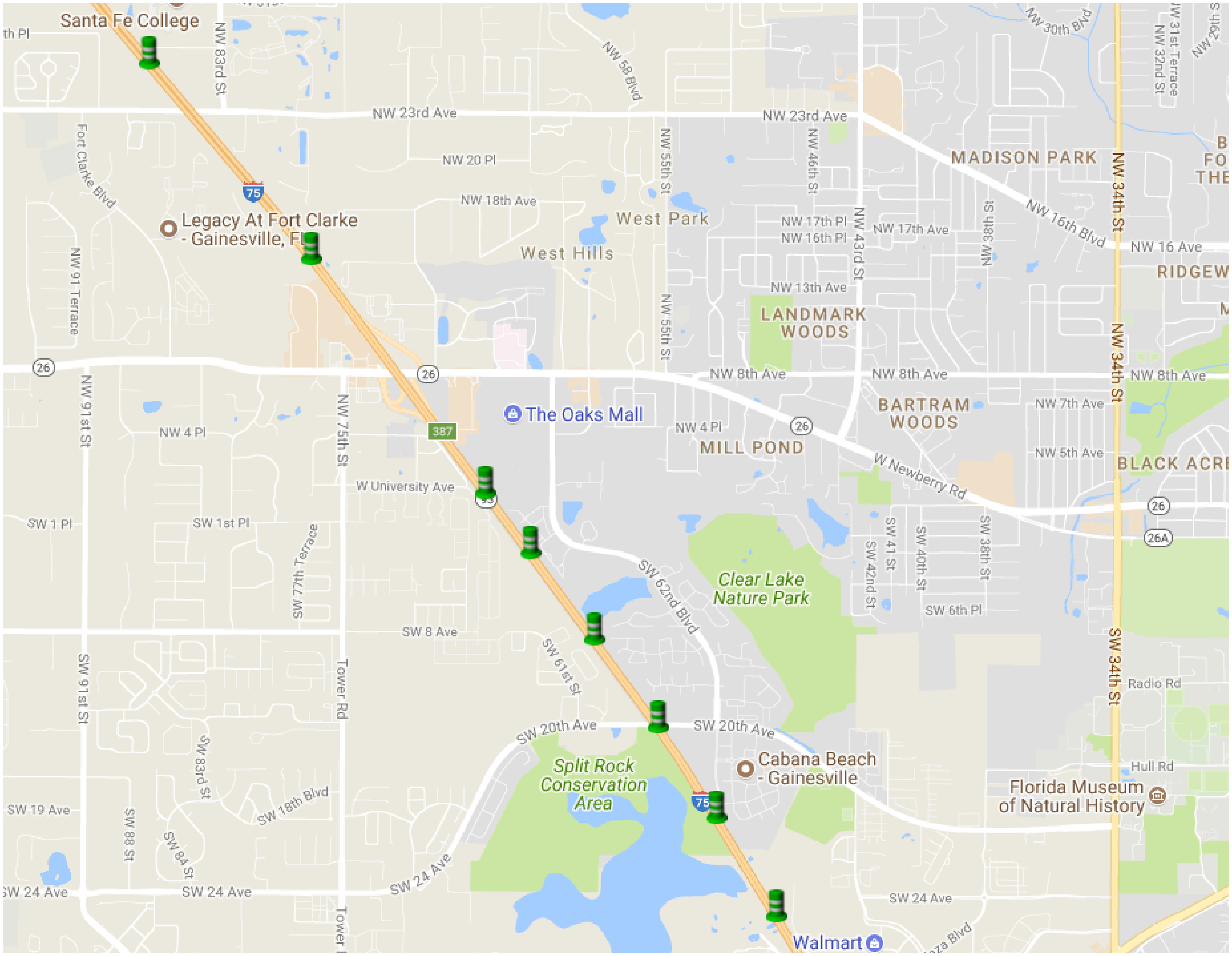


Figure A-14. Map of iCone Locations for Week 5, Sunday, 10-22-2017

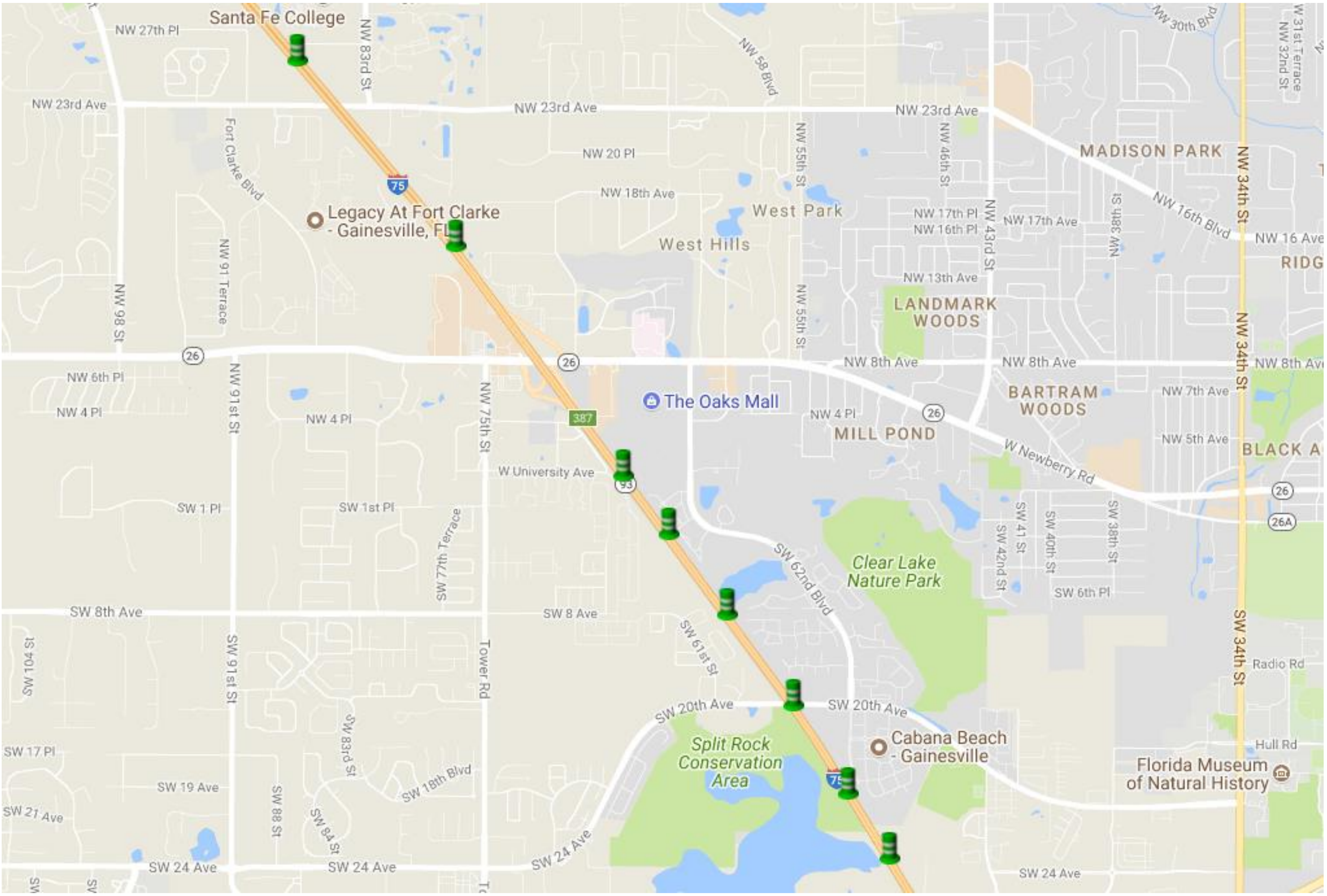


Figure A-15. Map of iCone Locations for Week 5, Tuesday, 10-24-2017

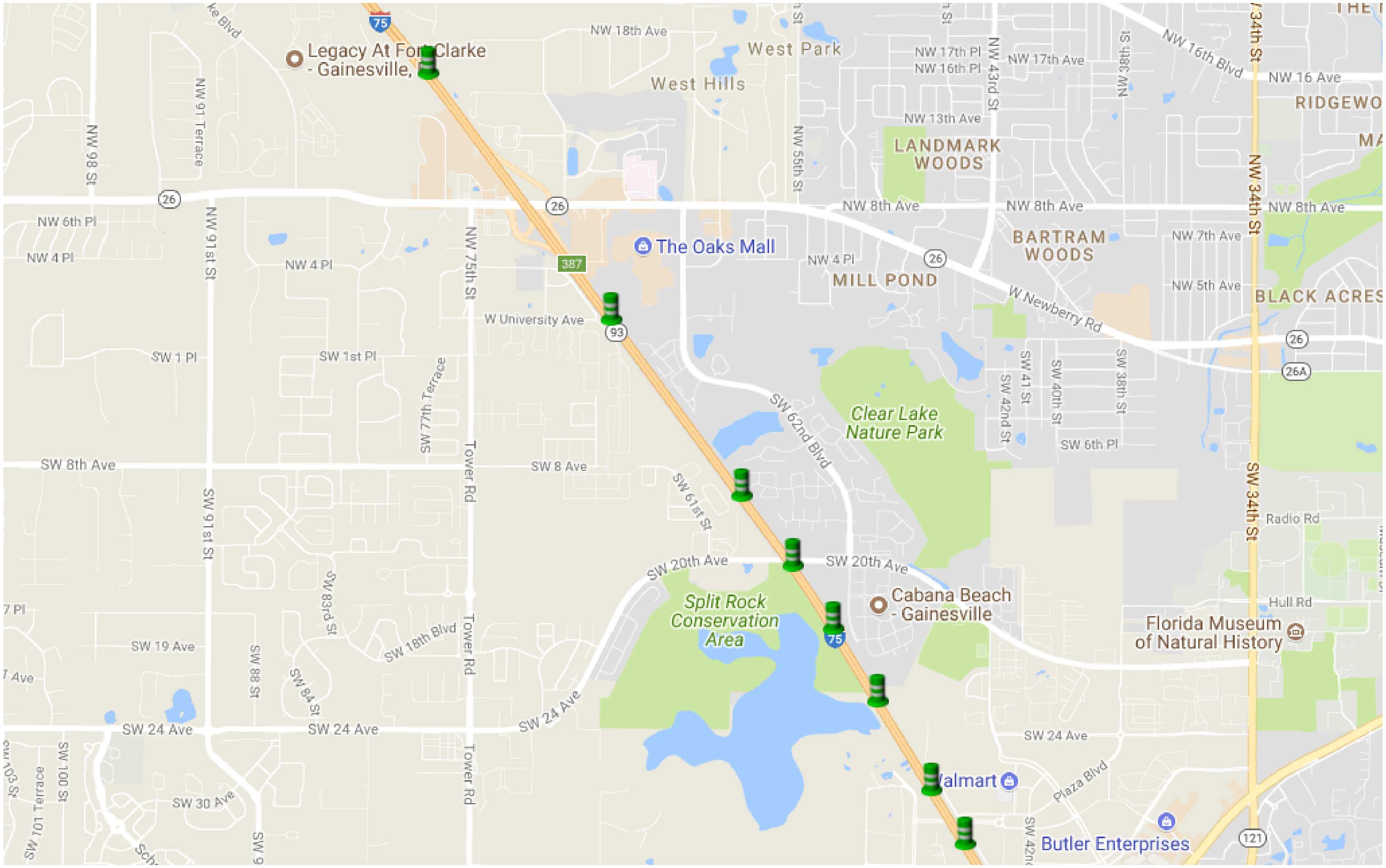


Figure A-16. Map of iCone Locations for Week 5, Wednesday, 10-25-2017

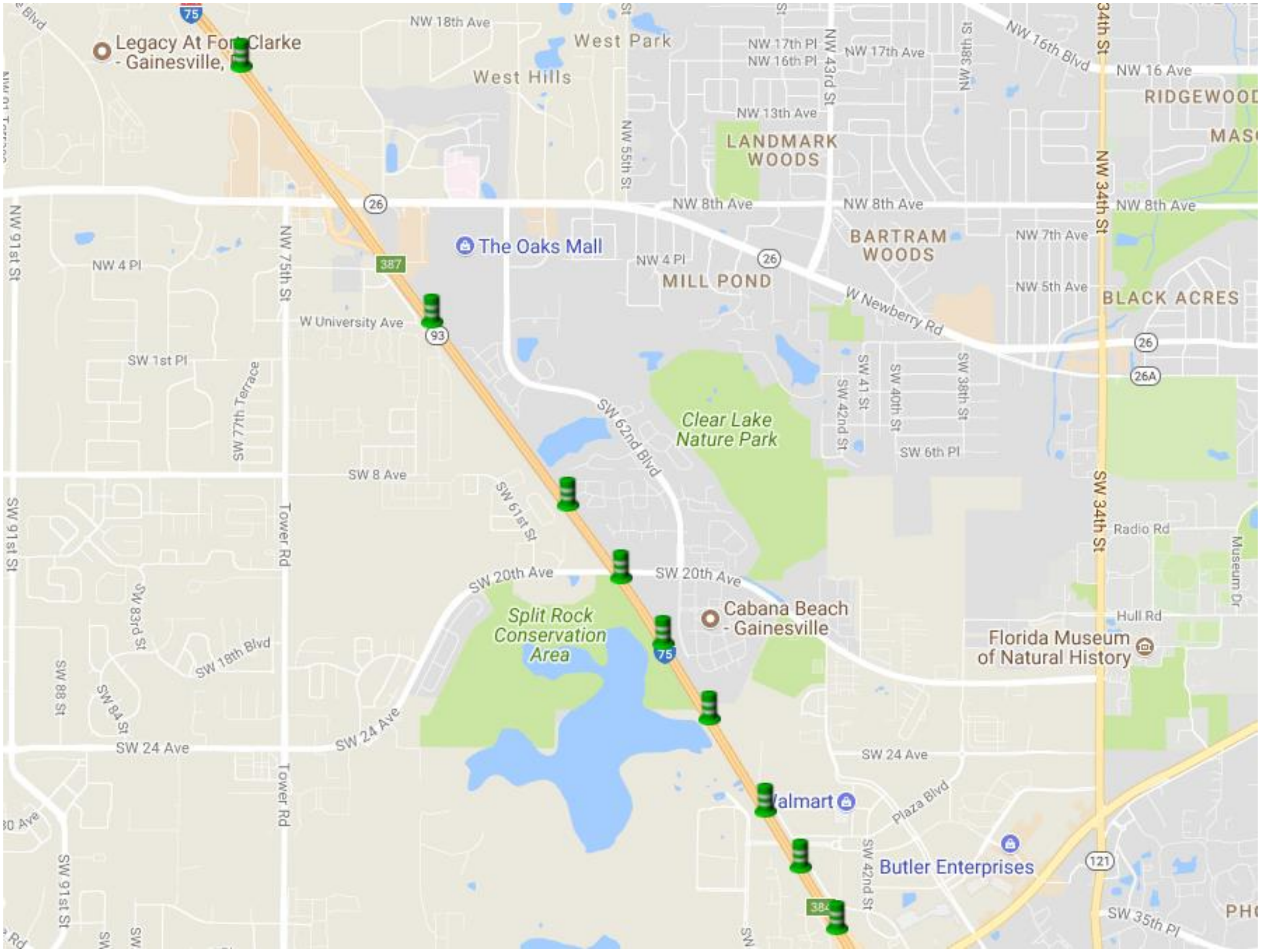


Figure A-17. Map of iCone Locations for Week 6, Sunday, 10-29-2017

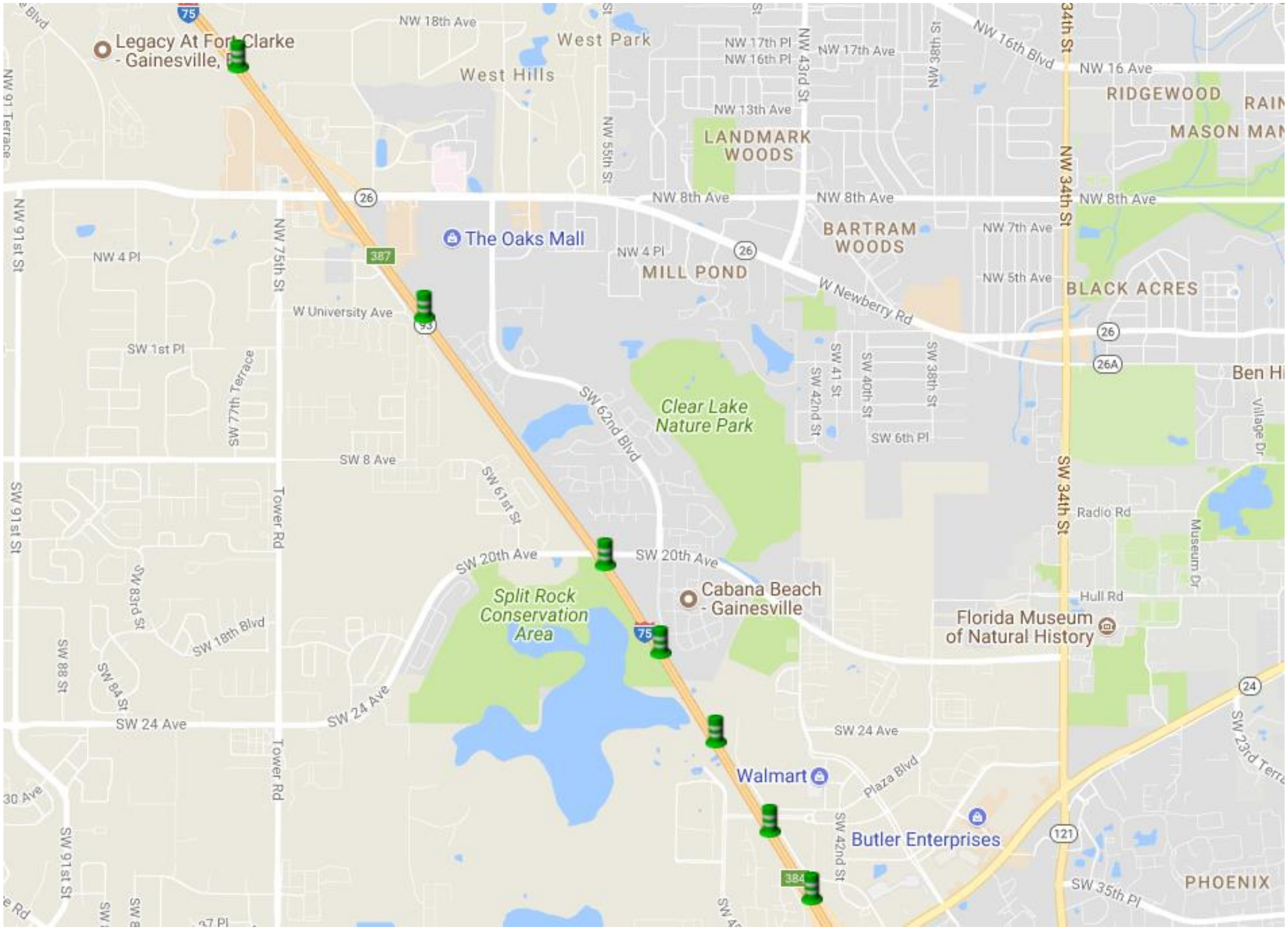


Figure A-18. Map of iCone Locations for Week 6, Tuesday, 10-31-2017

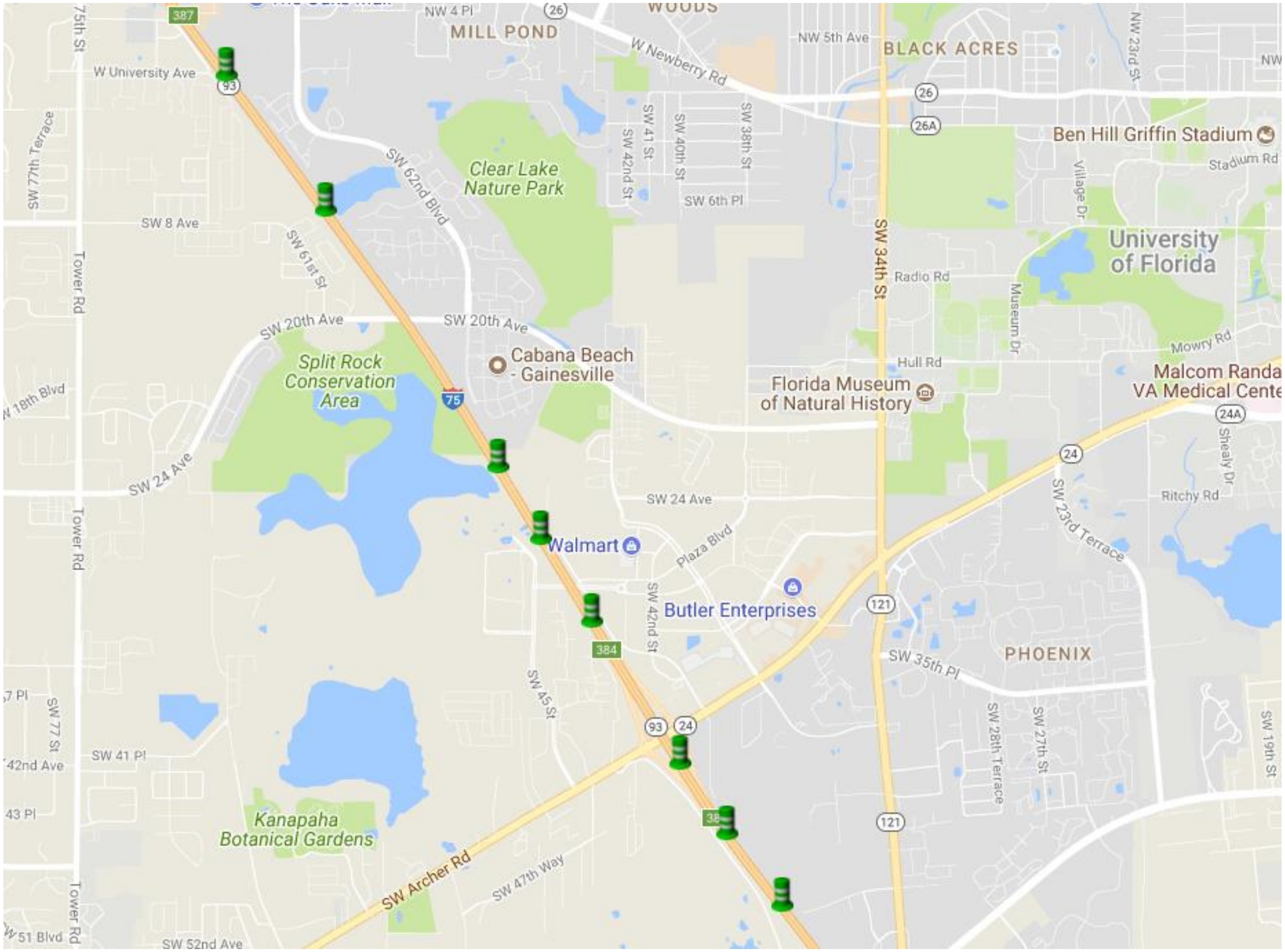


Figure A-19. Map of iCone Locations for Week 6, Wednesday, 11-01-2017

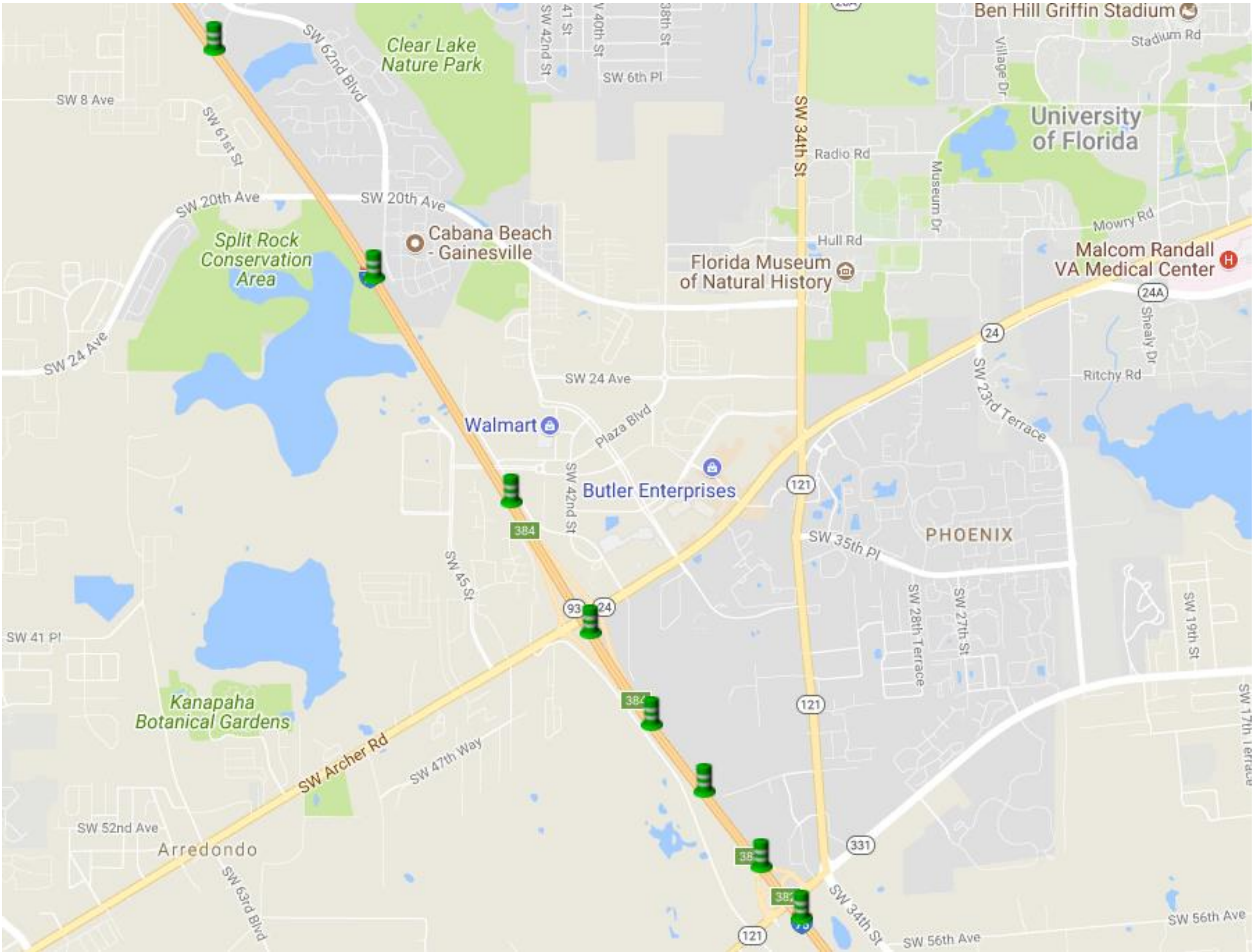


Figure A-20. Map of iCone Locations for Week 6, Thursday, 11-02-2017