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Traffic Signal Vehicle Detection, One Size Does Not Fit All

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16. Abstract

Traffic signals are traffic control devices that detect vehicles at intersections and assign right of way to road users of all types (including motorized and non-motorized vehicles and pedestrians). Vehicle detection sensors used today include inductive wire loops, video, radar, and magnetometers. Although used extensively, the performance of non-intrusive video-detectors is adversely affected by weather impacts of shadows, sun glare, fog, rain, and snow. Efficiency of remote sensing radar sensors is affected by spatially surrounded buildings and trees. All-weather operations of in-pavement sensors are disrupted by pavement degradation. The primary objectives of this research study are to review prior vehicle detection sensor evaluation studies, conduct field evaluations of vehicle detection call errors, evaluate the error in vehicle detection for selected sensor models, and interview the traffic signal engineers for field performance and cost. Field data sets were collected for four types of sensor call errors: dropped, missed, false, and locked. Data of 20 signal cycles were collected for nine vehicle detection sensor models at 30 signalized intersections (18 cities in 13 counties of the State of Mississippi). The statistical significance of the main effects of key factors (signal regions and sensor types, sensor models) using the collected call error data were analyzed. The result of statistical inference analysis including hypothesis testing and multiple comparisons at 90% certainty were used to evaluate the sensor models. There is no statistically significant difference among three signal regions and among eight sensor models and the difference in the means is relatively small. One radar, one radar/video, and two video sensor models outperformed other sensor models evaluated in this study. Additionally, hourly vehicle volume, calculated from the total vehicle counts in the 21st signal cycle, was used to estimate harmful vehicular emissions for each signal site. Emissions are higher for the signal site with the higher hourly traffic volume.

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LIST OF ABBREVIATIONS

ANOVA	ANalysis Of VAriance
CAIT	Center for Advanced Infrastructure Technology
CO	Carbon Monoxide
DOT	Department of Transportation
EPA	Environmental Protection Agency
ICC	IntraClass Correlation
ITS	Intelligent Transportation System
MANOVA	Multivariate ANalysis Of VAriance
MDOT	Mississippi Department of Transportation
NO_x	Nitrogen Oxides
$PM_{2.5}$	Particulate Matter, 2.5 micrometer
PM_{10}	Particulate Matter, 10 micrometer
SPSS	Statistical Package for the Social Sciences
VOC	Volatile Organic Compounds

EXECUTIVE SUMMARY

Traffic signals are traffic control devices that detect vehicles at intersections and assign right of way to road users of all types (including motorized and non-motorized vehicles and pedestrians). Vehicle detection sensors used today include inductive wire loops, video, radar, and magnetometers. Although used extensively, the performance of non-intrusive video-detectors is adversely affected by weather impacts of shadows, sun glare, fog, rain, and snow. Efficiency of remote sensing radar sensors is affected by spatially surrounded buildings and trees. All-weather operations of in-pavement sensors are disrupted by pavement degradation. The primary objectives of this research study are to review prior vehicle detection sensor evaluation studies, conduct field evaluations of vehicle detection call errors, evaluate the error in vehicle detection for selected sensor models, and interview the traffic signal engineers for field performance and cost. Field data sets were collected for four types of sensor call errors: dropped, missed, false, and locked. Data of 20 signal cycles were collected for nine vehicle detection sensor models at 30 signalized intersections (18 cities in 13 counties of the State of Mississippi). The statistical significance of the main effects of key factors (signal regions and sensor types, sensor models) using the collected call error data were analyzed. The result of statistical inference analysis including hypothesis testing and multiple comparisons at 90% certainty were used to evaluate the sensor models. There is no statistically significant difference among three signal regions and among eight sensor models and the difference in the means is relatively small. One radar, one radar/video, and two video sensor models outperformed other sensor models evaluated in this study. Additionally, hourly vehicle volume, calculated from the total vehicle counts in the 21st signal cycle, was used to estimate harmful vehicular emissions for each signal site. Emissions are higher for the signal site with the higher hourly traffic volume.

1. BACKGROUND AND OVERVIEW

1.1 Introduction

Background

Traffic signals are traffic control devices that assign right of way to road users of all types (including motorized and non-motorized vehicles and pedestrians) at intersections. Some traffic signals are actuated and some operate on a fixed-time basis. A fixed-time signal will always provide the same amount of green time for each phase regardless of traffic conditions. An actuated traffic signal relies on the use of traffic signal vehicle detectors to identify the presence of road users and assign them right of way on an as needed basis.

The design of a traffic signal system depends upon a number of factors, including the geometry of the intersection, traffic demand, and safety considerations, among others. Two critical components to efficient signal operations are the timing design and the vehicle detection. These two components work together to ensure the traffic signal provides the most efficient operation for all road users at an intersection. When detectors fail to identify the presence of road users at an intersection, the traffic signal defaults to fixed-time operation, leading to inefficient operations, increased delay, and frustrated road users.

The Mississippi Department of Transportation (MDOT) typically deploys actuated traffic signals in an effort to minimize delay and optimize the efficiency of traffic operations. Some different types of vehicle detectors used today include inductive wire loops, video, radar, standard magnetic detectors, and the use of magnetometers. Once favored, the performance of non-intrusive video detectors in all-weather operation is affected by the challenges of shadows, sun glare, fog, and snow. Two previous studies [1, 2] in Texas (2009) and Wisconsin (2013) evaluated the video, radar, and magnetic detection systems which overcame the in-pavement induction loop problems of pavement degradation. Newer type of vehicle detector systems include infrared thermal sensor with imaging video.

Objectives

The primary objectives of this research study are, as follows:

(1) Review vehicle detection sensor technologies and prior sensor evaluation studies for traffic signal control at intersections.
(2) Conduct field evaluations and compare the signal sensor models based on the vehicle count call error data collected at selected signal test sites.
(3) Interview the traffic signal engineer for field performance and cost of the signal sensor models.
(4) Compare the signal vehicle detection sensor systems used by the Mississippi DOT with respect to sensor capabilities, reliability, accuracy, weather impacts, and costs.

Scope

The scope of this research study is confined to signalized intersections in the State of Mississippi, but the results are expected to apply in similar operating environments in all climatic regions. Candidate signal sites were identified by the MDOT traffic signal engineers in each of the three signal regions established by the Mississippi DOT.

1.2 Study Overview

Methodology

The primary research methodology includes:

- Review of vehicle detection technologies used for traffic signal control at signalized road/highway intersections.
- Field evaluations of vehicle detection call errors in all signal regions of the Mississippi DOT.
- Interview of the Mississippi DOT Traffic Signal Engineers to benefit from their collective experience with vehicle detection sensor models used in the State of Mississippi.
- Presentation of the research study findings and recommendations for the most reliable and efficient vehicle detection sensor systems.

Relationships to the Existing Body of Knowledge

The study is motivated by a recent research project [2] sponsored by the Wisconsin DOT (2013), "A Signalized Intersection for Experimentation and Evaluation of Traffic Signal and Detection System Technology."

1.3 Accomplishments & Key Results

Key outcomes and achievements are summarized, as follows:

1. A detailed literature review was conducted for weather impacts, accuracy, and costs of signal vehicle detection sensor model systems. The findings were presented in a synthesis summary.
2. This study developed spatial maps of Mississippi DOT signal regions and districts using geospatial software.
3. Detailed field data collection forms and spreadsheet forms for office data processing were developed, which included photos and signal phase sketch used for field data collection for each site.
4. After selecting candidate signal sites and training by the Mississippi DOT traffic signal engineers the project team collected the signal vehicle detection sensor data at each of 30 signal sites. These signal sites were spatially distributed in 18 cities and 13 counties in the State of Mississippi. The team collected error call data for total 20 signal cycles and each

movement except the advance sensors. Additionally, all vehicle counts for all phases were recorded in the 21^{st} signal cycle.

5. A signal vehicle detection sensor database was developed using all collected data and a sensor code was assigned for the purpose of anonymity to each specific vehicle detection senor system. Plots of vehicle detection call errors were created by sensor code and signal region.
6. Statistical inference analyses were conducted for hypothesis testing of statistically significant difference in vehicle counts of call errors between signal regions and sensor models for applications to all Mississippi DOT signal sites in Mississippi.
7. Overall no statistically significant difference was found at 0.10 α probability of chance error for: (i) total counts of call errors among signal regions, (ii) total counts of call errors among sensor models, (iii) equivalent hourly volume call errors among sensor models, (iv) and total counts of each error types among the sensor models.
8. The hypothesis testing and multiple comparison at 90% certainty showed that the difference in the means is relatively small.
9. Additionally, harmful vehicle emissions were calculated using the equivalent hourly intersection traffic volume using the total vehicle counts recorded for the 21^{st} signal cycle. The results indicate that the emissions are higher for high volume signalized intersections.
10. An in-depth interview of the Mississippi DOT Traffic Signal Engineers was conducted to gain knowledge of their collective experience with the signal vehicle detection censor model systems. The interview questions included; sensor reliability, weather impacts, initial costs, annual maintenance cost, and overall satisfaction with field performance and vendor support.

1.4 Impacts on State of Practice

The statistical inference results of the field study and synthesis associated experience of traffic signal engineers improved understanding of the performance and efficiency of vehicle detection sensor models associated with reduced waiting time and incident-free traffic flow. These societal impacts and the emission modeling for the environmental and public health impacts, as well as the highway agency experience of sensor accuracy and costs, are indicative of the importance of selecting and operating appropriate vehicle detection sensor models. Guidelines and recommendations are made for future implementation of side-by-side comparison and procurement to improve road vehicle flow and safety.

The preliminary assessment of field data collection methodology for vehicle detection sensor study evolved using the Intelligent Transportation Systems (ITS) Model Laboratory, which was established with a video wall panel donation by the Mississippi DOT Traffic Engineering Division. The ITS model laboratory is housed in Center for Advanced Infrastructure Technology (CAIT) Transportation Modeling and Visualization Lab, shown in the following photo, at off-campus location of the University of Mississippi (UM) Jackson Center. The knowledge of vehicle detection sensor systems and the study results were implemented in undergraduate (UG) transportation course. This is a major impact of the study.

Photo: Model ITS laboratory at UM CAIT, Oxford, Mississippi

The study supported one PhD student (data analysis) and two M.S. students and five UG students (for field data collection and processing) at UM. Additionally, the UM students and four visiting M.S. students from Denmark learned the Mississippi DOT Traffic Engineering Division's state of the practice in signage, ITS, and traffic signal technologies. The education and training of future transportation engineering workforce is an additional impact of the study.

2. LITERATURE REVIEW

2.1 Traffic Signal Vehicle Detection Sensor Technologies

For many years, it was MDOT’s standard practice to use in-pavement inductive wire loops for vehicle detection at all signalized intersections. The life of a detection induction loop is closely tied to the pavement performance. If the pavement fails due to excessive asphalt rutting and/or cracking, inductive loops also begin to fail. Due to diminishing funds allocated for pavement preservation in-pavement detection has become less effective and MDOT has been seeking non-intrusive detection types to replace inductive wire loops. Currently, MDOT uses a variety of traffic signal detectors without clear criteria on what is best for determined locations.

Technology differs greatly among the various types of detectors and even among vendors of similar types of detectors. Coupled with this, the cost of the various types of detector varies greatly. All of this makes it difficult to select the best performing and most economical vehicle detectors for any given signalized intersection.
The non-intrusive signal vehicle detection sensor technologies being used in the MDOT signal regions include the following:

- Radar/Video (One System)
- Radar (Two Systems)
- Video (Four Systems)

Additionally, two magnetic sensor systems are used by installing in pavement layer. The thermal infrared sensor for vehicle detection has not been installed by the MDOT due to excessive cost.

2.2 Review of Prior Studies of Vehicle Detection Sensor Systems

A previous 2009 study in Texas [1] evaluated the video, radar, and magnetic detection system which overcame the in-pavement induction loop problems of pavement degradation. A newer type of vehicle detector system includes thermal sensor with imaging video [1] that is not used in Mississippi. Another detailed field study was conducted by the Wisconsin DOT [2] in 2013. These studies were impetus to planning the current study in Mississippi.

The performance of non-intrusive video-detectors is affected by the challenges of shadows, sun glare, fog, rain, snow, and lightning. On the other hand, the efficiency of radar sensors is affected by spatially surrounding buildings and trees. All weather operation is possible for magnetometers sensors with wireless data transfer, and conventional electric magnetic induction loop detectors with hard wiring installed in pavements. However, their operations are severely disrupted due to pavement distresses that require more maintenance. In summary, each vehicle detection sensor technology offers benefits or suffers limitations with respect to weather and/or operational constraints. Table 1 compares the capabilities, limitations, and cost of various different vehicle detection sensor models.

There are no well-defined standards on how to select the most efficient and cost-effective type of vehicle detectors to use at a signalized intersection. Therefore, there is a need to study the best practices of vehicle detection selection since the efficiency of certain detection sensor types depends upon traffic needs, environment, weather conditions, and geometry of the intersection. Consequently, this study is designed to collect common vehicle call error data for each type of vehicle detection sensor on selected signal sites in Mississippi.

Table 1. Comparison criteria for signal vehicle detection sensor systems

Vehicle Detection Sensor Code	Intersection Location/ Remote Sensing	Weather Impacts	Sensor Reliability	Average Life Expectancy	Initial Cost	Maintenance Frequency (Cost/year)	RF Signal Interference	Sensor Type
In-Pavement P1	In Pavement and On Pole	Rain & Snow	15-30% errors	Moderate (8 Years)	High (30,000-50,000 $)	Medium (~ 20,000 $)	Yes	Magnetic
Radar/Video RV	On Pole	Rain & Snow, Visibility, Dust, Sun Glare	0-5% errors	Moderate (8 Years)	High (30,000-40,000 $)	Low (≤ 5000$)	Yes (Radar)	Active Radar, Passive Video
Radar R1	On Pole	None	15-30% errors	Short (< 5 Years)	Medium (20,000-30,000 $)	Low (≤ 15000$)	Yes	Active
Radar R2	On Pole	None	5-15% errors	Long (10 Years)	High (30,000-40,000 $)	High (~ 30,000 $)	Yes	Active
Video A	On Pole	Rain & Snow, Visibility, Dust, Sun Glare	5-15% errors	Long (10 Years)	Medium (20,000-30,000 $)	Medium (~ 20,000$)	No	Passive
Video B	On Pole	Rain & Snow, Visibility, Dust, Sun Glare	5-15% errors	Long (10 Years)	High (30,000-40,000 $)	Low (≤ 10000$)	No	Passive
Video C	On Pole	Rain & Snow, Visibility, Dust, Sun Glare	0-5% errors	Long (10 Years)	Medium (20,000-30,000 $)	High (~ 30,000 $)	No	Passive
Video D	On Pole	Rain & Snow, Visibility, Dust, Sun Glare	> 30% errors	Short (< 5 Years)	Medium (20,000-30,000 $)	Low (≤ 10000$)	No	Passive
In-Pavement P2	In Pavement	Rain & Snow	0-5% errors	Long (10 Years)	Low (~20,000 $)	Medium (~ 20,000 $)	No (Wired)	Magnetic

2.3 Vehicle Detection Sensor Systems Used in Mississippi

Table 2 lists the sensor code assigned for each vehicle detection sensor model. For the purpose of keeping vendor anonymity, these codes are used for all plots, data analysis, and final report.

Table 2. Vehicle detection sensor codes

Vehicle Detection Sensor Code
1 In-Pavement P1
2 Radar/Video RV
3 Radar R1
4 Radar R2
5 Video A
6 Video B
7 Video C
8 Video D
9 In-Pavement P2

3. FIELD STUDY OF SIGNAL VEHICLE DETECTION IN MISSISSIPPI

3.1 Candidate Intersection Signal Sites in North, Central, and South Signal Regions

The state of Mississippi is divided into three traffic engineering signal regions, North, South, and Central, which are shown in Figure 1. Table 3 shows the sampling design for signal vehicle detection data collection. Data were collected using nine vehicle detection sensor models from 30 signal sites at different times of the day and ambient weather conditions. The selected signal sites are located in the three traffic engineering signal regions (18 cities in 13 counties) in the state of Mississippi. The field data were collected during summer and fall of 2017, and replicate tests were done on five sites in Fall 2018. The following explanations are provided for the reasons to conduct repeat test#2 on the five signal sites by the Signal Engineers:

(a) Concern with test#1 that prompted repeat test#2 on the five signal sites: Concern was obvious malfunction of vehicle detector units at these locations based on results in comparison to results from identical units.

(b) Changes in the physical location of the vehicle detection sensor was made, if any: No location changes, just adjustment in aiming the detector units.

(c) Other changes in the access point and software protocol parameters to improve vehicle detection sensors: No changes in software, just reconfiguration of detection zones after adjusting aim.

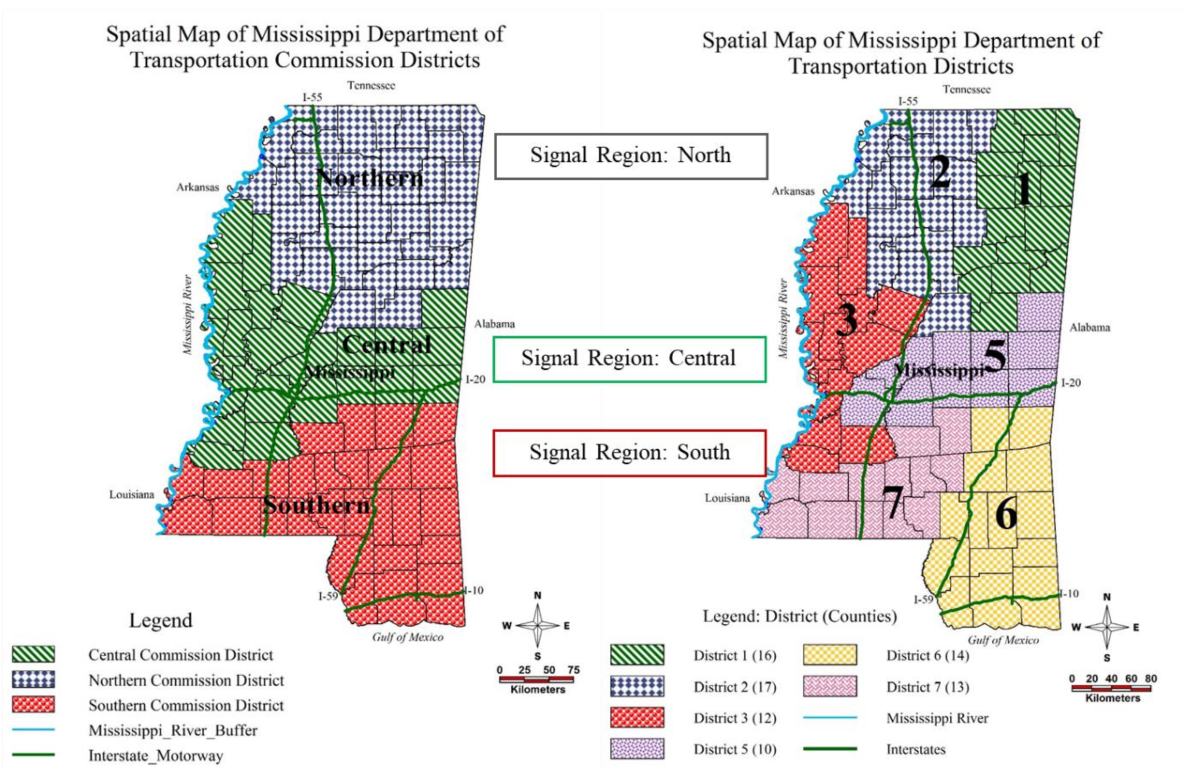


Figure 1. Mississippi DOT traffic engineering signal regions

Table 3. Sampling design for signal vehicle detection data collection

Vehicle Detection Sensor Model	Signal Sites of Signal Region			Total Sites
	North	Central	South	
1 In-Pavement P1	1	3	2	6
2 Radar/Video RV	1	1	1	3
3 Radar R1	0	1	2	3
4 Radar R2	1	3	1	5
5 Video A	3	0	1	4
6 Video B	0	2	2	4
7 Video C	0	0	2	2
8 Video D	0	0	2	2
9 In-Pavement P2	0	1	0	1
Total	North: 6	Central: 11	South: 13	Total Sites: 30

3.2 Data Collection, Data Processing, and Synthesis of Collected Data

Data Collection

Different signal devices may have different vehicle call errors depending upon the sensor type, circuitry, data processing algorithms, weather, and operational constraints, etc. Based on prior studies on vehicle detection technologies [1, 2] and recent preliminary field evaluation by the MDOT traffic signal engineers [7], the following types of vehicle call errors can be present in the measurements by vehicle detection sensors:

1. Dropped Calls
2. Missed Calls
3. False Calls
4. Locked Calls

For field evaluation of signal vehicle detection sensor models, on-site datasets were collected for 20 consecutive signal cycles and all vehicle counts in the 21st signal cycle at each selected signal site as follows:

- May 30, 2017: Signal Site 1C
- May 31, 2017: Signal Sites 2C, 3C, 4C, 5C
- June 1, 2017: Signal Sites 6C, 7C, 8C, 9C
- June 2, 2017: Signal Sites 10C, 11C, 1S, 2S, 3S
- August 15, 2017: Signal Sites 4S, 5S

- August 16, 2017: Signal Sites 6S, 7S, 8S, 9S
- August 17, 2017: Signal Sites 10S, 11S, 12S, 13S
- November 16, 2017: Signal Sites 1N, 2N
- December 12, 2017: Signal Sites 3N, 4N, 5N, 6N
- September 20, 2018: Signal Site (replicate) 7S
- October 8, 2018: Signal Sites (replicate) 4N, 5N
- October 11, 2018: Signal Sites (replicate) 5C, 6C

Figures 2, 3, 4 show signal vehicle detection field data collection for signal sites in Central, South, and North signal region, respectively.

Figure 2. Field data collection at Central Signal Region (Jackson)

Figure 3. Field data collection at South Signal Region (Jackson, Hattiesburg, Biloxi)

Figure 4. Field data collection at North Signal Region (Oxford, Olive Branch)

Data Processing

On-site datasets were collected for 20 consecutive signal cycles at each selected signal site for the field evaluation of signal vehicle detection sensors [7]. As discussed earlier, during the field data collection for signal vehicle detection at each signal site, the following four call error types were recorded: Dropped, Missed, False, and Locked. The combined database includes call errors and cycle lengths for 20 consecutive signal cycles, total vehicle counts for the 21st signal cycle, and cycle length for the 21st cycle.

Appendix A includes examples of the data compiled in spreadsheets for signal sites in each signal region.

Analysis of Call Errors

The numbers of call errors by types of errors for the three signal regions (Central, South, and North) are shown in Figure 5. The total call errors for all sections in each signal region are, as follows:

- Central Signal Region: 53 (Highest)

- South Signal Region: 22
- North Signal Region: 19

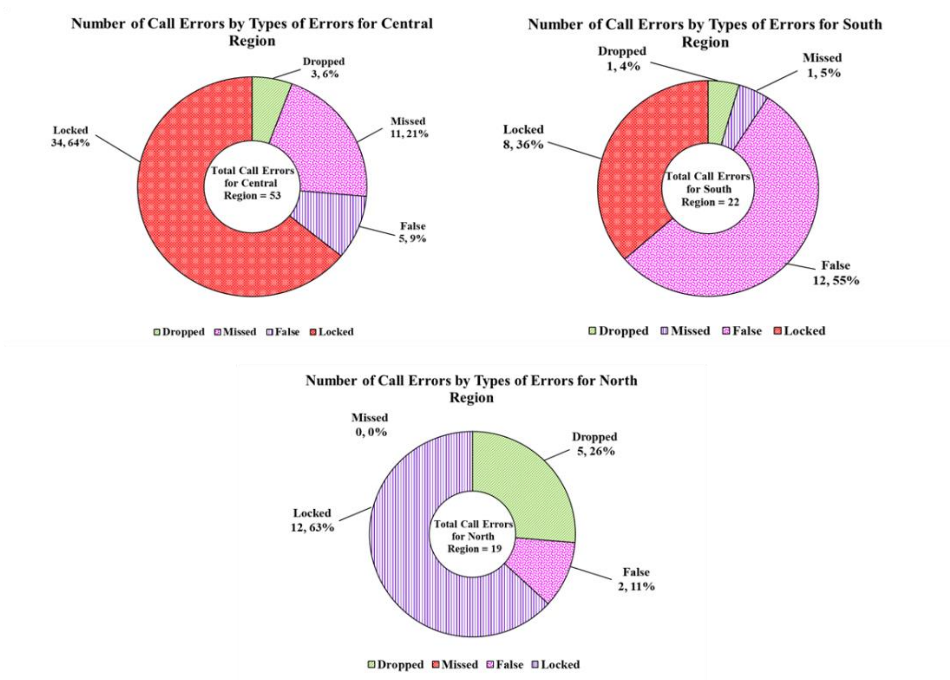


Figure 5. Number of call errors by types of errors for each signal region

The total numbers of call errors by error type for all three signal regions (Central, South, and North) are shown in Figure 6. The combined total call errors is 94 for all 30 selected signal sites.

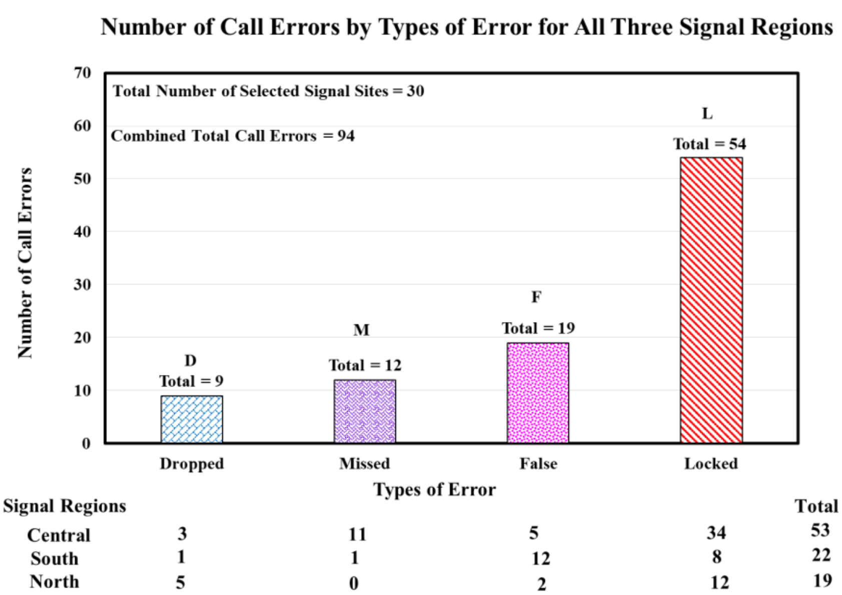


Figure 6. Total number of call errors by types of error for all three signal regions

The 20 signal cycle lengths (sec) for the 9 vehicle detection sensor models for all 30 selected signal sites in three signal regions are shown in Figure 7.

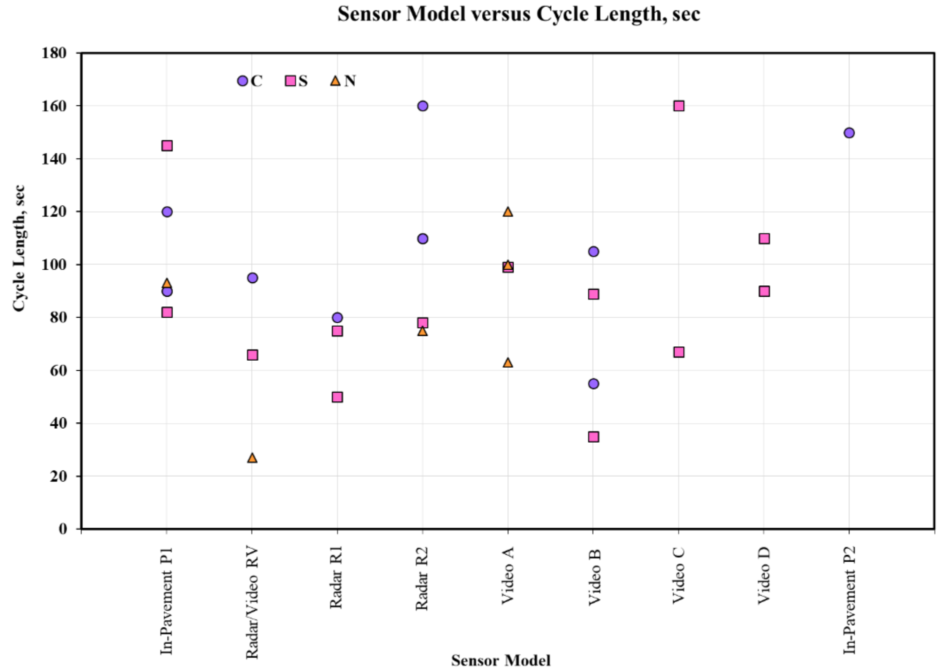


Figure 7. Cycle length by sensor model for each signal region

The total numbers of call errors (for 20 cycles) at signal sites by the call error types (dropped, missed, false and locked) for each sensor model are shown in Figure 8.

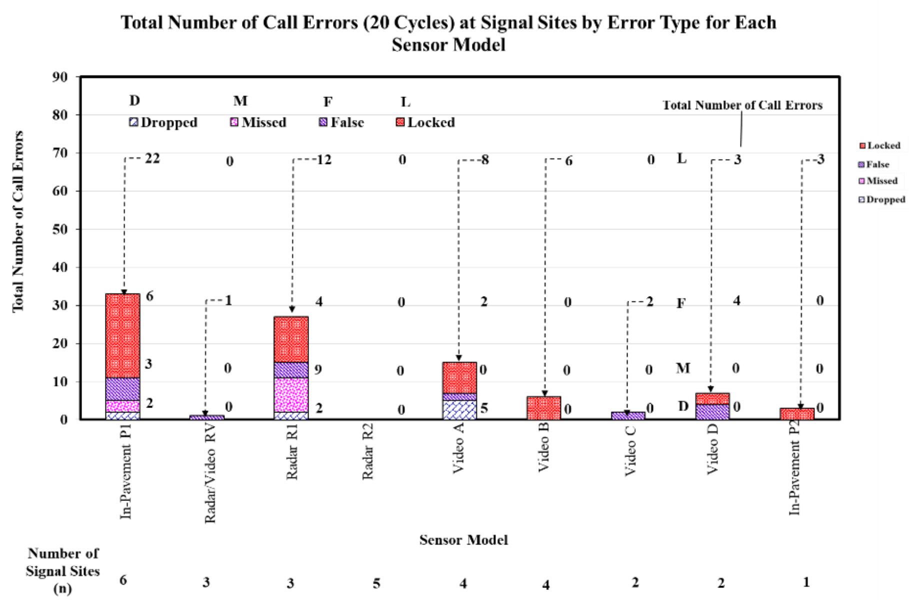


Figure 8. Total number of call errors (20 cycles) at signal sites by error type for each sensor model

The average numbers of call errors are calculated through dividing the total call error for each error type for each sensor model by the number of signal sites for each signal model. The average of numbers of call errors (20 cycles) at signal sites for each error type for each sensor model are shown in Figure 9.

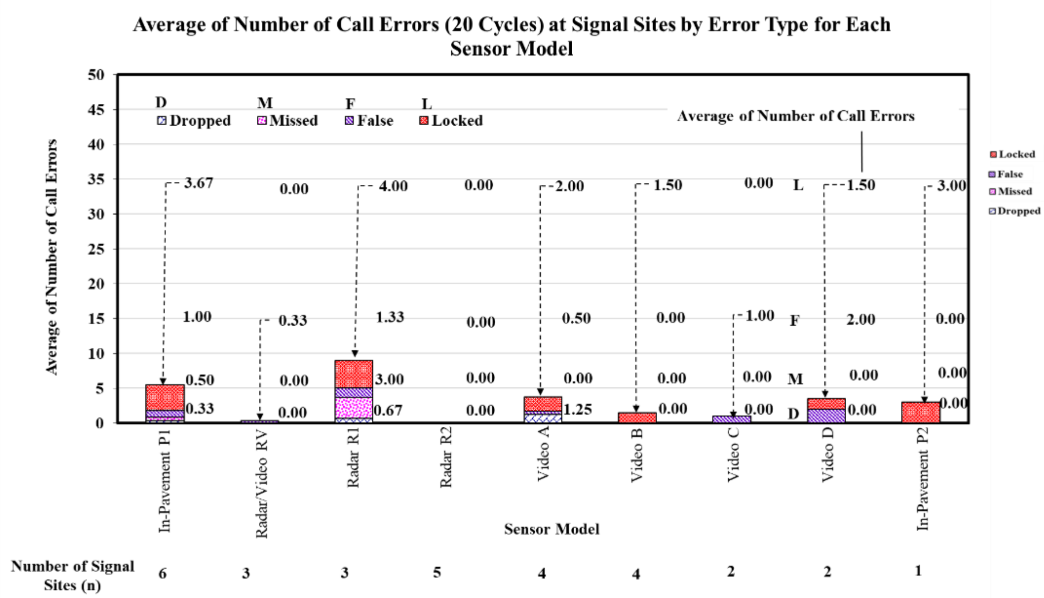


Figure 9. Average of number of call errors (20 cycles) at signal sites by error type for each sensor model

Analysis of Call Error Volumes per Hour

Vehicle volume per hour (veh/hr) at each signal site associated with total or each call error is calculated using the 20-cycle call error data and signal cycle length. The following formula (Eqn. 1) is used:

$$\text{Vehicle volume per hour (veh/hr)} = \frac{Vehicle\ Call\ Error\ Count}{Signal\ Cycle\ Length\ (s)} \times 3600\ \text{sec} \qquad \text{(Eq.1)}$$

The summary statistics of total call errors by sensor model are shown in Table 4. The average call error volume (% veh/hr) is also shown in Table 4.The following formula is used to calculate the average total call errors volume (% veh/hr) for each sensor model (Eq.2).

$$\text{Average total call error volume (\% veh/hr)} = \frac{Average\ Total\ Call\ Errors\ Volume\ (veh/hr)}{Average\ 21st\ Total\ Vehicles\ per\ hour} \times 100 \quad \text{(Eq. 2)}$$

The average total error calls for 20 signal cycles and average of 21st signal cycle's total volume of vehicles per hour for each sensor model are shown in Figure 10. The summary statistics of total call errors and the average call errors volume (%veh/hr) are also shown in Figure 10. The vertical bars in this histogram compare the average calculated vehicle volume per hour for each sensor model. The highest volume was at the In-pavement P2-site, and the highest average total call error was recorded at the Radar R1-site.

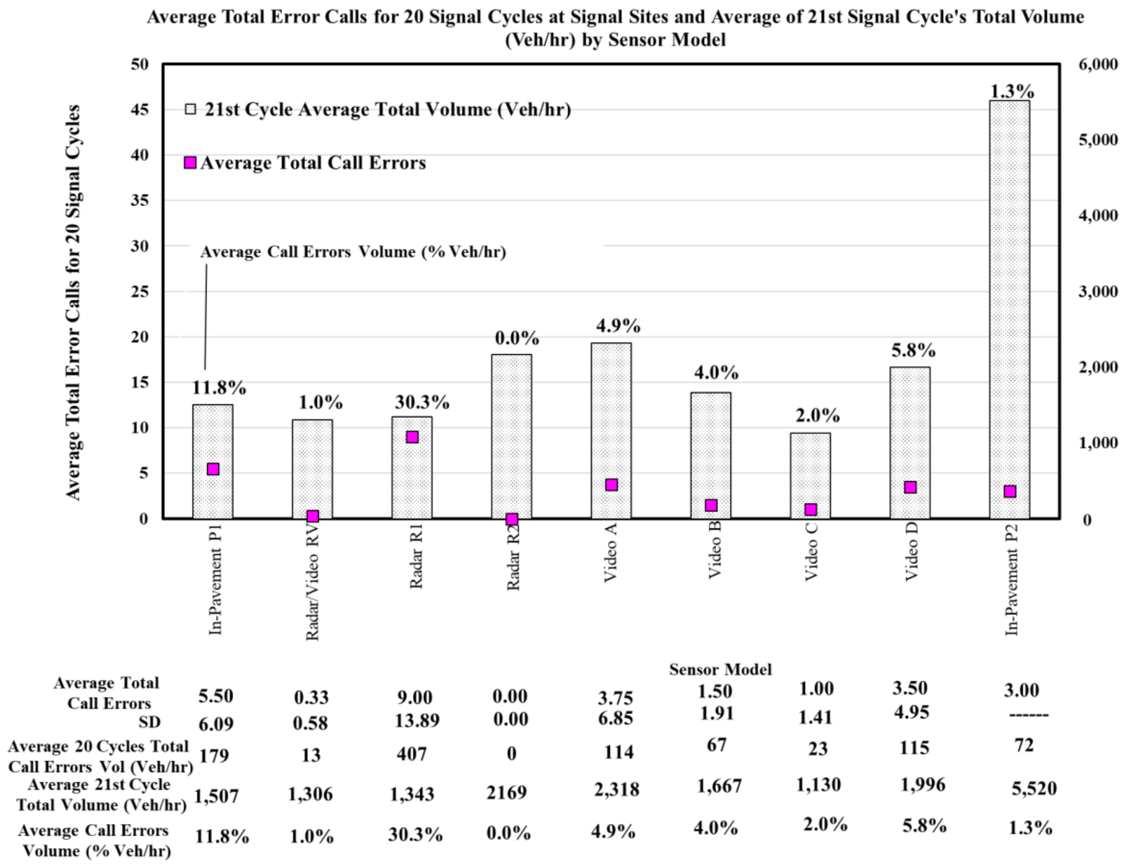


Figure 10. Average total error calls for 20 signal cycles and average of 21st signal cycle's total vehicles per hour by sensor model

Table 4. Summary statistics of total call errors by sensor model

Total Call Errors									
Sensor Model	1	2	3	4	5	6	7	8	10
Type of Sensor	1	2	3	3	4	4	4	4	5
Sensor Model Code	In-Pavement P1	Radar/Video RV	Radar R1	Radar R2	Video A	Video B	Video C	Video D	In-Pavement P2
Number of Signal Sites (n)	6	3	3	5	4	4	2	2	1
Total Call Errors (N)	33	1	27	0	15	6	2	7	3
Average	5.50	0.33	9.00	0.00	3.75	1.50	1.00	3.50	3.00
SD	6.09	0.58	13.89	0.00	6.85	1.91	1.41	4.95	----
COV (%)	110.7%	174.0%	154.3%	----	182.7%	127.3%	141.0%	141.4%	----
Average Total Call Errors Vol (Veh/hr)	178	13	407	0	114	67	23	115	72
Average Call Errors Vol (% Veh/hr)	11.8%	1.0%	30.3%	0.0%	4.9%	4.0%	2.0%	5.8%	1.3%
Average 21st Cycle Total Volume (Veh/hr)	1,507	1,306	1,343	2,169	2,318	1,667	1,130	1,996	5,520

Synthesis of Collected Data

Table 5 shows synthesis summary of all vehicle detection data sets for 30 signal sites.

Table 5. Synthesis of vehicle detection sensor field data collected and processed

Region	Factor 1 Signal Region#	Signal Region	District	Date (2017)	County	City	Roads	Site	Weather	Air Temp, °F	Factor 2T Sensor Type	Factor 2S Sensor Model	17 May 2019 Vehicle Detection Sensor Code	y_1 Subtotal Call Errors For 20 Cycles Dropped	y_2 Missed	y_3 False	y_4 Locked	y Total Call Errors	20 Cycles Cycle Length, s	20 Cycles * Call Errors Vol (Veh/hr)	21st Cycle Total Veh Counts	21st Cycle Cycle Length for Veh Counts, s	21st Cycle Total Volume (Veh/hr)	** Call Errors Vol (% Veh/hr)	Site
C	1	C	5	30-May-17	Hinds	Jackson	Lakeland/Treetops	1C	Clear	95°	5	10	In-Pavement P2	0	0	0	3	3	150	72	230	150	5,520	1.3%	1C
	1	C	5	31-May-17	Hinds	Jackson	Lakeland/Peachtree	2C	Cloudy	89°	3	3	Radar R1	2	9	3	11	25	80	1125	41	80	1,845	61.0%	2C
	1	C	5	31-May-17	Hinds	Raymond	MS18/County Farm E Main	3C	Cloudy	91°	1	1	In-Pavement P1	1	0	0	0	1	90	40	15	90	600	6.7%	3C
	1	C	5	31-May-17	Rankin	Pearl	US80/Flowood Dr.-Child Rd	4C	Clear	90°	2	2	Radio/Video RV	0	0	1	0	1	95	38	65	95	2,463	1.5%	4C
	1	C	5	11-Oct-18	Rankin	Brandon	US80/I20 EB Ramp	5C	Clear	89°	3	4	Radar R2	0	0	0	0	0	110	0	76	110	2,487	0.0%	5C
	1	C	5	11-Oct-18	Rankin	Brandon	Value/Marquette Rd	6C	Clear	84°	3	4	Radar R2	0	0	0	0	0	110	0	45	110	1,473	0.0%	6C
	1	C	5	1-Jun-17	Rankin	Flowood	MS25/Laurel Park Drive	7C	Rainy	86°	3	4	Radar R2	0	0	0	0	0	160	0	160	160	3,600	0.0%	7C
	1	C	5	1-Jun-17	Madison	Ridgeland	W Frontage Rd/Colony Parkway	8C	Cloudy	90°	4	6	Video B	0	0	0	2	2	55	131	5	55	327	40.0%	8C
	1	C	5	1-Jun-17	Madison	Madison	Madison Ave/Cottonhill Rd	9C	Cloudy	88°	4	6	Video B	0	0	0	4	4	105	137	53	105	1,817	7.5%	9C
	1	C	5	2-Jun-17	Madison	Gluckstadt	Gluckstadt/Industrial/I55 SB Ramp	10C	Rainy	82°	1	1	In-Pavement P1	0	2	1	14	17	120	510	26	120	780	65.4%	10C
	1	C	5	2-Jun-17	Madison	Gluckstadt	Gluckstadt/I55 NB Ramp	11C	Cloudy	89°	1	1	In-Pavement P1	0	0	0	0	0	90	0	49	90	1,960	0.0%	11C
S	2	S	7	6/2/2017	Simpson	Magee	US49/ Walmart	1S	Cloudy	75°	4	7	Video C	0	0	2	0	2	160	45	62	160	1,395	3.2%	1S
	2	S	7	6/2/2017	Lincoln	Brookhaven	US51/ Industrial Park Rd	2S	Cloudy	79°	3	3	Radar R1	0	0	1	1	2	75	96	29	75	1,392	6.9%	2S
	2	S	7	6/2/2017	Lincoln	Brookhaven	1st Street/ Monticello/MS184	3S	Cloudy/Rainy		3	3	Radar R1	0	0	0	0	0	50	0	11	50	792	0.0%	3S
	2	S	7	8/15/2017	Adams	Natchez	US61/ De Veraux Rd	4S	Cloudy	88°	4	5	Video A	0	0	0	0	0	99	0	38	104	1,315	0.0%	4S
	2	S	7	8/15/2017	Adams	Natchez	US61/ Walmart/HS Drive	5S	Cloudy	88°	4	7	Video C	0	0	0	0	0	67	0	31	129	865	0.0%	5S
	2	S	7	8/16/2017	Adams	Natchez	US84/Homochitto/Lower Woodville Dr.	6S	Cloudy	77°	4	8	Video D	0	0	4	3	7	110	229	61	112	1,961	11.7%	6S
	2	S	7	9/20/2018	Adams	Natchez	US61/Melrose-Monticello	7S	Clear	79°	4	8	Video D	0	0	0	0	0	90	0	57	101	2,032	0.0%	7S
	2	S	6	8/16/2017	Lamar	Hattiesburg	US49/N 31st Ave	8S	Cloudy	88°	1	1	In-Pavement P1	1	0	3	1	5	82	220	80	124	2,323	9.5%	8S
	2	S	6	8/16/2017	Lamar	Hattiesburg	US49/Mamie st.	9S	Cloudy	88°	1	1	In-Pavement P1	0	1	2	3	6	145	149	73	150	1,752	8.5%	9S
	2	S	6	8/17/2017	Harrison	Gulfport	US49/School Rd	10S	Clear	91°	3	4	Radar R2	0	0	0	0	0	78	0	60	153	1,412	0.0%	10S
	2	S	6	8/17/2017	Harrison	Biloxi	US90/Beauvoir Rd	11S	Clear	91°	4	6	Video B	0	0	0	0	0	35	0	17	41	1,493	0.0%	11S
	2	S	6	8/17/2017	Harrison	Biloxi	US90/ Porter Ave	12S	Clear	91°	4	6	Video B	0	0	0	0	0	89	0	69	82	3,029	0.0%	12S
	2	S	7	8/18/2017	Jackson	Pascagoula	MS611/Orchard Rd	13S	Clear	89°	2	2	Radar/Video RV	0	0	0	0	0	66	0	10	69	522	0.0%	13S
N	3	N	1	11/16/2017	Laffeyette	Oxford	Hwy 7 North/ Exit 6 West to7	1N	Clear	60°	3	4	Radar R2	0	0	0	0	0	75	0	39	75	1,872	0.0%	1N
	3	N	1	11/16/2017	Laffeyette	Oxford	Jackson Ave/W Oxford Loop	2N	Clear	60°	1	1	In-Pavement P1	0	0	0	4	4	93	155	42	93	1,626	9.5%	2N
	3	N	2	12/12/2017	Lee	Tupelo	Coley Road/ US78/I22	3N	Clear	53°	2	2	Radar/Video RV	0	0	0	0	0	27	0	7	27	933	0.0%	3N
	3	N	2	10/8/2018	Lee	Tupelo	MS 145/ Spicer Drive	4N	Clear	53°	4	5	Video A	1	0	0	0	1	100	36	80	137	2,102	1.7%	4N
	3	N	2	11/10/2018	Desoto	Horn Lake	Ms 302/ Horn Lake Rd	5N	Clear	45°	4	5	Video A	4	0	2	8	14	120	420	103	117	3,169	13.3%	5N
	3	N	2	12/12/2017	Desoto	Horn Lake	MS 302/ Walmart	6N	Clear	43°	4	5	Video A	0	0	0	0	0	63	0	47	63	2,686	0.0%	6N
														9	12	19	54	94	93.0	113.4	56.0	100.9	1,851.4		
														Total	Total	Total	Total	Total	Avg.	Avg.	Avg.	Avg.	Avg.		
																			32.67	225.08	45.23	35.00	1,039.76		
																			SD	SD	SD	SD	SD		

Total Number of Signal Sites Evaluated = 30

(North 6; Central 11; South 13; Total 30)

	Dropped	Missed	False	Locked	Total Call Errors
Total for C	3	11	5	34	53
Total for S	1	1	12	8	22
Total for N	5	0	2	12	19
Total Call Errors	9	12	19	54	94

Sensor Type Factor 2T	Vehicle Detection Sensor Code	Number of Signal Sites	Site #
1	In-Pavement P1	6	3C,10C,11C,8S,9S,2N
2	Radar/Video RV	3	4C,13S,3N
3	Radar R1	3	2C,2S,3S
	Radar R2	5	5C,6C,7C,10S,1N
4	Video A	4	4S,4N,5N,6N
	Video B	4	8C,9C,11S,12S
	Video C	2	1S,5S
	Video D	2	6S,7S
5	In-Pavement P2	1	1C

* Call Errors Volume (Veh/hr) = (Total Call Error/20 Cycles Length, s) x 3600

** Call Error Volume (Percent of 21st Cycle Volume) = 100 x (20 Cycles Call Error Volume (veh/hr)/21st Cycle Total Volume (veh/hr))

Note 1 Edited and Corrected after Chceking Raw Datasheet.

Note 2 Vehicle detection sensor code is assigned to each sensor model to make plots and analysis. 17 May 2019

3.3 Statistical Inference Analyses and Key Results of Vehicle Detection Errors

The statistical significance of the main effects of key factors (signal regions and sensor types, sensor models) using the collected call error data were analyzed by hypothesis testing for statistical inference. The interpretation of the results for sample data leads to the estimation of population parameters, which is the overall goal of statistical inference analysis. The summary of vehicle detection sensor types used for statistical hypothesis testing is shown in Table 6. The vehicle detection sensor type In-Pavement P2 was available for only one signal intersection site in the Central region. Therefore, it was excluded from the statistical hypothesis testing, which was conducted by using the Statistical Package for the Social Sciences (SPSS) software [8, 9] for the three signal regions (Central, South, and North) and eight vehicle detection sensor models.

Table 6. Vehicle detection sensor type summary for ANOVA

Factor 2T (Sensor Type)	Vehicle Detection Sensor Type	Factor 2S (Sensor Model)	Vehicle Detection Sensor Code	Site #
1	In-Pavement P1 (Magnetic)	1	In-Pavement P1	6 (3C,10C,11C,8S,9S,2N)
2	Radar/Video RV	2	Radar/Video RV	3 (4C,13S,3N)
3	Radar	3	Radar R1	3 (2C,2S,3S)
		4	Radar R2	5 (5C,6C,7C,10S,1N)
4	Video	5	Video A	4 (4S,4N,5N,6N)
		6	Video B	4 (8C,9C,11S,12S)
		7	Video C	2 (1S,5S)
		8	Video D	2 (6S,7S)
5	In-Pavement P2 (Magnetic)	9	In-Pavement P2	1 (1C)

The hypothesis testing for statistical inference analysis included:

- *Univariate analysis*: Univariate variable implies one outcome or one set of dependent y values (total call errors and total call error volumes in veh/hr).
- *Multivariate analysis*: Multivariate variables imply more than one outcome or more than one set of dependent y values (call error by four call error types).
- *Multiple comparisons*: Multiple comparisons of sample means for each sensor model with all other sensor models provide the difference in each set of the mean call error (or call error volume per hour) at 90% confidence intervals.

➢ ANOVA for Signal Region and Sensor Type and Interpretation of Results

The following linear ANalysis Of VAriances (ANOVA) model (Eq. 3) was used for this inference analysis:

$$y_{ijn} = C + \mu_m + A_i + \beta_j + A_i*\beta_j + \varepsilon_{ijn} \quad \text{(Eq.3)}$$

Where, i = 1, 2, 3   j = 1,2,3,4   n = 1, 2, 3, 4, …29

(total 29 observations excluding In-Pavement P2 signal site)

y_{ijn} = Dependent Variable (Response Variable) of total call errors for i^{th} signal region and j^{th} sensor type, and n^{th} observation

C = Constant (intercept term)

μ_m = Grand mean (for all y_{ijn})

A_i = Main effect of Factor 1 (Signal Region, i = 1, 2, 3)

β_j = Main effect of Factor 2T (Sensor Type, j = 1, 2, 3, 4)

$A_i*\beta_j$ = Interaction effect of Factor 1 and Factor 2T (Signal Region*Sensor Type)

ε_{ijn} = The chance error of the observations (ε_{ijn} is independently and normally distributed with the mean of 0). See Figure 11.

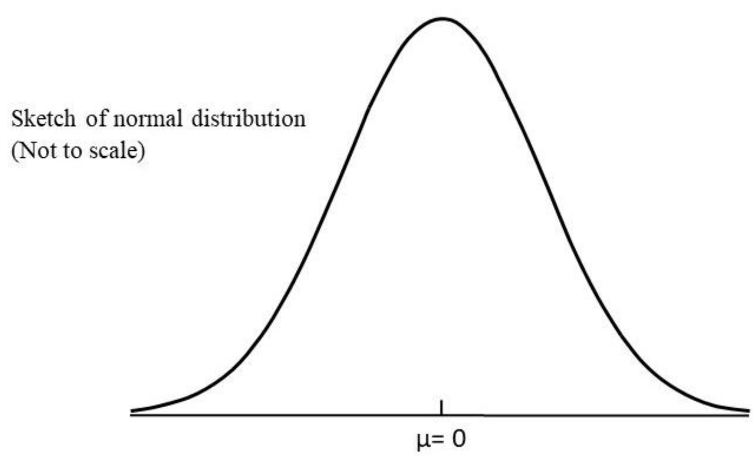


Figure 11. Normal Distribution

ANOVA Hypothesis Testing

Step by step procedure

Step 1: Setup null hypothesis and alternative hypothesis.

Hypothesis Testing Formulation for the Main Effect of Factor 1 (Signal Region):

Null Hypothesis: H_0: μ1 = μ2 = μ3

The population means of the samples in regions C, S, and N are equal. This implies that all samples are from the same population.

Alternative Hypothesis: H_A: μ1 ≠ μ2 ≠ μ3

The population means of the samples in regions C, S, and N are not equal. This implies that each sample is from a different population.

Hypothesis Testing Formulation for the Main Effect of Factor 2T (Sensor Type):

Null Hypothesis: H_0: μ1 = μ2 = μ3= μ4

The population means of the samples for four sensor types (In-pavement P1, Radar/Video RV, Radar, and Video) are equal. This implies that all samples are from the same population.

Alternative Hypothesis: H_A: μ1 ≠ μ2 ≠ μ3≠ μ4

The population means of the samples for four sensor types (In-pavement P1, Radar/Video RV, Radar, and Video) are not equal. This implies that each sample is from a different population.

Step 2: Select α probability of Type 1 chance error for α level of statistical significance.

α = 0.10

Note: The SPSS input screen for significance is α value, which is 0.10 in this analysis. This input is used by SPSS to generate 100× (1-0.10) or 90% confidence intervals for parameter estimates.

Figure 12 shows F_{v1v2} probability distribution.

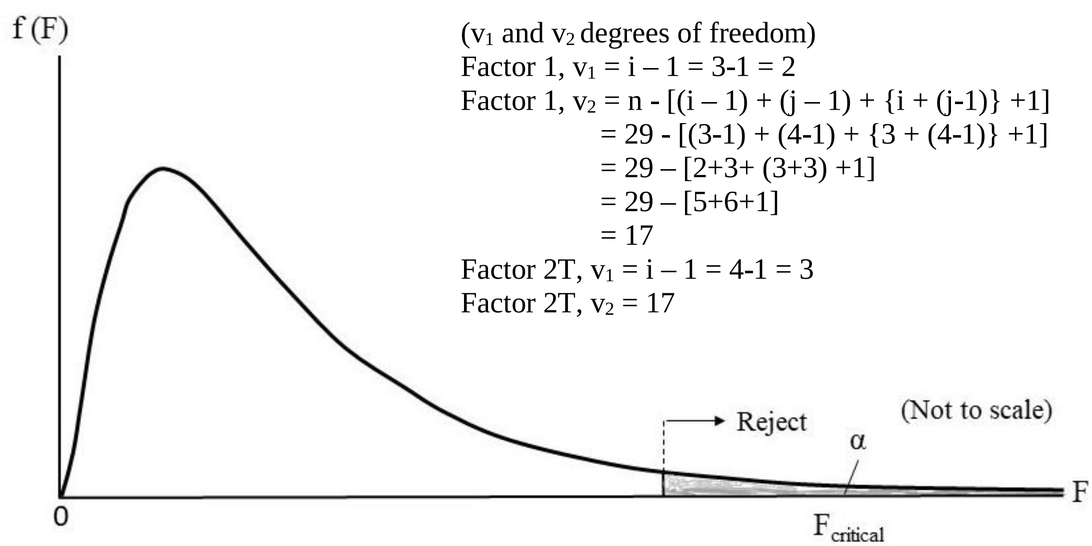


Figure 12. F_{v1v2} Probability distribution graph

Step 3: Define test criteria and the decision rule for rejecting H_0.

Test Criteria:

For Factor 1 (Signal Region), $F_{critical}$ = 2.64 for degree of freedom (dof_1 = 2) and (dof_2 = 17) and $\alpha = 0.10$

For Factor 2T (Sensor Type), $F_{critical}$ = 2.44 for degree of freedom (dof_1 = 3) and (dof_2 = 17) and $\alpha = 0.10$

For Factor 1*Factor 2T (Signal Region * Sensor Type), $F_{critical}$ = 2.15 for degree of freedom

(dof_1 = 6) and (dof_2 = 17) and $\alpha = 0.10$

Decision Rule: Reject H_0 if F-test statistics F_{test} exceeds the absolute value of $F_{critical}$ ($F_{test} > F_{critical}$) and probability of significance value, p ≤ Probability of Type-1 chance error, α.

Step 4: Calculate F test statistics, F_{test}, and p-significance value.

For Factor 1 (Signal Region), F_{test} = 0.216 (Table 7), and probability of significance, p-value = 0.808

For Factor 2T (Sensor Type), F_{test} = 0.326 (Table 7), and probability of significance, p-value = 0.806

For Factor 1* Factor 2T (Signal Region*Sensor Type), F_{test} = 0.177 (Table 7), and probability of significance, p-value = 0.980

Table 7. Univariate ANOVA results from SPSS

Tests of Between-Subjects Effects					
Dependent Variable: y Total Call Errors					
Source	Type III Sum of Squares	df	Mean Square	F_{test}	p-Sig.
Corrected Model	162.103[a]	11	14.737	.306	.975
Intercept	144.659	1	144.659	3.001	.101
Factor1 Signal Region	20.787	2	10.393	.216	.808
Factor2T Sensor Type	47.195	3	15.732	.326	.806
Factor1 Signal Region * Factor2T Sensor Type	51.057	6	8.510	.177	.980
Error	819.345	17	48.197		
Total	1267.000	29			
Corrected Total	981.448	28			
a. R Squared = .165 (Adjusted R Squared = -.375)					

Step 5: Interpret the results.

(a) For Factor 1 (Signal Region), F_{test} (0.216) < $F_{critical}$ (2.64) and p (0.808) > α 0.10 Therefore, the test fails to reject the null hypothesis for the main effect of Factor 1 (Signal Region). The results show that the differences in the means of Total Call Errors for Regions C, S, and N are not statistically significant at α 0.10 level chance error. This implies that at 90% certainty all signal regions data are from the same population.

(b) For Factor 2T (Sensor Type), F_{test} (0.326) < F critical (2.44) and p (0.806) > α 0.10. Therefore, the test fails to reject the null hypothesis for the main effect of Factor 2T (Sensor Type). The results show that the differences in the means of Total Call Errors of In-pavement P1, Radar/Video RV, Radar, and Video are not statistically significant at α 0.10 level chance error. This implies that at 90% certainty all sensor types data are from the same population.

(c) For Factor 1* Factor 2T (Signal Region*Sensor Type),
F_{test} (0.177) < $F_{critical}$ (2.15) and p (0.980) > α 0.10.
The test fails to reject the null hypothesis for the interaction effect of Factor 1 and Factor 2T (Signal Region*Sensor Type). Therefore, the interaction of the Signal Region and Sensor Type is not statistically significant at α 0.10 level chance error.

(d) In summary, these ANOVA results for Total Call Errors data show no statistically significant difference among Signal Regions and among vehicle detection Sensor Types.

(e) Therefore, for the subsequent hypothesis testing, the call errors and call error volumes data for all three regions were combined.

(f) Post Hoc Multiple Comparison test results are, as follows:

- The largest absolute difference (3.31) in total call errors for signal regions is between Central and South signal regions, followed by the absolute difference (1.83) between Central and North signal regions. The least absolute difference (1.47) is between North and South signal regions.
- The largest absolute difference (5.17) in total call errors for sensor types is between In-Pavement P1 and Radar/Video RV, followed by the absolute difference (3.04) between Radar/Video RV and Radar, In-Pavement P1 and Video (3.00), Video and Radar/Video RV (2.17) and In-Pavement P1 and Radar (2.13). The least absolute difference (0.88) is between Radar and Video.

The Post Hoc results for the difference in total call errors indicate that Radar and Video are relatively similar, compared to other sensor types. The error variance is not homogeneous because the results of Levene's test of significance rejects the null hypothesis.

(g) The descriptive statistics are as follows.

- The overall (Total) mean values of total call errors for each sensor type in 20 cycles are listed from the lowest to the largest mean value, as follow:

Type #	Sensor Type Name	Mean of Total Call Errors
2	Radar/Video (one model)	0.33
4	Video (four models)	2.50
3	Radar (two models)	3.38
1	In-Pavement P1 (one model)	5.50

- The total call error for sensor type In-Pavement P2 is 3 for the single signal site in the Central signal region, which places it between Video and Radar.

The subsequent statistical inference analysis was conducted by analyzing all eight sensor models (excluding the In-Pavement P2 sensor model).

- **ANOVA for Sensor Model and Interpretation of Results**

The following linear ANOVA model (Eq. 4) was used for this inference analysis:

$$y_{in} = C + \mu_m + A_i + \varepsilon_{in} \quad \text{(Eq.4)}$$

Where, $i = 1, 2……8$ (eight sensor models)
$n = 1,2,3,4,5,6,7,8,9,10,……………….. 29$ (total 29 observations excluding In-pavement P2 signal site)
y_{in} = Dependent variable (response variable) of total call errors for i^{th} sensor model and n^{th} observation
C = Constant (intercept term)
μ_m = Grand mean (for all y_{in})
A_i = Main effect of Factor 2S (Sensor Model, $i = 1, 2, 3……8$)
ε_{in} = The chance error of the observations (ε_{in} is independently and normally distributed with the mean of 0).

The univariate ANOVA procedure was implemented for total call errors. The step-by-step procedure for total call errors is discussed as follows:

- Dependent Variable: Total Call Errors (at 29 signal sites)
- Factor: Sensor Models (at 8 levels)
- Hypothesis:
  - Ho: μ1 = μ2 = μ3 = μ4 = μ5 = μ6 = μ7 = μ8
  - HA: μ1 ≠ μ2 ≠ μ3≠ μ4 ≠ μ5 ≠ μ6 ≠ μ7≠ μ8

    -Where μ1, μ2, μ3, μ4, μ5, μ6, μ7, and μ8 are the population means of samples for 1-In-Pavement P1, 2-Radar/Video RV, 3-Radar R1, 4-Radar R2, 5-Video A, 6-Video B, 7-Video C, and 8-Video D sensor models, respectively.
- Level of significance α = 0.10 (Probability of Type-1 chance error)
- Decision Rule: Reject H_o if F-test statistics F_{test} exceeds the absolute value of $F_{critical}$ ($F_{test} > F_{critical}$) and probability of significance value, p ≤ α.

Results and Summary Interpretation

F_{test} (0.924) < $F_{critical}$ (2.03) and p (0.508) > α 0.10. Therefore, the test fails to reject the null hypothesis. The result shows that the differences in the means of Total Call Errors of 1-In-Pavement P1, 2-Radar/Video RV, 3-Radar R1, 4-Radar R2, 5-Video A, 6-Video B, 7-Video C, and 8-Video are not statistically significant at α 0.10 level. This implies that 90% certainty the vehicle detection call error data for all sensor models are from the same population.

The overall (Total) mean values of total call errors in 20 cycles for each sensor model are listed from the lowest to largest mean value, as follows:

Model #	Sensor Model Name	Mean Total Call Errors	Number of Signal Sites
4	Radar R2	0.00	5
2	Radar/Video RV	0.33	3
7	Video C	1.00	2
6	Video B	1.50	4
8	Video D	3.50	2
5	Video A	3.75	4
1	In-Pavement P1	5.50	6
3	Radar R1	9.00	3

The least call error is for sensor model 4 Radar R2, which is followed by 2 Radar/Video RV and 7 Video C. The total call errors for sensor model 9 In-Pavement P2 is 3.00 for the single signal site in Central signal region. This places 9 In-pavement P2 between 6 Video B and 8 Video D.

- **ANOVA for Sensor Model and Interpretation of Results**

The following linear ANOVA model (Eq. 5) was used for this inference analysis:

$$y_{in} = C + \mu_m + A_i + \varepsilon_{in} \qquad \text{(Eq.5)}$$

Where, i = 1, 2……8 (eight sensor models)
n = 1,2,3,4,5,6,7,8,9,10,………………. 29 (total 29 observations excluding In-pavement P2 signal site)
y_{in} = Dependent variable (response variable) of total call error volumes (veh/hr) for i^{th} sensor model and n^{th} observation
C = Constant (intercept term)
μ_m = Grand mean (for all y_{in})
A_i = Main effect of Factor 2S (Sensor Model, i = 1, 2, 3…….8)
ε_{in} = The chance error of the observations (ε_{in} is independently and normally distributed with the mean of 0).

The univariate ANOVA procedure was implemented for total call error volumes (veh/hr). The step-by-step procedure for total call error volumes (veh/hr) is discussed as follows:

- Dependent Variable: Total Call Error Volumes (veh/hr at 29 signal sites)
- Factor: Sensor Models (at 8 levels)
- Hypothesis:
  - Ho: $\mu1 = \mu2 = \mu3 = \mu4 = \mu5 = \mu6 = \mu7 = \mu8$
  - HA: $\mu1 \neq \mu2 \neq \mu3 \neq \mu4 \neq \mu5 \neq \mu6 \neq \mu7 \neq \mu8$
    -Where μ1, μ2, μ3, μ4, μ5, μ6, μ7, and μ8 are the population means of samples for 1-In-Pavement P1, 2-Radar/Video RV, 3-Radar R1, 4-Radar R2, 5-Video A, 6-Video B, 7-Video C, and 8-Video D sensor models respectively.
- Level of significance $\alpha = 0.10$ (Probability of Type-1 chance error)
- Decision Rule: Reject H_o if F-test statistics F_{test} exceeds the absolute value of $F_{critical}$ ($F_{test} > F_{critical}$) and probability of significance value, $p \leq \alpha$.

Results and Summary Interpretation

F_{test} (1.089) < $F_{critical}$ (2.023) and p (0.405) > α 0.10. Therefore, the test fails to reject the null hypothesis. The result shows that the differences in the means of Total Call Error Volumes (veh/hr) of 1-In-Pavement P1, 2-Radar/Video RV, 3-Radar R1, 4-Radar R2, 5-Video A, 6-Video B, 7-Video C, and 8-Video are not statistically significant at α 0.10 level chance error. This implies that at 90% certainty the vehicle detection call error volume (veh/hr) data for all sensor models are from the same population.

The overall (Total) mean values of total call error volumes in 20 cycles for each sensor model are listed from the lowest to largest mean value (veh/hr), as follows:

Model #	Sensor Model Name	Mean Total Call Error Volumes	Number of Signal Sites
4	Radar R2	0.00	5
2	Radar/Video RV	12.63	3
7	Video C	22.50	2

6	Video B	67.01	4
8	Video D	114.00	2
5	Video A	114.54	4
1	In-Pavement P1	178.88	6
3	Radar R1	407.00	3

The least total call error volumes (veh/hr) is for sensor model 4 Radar R2, which is followed by 2 Radar/Video RV and 7 Video C. The sensor model 9 In-Pavement P2's total call error volume is 72 (veh/hr) for the single signal site in Central signal region. This places In Pavement P2 between 7 Video B and 8 Video D.

- **MANOVA for Sensor Model and Interpretation of Results**

The following liner Multivariate ANalysis Of VAriances (MANOVA) model (Eq. 6) was used for this inference analysis:

$$[y_{in}]_r = C + \mu_m + A_i + \varepsilon_{in} \qquad \text{(Eq.6)}$$

Where i = 1, 2……8 (eight sensor models)
n = 1,2,3,4,5,6,7,8,9,10,………………. 29 (total 29 observations excluding In-pavement P2 signal site)
$[y_{in}]_r$ = Vector of Dependent or response variables for Call Errors, r = 1, 2, 3, 4
(y_{in1} , y_{in2} , y_{in3} , y_{in4})
y_{in1} = Dependent variable (response variable) of Dropped call errors for i^{th} sensor model and n^{th} observation
y_{in2} = Dependent variable (response variable) of Missed call errors for i^{th} sensor model and n^{th} observation
y_{in3} = Dependent variable (response variable) of False call errors for i^{th} sensor model and n^{th} observation
y_{in4} = Dependent variable (response variable) of Locked call errors for i^{th} sensor model and n^{th} observation
C = Constant (The intercept term in SPSS output)
μ_m = Grand mean (for all y_{in})
A_i = Main effect of Factor 2S (Sensor Model, i = 1, 2, 3…….8)
ε_{in} = The chance error of the observations (ε_{in} is independently and normally distributed with the mean of zero).

The MANOVA procedure was implemented for call errors by four call error types. The step-by-step procedure for call error by four call error types is discussed as follows:

- Dependent Variables: Call Error (by four call error types at 29 signal sites)
- Factor: Sensor Models (8 levels)

- Hypothesis:
  - H_o: μ1 = μ2 = μ3 = μ4 = μ5 = μ6 = μ7 = μ8
  - H_A: μ1 ≠ μ2 ≠ μ3≠ μ4 ≠ μ5 ≠ μ6 ≠ μ7≠ μ8

    -Where μ1, μ2, μ3, μ4, μ5, μ6, μ7, and μ8 are the population means of samples for 1-In-Pavement P1, 2-Radar/Video RV, 3-Radar R1, 4-Radar R2, 5-Video A, 6-Video B, 7-Video C, and 8-Video D sensor models, respectively.
- Level of significance α = 0.10 (Probability of Type-1 chance error)
- Decision Rule: Reject Ho if F-test statistics F_{test} exceeds the absolute value of $F_{critical}$ ($F_{test} > F_{critical}$) and probability of significance value, $p \leq \alpha$.

Results and Summary Interpretation

From the MANOVA, the p-significance value for four dependent variables of error types Dropped (0.393 > α), Missed (0.332 > α), False (0.364 > α), and Locked (0.644 < α) was found. Thus, the test fails to reject the null hypothesis. The results show that the differences in the means of call error by four call error types from each of the eight sensor model are not statistically significant at α 0.1 level chance error. These results indicate that at 90% certainty the eight sensor models are not statistically significantly different with respect to Dropped, Missed, False, and Locked Call error types. The mean differences are relatively small.

IntraClass Correlation Test

The intraclass correlation (ICC) test [9] to characterize the similarity of measures across the sensor models for means and variance could not be conducted. The reason was that the sensor models were not the same on all signal sites.

4. EVALUATION AND COMPARISON OF VHICLE DETECTION SENSORS

4.1 Comparison Criteria and Synthesis of Findings

The following criteria were used to evaluate vehicle detection sensor systems based on literature review:

- Location / Remote Sensing
- Weather Impacts
- Sensor Reliability
- Average Life Expectancy
- Initial Cost (Equipment, Installation)
- Maintenance Frequency (Cost per year)
- RF Signal Interference
- Sensor Type (induction loop, video, radar, etc.)

The following vehicle detection sensor models were evaluated and results are presented in Table 1.

- In-Pavement P1 (Magnetic)
- Radar/Video RV
- Radar R1
- Radar R2
- Video A
- Video B
- Video C
- Video D
- In-Pavement P2 (Magnetic)

The thermal infrared imaging sensor model for signal vehicle detection was not included in the comparison study because it is not used by the Mississippi DOT due to exceptionally high initial costs.

The traffic counts data for the 21st signal cycle was used to calculate the following hourly traffic volume and vehicular emissions.

Total Traffic Volume (Vehicle Per Hour)

Figure 13 shows the total traffic volume (vph) for the 21st signal cycle at each signal site.

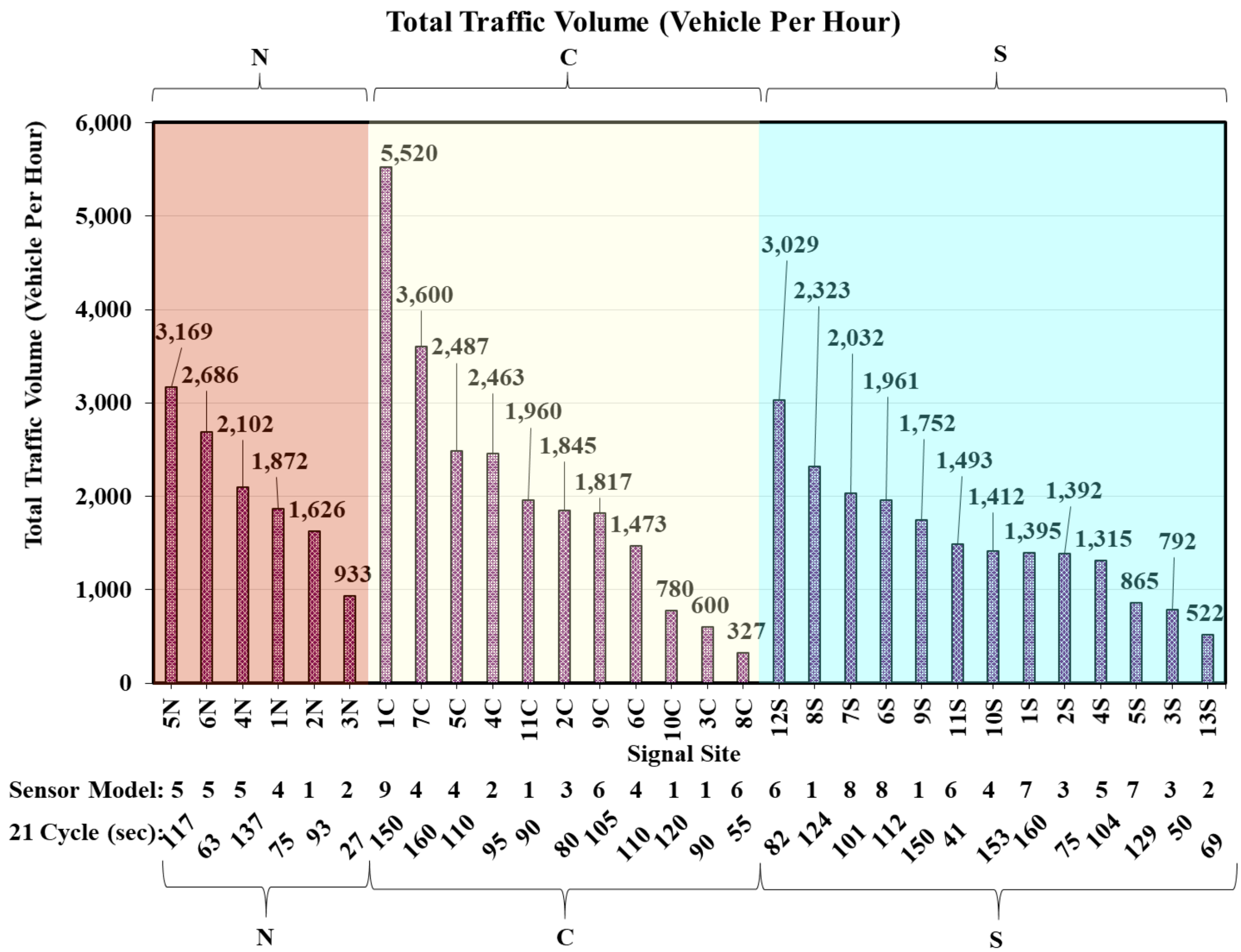


Figure 13. Total traffic volume (vehicle per hour)

Hourly Emission (kg) based on Signal Cycle 21 Traffic Volume Vehicle Per Hour (vph)

The harmful hourly emission (kg) based on Signal Cycle 21 were calculated based on the Environmental Protection Agency (EPA) emission factors analyzed for Jackson, Mississippi in an earlier study [10]. The following emission factors were used.

- Particulate Matter, 2.5 micrometer ($PM_{2.5}$) 0.165 g/km/veh
- Particulate Matter, 10 micrometer (PM_{10}) 0.129 g/km/veh
- Nitrogen Oxides (NO_x) 1.738 g/km/veh
- Carbon Monoxide (CO) 9.988 g/km/veh
- Volatile Organic Compounds (VOC) 0.803 g/km/veh

Eq. 7 was used to calculate vehicle emissions in kilograms for each pollutant.

Emission (kg) = (Emission factor (g/km/veh) x Hourly Volume on an Intersection (veh/h) x Average Velocity (km/h) x Hour) / 1000 (Eq.7)

While the emission factors depend on emission type, the hourly volume was based on the total traffic volume observed for Signal Cycle 21 at each signal site. The average velocity was 30 mph (48 km/h). The hourly emission (kg) of each pollutant was calculated using Eq. 7 for each of the 30 signal sites, as follows:

$$\text{Hourly emission (kg) of } PM_{2.5} \text{ for Signal Site 5N} = \frac{(0.165)\times(3{,}169)\times(48)\times(1)}{1{,}000} = 25\ kg$$

Table 8 presents a summary of hourly emissions (kg) of each pollutant and the total emission for all of the 30 signal sites of Signal Cycle 21. Figures 14, 15, 16, 17, 18, and 19 present pollutant emissions for signal sites.

Table 8. Summary of hourly vehicle emissions for all 30 signal sites

Site	$PM_{2.5}$ Emission (kg)	PM_{10} Emission (kg)	NOx Emission (kg)	CO Emission (kg)	VOC Emission (kg)	Total Emission (kg)
1C	44	34	461	2,646	213	3,398
2C	15	11	154	885	71	1,136
3C	5	4	50	288	23	369
4C	20	15	205	1,181	95	1,516
5C	20	15	207	1,192	96	1,531
6C	12	9	123	706	57	906
7C	29	22	300	1,726	139	2,216
8C	3	2	27	157	13	201
9C	14	11	152	871	70	1,118
10C	6	5	65	374	30	480
11C	16	12	164	940	76	1,206
1S	11	9	116	669	54	859
2S	11	9	116	667	54	857
3S	6	5	66	380	31	487
4S	10	8	110	631	51	810
5S	7	5	72	415	33	532
6S	16	12	164	940	76	1,207
7S	16	13	169	974	78	1,251
8S	18	14	194	1,114	90	1,430
9S	14	11	146	840	68	1,078
10S	11	9	118	677	54	869
11S	12	9	125	716	58	919
12S	24	19	253	1,452	117	1,865
13S	4	3	44	250	20	321
1N	15	12	156	897	72	1,152
2N	13	10	136	779	63	1,001
3N	7	6	78	447	36	574
4N	17	13	175	1,008	81	1,294
5N	25	20	264	1,519	122	1,951
6N	21	17	224	1,288	104	1,653
Total	442	344	4,634	26,629	2,145	34,187

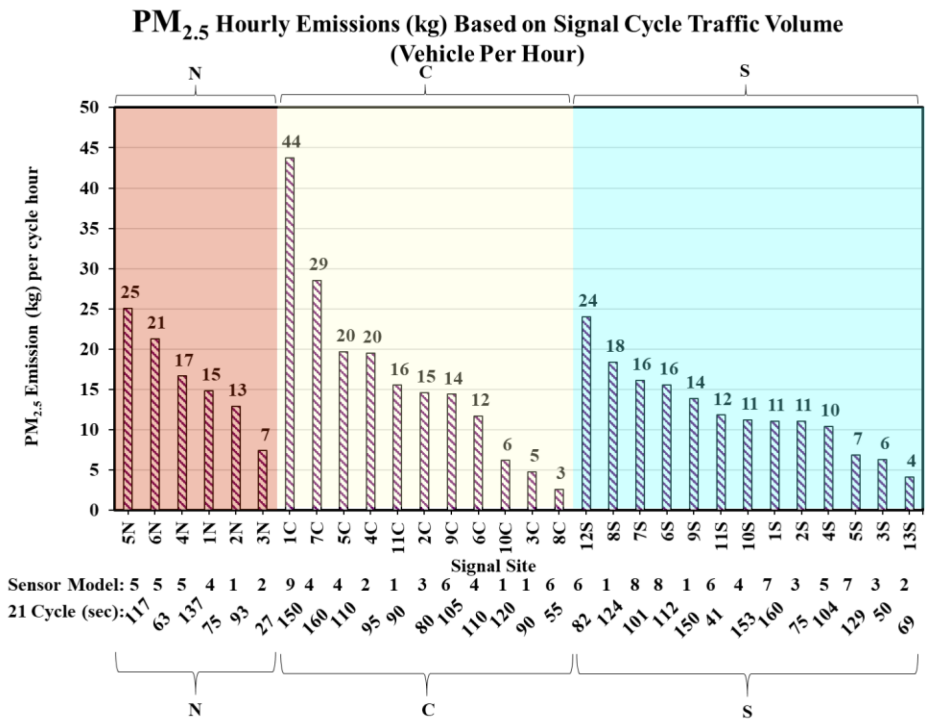


Figure 14. $PM_{2.5}$ hourly emissions (kg)

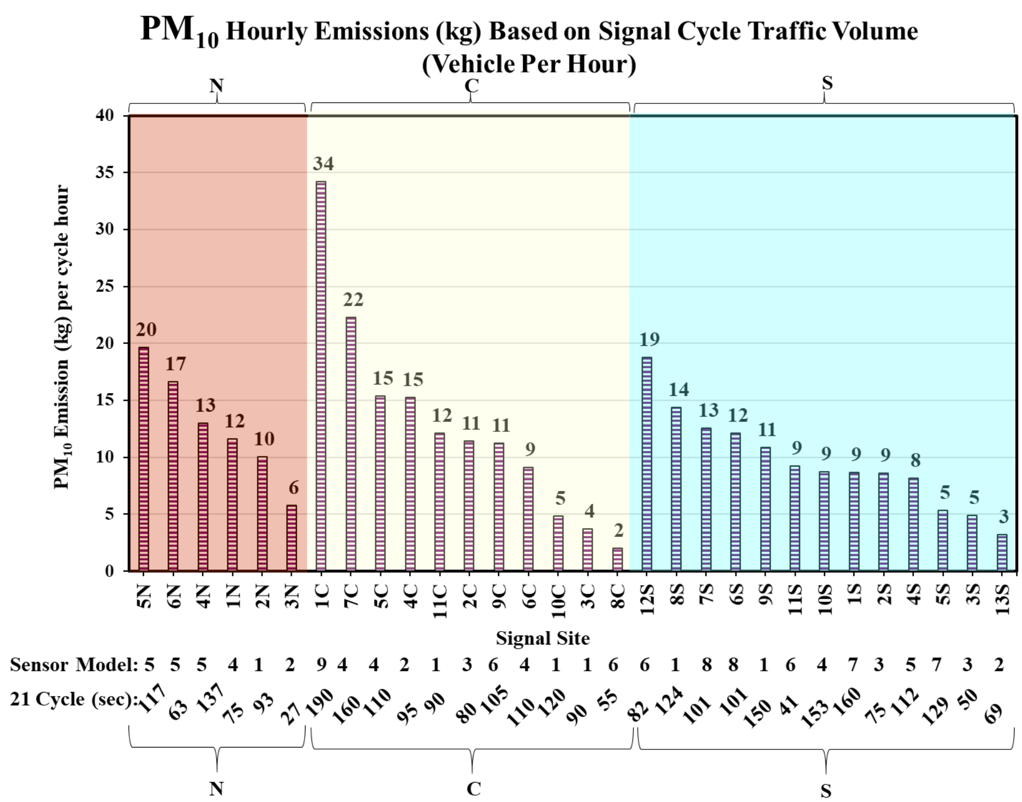


Figure 15. PM_{10} hourly emissions (kg)

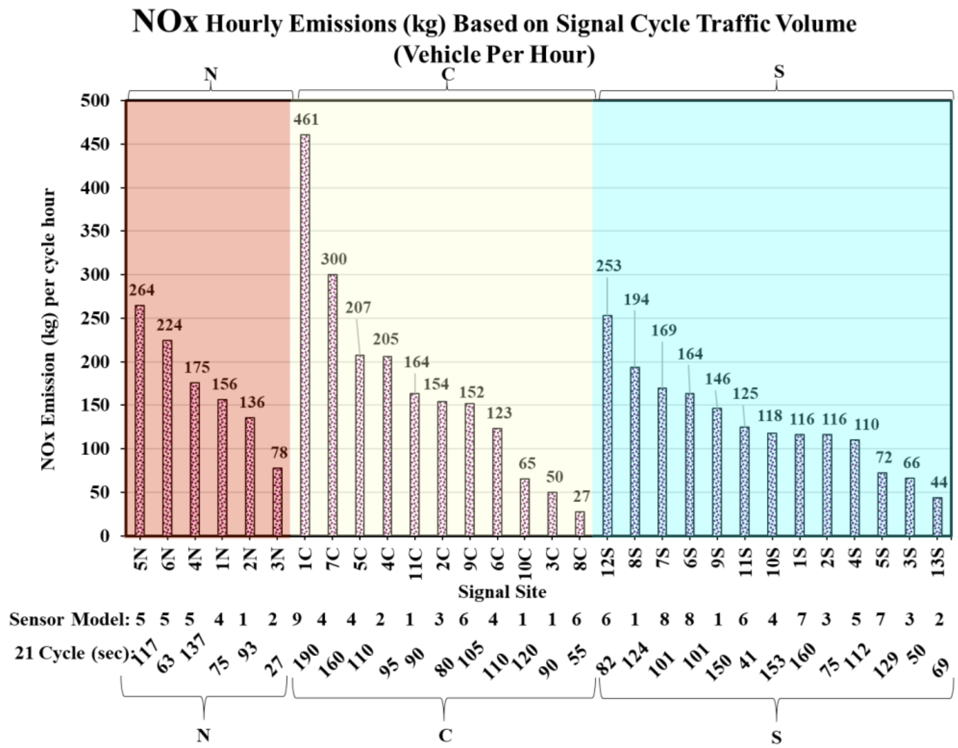


Figure 16. NOx hourly emissions (kg)

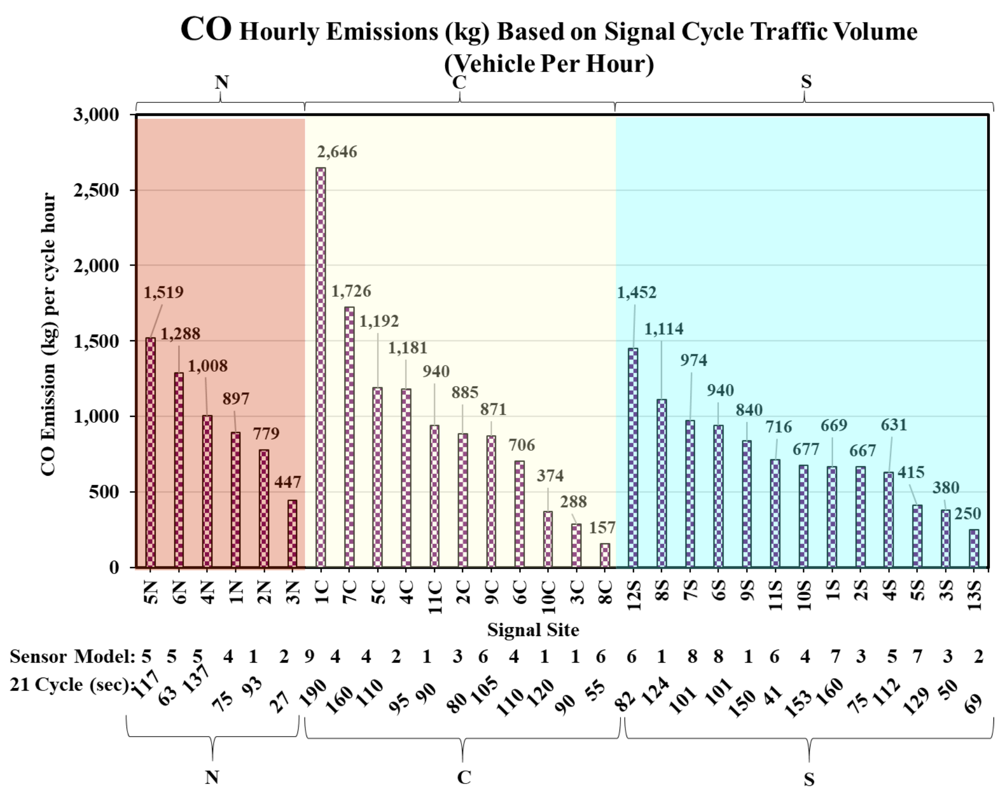


Figure 17. CO hourly emissions (kg)

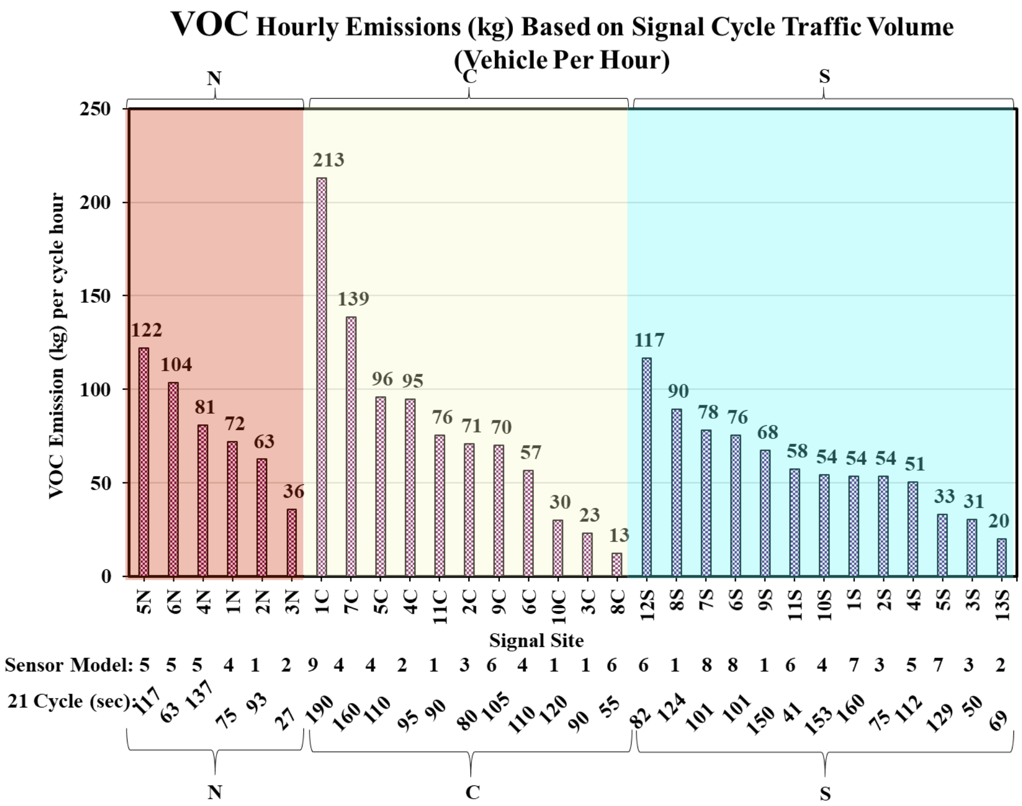


Figure 18. VOC hourly emissions (kg)

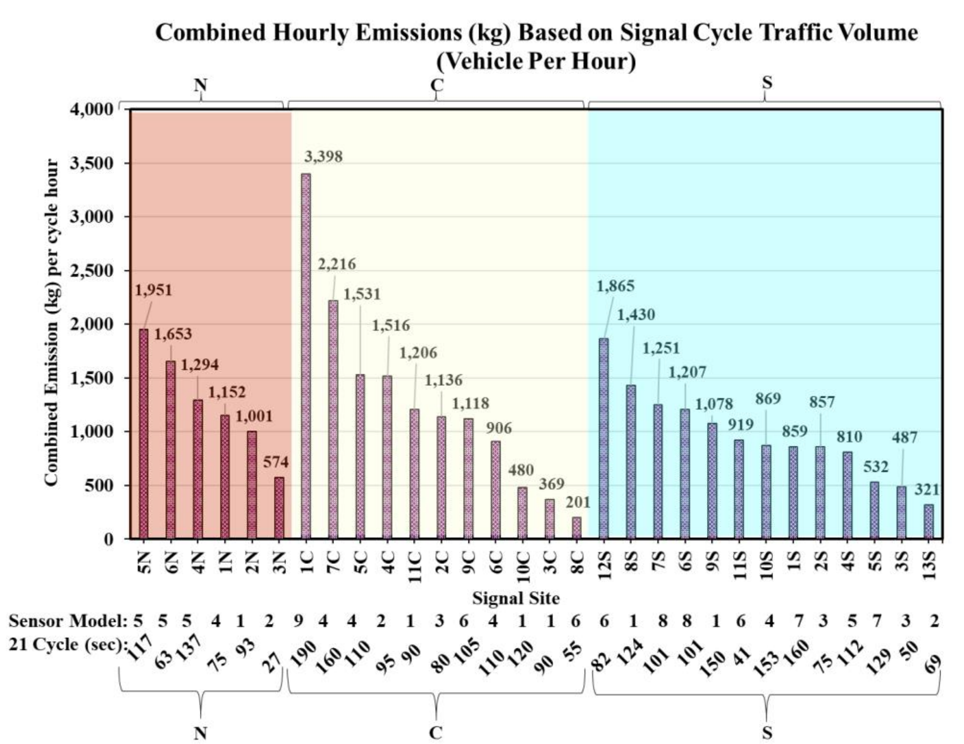


Figure 19. Combined hourly emissions (kg)

Figure 20 presents the total hourly traffic volume of the signal sites for each of the regions. It shows that the Central signal region has the highest volume (22,873 vph, 41%), followed by South signal region (20,282 vph, 37%), and North signal region (12,388 vph, 22%).

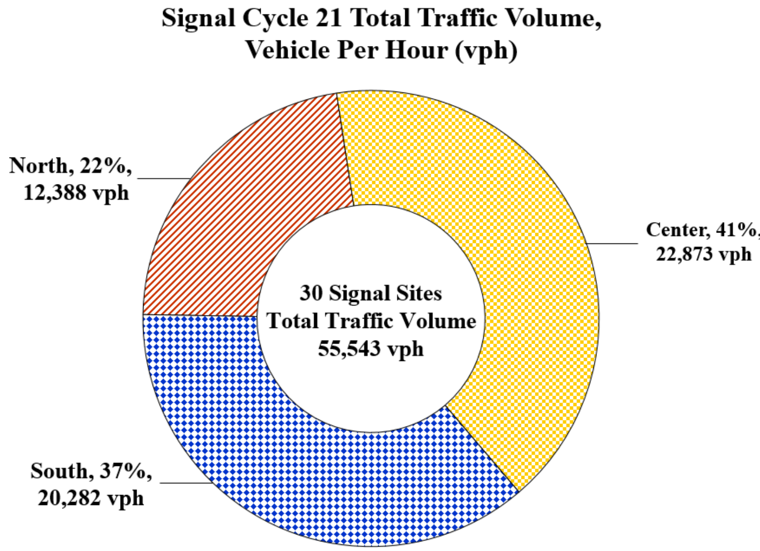


Figure 20. Signal cycle 21 total traffic volume (vph)

Figure 21 presents the combined hourly emissions (kg) of the signal sites for each of the regions of the signal sites. It shows that the hourly emission is directly related to the total hourly traffic volume, the higher the volume, the higher the emission. The Central signal region has the highest emission (14,078 kg, 41%), followed by South signal region (12,484 kg, 37%) and North signal region (7,625 kg, 22%).

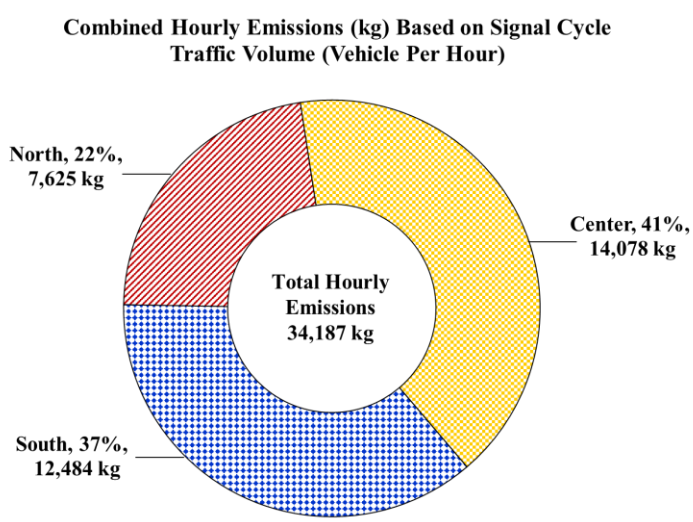


Figure 21. Combined hourly emission (kg)

4.2 Interview of Mississippi DOT Traffic Signal Engineers

The following interview questions were used to share the collective experience of the MDOT Traffic Signal Engineers associated with the signal vehicle detection sensor systems used in the three MDOT signal regions:

1. Vehicle Detection Sensor Type
2. Sensor System Reliability (1 to 5)
   (1 Best; 2 Good; 3 Fair; 4 Poor; 5 Worst)
3. Radio Frequency (RF) Signal Interference (Y, N)
4. Weather Impacts
5. Location of Installation at Intersection
6. Traffic Disruption During Checking for Malfunction and/or Maintenance
   (Y, N, Potential)
7. Signal System Vendor Support Quality (1 to 5)
   (1 Best; 2 Good; 3 Fair; 4 Poor; 5 Worst)
8. Maintenance Frequency (times in ? years)
9. Average Life Expectancy of Sensor System (years)
10. Initial Cost of System (typical) and 11. Cost of Installation (typical), $
12. Average Annual Maintenance Cost, $
13. Number of Sites Operating Sensor Systems (Mississippi DOT)
14. Overall Satisfaction of Traffic Signal Engineers (1 to 5)
    (1 Best; 2 Good; 3 Fair; 4 Poor; 5 Worst)
15. Comments

The interview was conducted in-person in a joint project meeting. The detailed responses of the MDOT Traffic Signal Engineers for each of the sensor models are included in Appendix B. Table 9 presents a synthesis summary of the interview responses. Based on the performance related to the sensor reliability, weather impacts, average life, maintenance cost, and overall satisfaction the following vehicle detection sensor models (in alphabetical order) outperform other models evaluated in this study:

- Radar R2
- Radar/Video RV
- Video A
- Video C

4.3 Strength and Weakness of Signal Vehicle Detection Sensor Systems

Each vehicle detection sensor model has the obvious strength of detecting vehicles reasonably well but suffers from some vehicle call errors, as well as one or more weakness as follows:

- Failure and maintenance related traffic disruptions due to pavement degradation with traffic and interactions with climate impacts:
  In-pavement (Magnetic) P1 and P2
  PI also suffers from RF interference; exposure to heat affects battery life; and moisture into repeaters.
- RF Signal Interference and heavy rain causing call errors: Radar R1 and R2,
- Weather impacts (rain, fog, snow, lightning, sun glare, shadows): Video A, B, C, D
- Weather impacts (heavy rain, fog, snow, lightning, sun glare): Radar/Video RV

Table 9. Summary of Mississippi DOT responses to interview questions

Signal Vehicle Detection Sensor Code →	In-Pavement P1	Radar/Video RV	Radar R1	Radar R2	Video A	Video B	Video C	Video D	In-Pavement P2
↓ Interview Questions 1. Vehicle Detection Sensor Type	Magnetic	Video, Radar (Advanced)	Radar	Radar	Video	Video	Video	Video	Magnetic
2. Sensor System Reliability (1 to 5) (1 Best; 2 Good; 3 Fair; 4 Poor; 5 Worst)	4	2	5	1	2	3	1	4	1
3. RF Signal Interference (Y, N)	Y	N	Y	Y	N	N	N	N	N
4. Weather Impacts	Prolonged exposure to heat reduces the battery life, moisture into the repeater, lightning	Heavy rain, sun glare, fog, snow, lightning	Heavy rain	Heavy rain	Rain, fog, sun glare, shadows, snow, lightning	Rain, fog, sun glare, shadows, snow, lightning	Rain, fog, sun glare, shadows, snow, lightning	Wind, rain, fog, sun glare, shadows, snow, lightning	None
5.Location of Installation at Intersection	In-Pavement and On Pole	Pole. Arm (Mast)	Pole (Stable). Arm.	Pole (typical). Arm (Mast)	Arm/Span Arm	Arm	Arm/Pole	Span (Cable)	In-Pavement
6. Traffic Disruption During Checking for Malfunction and/or Maintenance (Y, N, Potential)	Potential	Potential	Potential	Potential	Potential	Potential	Potential	Potential	Potential
7. Signal System Vendor Support Quality (1 to 5) (1 Best; 2 Good; 3 Fair; 4 Poor; 5 Worst)	1	1	3	3	1	3	1	1	Not Applicable
8. Maintenance Frequency (times in ? years)	24x per year	2x per year	30x per year	1x per year	2x per year	4x per year	< 1x per year	12x per year	5x per year
9. Average Life Expectancy of Sensor System (years)	3-5 Years	6+ Years	2 Years	7+ Years	10+ Years	10 Years	6+ Years	3+ Years	6-8 Years
10. Initial Cost of System (typical) 11. Cost of Installation (typical), $	$40,000	$36,000	$24,000	$30,000	$23,000	$35,000	$26,000	$27,000	$21,000
12. Average Annual Maintenance Cost, $	$12,000	$1,000	$15,000	$500	$1,000	$2,000	< $500	$6,000	$2,500
13. Number of Sites Operating Sensor Systems (Mississippi DOT)	65	20	20	75	70	40	4	6	800
14. Overall Satisfaction of Traffic Signal Engineers (1 to 5) (1 Best; 2 Good; 3 Fair; 4 Poor; 5 Worst)	4	2	5	1	2	3	1	4	3

Table 9. Summary of Mississippi DOT responses to interview questions (continued)

Signal Vehicle Detector Sensor Code	15. Comments
In-Pavement P1	Stopped installing. Replacing them as well. Will not be installed in future
Radar/Video RV	If it can't see, gives false call. Radar (advanced function) occasionally gives missed call
Radar R1	No longer used in Mississippi. No new installation. Old one will be replaced
Radar R2	No Comments
Video A	Good experience, good support. In East-West direction, they got problem with glare. Shadows (needs good intersection lighting)
Video B	No longer supported. Needs salt cleaning in coastal environment. Shadows (needs good intersection lighting)
Video C	It's limited to small intersection. It is good for cities. Alternative for video-vantage. Shadows (needs good intersection lighting)
Video D	Bad for large intersection and windy condition. Wind effect functionality heavily. Heavily depends on stripping. Shadows (needs good intersection lighting)
In-Pavement P2	Depends on pavement condition. If pavement condition is good, it works best. If pavement condition is bad, it works badly.

5. RESEARCH FINDINGS AND APPLICATIONS

5.1 Research Findings

This study accomplished the research objectives by evaluating the performance of traffic signal sensors at intersections that assign right of way to motorists and other road users. Efficiency and operational limitations of different types of vehicle detection sensor were evaluated, which included inductive wire loops, video, radar, radar/video, and magnetic. Vehicle call error data were collected using nine vehicle detection sensor models from 30 signal sites (18 cities in 13 counties of Mississippi) at different times of the day and weather conditions in summer and fall of 2017. Further, replicate data of call errors were collected in Fall 2018 on five signal sites. Additionally, an in-person interview of the MDOT Traffic Engineers was conducted to access their collective experience and knowledge of operating the selected signal vehicle detection systems. Based on the study result and the interview responses, the following types of vehicle detection sensor model were identified as the most reliable:

- Radar Device (Radar R2)
- Radar/Video Device (RV)
- Video Devices (Video A, Video C)

5.2 Establishing a "Test Deck" of Candidate Devices

It is recommended to select a suitable signalized intersection site for establishing a 'test deck' of the most reliable candidate devices for side-by-side monitoring and evaluation considering the following criteria:

- Hourly volume in the range of 2,000 to 5,000 vehicles per hour.
- Four-legged divided roads and/or highways, preferably in the MDOT Central signal region.
- The top most reliable vehicle detection sensor system be used for evaluation reference to other system(s).
- Vehicle detection count error tests be conducted at least three times a day for 20 consecutive signal cycles and the 21st cycle be used for all vehicle counts of all movements.
- Tests be repeated at least three different days.
- ANOVA Hypothesis testing of statistically significant difference of sample means of total call errors for chance error probability of 0.1 and multiple comparison be conducted considering the main factor of the detection sensor model.
- MANOVA Hypothesis testing of statistically significant difference of sample means of each call error type be conducted for chance error probability of 0.1 considering the main factor of the detection sensor model.

Based on the above guidance and the results of the final report, a decision can be made to proceed further with the ‘test deck’ evaluation.

6. CONCLUSIONS

The statistical significance of the main effects of key factors (signal regions and sensor type, sensor models) using the collected detection call error data were analyzed by statistical inference analysis. The ANOVA results of total call errors data show no statistically significant difference among three signal regions and among four vehicle detection sensor types. The sensor model ANOVA results of total call error volumes (in vehicles per hour) data show no statistically significant difference among vehicle detection sensor models. Additionally, hourly vehicle volume, calculated from the total vehicle counts in the 21st signal cycle, was used to estimate harmful vehicular emissions. It is concluded considering reliability and accuracy that four devices (Radar R2, Radar/Video, Video A, and Video C) outperform other sensor models as evaluated in this study.

This results are useful in the MDOT decision-making for procurement of reliable and accurate vehicle detection sensor systems for future needs. This objective decision-making process will ensure acceptable field performance of intersection signal systems for smooth flow of vehicles and reduction in incidences/crashes. The benefit/cost ratio will be relatively high because of deploying the recommended vehicle detection sensor systems, which have demonstrated lower maintenance frequency and costs.

7. RECOMMENDATIONS/IMPLEMENTATION PLAN

It is recommended that the most reliable and accurate vehicle detection sensor systems be used in a 'test deck' using the guidance provide in Section 5.2 at a selected signal site for further side-by-side monitoring and evaluation. Further, this signal site should be at least four-legged intersection with reasonably high traffic volume in the range of 2,000 to 5,000 vehicles per hour. This recommended 'test deck' field study will compare the side-by-side performance of the recommended vehicle detection sensor systems considering the same intersection geometry, same signal cycle length, same traffic volume, same weather condition, and same climate conditions.

8. REFERENCES

[1] TTI. Alternate Vehicle Detection Technologies for Traffic Signal Systems: Technical Report. FHWA/TX-09/0-5845-1, Prepared for the Texas Department of Transportation, Texas Transportation Institute (TTI), The Texas A&M University System, College Station, Texas, February 2009.

[2] TOPS. A signalized Intersection for Experimentation and Evaluation of Traffic Signal and Detection System Technology. Final Report, Traffic Operations and Safety (TOPS) Laboratory, University of Wisconsin-Madison, Department of Civil and Environmental Engineering, Prepared for the Wisconsin Department of Transportation, Madison, WI, May 2013.

[3] Sobie, C., EIT. Life Cycle Cost Analysis of Vehicle Detection Technologies and their Impact on Adaptive Traffic Control Systems. April 26, 2016. https://www.westernite.org/annualmeetings/16_Albuquerque/Papers/7B_Sobie.pdf Accessed April 1, 2019.

[4] Zender, R. L., Chang, K., & Abdel-Rahim, A. Evaluation of Vehicle Detection Systems for Traffic Signal Operations. October 16, 2016. Retrieved from https://rosap.ntl.bts.gov/view/dot/34949 Accessed April 1, 2019.

[5] Medina, J. C., Benekohal, R. F., & Ramezani, H. Field Evaluation of Smart Sensor Vehicle Detectors at Intersections— Volume 1: Normal Weather Conditions. October 2012. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.390.6461&rep=rep1&type=pdf Accessed March 22, 2019.

[6] Grenard, J., Bullock, D., & Tarko, A. P. Evaluation of Selected Video Detection Systems at Signalized Intersections. November 2001. Retrieved from https://docs.lib.purdue.edu/cgi/viewcontent.cgi?referer=https://scholar.google.com/&httpsredir=1&article=1562&context=jtrp Accessed March 22, 2019.

[7] MDOT. Research Work Plan, Scope of Work. Study SS282: Traffic Signal Vehicle Detection, One Size Does Not Fit All. Mississippi Department of Transportation (MDOT), Center for Advanced Infrastructure Technology (CAIT), University of Mississippi, 2016.

[8] Elliott, Alan C. and Wayne A.Woodward. Statistical Analysis Quick Reference Guidebook: With SPSS Examples. California: SAGE Publications, 2007.

[9] IBM SPSS software, IBM SPSS Statistics 25. International Business Machine (IBM). https://www.ibm.com/analytics/data-science/predictive-analytics/spss-statistical-software. Accessed June 1, 2018.

[10] Uddin, W. Air Quality Management Using Modern Remote Sensing and Spatial Technologies and Associated Societal Costs. Int J Environ Res Public Health, 2006, p235–243.

APPENDIX A

Samples of Compiled Field Data Collected at Signal Vehicle Detection Sites

Sensor Code: In-Pavement P2 Site 1C

THE UNIVERSITY OF MISSISSIPPI
DEPARTMENT OF CIVIL ENGINEERING
CENTER FOR ADVANCED INFRASTRUCTURE TECHNOLOGY
MDOT PROJECT: TRAFFIC SIGNAL DETECTION

Road / Intersection Information	Signal Sensor Information	Data Location Information:
City: **Jackson**	Sensor Type: **Magnetic**	Date Collected: **5/30/2017** **Test # 1**
Road Classification: **Major**	No. of Sensors: **8**	Site: **1C**
		Collected By: **CAIT**
Road Name: **Lakeland / Treetops**	Location: **Ground** / Pole /	Signal Region: N / **C** / S District: **5**
Intersection Type: **Signal /**	[redacted]	Weather: **Clear** / Cloudy / Rainy / Foggy Other (Specify):____________

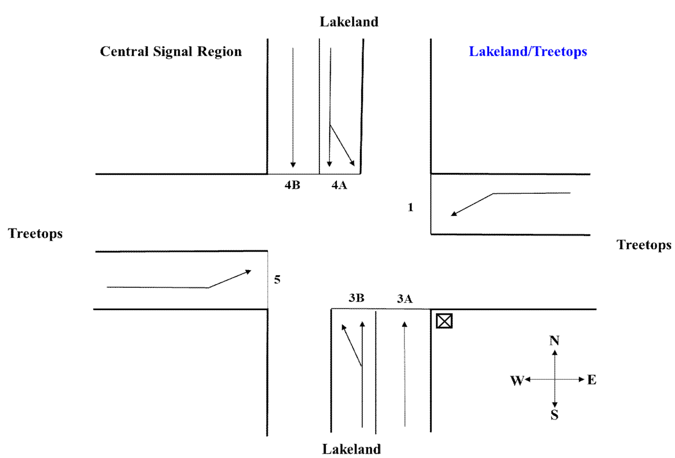
Air Temperature: 95 °F

Intersection Location: Lakeland No. of Legs: 3 / **4** / 5 / 6 Center GPS Coordinates: **32°14'44.63"N, 90°7'4.82"W**

Image Information: ITS Panel / **Photo Onsite** / Google Earth Date: **5/30/2017** Road Section Image **N**

Lane	Lane Width (*m*)	Road Direc-tion	Veh. Movement Type Th / R/ L	Signal Phase # (sec.)
		W	L	1
		N	Th	3A
		N	Th, L	3B
		S	Th, L	4A
		S	Th	4B
		E	L	5

Phase Sketches   Phase Sketches



Checked by: WU/SS
Comments: Test #1 field data sheets
All MDOT Signal Engineers, Marta and Tucker from Research were present on the site

# of Phases: **6** Signal Cylce (sec.) **150** **Total Cycles 20**
Time Started: **2:40** Time Ended: **3:15** **Test # 1**

Sensor Code: In-Pavement P2 Site 1C

MDOT PROJECT: TRAFFIC SIGNAL VEHICLE DETECTION / UM CAIT

City: **Jackson** Signal Section: N / **C** / S District: **5** Road: **Lakeland/Treetops** Intersection:___________ **Test # 1**

# of Phases: **6** Signal Cycle (sec.): **150** **Cycles: 20** Date: 5/30/17 Time Started: **2:40** Time Ended: **3:15**

Cycle #	Veh. Movt Th/ R /L	**Signal Phase # (sec.)**	Road Vehicle Detection	Signal Vehicle Detection					
				Dropped	Missed	FALSE	Locked	Other	Total
# 1	L	1							
	Th	3A							
	Th, L	3B					1		
	Th, L	4A							
	Th	4B							
	L	5							
# 2	L	1							
	Th	3A							
	Th, L	3B					1		
	Th, L	4A							
	Th	4B							
	L	5							
# 3	L	1							
	Th	3A							
	Th, L	3B							
	Th, L	4A							
	Th	4B							
	L	5							
# 4	L	1							
	Th	3A							
	Th, L	3B							
	Th, L	4A							
	Th	4B							
	L	5							
# 5	L	1							
	Th	3A							
	Th, L	3B							
	Th, L	4A							
	Th	4B							
	L	5							
# 6	L	1							
	Th	3A							
	Th, L	3B							
	Th, L	4A							
	Th	4B							
	L	5							
#	L	1							
	Th	3A					1		
	Th, L	3B							

7	Th, L	4A							
	Th	4B							
	L	5							
	L	1							
	Th	3A							
#	Th, L	3B							
8	Th, L	4A							
	Th	4B							
	L	5							
	L	1							
	Th	3A							
#	Th, L	3B							
9	Th, L	4A							
	Th	4B							
	L	5							
	L	1							
	Th	3A							
#	Th, L	3B							
10	Th, L	4A							
	Th	4B							
	L	5							
	L	1							
	Th	3A							
#	Th, L	3B							
11	Th, L	4A							
	Th	4B							
	L	5							
	L	1							
	Th	3A							
#	Th, L	3B							
12	Th, L	4A							
	Th	4B							
	L	5							
	L	1							
	Th	3A							
#	Th, L	3B							
13	Th, L	4A							
	Th	4B							
	L	5							
	L	1							
	Th	3A							
#	Th, L	3B							
14	Th, L	4A							
	Th	4B							
	L	5							
	L	1							
	Th	3A							

# 15	Th, L	3B							
	Th, L	4A							
	Th	4B							
	L	5							
# 16	L	1							
	Th	3A							
	Th, L	3B							
	Th, L	4A							
	Th	4B							
	L	5							
# 17	L	1							
	Th	3A							
	Th, L	3B							
	Th, L	4A							
	Th	4B							
	L	5							
# 18	L	1							
	Th	3A							
	Th, L	3B							
	Th, L	4A							
	Th	4B							
	L	5							
# 19	L	1							
	Th	3A							
	Th, L	3B							
	Th, L	4A							
	Th	4B							
	L	5							
# 20	L	1							
	Th	3A							
	Th, L	3B							
	Th, L	4A							
	Th	4B							
	L	5							
Totals				0	0	0	3	0	3
Percent Signal Det.									

Sensor Code: In-Pavement P2   Site 1C

MDOT PROJECT: TRAFFIC SIGNAL VEHICLE DETECTION / UM CAIT

City: **Jackson** Signal Section: N / **C** / S District: **5**   Road: **Lakeland/Treetops** Intersection:___________**Test # 1**

# of Phases: **6**   Signal Cycle (sec.): **150** **Cycles: 21** Date: 5/30/17 Time Started: **2:40** Time Ended: **3:15**

Cycle #	Veh. Movt Th/ R /L	**Signal Phase # (sec.)**	Road Vehicle Detection	Signal Vehicle Detection				
				Dropped	Missed	FALSE	Locked	Total
# 21		1	5					5
		2	117					117
		3A	8					8
		3B	10					10
		4A	2					
		4B	1					
		5	1					1
		6	86					86
Totals			230	0	0	0	0	230
Percent Signal Det.								

Sensor Code: Radar R1 Site 2C

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MDOT PROJECT: TRAFFIC SIGNAL DETECTION

Road / Intersection Information	Signal Sensor Information	Data Location Information:
City: **Jackson**	Sensor Type: **Radar**	Date Collected: **5/31/2017** **Test #1**
Road Classification: **Major**	No. of Sensors: **4**	Site: **2C**
		Collected By: **Will, Craig, Tucker, Uddin**
Road Name: **Peachtree & Lakeland**	Location: Ground / **Pole** /	Signal Region: N / **C** / S District: **5**
Intersection Type: **Signal /**		Weather: Clear / **Cloudy** / Rainy / Foggy Other (Specify):___________

Air Temperature:__________ °F

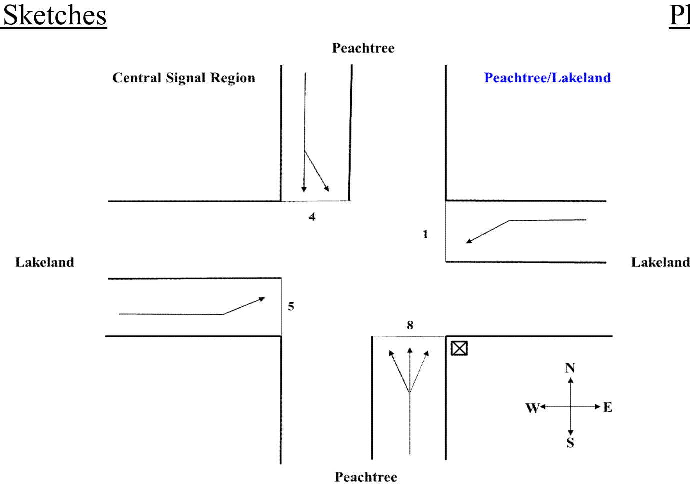
Intersection Location: Peachtree No. of Legs: **3** / 4 / 5 / 6 Center GPS Coordinates: **32°20'01.66"N, 90°10'15.82"W**

Image Information: ITS Panel / **Photo Onsite** / Google Earth Date: **5/31/2017** Road Section Image N

Lane	Lane Width (m)	Road Direc-tion	Veh. Movement Type Th / R/ L	Signal Phase # (sec.)
		W	L	1
		S	Th, L	4
		E	L	5
		N	Th, L	8

Phase Sketches

Phase Sketches



Checked by: WU/SS
Comments: Test #1 field data sheets

# of Phases: **4** Signal Cylce (sec.) **80 Total Cylces 20**
Time Started: **11:10** Time Ended: **11:40** **Test # 1**

Sensor Code: Radar R1 Site 2C

MDOT PROJECT: TRAFFIC SIGNAL VEHICLE DETECTION / UM CAIT

City: **Jackson** Signal Section: N / **C** / S District: 5 Road:**Peachtree/Lakeland** Intersection:___________**Test** # 1

# of Phases: **4** Signal Cycle (sec.): **80** **Cycles: 20** Date: **5/31/17** Time Started:**11:10** Time Ended: **11:40**

Cycle #	Veh. Movt Th/ R /L	**Signal Phase # (sec.)**	Road Vehicle Detection	Signal Vehicle Detection					
				Dropped	Missed	FALSE	Locked	Other	Total
# 1		1							
		2							
		3							
		4							
		5							
		8		1					
# 2		1							
		2							
		3							
		4							
		5							
		8					1		
# 3		1							
		2							
		3							
		4							
		5							
		8			1				
# 4		1							
		2							
		3							
		4							
		5							
		8							
# 5		1							
		2							
		3							
		4					1		
		5							
		8			1				
# 6		1							
		2							
		3							
		4							
		5							
		8							
# 7		1							
		2							
		3							
		4							

′		5							
		8				1	1		
# 8		1							
		2							
		3							
		4							
		5							
		8			1				
# 9		1							
		2							
		3							
		4							
		5							
		8							
# 10		1							
		2							
		3							
		4							
		5							
		8		1					
# 11		1							
		2							
		3							
		4							
		5							
		8							
# 12		1							
		2							
		3							
		4				1	1		
		5							
		8							
# 13		1							
		2							
		3							
		4					2		
		5							
		8							
# 14		1							
		2							
		3							
		4					2		
		5							
		8							
#		1							
		2							
		3							

15		4							
		5							
		8			1				
# 16		1							
		2							
		3							
		4				1	1		
		5							
		8							
# 17		1					1		
		2							
		3							
		4					1		
		5							
		8							
# 18		1							
		2							
		3							
		4							
		5							
		8							
# 19		1							
		2							
		3							
		4							
		5							
		8			4				
# 20		1							
		2							
		3							
		4							
		5							
		8			1				
	Totals			2	9	3	11	0	25
	Percent Signal Det.								

Sensor Code: Radar R1 Site 2C

MDOT PROJECT: TRAFFIC SIGNAL VEHICLE DETECTION / UM CAIT

City: **Jackson** Signal Section: N / C / S District: **5** Road:**Peachtree/Lakeland** Intersection:___________**Test** # 1

# of Phases: **4** Signal Cycle (sec.): **80** **Cycles: 21** Date: **5/31/17** Time Started:**11:10** Time Ended: **11:40**

Cycle #	Veh. Movt Th/ R /L	**Signal Phase # (sec.)**	Road Vehicle Detection	Signal Vehicle Detection				
				Dropped	Missed	FALSE	Locked	Total
# 21		1	3					3
		2A	11					11
		2B	11					11
		8A	0					0
		8B	1					
		4A	2					
		4B	0					0
		5	0					0
		6A	7					7
		6B	6					6
Totals			41	0	0	0	0	41
Percent Signal Det.								

Sensor Code: Radar R2 Site 5C

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MDOT PROJECT: TRAFFIC SIGNAL DETECTION

Road / Intersection Information	Signal Sensor Information	Data Location Information:
City: **Brandon**	Sensor Type: **Radar**	Date Collected: **10/11/2018** **Test # 2**
Road Classification: **US Highway**	No. of Sensors: **3**	Site: **5C**
Road Name: **US80/ I-20 EB Ramp**	Location: Ground / **Pole** /	Collected By: **UM / Amrik**
		Signal Region: N / **C** / S District: **5**
Intersection Type: **Signal** /	[redacted]	Weather: **Clear** / Cloudy / Rainy / Foggy Other (Specify):___________

Air Temperature:__________ °F

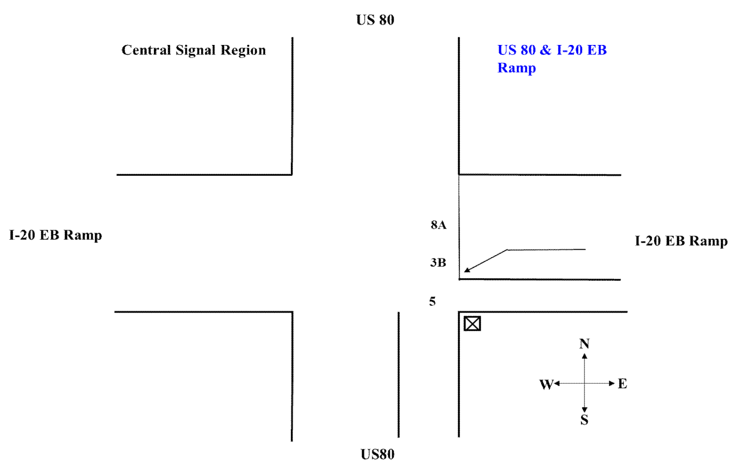
Intersection Location: US80 No. of Legs: 3 / **4** / 5 / 6 Center GPS Coordinates:________N,__________W

Image Information: ITS Panel / **Photo Onsite** / Google Earth Date: **5/31/2017** Road Section Image **N**

Lane	Lane Width (*m*)	Road Direc-tion	Veh. Movement Type Th / R/ L	Signal Phase # (sec.)
				1
				2
		NE	L	3 B
		NE	R	8 A/B
		SE	L	5
				6

Phase Sketches

Phase Sketches



Checked by: WU/SS
Comments: MDOT Test #2 field data sheet

# of Phases: 3 Signal Cycle (sec.): **110** **Total Cycles: 20**
Time Started: **2:30** Time Ended: **3:09** **Test # 2**
Test #2 Cycle 21 Vehicle Data Counts Not Used **Page 1**

Sensor Code: Radar R2 Site 5C

MDOT PROJECT: TRAFFIC SIGNAL VEHICLE DETECTION / UM CAIT

City: **Brandon** Signal Section: N / **C** / S District: **5** Road: **US80/I20 EB Ramp** Intersection:_______ **Test # 2**

# of Phases: **3** Signal Cycle (sec.): **110** **Cycles: 20** Date: **10/11/2018** Time Started: **2:30** Time Ended: **3:09**

Cycle #	Veh. Movt Th/ R /L	**Signal Phase # (sec.)**	Road Vehicle Detection	Signal Vehicle Detection					
				Dropped	Missed	FALSE	Locked	Other	Total
# 1		1							
		2							
		3							
		8							
		5							
		6							
# 2		1							
		2							
		3							
		8							
		5							
		6							
# 3		1							
		2							
		3							
		8							
		5							
		6							
# 4		1							
		2							
		3							
		8							
		5							
		6							
# 5		1							
		2							
		3							
		8							
		5							
		6							
# 6		1							
		2							
		3							
		8							
		5							
		6							
# 7		1							
		2							
		3							
		8							

		5							
		6							
# 8		1							
		2							
		3							
		8							
		5							
		6							
# 9		1							
		2							
		3							
		8							
		5							
		6							
# 10		1							
		2							
		3							
		8							
		5							
		6							
# 11		1							
		2							
		3							
		8							
		5							
		6							
# 12		1							
		2							
		3							
		8							
		5							
		6							
# 13		1							
		2							
		3							
		8							
		5							
		6							
# 14		1							
		2							
		3							
		8							
		5							
		6							
#		1							
		2							
		3							

15		8						
		5						
		6						
# 16		1						
		2						
		3						
		8						
		5						
		6						
# 17		1						
		2						
		3						
		8						
		5						
		6						
# 18		1						
		2						
		3						
		8						
		5						
		6						
# 19		1						
		2						
		3						
		8						
		5						
		6						
# 20		1						
		2						
		3						
		8						
		5						
		6						
Totals				0	0	0	0	0	0
Percent Signal Det.								

Sensor Code: Radar R2   Site 5C

MDOT PROJECT: TRAFFIC SIGNAL VEHICLE DETECTION / UM CAIT

Test #2 Cycle 21 Vehicle Counts Data Collected on 10/11/2018 Not Used

City: **Brandon** Signal Section: N / **C** / S District: **5** Road: **US80/I20 EB Ramp** Intersection:_______ **Test # 1**

# of Phases: **3** Signal Cycle (sec.): **110** **Cycles: 21** Date: **5/31/17** Time Started: **3:12** Time Ended: **3:14**

Cycle #	Veh. Movt Th/ R /L	**Signal Phase # (sec.)**	Road Vehicle Detection	Signal Vehicle Detection				
				Dropped	Missed	FALSE	Locked	Total
# 21		1	0					0
		2A	13					13
		2B	14					14
		3	2					2
		8A	5					5
		8B	7					7
		5	2					2
		6A	13					13
		6B	20					20
		--	--					0
		--	--					0
		--	--					0
		--	--					0
		--	--					0
		--	--					0
	Totals		76	0	0	0	0	76
	Percent Signal Det.							

Sensor Code: Video C   Site 5S

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MDOT PROJECT: TRAFFIC SIGNAL DETECTION

Road / Intersection Information	Signal Sensor Information	Data Location Information:
City: **Natchez**	Sensor Type: **Video**	Date Collected: **8/15/2017** **Test # 1**
Road Classification: **US Highway**	No. of Sensors: **4**	Site: **5S** Collected By: **CAIT**
Road Name: **US61/ Natchez High School Drive**	Location: **Ground** / **Pole** /	Signal Region: N / C / **S** District: **7**
Intersection Type: **Signal** /		Weather: Clear / **Cloudy** / Rainy / Foggy Other (Specify): **Raindrops**

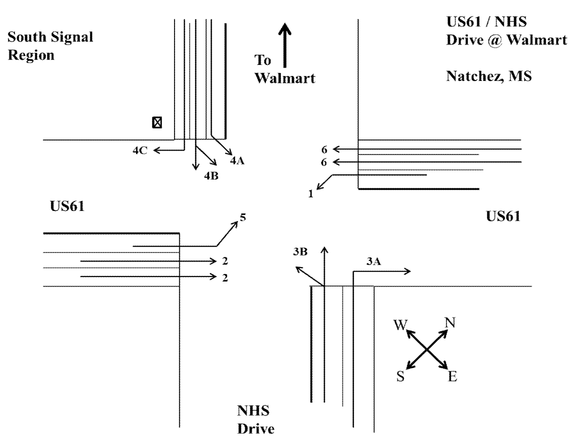
Air Temperature: **88** °F

Intersection Location: US61 at Walmart No. of Legs: 3 / **4** / 5 / 6 Center GPS Coordinates: ____N, ____W

Image Information: ITS Panel / **Photo Onsite** / Google Earth   Date: **8/15/2017**   Road Section Image **N**

Lane	Lane Width (*m*)	Road Direc-tion	Veh. Movement Type Th / R/ L	Signal Phase # (sec.)
			L	1
			Th	2
			Th/L	3
			Th/L/R	4
			L	5
			Th	6

Phase Sketches



Phase Sketches

Checked by: WU/SS Comments: Test#1 field data sheets

# of Phases: **4** Signal Cylce (sec.) **40-124** **Total Cycles** **20**
Time Started: **4:15**   Time Ended: **4:46**   **Test #** **1**

Page 1

Sensor Code: Video C Site 5S

MDOT PROJECT: TRAFFIC SIGNAL VEHICLE DETECTION / UM CAIT

City: **Natchez** Signal Section: N / C / **S** District: **7** Road: **US61@Walmart** Intersection: **NHS Drive** **Test # 1**

# of Phases: **4** Signal Cycle (sec.): **67** **Cycles: 20** Date: **8/15/2017** Time Started: **4:15** Time Ended: **4:46**

Cycle #	Veh. Movt Th/ R /L	Signal Phase # (sec.)	Road Vehicle Detection	Signal Vehicle Detection					
				Dropped	Missed	FALSE	Locked	Other	Total
# 1	L	1							
	Th	2							
	Th/L	3							
	Th/L/R	4							
	L	5							
	Th	6							
# 2	L	1							
	Th	2							
	Th/L	3							
	Th/L/R	4							
	L	5							
	Th	6							
# 3	L	1							
	Th	2							
	Th/L	3							
	Th/L/R	4							
	L	5							
	Th	6							
# 4	L	1							
	Th	2							
	Th/L	3							
	Th/L/R	4							
	L	5							
	Th	6							
# 5	L	1							
	Th	2							
	Th/L	3							
	Th/L/R	4							
	L	5							
	Th	6							
# 6	L	1							
	Th	2							
	Th/L	3							
	Th/L/R	4							
	L	5							
	Th	6							
#	L	1							
	Th	2							
	Th/L	3							

7	Th/L/R	4							
	L	5							
	Th	6							
# 8	L	1							
	Th	2							
	Th/L	3							
	Th/L/R	4							
	L	5							
	Th	6							
# 9	L	1							
	Th	2							
	Th/L	3							
	Th/L/R	4							
	L	5							
	Th	6							
# 10	L	1							
	Th	2							
	Th/L	3							
	Th/L/R	4							
	L	5							
	Th	6							
# 11	L	1							
	Th	2							
	Th/L	3							
	Th/L/R	4							
	L	5							
	Th	6							
# 12	L	1							
	Th	2							
	Th/L	3							
	Th/L/R	4							
	L	5							
	Th	6							
# 13	L	1							
	Th	2							
	Th/L	3							
	Th/L/R	4							
	L	5							
	Th	6							
# 14	L	1							
	Th	2							
	Th/L	3							
	Th/L/R	4							
	L	5							
	Th	6							
#	L	1							
	Th	2							

# 15	Th/L	3							
	Th/L/R	4							
	L	5							
	Th	6							
# 16	L	1							
	Th	2							
	Th/L	3							
	Th/L/R	4							
	L	5							
	Th	6							
# 17	L	1							
	Th	2							
	Th/L	3							
	Th/L/R	4							
	L	5							
	Th	6							
# 18	L	1							
	Th	2							
	Th/L	3							
	Th/L/R	4							
	L	5							
	Th	6							
# 19	L	1							
	Th	2							
	Th/L	3							
	Th/L/R	4							
	L	5							
	Th	6							
# 20	L	1							
	Th	2							
	Th/L	3							
	Th/L/R	4							
	L	5							
	Th	6							
Totals				0	0	0	0	0	0
Percent Signal Det.									

Sensor Code: Video C   Site 5S

MDOT PROJECT: TRAFFIC SIGNAL VEHICLE DETECTION / UM CAIT

City: **Natchez** Signal Section: N / C / **S** District: **7** Road: **US60@Walmart** Intersection: **NHS Drive** **Test** # **1**

# of Phases: **4** Signal Cycle (sec.): **129** **Cycles: 21** Date: **8/15/17** Time Started: **4:49** Time Ended: **4:50**

Cycle #	Veh. Movt Th/ R /L	**Signal Phase # (sec.)**	Road Vehicle Detection	Signal Vehicle Detection				
				Dropped	Missed	FALSE	Locked	Total
# 21		1	0					0
		2	11					11
		3	1					1
		4A	4					4
		4B	3					
		4C						
		5	0					0
		6	12					12
Totals			31	0	0	0	0	31
Percent Signal Det.								

Sensor Code: Video D Site 6S

THE UNIVERSITY OF MISSISSIPPI
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MDOT PROJECT: TRAFFIC SIGNAL DETECTION

Road / Intersection Information	Signal Sensor Information	Data Location Information:
City: **Natchez**	Sensor Type: **Video**	Date Collected: **8/16/2017** **Test # 1**
Road Classification: **US Highway**	No. of Sensors: **4**	Site: **6S**
Road Name: **US84 at Homochitto/ Lower Woodville Dr.**	Location: Ground / Pole / **Wire**	Collected By: **CAIT**
Intersection Type: **Signal** /		Signal Region: N / C / **S** District: **7**
		Weather: Clear / **Cloudy** / Rainy / Foggy Other (Specify):

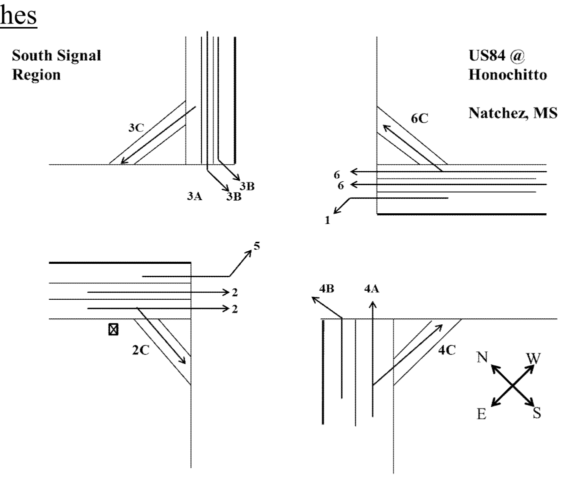
Air Temperature: 77 °F

Intersection Location: US84 No. of Legs: 3 / **4** / 5 / 6 Center GPS Coordinates: **31.539108** N,**-91.39716** W

Image Information: ITS Panel / **Photo Onsite** / Google Earth Date: **8/16/2017** Road Section Image **N**

Lane	Lane Width (*m*)	Road Direc-tion	Veh. Movement Type Th / R/ L	Signal Phase # (sec.)
			L/L	1/5
			Th / Th	2/6
			Th / L	3
			Th / L	4

Phase Sketches Phase Sketches



Checked by: WU/SS Comments: Test#1 field data sheets	# of Phases: 4 Signal Cylce (sec.) 110 **Total Cycles** 20 Time Started: 8:37 Time Ended: 9:15 **Test #** 1 **Page 1**

Sensor Code: Video D Site 6S

MDOT PROJECT: TRAFFIC SIGNAL VEHICLE DETECTION / UM CAIT

City: **Natchez** Signal Section: N / C / **S** District: **7** Road: **US61** Intersection: **Homochitto** **Test** # **1**

# of Phases: **4** Signal Cycle (sec.): **101** **Cycles:** **20** Date: **8/16/2017** Time Started: **8:37** Time Ended: **9:15**

Cycle #	Veh. Movt Th/ R /L	**Signal Phase # (sec.)**	Road Vehicle Detection	Signal Vehicle Detection					
				Dropped	Missed	FALSE	Locked	Other	Total
# 1	L/L	1/5							
	Th / Th	2/6							
	Th / L	3							
	Th / L	4							
# 2	L/L	1/5							
	Th / Th	2/6							
	Th / L	3					1		
	Th / L	4							
# 3		1/5							
		2/6							
		3							
		4					1		
# 4	L/L	1/5							
	Th / Th	2/6							
	Th / L	3					1		
	Th / L	4							
# 5	L/L	1/5							
	Th / Th	2/6							
	Th / L	3							
	Th / L	4							
# 6	L/L	1/5							
	Th / Th	2/6							
	Th / L	3							
	Th / L	4							
#	L/L	1/5							
	Th / Th	2/6							
	Th / L	3							

7	Th / L	4							
	L/L	1/5							
#	Th / Th	2/6							
	Th / L	3							
8	Th / L	4							
	L/L	1/5							
#	Th / Th	2/6							
	Th / L	3							
9	Th / L	4							
	L/L	1/5							
#	Th / Th	2/6							
	Th / L	3							
10	Th / L	4							
	L/L	1/5							
#	Th / Th	2/6							
	Th / L	3				1			
11	Th / L	4							
	L/L	1/5							
#	Th / Th	2/6							
	Th / L	3							
12	Th / L	4							
	L/L	1/5							
#	Th / Th	2/6							
	Th / L	3							
13	Th / L	4							
	L/L	1/5				1			
#	Th / Th	2/6							
	Th / L	3							
14	Th / L	4							
	L/L	1/5				1			
#	Th / Th	2/6							

# 15	Th / L	3							
	Th / L	4							
# 16	L/L	1/5				1			
	Th / Th	2/6							
	Th / L	3							
	Th / L	4							
# 17	L/L	1/5							
	Th / Th	2/6							
	Th / L	3							
	Th / L	4							
# 18	L/L	1/5							
	Th / Th	2/6							
	Th / L	3							
	Th / L	4							
# 19	L/L	1/5							
	Th / Th	2/6							
	Th / L	3							
	Th / L	4							
# 20	L/L	1/5							
	Th / Th	2/6							
	Th / L	3							
	Th / L	4							
	Totals			0	0	4	3	0	7
	Percent Signal Det.								

Sensor Code: Video D   Site 6S

MDOT PROJECT: TRAFFIC SIGNAL VEHICLE DETECTION / UM CAIT

City: **Natchez** Signal Section: N / C / **S** District: **7** Road: **US61** Intersection: **Honochitto** **Test # 1**

\# of Phases: **4** Signal Cycle (sec.): **112** **Cycles: 21** Date: **8/16/2017** Time Started: **9:22** Time Ended: **9:25**

Cycle #	Veh. Movt Th/ R /L	**Signal Phase # (sec.)**	Road Vehicle Detection	Signal Vehicle Detection				
				Dropped	Missed	FALSE	Locked	Total
# 21		1	1					1
		2	21					21
		2C	1					1
		3	2					2
		3C	0					0
		4	6					
		4C	2					
		5	3					3
		6	17					17
		6C	8					8
	Totals		61	0	0	0	0	61
	Percent Signal Det.							

Sensor Code: In-Pavement P1 Site 8S

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MDOT PROJECT: TRAFFIC SIGNAL DETECTION

Road / Intersection Information	Signal Sensor Information	Data Location Information:
City: **Hattiesburg**	Sensor Type: **Magnetic**	Date Collected: **8/16/2017** **Test # 1**
Road Classification: **US Highway**	No. of Sensors: **4**	Site: **8S** Collected By: **CAIT**
Road Name: **US49/ N 31st Ave**	Location: **Ground** / Pole	Signal Region: N / C / **S** District: **6**
Intersection Type: **Signal** /	[redacted]	Weather: Clear / **Cloudy** / Rainy / Foggy Other (Specify):

Air Temperature: __88__ °F

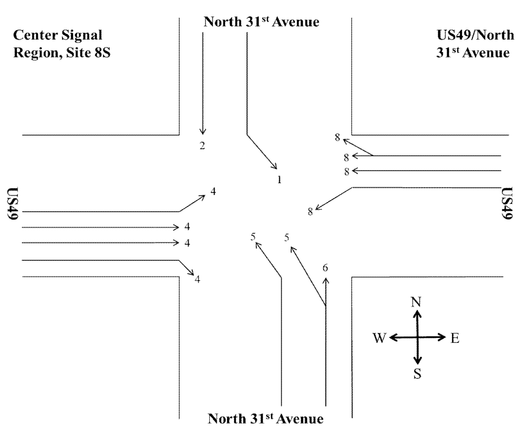
Intersection Location: US49 No. of Legs: 3 / **4** / 5 / 6 Center GPS Coordinates:__________ N, __________ W

Image Information: ITS Panel / **Photo Onsite** / Google Earth Date: **8/16/2017** Road Section Image **N**

Lane	Lane Width (m)	Road Direc-tion	Veh. Movement Type Th / R/ L	Signal Phase # (sec.)
			L	1
			Th	2
			Th/L	8
			Th/L	4
			L	5
			Th	6

Phase Sketches

Phase Sketches



Checked by: WU/SS
Comments: Test #1 field data sheets

# of Phases: __4__ Signal Cycle (sec.) __64-124__ **Total Cycles** __20__
Time Started: __2:50__ Time Ended: __3:28__ **Test #** __1__

Sensor Code: In-Pavement P1 Site 8S

MDOT PROJECT: TRAFFIC SIGNAL VEHICLE DETECTION / UM CAIT

City: **Hattiesburg** Signal Section: N / C / **S** District: **6** Road: **US49** Intersection: **N 31st Avenue** **Test** # **1**

# of Phases: **4** Signal Cycle (sec.): **82** **Cycles: 20** Date: **8/16/2017** Time Started: **2:50** Time Ended: **3:28**

Cycle #	Veh. Movt Th/ R /L	Signal Phase # (sec.)	Road Vehicle Detection	Signal Vehicle Detection					
				Dropped	Missed	FALSE	Locked	Other	Total
# 1	L	1							
	Th	2							
	Th/L	8							
	Th/L	4							
	L	5							
	Th	6							
# 2	L	1							
	Th	2							
	Th/L	8							
	Th/L	4							
	L	5							
	Th	6							
# 3	L	1							
	Th	2							
	Th/L	8							
	Th/L	4							
	L	5							
	Th	6							
# 4	L	1							
	Th	2							
	Th/L	8							
	Th/L	4							
	L	5				1	1		
	Th	6							
# 5	L	1							
	Th	2							
	Th/L	8							
	Th/L	4							
	L	5							
	Th	6							
# 6	L	1							
	Th	2							
	Th/L	8							
	Th/L	4							
	L	5							
	Th	6							
#	L	1				1			
	Th	2							
	Th/L	8							

7	Th/L	4							
	L	5							
	Th	6							
# 8	L	1							
	Th	2							
	Th/L	8							
	Th/L	4							
	L	5							
	Th	6							
# 9	L	1							
	Th	2							
	Th/L	8							
	Th/L	4							
	L	5							
	Th	6							
# 10	L	1							
	Th	2							
	Th/L	8							
	Th/L	4							
	L	5							
	Th	6							
# 11	L	1							
	Th	2							
	Th/L	8							
	Th/L	4							
	L	5							
	Th	6							
# 12	L	1							
	Th	2							
	Th/L	8							
	Th/L	4							
	L	5							
	Th	6							
# 13	L	1							
	Th	2							
	Th/L	8							
	Th/L	4							
	L	5							
	Th	6							
# 14	L	1							
	Th	2							
	Th/L	8							
	Th/L	4							
	L	5							
	Th	6							
#	L	1							
	Th	2							

# 15	Th/L	8							
	Th/L	4							
	L	5							
	Th	6							
# 16	L	1							
	Th	2							
	Th/L	8							
	Th/L	4							
	L	5							
	Th	6							
# 17	L	1							
	Th	2							
	Th/L	8							
	Th/L	4							
	L	5				1			
	Th	6							
# 18	L	1							
	Th	2							
	Th/L	8							
	Th/L	4							
	L	5							
	Th	6							
# 19	L	1							
	Th	2							
	Th/L	8							
	Th/L	4							
	L	5							
	Th	6							
# 20	L	1							
	Th	2							
	Th/L	8							
	Th/L	4							
	L	5		1					
	Th	6							
Totals				1	0	3	1	0	5
Percent Signal Det.									

Sensor Code: In-Pavement P1 Site 8S

MDOT PROJECT: TRAFFIC SIGNAL VEHICLE DETECTION / UM CAIT

City: **Hattiesburg** Signal Section: N / C / **S** District: **6** Road: **US49** Intersection: **N 31st Avenue** **Test** # **1**

# of Phases: **4** Signal Cycle (sec.): **124** **Cycles: 21** Date: **8/16/2017** Time Started: **3:32** Time Ended:

Cycle #	Veh. Movt Th/ R /L	**Signal Phase # (sec.)**	Road Vehicle Detection	Signal Vehicle Detection				
				Dropped	Missed	FALSE	Locked	Total
# 21		1	2					2
		2	38					38
		8	2					2
		8C	2					2
		4	4					4
		4C	1					
		5	2					
		6	29					29
		--	0					0
		--	0					0
	Totals		80	0	0	0	0	80
	Percent Signal Det.							

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MDOT PROJECT: TRAFFIC SIGNAL DETECTION

Road / Intersection Information	Signal Sensor Information	Data Location Information:
City: **Biloxi**	Sensor Type: **Video**	Date Collected: **8/17/2017** **Test # 1**
Road Classification: **US Highway**	No. of Sensors: **4**	Site: **12S**
		Collected By: **CAIT**
Road Name: **US90 at Porter Ave.**	Location: Ground / **Pole** /	Signal Region: N / C / **S** District: **6**
Intersection Type: **Signal** /	[redacted]	Weather: **Clear** / Cloudy / Rainy / Foggy Other (Specify):

Air Temperature: __91__ °F

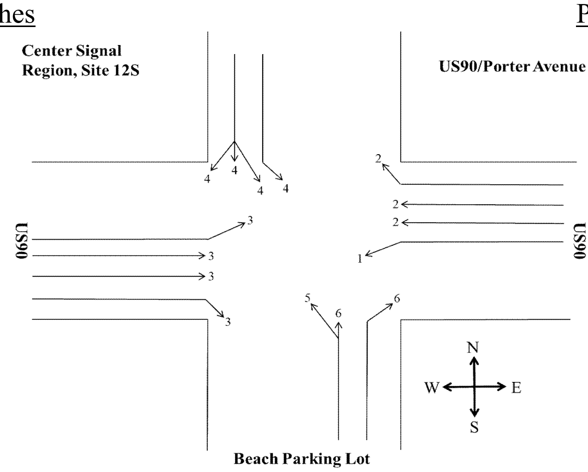
Intersection Location: US90 No. of Legs: 3 / **4** / 5 / 6 Center GPS Coordinates: **30.394679** N, **-88.902016** W

Image Information: ITS Panel / **Photo Onsite** / Google Earth   Date: **8/17/2017**   Road Section Image

N

Lane	Lane Width (*m*)	Road Direc-tion	Veh. Movement Type Th / R/ L	Signal Phase # (sec.)
			L	1
			Th / R	2
			Th/R/L	3
			Th/R/L	4
			L	5
			Th/R	6

Phase Sketches   Phase Sketches



Checked by: WU/SS
Comments: Test #1 field data sheets

# of Phases: __4__ Signal Cycle (sec.) __73-150__ **Total Cycles** __20__
Time Started: __4:10__ Time Ended: __5:06__ **Test #** __1__

Sensor Code: Video B Site 12S

MDOT PROJECT: TRAFFIC SIGNAL VEHICLE DETECTION / UM CAIT

City: **Biloxi** Signal Section: N / C / **S** District: **6** Road: **US90** Intersection: **Porter Ave.** **Test** # **1**

# of Phases: **4** Signal Cycle (sec.): **73/89** **Cycles: 21** Date: **8/17/2017** Time Started: **4:25** Time Ended: **5:06**

Cycle #	Veh. Movt Th/ R /L	**Signal Phase # (sec.)**	Road Vehicle Detection	Signal Vehicle Detection					
				Dropped	Missed	FALSE	Locked	Other	Total
# 1	L	1							
	Th / R	2							
	Th/R/L	3							
	Th/R/L	4							
	L	5							
	Th/R	6							
# 2	L	1							
	Th / R	2							
	Th/R/L	3							
	Th/R/L	4							
	L	5							
	Th/R	6							
# 3	L	1							
	Th / R	2							
	Th/R/L	3							
	Th/R/L	4							
	L	5							
	Th/R	6							
# 4	L	1							
	Th / R	2							
	Th/R/L	3							
	Th/R/L	4							
	L	5							
	Th/R	6							
# 5	L	1							
	Th / R	2							
	Th/R/L	3							
	Th/R/L	4							
	L	5							
	Th/R	6							
# 6	L	1							
	Th / R	2							
	Th/R/L	3							
	Th/R/L	4							
	L	5							
	Th/R	6							
#	L	1							
	Th / R	2							
	Th/R/L	3							

7	Th/R/L	4							
	L	5							
	Th/R	6							
# 8	L	1							
	Th / R	2							
	Th/R/L	3							
	Th/R/L	4							
	L	5							
	Th/R	6							
# 9	L	1							
	Th / R	2							
	Th/R/L	3							
	Th/R/L	4							
	L	5							
	Th/R	6							
# 10	L	1							
	Th / R	2							
	Th/R/L	3							
	Th/R/L	4							
	L	5							
	Th/R	6							
# 11	L	1							
	Th / R	2							
	Th/R/L	3							
	Th/R/L	4							
	L	5							
	Th/R	6							
# 12	L	1							
	Th / R	2							
	Th/R/L	3							
	Th/R/L	4							
	L	5							
	Th/R	6							
# 13	L	1							
	Th / R	2							
	Th/R/L	3							
	Th/R/L	4							
	L	5							
	Th/R	6							
# 14	L	1							
	Th / R	2							
	Th/R/L	3							
	Th/R/L	4							
	L	5							
	Th/R	6							
#	L	1							
	Th / R	2							

# 15	Th/R/L	3							
	Th/R/L	4							
	L	5							
	Th/R	6							
# 16	L	1							
	Th / R	2							
	Th/R/L	3							
	Th/R/L	4							
	L	5							
	Th/R	6							
# 17	L	1							
	Th / R	2							
	Th/R/L	3							
	Th/R/L	4							
	L	5							
	Th/R	6							
# 18	L	1							
	Th / R	2							
	Th/R/L	3							
	Th/R/L	4							
	L	5							
	Th/R	6							
# 19	L	1							
	Th / R	2							
	Th/R/L	3							
	Th/R/L	4							
	L	5							
	Th/R	6							
# 20	L	1							
	Th / R	2							
	Th/R/L	3							
	Th/R/L	4							
	L	5							
	Th/R	6							
Totals				0	0	0	0	0	0
Percent Signal Det.									

Sensor Code: Video B   Site 12S

MDOT PROJECT: TRAFFIC SIGNAL VEHICLE DETECTION / UM CAIT

City: **Biloxi** Signal Section: N / C / **S** District: **6** Road: **US90** Intersection: **Porter Ave.** **Test # 1**

# of Phases: **4** Signal Cycle (sec.): **82** **Cycles: 21** Date: **8/17/2017** Time Started: **5:02** Time Ended: **5:06**

Cycle #	Veh. Movt Th/ R /L	Signal Phase # (sec.)	Road Vehicle Detection	Signal Vehicle Detection				
				Dropped	Missed	FALSE	Locked	Total
# 21		1	0					0
		2	22					22
		3	0					0
		4	13					13
		4C	3					3
		5	1					
		6	30					
		--						0
		--						0
		--						0
	Totals		69	0	0	0	0	69
	Percent Signal Det.							

Sensor Code: Radar/Video RV   Site 3N

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MDOT PROJECT: TRAFFIC SIGNAL DETECTION

Road / Intersection Information	Signal Sensor Information	Data Location Information:
City: **Tupelo**	Sensor Type: **Radar/Video RV**	Date Collected:**12/12/2017** **Test #1**
Road Classification: **Major**	No. of Sensors: **4**	Site: **3N**
		Collected By: **CAIT**
Road Name:**Coley Road/I-22 & US 78**	Location: Ground / **Pole** /	Signal Region: **N** / C / S District: **2**
Intersection Type: **Signal** /	[redacted]	Weather: **Clear** / Cloudy / Rainy / Foggy Other (Specify):____________

Air Temperature:_________°F

Intersection Location: Coley Road   No. of Legs: 3 / **4** / 5 / 6 Center GPS Coordinates:________N,_________W

Lat:34.306579°   **Lo.: -88.769197°**

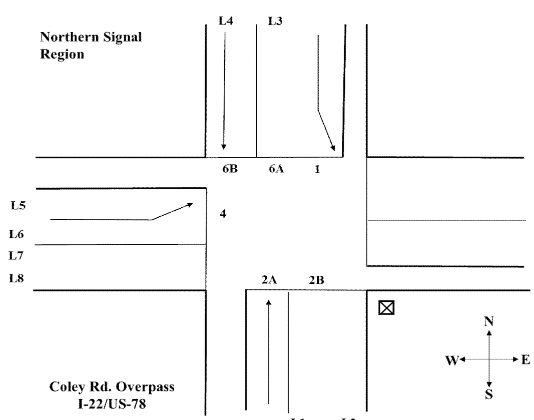
Image Information: ITS Panel / **Photo Onsite** / Google Earth   Date: **12/12/2017**   Road Section Image

N

Lane	Lane Width (m)	Road Direc-tion	Veh. Movement Type Th / R/ L	Signal Phase # (sec.)
			L	1
			Th	2
				3
			L/R	4
				5
			TH	6

Phase Sketches

Phase Sketches



Checked by:WU/SS
Comments: Test #1 field data sheets

# of Phases:_4_ Signal Cylce (sec.)_25-37_ **Total Cylces:_20_**
Time Started: **11:08**   Time Ended:_**11:25**_   **Test #** ___**1**___

Sensor Code: Radar/Video RV Site 3N

MDOT PROJECT: TRAFFIC SIGNAL VEHICLE DETECTION / UM CAIT

City: **Tupelo** Signal Section: **N** / C / S District: **1** Road: **Coley Road/I-22/US 78** Intersection:___________ **Test** #1

# of Phases: **4** Signal Cycle (sec.): **27** **Cycles: 20** Date: **12/12/2017** Time Started: **11:08** Time Ended: **11:25**

Cycle #	Veh. Movt Th/ R /L	Signal Phase # (sec.)	Road Vehicle Detection	Signal Vehicle Detection					
				Dropped	Missed	FALSE	Locked	Other	Total
# 1	L	1							
	Adv. TH	2							
		3							
	R/L	4							
	Th/L	5							
	Adv. TH	6							
# 2	L	1							
	Adv. TH	2							
		3							
	R/L	4							
	Th/L	5							
	Adv. TH	6							
# 3	L	1							
	Adv. TH	2							
		3							
	R/L	4							
	Th/L	5							
	Adv. TH	6							
# 4	L	1							
	Adv. TH	2							
		3							
	R/L	4							
	Th/L	5							
	Adv. TH	6							
# 5	L	1							
	Adv. TH	2							
		3							
	R/L	4							
	Th/L	5							
	Adv. TH	6							
# 6	L	1							
	Adv. TH	2							
		3							
	R/L	4							
	Th/L	5							
	Adv. TH	6							
#	L	1							
	Adv. TH	2							
		3							

7	R/L	4							
	Th/L	5							
	Adv. TH	6							
# 8	L	1							
	Adv. TH	2							
		3							
	R/L	4							
	Th/L	5							
	Adv. TH	6							
# 9	L	1							
	Adv. TH	2							
		3							
	R/L	4							
	Th/L	5							
	Adv. TH	6							
# 10	L	1							
	Adv. TH	2							
		3							
	R/L	4							
	Th/L	5							
	Adv. TH	6							
# 11	L	1							
	Adv. TH	2							
		3							
	R/L	4							
	Th/L	5							
	Adv. TH	6							
# 12	L	1							
	Adv. TH	2							
		3							
	R/L	4							
	Th/L	5							
	Adv. TH	6							
# 13	L	1							
	Adv. TH	2							
		3							
	R/L	4							
	Th/L	5							
	Adv. TH	6							
# 14	L	1							
	Adv. TH	2							
		3							
	R/L	4							
	Th/L	5							
	Adv. TH	6							
#	L	1							
	Adv. TH	2							

# 15		3							
	R/L	4							
	Th/L	5							
	Adv. TH	6							
# 16	L	1							
	Adv. TH	2							
		3							
	R/L	4							
	Th/L	5							
	Adv. TH	6							
# 17	L	1							
	Adv. TH	2							
		3							
	R/L	4							
	Th/L	5							
	Adv. TH	6							
# 18	L	1							
	Adv. TH	2							
		3							
	R/L	4							
	Th/L	5							
	Adv. TH	6							
# 19	L	1							
	Adv. TH	2							
		3							
	R/L	4							
	Th/L	5							
	Adv. TH	6							
# 20	L	1							
	Adv. TH	2							
		3							
	R/L	4							
	Th/L	5							
	Adv. TH	6							
	Totals			0	0	0	0	0	0
	Percent Signal Det.								

Sensor Code: Radar/Video RV Site 3N

MDOT PROJECT: TRAFFIC SIGNAL VEHICLE DETECTION / UM CAIT

City: **Tupelo** Signal Section: **N** / C / S District: **1** Road: **Coley Road/I-22/US 78** Intersection:___________ **Test** #1

# of Phases: **4** Signal Cycle (sec.): **27** **Cycles: 21** Date: **12/12/2017** Time Started: **11:08** Time Ended: **11:25**

Cycle #	Veh. Movt Th/ R /L	**Signal Phase # (sec.)**	Road Vehicle Counts	Signal Vehicle Counts				
				Dropped	Missed	FALSE	Locked	Total
# 21		1	1					
		2	0					
		3						
		4	2					
		5						
		6	4					
		7						
		8						
	Totals		7					
	Percent Signal Det.							

Sensor Code: Video A Site 5N

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MDOT PROJECT: TRAFFIC SIGNAL DETECTION

Road / Intersection Information	Signal Sensor Information	Data Location Information:
City: **Horn Lake (Desoto County)**	Sensor Type: **Video**	
		Date Collected:**11/10/2018** **Test #2**
Road Classification: **Arterial**	No. of Sensors: **4**	Site: **5N**
	(4 Advanced, 4 Magnetic)	Collected By: **Amanda Clark**
Road Name:**MS 302 / Horn Lake Rd**	Location: Ground / **Pole** /	Signal Region: **N** / C / S District: **2**
Intersection Type: **Signal** /	[redacted]	Weather: **Clear** / Cloudy / Rainy / Foggy Other (Specify):_**Windy**_

Air Temperature:___**45**___°F

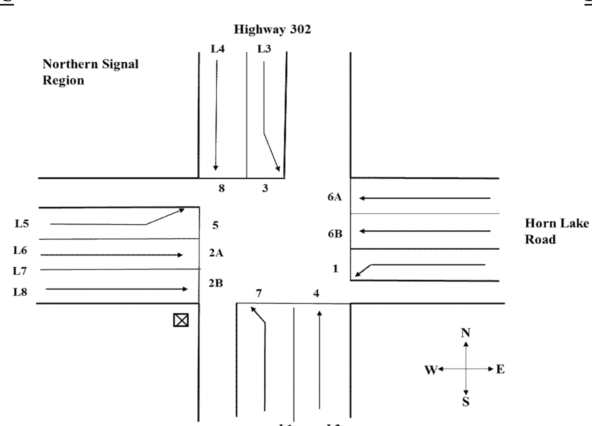
Intersection Location: MS302 No. of Legs: 3 / **4** / 5 / 6 Center GPS Coordinates:________N,_________W

Lat:34.962489° **Long. -90.061022°**

Image Information: ITS Panel / **Photo Onsite** / Google Earth Date: **12/12/2017** Road Section Image **N**

Lane	Lane Width (*m*)	Road Direc-tion	Veh. Movement Type Th / R/ L	Signal Phase # (sec.)
			L	1
			Th/R	2
			L	3
			Th/R	4
			L	5
			TH/R	6
			L	7
			TH/R	8

Phase Sketches Phase Sketches



Checked by: WU/SS
Comments: MDOT Test #2 field data sheets

# of Phases:_**8**_ Signal Cycle (sec.)_**120**_ **Total Cycles:_20_**
Time Started**: 11:10** Time Ended:_**11:45**_ **Test # 2**
Test #2 Cycle 21 Vehicle Data Counts Not Used **Page 1**

Sensor Code: Video A   Site 5N

MDOT PROJECT: TRAFFIC SIGNAL VEHICLE DETECTION / UM CAIT

City: **_Horn Lake_** Signal Section: **N** / C / S District: **2** Road: **MS 302 / Horn Lake Rd** Intersection:___________ **Test #2**

# of Phases: **8** Signal Cycle (sec.): **120** **Cycles: 20** Date: **11/10/2018** Time Started: **11:10** Time Ended: **11:45**

Cycle #	Veh. Movt Th/ R /L	Signal Phase # (sec.)	Road Vehicle Detection	Signal Vehicle Detection					
				Dropped	Missed	FALSE	Locked	Other	Total
# 1	L	1							
	Th/L	3							
	Th/R	4							
	L	5							
	Th/L	7							
	TH/R	8							
# 2	L	1							
	Th/L	3							
	Th/R	4							
	L	5							
	Th/L	7							
	TH/R	8							
# 3	L	1							
	Th/L	3							
	Th/R	4							
	L	5							
	Th/L	7		1					
	TH/R	8							
# 4	L	1							
	Th/L	3				1			
	Th/R	4							
	L	5							
	Th/L	7		1					
	TH/R	8							
# 5	L	1							
	Th/L	3							
	Th/R	4							
	L	5		1					
	Th/L	7							
	TH/R	8							
# 6	L	1							
	Th/L	3							
	Th/R	4							
	L	5							
	Th/L	7							
	TH/R	8							
#	L	1							
	Th/L	3							
	Th/R	4							

7	L	5							
	Th/L	7							
	TH/R	8							
	L	1							
	Th/L	3							
#	Th/R	4							
8	L	5							
	Th/L	7							
	TH/R	8							
	L	1							
	Th/L	3				1			
#	Th/R	4							
9	L	5							
	Th/L	7							
	TH/R	8							
	L	1					1		
	Th/L	3							
#	Th/R	4							
10	L	5							
	Th/L	7							
	TH/R	8							
	L	1							
	Th/L	3					1		
#	Th/R	4							
11	L	5							
	Th/L	7							
	TH/R	8							
	L	1							
	Th/L	3					1		
#	Th/R	4							
12	L	5							
	Th/L	7							
	TH/R	8							
	L	1							
	Th/L	3					1		
#	Th/R	4							
13	L	5							
	Th/L	7							
	TH/R	8							
	L	1							
	Th/L	3					1		
#	Th/R	4							
14	L	5							
	Th/L	7							
	TH/R	8							
	L	1							
	Th/L	3					1		

# 15	Th/R	4							
	L	5							
	Th/L	7							
	TH/R	8							
# 16	L	1							
	Th/L	3					1		
	Th/R	4							
	L	5							
	Th/L	7							
	TH/R	8							
# 17	L	1							
	Th/L	3					1		
	Th/R	4							
	L	5							
	Th/L	7							
	TH/R	8							
# 18	L	1		1					
	Th/L	3					1		
	Th/R	4							
	L	5							
	Th/L	7							
	TH/R	8							
# 19	L	1							
	Th/L	3							
	Th/R	4							
	L	5							
	Th/L	7							
	TH/R	8							
# 20	L	1							
	Th/L	3							
	Th/R	4							
	L	5							
	Th/L	7							
	TH/R	8							
	Totals			4	0	2	9	0	15
	Percent Signal Det.								

Sensor Code: Video A   Site 5N

MDOT PROJECT: TRAFFIC SIGNAL VEHICLE DETECTION / UM CAIT

Test 2 Cycle 21 Vehicle Counts Data Collected on 11/10/2018 Not Used

City: **Horn Lake** Signal Section: N / C / S District: **2** Road: **MS 302 / Horn Lake Rd** Intersection:___________ **Test** #1

# of Phases: **8** Signal Cycle (sec.): **120** **Cycles: 21** Date: **11/10/2018** Time Started: **11:10** Time Ended: **11:45**

Cycle #	Veh. Movt Th/ R /L	**Signal Phase # (sec.)**	Road Vehicle Counts	Signal Vehicle Counts				
				Dropped	Missed	FALSE	Locked	Total
# 21		1	6					
		2	21					
		3	12					
		4	12					
		5	5					
		6	33					
		7	4					
		8	10					
Totals			103					
Percent Signal Det.								

APPENDIX B

Interview Responses of Mississippi DOT Traffic Signal Engineers

MDOT SS282: Traffic Signal Vehicle Detection, One Size Does Not Fit All

Sensor Code: In-Pavement P1 [redacted]

	Interview Questions	MDOT Traffic Signal Engineers' Response
1	Vehicle Detection Sensor Type	Magnetic
2	Sensor System Reliability (1 to 5) (1 Best; 2 Good; 3 Fair; 4 Poor; 5 Worst)	4
3	RF Signal Interference (Y,N)	Y
4	Weather Impacts	Prolonged exposure to heat reduces the battery life, moisture into the repeater and lightning damage (burned up some access point in the cabinet)
5	Location of Installation at Intersection	In-Pavement and On-pole
6	Traffic Disruption During Checking for Malfunction and/or Maintenance (Y,N, Potential)	Potential
7	Signal System Vendor Support Quality (1 to 5) (1 Best; 2 Good; 3 Fair; 4 Poor; 5 Worst)	1
8	Maintenance Frequency (times in ? years)	24 times per year
9	Average Life Expectancy of Sensor System (years)	3 to 5 Years
10	Initial Cost of System (typical), $	10 and 11 combined cost of system and installation $40,000
11	Initial Cost of Installation (typical), $	
12	Average Annual Maintenance Cost, $	$500 x 24 = $12,000
13	Number of Sites Operating Sensor Systems (Mississippi DOT)	65
14	Overall Satisfaction of Traffic Signal Engineers (1 to 5) (1 Best; 2 Good; 3 Fair; 4 Poor; 5 Worst)	4
15	Other Comments	Stopped installing this. Replacing them as well. Will not be installed in future.

MDOT SS282: Traffic Signal Vehicle Detection, One Size Does Not Fit All

Sensor Code: Radar/Video RV [redacted]

	Interview Questions	MDOT Traffic Signal Engineers' Response
1	Vehicle Detection Sensor Type	Video Radar (Advanced)
2	Sensor System Reliability (1 to 5) (1 Best; 2 Good; 3 Fair; 4 Poor; 5 Worst)	2
3	RF Signal Interference (Y,N)	N
4	Weather Impacts	Heavy rain, sun glare, fog, snow, and lightning
5	Location of Installation at Intersection	Pole. Arm (Mast)
6	Traffic Disruption During Checking for Malfunction and/or Maintenance (Y,N, Potential)	Potential
7	Signal System Vendor Support Quality (1 to 5) (1 Best; 2 Good; 3 Fair; 4 Poor; 5 Worst)	1
8	Maintenance Frequency (times in ? years)	2 times per year
9	Average Life Expectancy of Sensor System (years)	6 + (Since 2013 no failure)
10	Initial Cost of System (typical), $	10 and 11 combined cost of system and installation $36,000
11	Initial Cost of Installation (typical), $	
12	Average Annual Maintenance Cost, $	$500 x 2 = $1,000
13	Number of Sites Operating Sensor Systems (Mississippi DOT)	20
14	Overall Satisfaction of Traffic Signal Engineers (1 to 5) (1 Best; 2 Good; 3 Fair; 4 Poor; 5 Worst)	2
15	Other Comments	If it can't see, gives false call. Radar (advanced function) occasionally gives missed call.

MDOT SS282: Traffic Signal Vehicle Detection, One Size Does Not Fit All

Sensor Code: Radar R1 [redacted]

	Interview Questions	MDOT Traffic Signal Engineers' Response
1	Vehicle Detection Sensor Type	Radar
2	Sensor System Reliability (1 to 5) (1 Best; 2 Good; 3 Fair; 4 Poor; 5 Worst)	5
3	RF Signal Interference (Y,N)	Y
4	Weather Impacts	Heavy Rain (2-3 inch rain)
5	Location of Installation at Intersection	Pole (stable). Arm. Work best on the pole.
6	Traffic Disruption During Checking for Malfunction and/or Maintenance (Y,N, Potential)	Potential
7	Signal System Vendor Support Quality (1 to 5) (1 Best; 2 Good; 3 Fair; 4 Poor; 5 Worst)	3
8	Maintenance Frequency (times in ? years)	30 times per year
9	Average Life Expectancy of Sensor System (years)	2 Years
10	Initial Cost of System (typical), $	10 and 11 combined cost of system and installation $24,000
11	Initial Cost of Installation (typical), $	
12	Average Annual Maintenance Cost, $	$500 x 30 = $15,000
13	Number of Sites Operating Sensor Systems (Mississippi DOT)	20
14	Overall Satisfaction of Traffic Signal Engineers (1 to 5) (1 Best; 2 Good; 3 Fair; 4 Poor; 5 Worst)	5
15	Other Comments	No longer used in Mississippi. No new installation. Old one will be replaced.

MDOT SS282: Traffic Signal Vehicle Detection, One Size Does Not Fit All

Sensor Code: Radar R2 [redacted]

	Interview Questions	MDOT Traffic Signal Engineers' Response
1	Vehicle Detection Sensor Type	Radar
2	Sensor System Reliability (1 to 5) (1 Best; 2 Good; 3 Fair; 4 Poor; 5 Worst)	1
3	RF Signal Interference (Y,N)	Y
4	Weather Impacts	Heavy Rain
5	Location of Installation at Intersection	Pole (Typical). Arm (Mast)
6	Traffic Disruption During Checking for Malfunction and/or Maintenance (Y,N, Potential)	Potential
7	Signal System Vendor Support Quality (1 to 5) (1 Best; 2 Good; 3 Fair; 4 Poor; 5 Worst)	3
8	Maintenance Frequency (times in ? years)	1
9	Average Life Expectancy of Sensor System (years)	7+ (2012 to Present)
10	Initial Cost of System (typical), $	10 and 11 combined cost of system and installation $30,000
11	Initial Cost of Installation (typical), $	
12	Average Annual Maintenance Cost, $	$500 x 1 = $500
13	Number of Sites Operating Sensor Systems (Mississippi DOT)	75
14	Overall Satisfaction of Traffic Signal Engineers (1 to 5) (1 Best; 2 Good; 3 Fair; 4 Poor; 5 Worst)	1
15	Other Comments	No comments

MDOT SS282: Traffic Signal Vehicle Detection, One Size Does Not Fit All

Sensor Code: Video A [redacted]

	Interview Questions	MDOT Traffic Signal Engineers' Response
1	Vehicle Detection Sensor Type	Video
2	Sensor System Reliability (1 to 5) (1 Best; 2 Good; 3 Fair; 4 Poor; 5 Worst)	2
3	RF Signal Interference (Y,N)	N
4	Weather Impacts	Rain, Fog, Sun glare, Shadows, Snow, and Lightning
5	Location of Installation at Intersection	Arm/ Span Arm
6	Traffic Disruption During Checking for Malfunction and/or Maintenance (Y,N, Potential)	Potential
7	Signal System Vendor Support Quality (1 to 5) (1 Best; 2 Good; 3 Fair; 4 Poor; 5 Worst)	1
8	Maintenance Frequency (times in ? years)	2 times per year
9	Average Life Expectancy of Sensor System (years)	10+ Years
10	Initial Cost of System (typical), $	10 and 11 combined cost of system and installation $23,000
11	Initial Cost of Installation (typical), $	
12	Average Annual Maintenance Cost, $	$500 x 2 = $1,000
13	Number of Sites Operating Sensor Systems (Mississippi DOT)	70
14	Overall Satisfaction of Traffic Signal Engineers (1 to 5) (1 Best; 2 Good; 3 Fair; 4 Poor; 5 Worst)	2
15	Other Comments	Good experience, good support. In East-West direction, they got problem with glare. Have to find another alternative for this. Shadows (needs good intersection lighting)

Sensor Code: Video B [redacted]

	Interview Questions	MDOT Traffic Signal Engineers' Response
1	Vehicle Detection Sensor Type	Video
2	Sensor System Reliability (1 to 5) (1 Best; 2 Good; 3 Fair; 4 Poor; 5 Worst)	3
3	RF Signal Interference (Y,N)	N
4	Weather Impacts	Rain, Fog, Sun glare, Shadows, and Lightning for sandy soil.
5	Location of Installation at Intersection	Arm
6	Traffic Disruption During Checking for Malfunction and/or Maintenance (Y,N, Potential)	Potential
7	Signal System Vendor Support Quality (1 to 5) (1 Best; 2 Good; 3 Fair; 4 Poor; 5 Worst)	3
8	Maintenance Frequency (times in ? years)	4 times per year
9	Average Life Expectancy of Sensor System (years)	Approximately 10 Years
10	Initial Cost of System (typical), $	10 and 11 combined cost of system and installation $35,000
11	Initial Cost of Installation (typical), $	
12	Average Annual Maintenance Cost, $	$500 x 4 = $2,000
13	Number of Sites Operating Sensor Systems (Mississippi DOT)	40
14	Overall Satisfaction of Traffic Signal Engineers (1 to 5) (1 Best; 2 Good; 3 Fair; 4 Poor; 5 Worst)	3
15	Other Comments	No longer supported. Needs salt cleaning in coastal environment. Shadows (needs good intersection lighting)

MDOT SS282: Traffic Signal Vehicle Detection, One Size Does Not Fit All

Sensor Code: Video C [redacted]

	Interview Questions	MDOT Traffic Signal Engineers' Response
1	Vehicle Detection Sensor Type	Video
2	Sensor System Reliability (1 Best; 2 Good; 3 Fair; 4 Poor; 5 Worst)	1
3	RF Signal Interference (Y,N)	N
4	Weather Impacts	Rain, Fog, Sun glare, Shadows, Snow, and, Lightning
5	Location of Installation at Intersection	Arm/Pole
6	Traffic Disruption During Checking for Malfunction and/or Maintenance (Y,N, Potential)	Potential
7	Signal System Vendor Support Quality (1 Best; 2 Good; 3 Fair; 4 Poor; 5 Worst)	1
8	Maintenance Frequency (times in ? years)	Less than 1 time per year
9	Average Life Expectancy of Sensor System (years)	6+ Years
10	Initial Cost of System (typical), $	10 and 11 combined cost of system and installation $26,000
11	Initial Cost of Installation (typical), $	
12	Average Annual Maintenance Cost, $	Less than $500 per year
13	Number of Sites Operating Sensor Systems	4
14	Overall Satisfaction of Traffic Signal Engineers (1 to 5) (1 Best; 2 Good; 3 Fair; 4 Poor; 5 Worst)	1
15	Other Comments	It's limited to small intersection. It is good for cities. Alternative for video-vantage. Shadows (needs good intersection lighting)

MDOT SS282: Traffic Signal Vehicle Detection, One Size Does Not Fit All

Sensor Code: Video D [redacted]

	Interview Questions	MDOT Traffic Signal Engineers' Response
1	Vehicle Detection Sensor Type	Video
2	Sensor System Reliability (1 to 5) (1 Best; 2 Good; 3 Fair; 4 Poor; 5 Worst)	4
3	RF Signal Interference (Y,N)	N
4	Weather Impacts	Wind, Rain, Fog, Sun glare, Shadows, Snow, and, Lightning
5	Location of Installation at Intersection	Span (Cable)
6	Traffic Disruption During Checking for Malfunction and/or Maintenance (Y,N, Potential)	Potential
7	Signal System Vendor Support Quality (1 to 5) (1 Best; 2 Good; 3 Fair; 4 Poor; 5 Worst)	1
8	Maintenance Frequency (times in ? years)	12 times per year
9	Average Life Expectancy of Sensor System (years)	3+ Years
10	Initial Cost of System (typical), $	10 and 11 combined cost of system and installation $27,000
11	Initial Cost of Installation (typical), $	
12	Average Annual Maintenance Cost, $	$500 x 12 = $6,000
13	Number of Sites Operating Sensor Systems (Mississippi DOT)	6
14	Overall Satisfaction of Traffic Signal Engineers (1 to 5) (1 Best; 2 Good; 3 Fair; 4 Poor; 5 Worst)	4
15	Other Comments	Bad for large intersection and windy condition. Wind effect functionality heavily. Heavily depends on stripping. Shadows (needs good intersection lighting)

MDOT SS282: Traffic Signal Vehicle Detection, One Size Does Not Fit All

Sensor Code: In-Pavement P2 [redacted]

	Interview Questions	MDOT Traffic Signal Engineers' Response
1	Vehicle Detection Sensor Type	Magnetic
2	Sensor System Reliability (1 to 5) (1 Best; 2 Good; 3 Fair; 4 Poor; 5 Worst)	1
3	RF Signal Interference (Y,N)	N
4	Weather Impacts	N
5	Location of Installation at Intersection	In-Pavement
6	Traffic Disruption During Checking for Malfunction and/or Maintenance (Y,N, Potential)	Potential (High)
7	Signal System Vendor Support Quality (1 to 5) (1 Best; 2 Good; 3 Fair; 4 Poor; 5 Worst)	Not applicable
8	Maintenance Frequency (times in ? years)	5 times per year
9	Average Life Expectancy of Sensor System (years)	6-8 years
10	Initial Cost of System (typical), $	10 and 11 combined cost of system and installation $21,000
11	Initial Cost of Installation (typical), $	
12	Average Annual Maintenance Cost, $	$500 x 5 = $2,500
13	Number of Sites Operating Sensor Systems (Mississippi DOT)	800
14	Overall Satisfaction of Traffic Signal Engineers (1 to 5) (1 Best; 2 Good; 3 Fair; 4 Poor; 5 Worst)	3
15	Other Comments	Depends on pavement condition. If pavement condition is good, it works best. If pavement condition is bad, it works badly.