Stantec

Traffic Signal Retiming Report & Traffic Signal Operations Assessment

Prepared For:
City of Charleston

July 2017

Traffic Signal Timing Report & Traffic Signal Operations Assessment

Northbridge, Savannah
Highway, Folly Road, and
East Bay Street Corridors in
Charleston, South Carolina

Prepared for:
City of Charleston

Stantec Consulting Services Inc.
4969 Centre Pointe Drive, Suite 200
North Charleston, SC 29418

JULY 2017

City of Charleston
South Carolina

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Mayor

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Robert Somerville
Assistant Director of Traffic & Transportation

Troy Mitchell
Traffic Signal Systems Manager

Michael Mathis
Transportation Project Manager

Prepared by:
Stantec Consulting Services Inc.
in association with
Kimley-Horn and Associates, Inc.

July 2017

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1.0 EXECUTIVE SUMMARY

Stantec Consulting Services Inc. (Stantec), in association with Kimley-Horn and Associates, Inc. (Kimley-Horn), was retained by the City of Charleston (City) to develop and implement new coordinated signal timings for sixty-four (64) intersections along and near four (4) major corridors within the City:

- Eight (8) signals along and near SC 7 (Sam Rittenberg Boulevard) & SC 171 (Old Towne Road) in the Northbridge area of West Ashley;
- Twenty-two (22) signals along and near US 17 (Savannah Highway) in West Ashley;
- Twenty (20) signals along and near SC 171 (Folly Road) on James Island; and
- Fourteen (14) signals along East Bay Street on the Cooper River side of the peninsula.

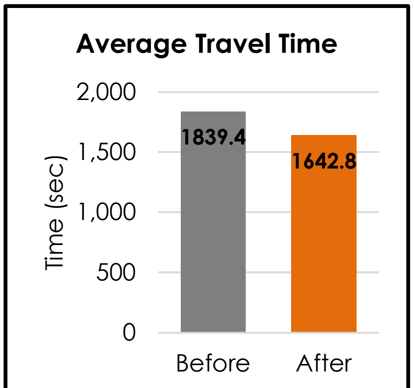
The City's current traffic signal timing plans were last updated in 2008/2009 and are now beyond their intended lifespan, which adversely impacts motorists through increased number of stops, longer delays per stop, and excessive fuel consumption and pollutant emissions.

As an additional task in this project, the City asked Stantec to evaluate its current traffic signal system and make recommendations as to whether other types of signal control would be more appropriate for more efficiently moving traffic. Related to that task, Stantec also evaluated the City's current Traffic Signal Control Center (TSCC) and provided recommendations based upon analysis of comparable peer cities.

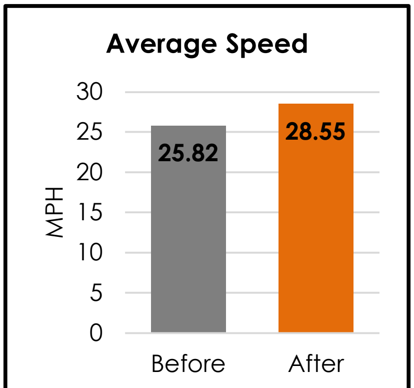
1.1 TRAFFIC SIGNAL RETIMING OVERVIEW

To determine the effectiveness of the new signal timing plans, travel time studies were performed using GPS for each corridor to evaluate and document the results of the plan development process. This report presents the results of the "before" and "after" studies that were conducted along the Northbridge, US 17 (Savannah Highway), and SC 171 (Folly Road) corridors. It was determined that the after study for the East Bay Street corridor was performed while nearby construction projects were ongoing and while a cruise ship was in port, which was not consistent with the conditions during the before runs. Due to these inconsistencies, the results of the study are inconclusive and an additional after study will be performed in the fall of 2017 to gather more information which will be documented at that time as an addendum to this report.

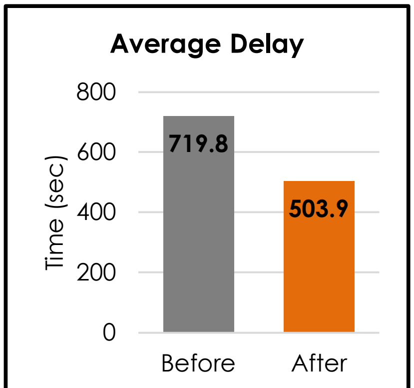
The travel time studies for the Northbridge, US 17 (Savannah Highway), and SC 171 (Folly Road) corridors were conducted on typical weekdays during three (3) time periods of the day: AM Peak (7:00-9:00), Midday (11:00-13:00), and PM Peak (16:00-18:00). The following charts show the cumulative average improvements in travel time, travel speed, delay, and emissions experienced along these corridors for both directions of travel during all three (3) time periods. Charts summarizing the detailed results by each corridor are presented in subsequent sections of this report.



10.69% Decrease



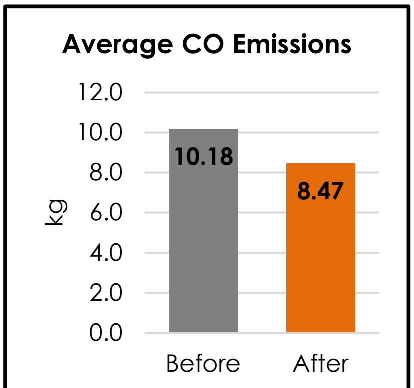
10.59% Increase



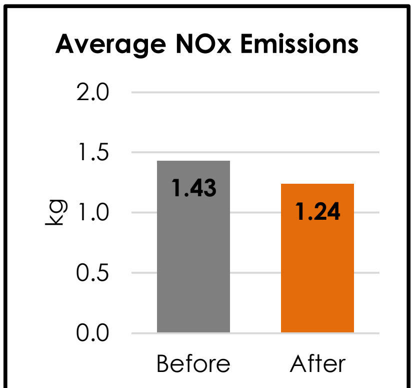
29.99% Decrease

As evident in the graphs above, improvements were shown in travel time, speed, and delay with consideration to the overall project.

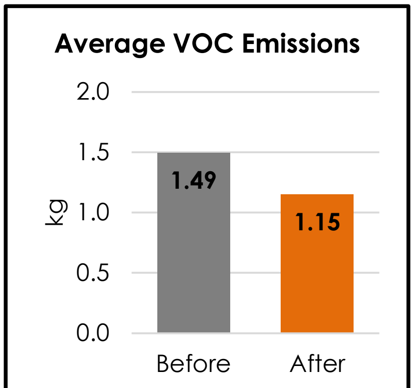
Carbon monoxide (CO), oxides of nitrogen (NOx), and volatile organic compounds (VOC) are three (3) types of vehicle emissions regulated by federal law. The following charts show the cumulative average reductions in emissions experienced along the Northbridge, US 17 (Savannah Highway), and SC 171 (Folly Road) corridors for both directions of travel during all three (3) time periods. Charts summarizing the detailed results by each corridor are presented in subsequent sections of this report.



16.79% Decrease



13.51% Decrease



22.84% Decrease

As evident in the graphs above, improvements were shown in the carbon monoxide, oxides of nitrogen, and volatile organic compound emissions with consideration to the overall project.

Delay incurs direct costs upon motorists in the form of increased fuel consumption and the value of their time wasted while waiting in traffic. Motorists using the project corridors during the AM, Midday, and PM peak periods will save an estimated 273,441 hours each year because of the improved traffic flow due to the new timing plans.

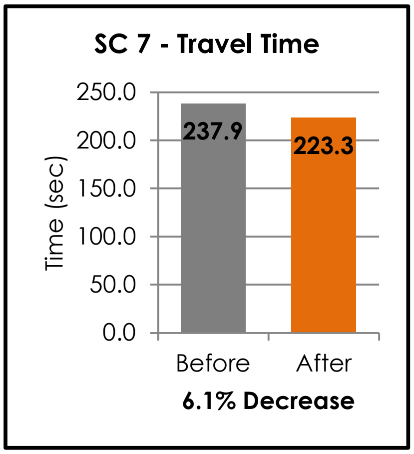
Conservatively assuming a vehicle occupancy of 1.2 persons/vehicle, $12.00 per hour for the value of motorist's time, and $2.34 per gallon for gasoline, annual savings to motorists will be an estimated $3,937,546 in the form of reduced delay and $31,644 decrease in cost due to decreased fuel consumption, for an estimated total annual savings of $3,969,190.

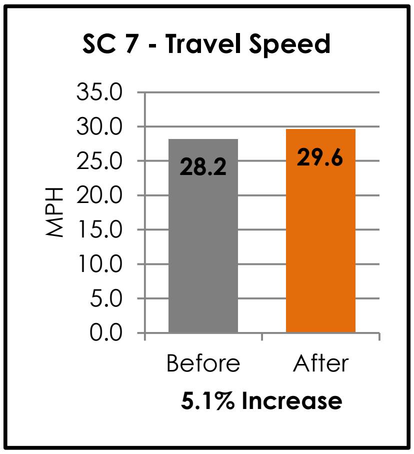
Based on equivalent annual cost of designing, implementing, and documenting signal timing plan improvements, the benefit to cost ratios for interest rates ranging from 4% to 8% were calculated to be between 44.7:1 and 47.3:1 for the overall project.

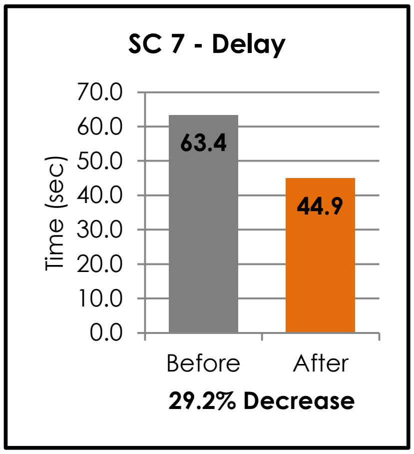
1.1.1 Northbridge Summary

The consultant team, under contract to the City of Charleston, recently completed a project to develop and implement new coordinated signal timings for eight (8) signals along and near SC 7 (Sam Rittenberg Boulevard) and SC 171 (Old Towne Road) in the City of Charleston, Charleston County, South Carolina. The five (5) signals along the SC 7 (Sam Rittenberg Boulevard) corridor are located between Ashley Hall Road to the southwest and Durham Place/Poston Road to the north. The five (5) signals along the SC 171 (Old Towne Road) corridor are located between Charlestowne Landing to the south and Durham Place/Poston Road to the north. New coordinated signal timings were also developed and implemented for the nearby Ashley Hall Road & Orange Grove Road intersection.

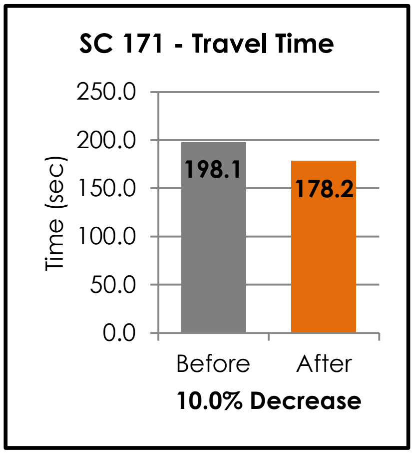
To determine the effectiveness of the new signal timing plans, travel time studies were performed using GPS for the SC 7 (Sam Rittenberg Boulevard) and SC 171 (Old Towne Road) corridors to evaluate and document the results of the timing plan development process. This report presents the results of the "before" and "after" studies that were conducted along the eight (8) intersections included in this project. The approximate lengths of the SC 7 (Sam Rittenberg Boulevard) and SC 171 (Old Towne Road) corridors are 1.8 miles and 1.4 miles, respectively. The travel time studies were conducted on typical weekdays during three (3) time periods of the day: AM Peak (7:00-9:00), Midday (11:00-13:00), and PM Peak (16:00-18:00). The following charts show the average improvements in travel time, travel speed, delay, and emissions experienced along SC 7 (Sam Rittenberg Boulevard) and SC 171 (Old Towne Road) for both directions of travel during all three (3) time periods. Charts summarizing the detailed results by each timing plan are presented in subsequent sections of this report.

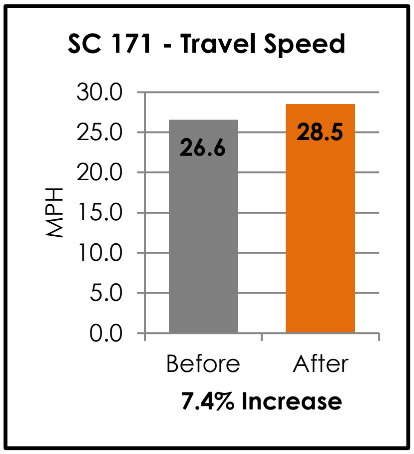


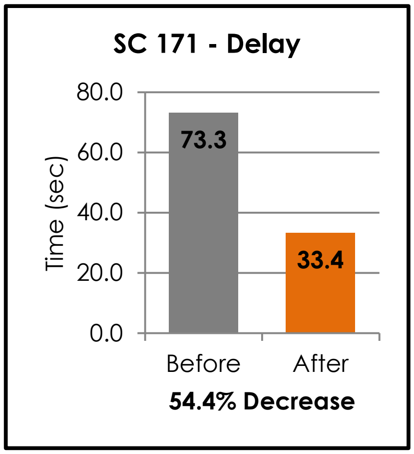




As evident in the graphs above, improvements were shown in travel time, speed, and delay for the SC 7 (Sam Rittenberg Boulevard) corridor.

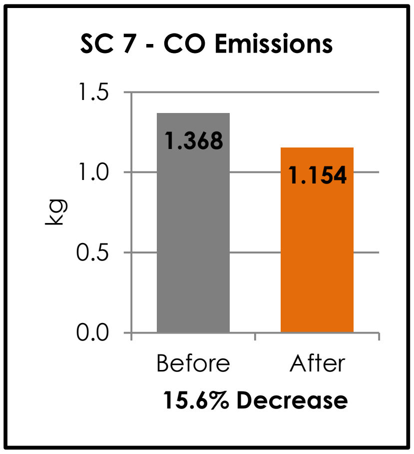


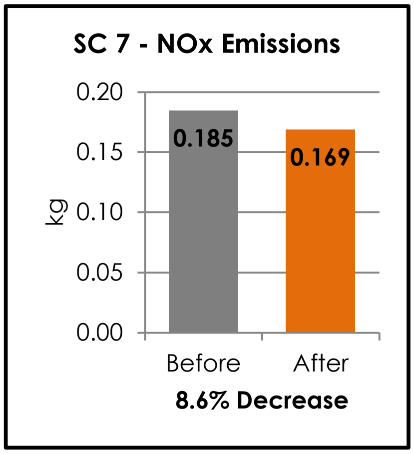


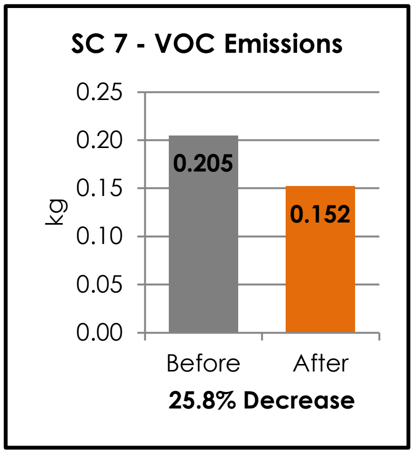


As evident in the graphs above, improvements were shown in travel time, speed, and delay for the SC 171 (Old Towne Road) corridor.

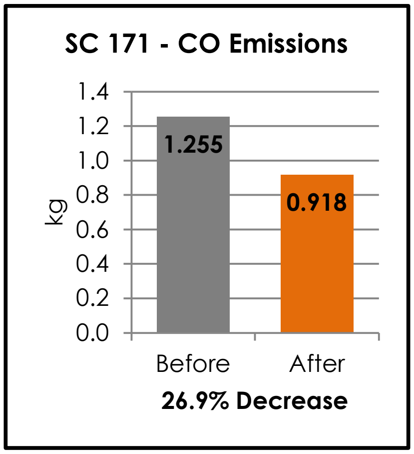
Carbon monoxide (CO), oxides of nitrogen (NOx), and volatile organic compounds (VOC) are three (3) types of vehicle emissions regulated by federal law. The following charts show the average improvements experienced along SC 7 (Sam Rittenberg Boulevard) and SC 171 (Old Towne Road) for both directions of travel during all three (3) time periods. Charts summarizing the detailed results by each timing plan are presented in subsequent sections of this report.

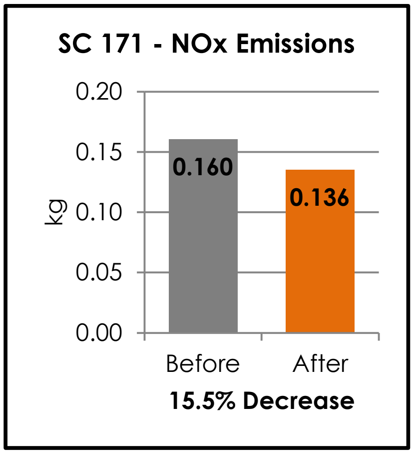


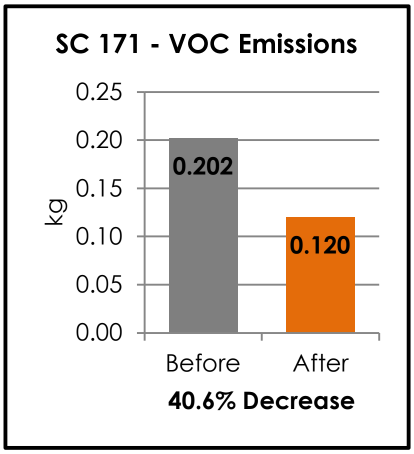




As evident in the graphs above, improvements were shown in the carbon monoxide, oxides of nitrogen, and volatile organic compound emissions along SC 7 (Sam Rittenberg Boulevard).







As evident in the graphs above, improvements were shown in the carbon monoxide, oxides of nitrogen, and volatile organic compound emissions along SC 171 (Old Towne Road).

Delay incurs direct costs upon motorists in the form of increased fuel consumption and the value of their time wasted while waiting in traffic. Motorists using SC 7 (Sam Rittenberg Boulevard) and SC 171 (Old Towne Road) during the AM, Midday, and PM peak periods will save an estimated 27,937 hours each year because of the improved traffic flow due to the new timing plans.

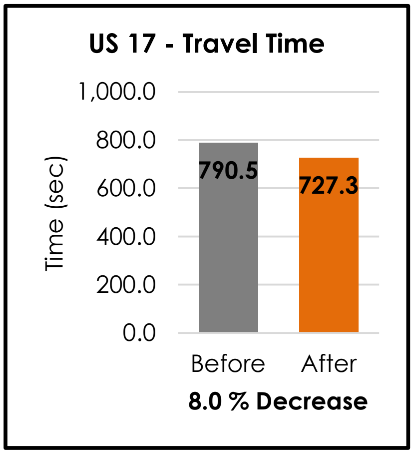
Conservatively assuming a vehicle occupancy of 1.2 persons/vehicle, $12.00 per hour for the value of motorists' time, and $2.34 per gallon for gasoline, annual savings to motorists along SC 7 (Sam Rittenberg Boulevard) and SC 171 (Old Towne Road) will be an estimated $402,289 in the form of reduced delay and $1,519 decrease in cost due to decreased fuel consumption, for an estimated total annual savings of $403,808.

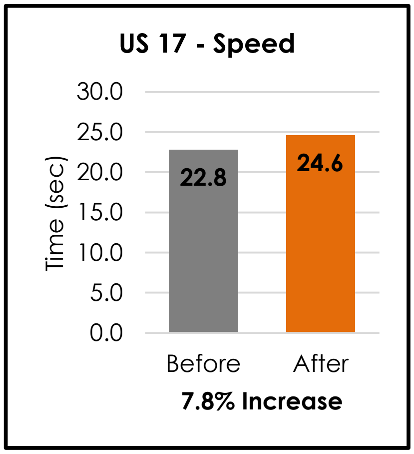
Based on equivalent annual cost of designing, implementing, and documenting signal timing plan improvements, the benefit to cost ratios for interest rates ranging from 4% to 8% were calculated to be between 21.8:1 and 23.0:1 for the SC 7 (Sam Rittenberg Boulevard) and SC 171 (Old Towne Road) corridors.

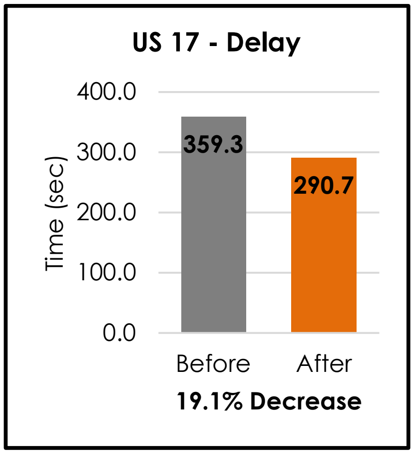
1.1.2 Savannah Highway Summary

The consultant team, under contract to the City of Charleston, recently completed a project to develop and implement new coordinated signal timings for twenty-two (22) signals along and surrounding US 17 (Savannah Highway) in the City of Charleston, Charleston County, South Carolina. The seventeen (17) signals along US 17 (Savannah Highway) are located between Dobbin Road to the west and Wesley Drive to the east. The remainder of the signals retimed in this area are along SC 7 (Sam Rittenberg Boulevard) and Orleans Road.

To determine the effectiveness of the new signal timing plans, travel time studies were performed using GPS for the seventeen (17) signals along the US 17 (Savannah Highway) corridor to review and document the results of the timing plan development process. This report presents the results of the "before" and "after" studies that were conducted along the seventeen (17) intersections included in this project. The length of the corridor is approximately 4.5 miles. The travel time studies were conducted on typical weekdays during three (3) time periods of the day: AM Peak (07:00-09:00), Midday (11:00-13:00), and PM Peak (16:00-18:00). The following charts show the average improvements experienced along US 17 (Savannah Highway) for both directions of travel during all three (3) time periods. Charts summarizing the detailed results by each timing plan are presented later in the report.

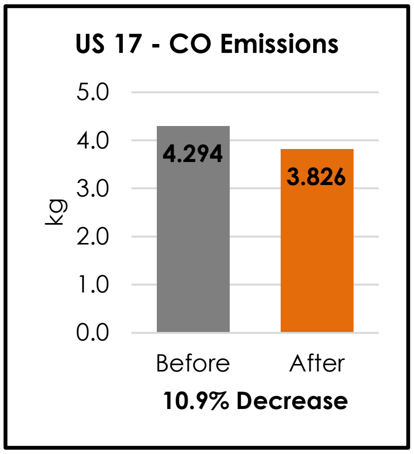


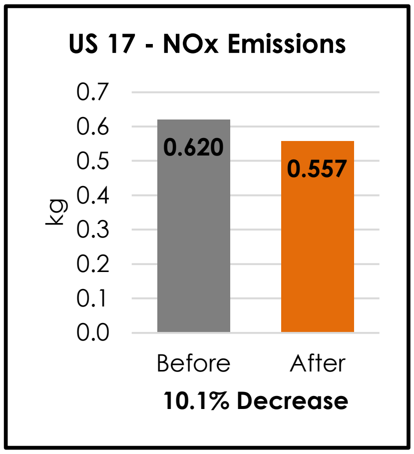


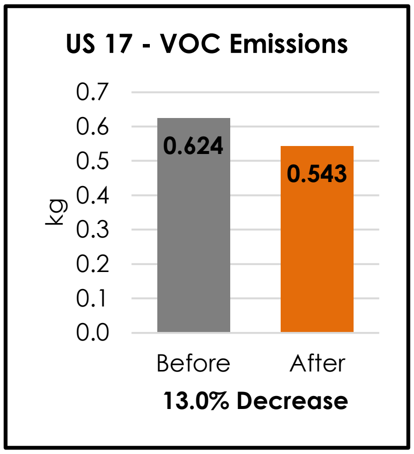


As shown in the graphs above, improvements were shown in travel time, delay and speed for the overall length of the US 17 (Savannah Highway) corridor.

Carbon monoxide (CO), oxides of nitrogen (NOx), and volatile organic compounds (VOC) are three (3) types of vehicle emissions regulated by federal law. The following charts show the improvements experienced along US 17 (Savannah Highway) for both directions of travel during all three (3) time periods. Charts summarizing the detailed results by each timing plan are present in subsequent sections of this report.







As shown in the graphs above, improvements were shown in the carbon monoxide, oxides of nitrogen, and volatile organic compound emissions as measured for the length of the US 17 (Savannah Highway) corridor.

Delay incurs direct costs upon motorists in the form of increased fuel consumption and the value of their time wasted while waiting in traffic. Motorists using US 17 (Savannah Highway) during the AM, Midday, and PM peak periods will save 98,878 hours each year because of the improved traffic flow due to the new timing plans.

Conservatively assuming a vehicle occupancy of 1.2 persons/vehicle, $12.00 per hour for the value of motorist's time, and $2.34 per gallon for gasoline, annual savings to motorists along US 17 (Savannah Highway) will be $1,423,843 in the form of reduced delay and $10,921 due to decreased fuel consumption, for a total annual savings of $1,434,764.

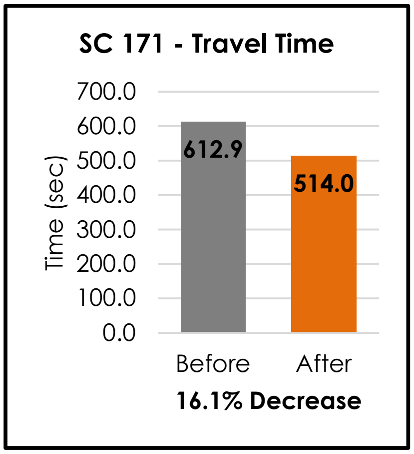
Other benefits not considered in this analysis include lower driver frustration levels and a potential reduction of accidents. All of the results mentioned in the report are for six (6) hours a day for each weekday during the AM, Midday, and PM peak periods, along US 17 (Savannah Highway). New signal timing plans were also implemented during off-peak and weekend hours. However, because benefit/cost "before" and "after" studies were not conducted during these time periods, additional savings could not be quantified during these periods.

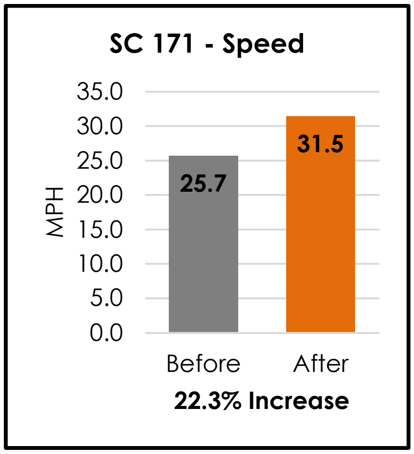
Based on equivalent annual cost of designing, implementing, and documenting signal timing plan improvements, the benefit to cost ratios for interest rates ranging from 4% to 8% were calculated to be between 37.0:1 and 39.2:1 for the US 17 (Savannah Highway) corridor.

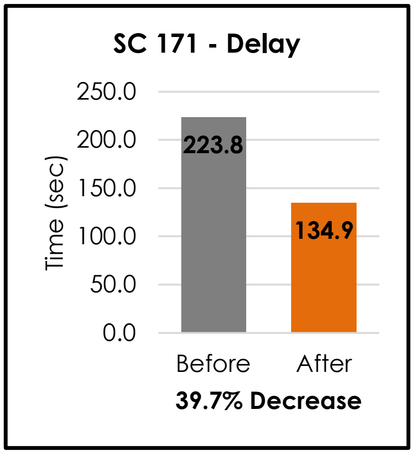
1.1.3 Folly Road Summary

The consultant team, under contract to the City of Charleston, recently completed a project to develop and implement new coordinated signal timings for twenty (20) signals along and surrounding SC 171 (Folly Road) in the City of Charleston, Charleston County, South Carolina. The thirteen (13) signals along the corridor are located between Grimball Road/Fort Johnson Road to the south and SC 171 (Wesley Drive)/SC 700 (Folly Road Boulevard) to the north. The remainder of the signals retimed in this area are along SC 700 (Maybank Highway), SC 700 (Folly Road Boulevard), and SC 61/Fielding Connector.

To determine the effectiveness of the new signal timing plans, travel time studies were performed using GPS for the thirteen (13) signals along the SC 171 (Folly Road) corridor to review and document the results of the timing plan development process. This report presents the results of the "before" and "after" studies that were conducted along the thirteen (13) intersections included in this project. The length of the corridor is approximately 4.5 miles. The travel time studies were conducted on typical weekdays during three (3) time periods of the day: AM Peak (07:00-09:00), Midday (11:00-13:00), and PM Peak (16:00-18:00). The following charts show the average improvements experienced along SC 171 (Folly Road) for both directions of travel during all three (3) time periods. Charts summarizing the detailed results by each timing plan are presented later in the report.

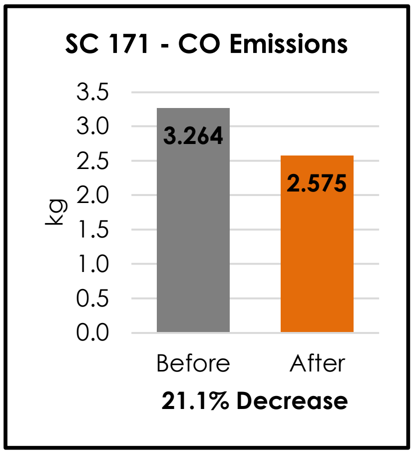


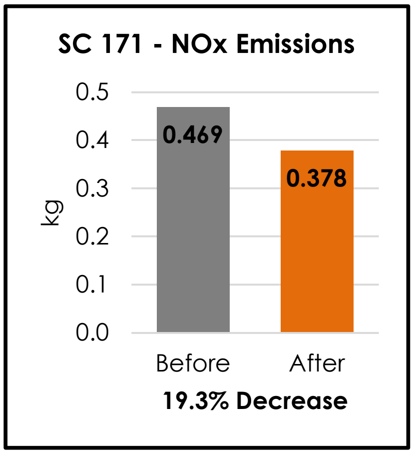


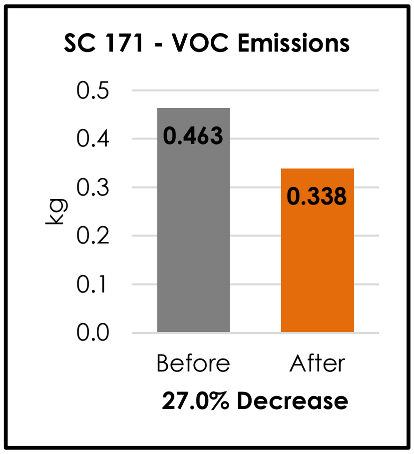


As evident in the graphs above, improvements were shown in travel time, delay and speed for the SC 171 (Folly Road) corridor.

Carbon monoxide (CO), oxides of nitrogen (NOx), and volatile organic compounds (VOC) are three (3) types of vehicle emissions regulated by federal law. The following charts show the average improvements experienced along SC 171 (Folly Road) for both directions of travel during all three (3) time periods. Charts summarizing the detailed results by each timing plan are present in subsequent sections of this report.







As evident in the graphs above, improvements were shown in the carbon monoxide, oxides of nitrogen, and volatile organic compound emissions along SC 171 (Folly Road).

Other benefits not considered in this analysis include lower driver frustration levels and a potential reduction of accidents. All of the improvements mentioned in the report are for six (6) hours a day for each weekday during the AM, Midday, and PM peak periods. New signal timing plans were also implemented during the off-peak and weekend hours. However, because benefit/cost "before" and "after" studies were not conducted during these time periods, additional savings could not be quantified during these periods.

Delay incurs direct costs upon motorists in the form of increased fuel consumption and the value of their time wasted while waiting in traffic. Motorists using SC 171 (Folly Road) during the AM, Midday, and PM peak periods will save 146,626 hours each year because of the improved traffic flow due to the new timing plans.

Conservatively assuming a vehicle occupancy of 1.2 persons/vehicle, $12.00 per hour for the value of motorists' time, and $2.34 per gallon for gasoline, annual savings to motorists along SC 171 (Folly Road) will be $2,111,414 in the form of reduced delay and $19,204 decrease in cost due to decreased fuel consumption, for a total annual savings of $2,130,618.

Based on equivalent annual cost of designing, implementing, and documenting signal timing plan improvements, the benefit to cost ratios for interest rates ranging from 4% to 8% were calculated to be between 67.7:1 and 71.6:1 for this project.

1.1.4 East Bay Street Summary

The consultant team, under contract to the City of Charleston, recently developed and implemented new coordinated signal timings for fourteen (14) signals along Mount Pleasant Street & Morrison Drive/East Bay Street in the City of Charleston, Charleston County, South Carolina. The fourteen (14) signals along the corridor are located between Broad Street to the south and King Street Extension to the north. For the purposes of this report, the fourteen (14) signal system will be referred to as the East Bay Street corridor.

To determine the effectiveness of the new signal timing plans, travel time studies were performed using GPS for the East Bay Street corridor to evaluate and document the results of the timing plan development process. This analysis evaluated the preliminary findings of the "before" and "after" studies that were conducted along the fourteen (14) intersections included in this project. The approximate length of the East Bay Street corridor is 3.0 miles. The travel time studies were conducted on weekdays during three (3) time periods of the day: AM Peak (7:00-9:00), Midday (11:00-13:00), and PM Peak (16:00-18:00).

Upon a closer review of both the before and after travel runs, the results did not indicate a positive increase in speed and reduction in stops and delays as was noted by the consultant team. It was determined that the after study was performed while nearby construction projects were ongoing and while a cruise ship was in port, which was not consistent with the conditions during the before runs. Due to these inconsistencies, the results of the comparative before and after study are inconclusive. An additional after study will be performed in the fall of 2017 to gather more information. If the additional after runs indicate positive results were achieved, these will be documented at that time and an addendum to this report will be submitted. If positive results are not indicated, additional retiming work will be performed until positive results are achieved.

1.2 SIGNAL SYSTEM AND OPERATIONS EVALUATION

1.2.1 Introduction & Purpose

The City of Charleston, South Carolina is experiencing rapid population and economic growth which is exerting growing pressure on its transportation infrastructure. Unique challenges such as narrow rights-of-way, few corridors to accommodate highly directional commuter traffic, and abundant cultural and historic sites all contribute to the difficulty of improving and expanding the City's transportation infrastructure. Maintaining and optimizing the existing network is integral to preparing for future demands.

In addition to regular commuter travel on City arterials, traffic in Charleston varies by season due to the influence of traffic centered around several colleges on the peninsula during the fall, winter, and spring months and further by heavy tourist traffic to the beaches and the peninsula primarily during the summer months but also throughout the year. The need for a robust operations program and management center is heightened due to the potential impact that hurricane evacuation can have on the City. It is important that the City has the ability to monitor traffic conditions in real-time along all major roadways and be able to adjust traffic control systems to accommodate shifting demand while maintaining interconnectivity and communication between the City and SCDOT during critical events.

1.2.2 Traffic Signal System Evaluation

The City is currently in the process of upgrading traffic signal controller hardware for the two hundred and seven (207) intersections within its jurisdictional boundaries. Approximately ninety (90) signals have been upgraded as of September 2016. While some locations utilize inductive loop or video detection systems, many intersections on the peninsula operate under pre-timed control. The City is currently in the process of pursuing the long-range goal of upgrading the transportation communication network entirely to fiber-optic cable, which will allow video monitoring capabilities for responding to incidents in real-time and communicating with SCDOT.

In addition to the ongoing deployment of upgraded signal timing and hardware, the City is contemplating alternative timing technologies such as adaptive signal control and traffic responsive signal control. Although these technologies have their place in the traffic engineer's toolkit, careful evaluation is needed to select corridors where they will be successful. These systems represent large investments of resources and require ongoing maintenance to be successful.

Performance measures-based management of the traffic signal system is a rapidly growing technology. Charleston already has much of the needed infrastructure to put this data into use. Given Charleston's need to optimize the efficiency with which it operates the transportation network, these performance measures can provide invaluable information about the health of the City's system. Therefore, it is Stantec's recommendation to pursue further enhancement and utilization of the existing traffic signal performance measures rather than a strategy to implement adaptive or traffic responsive signal control.

1.2.3 Traffic Signal System Recommendations

Short-term (12-18 months) recommendations include completion of traffic signal controller upgrades, configuration of the existing traffic management software to utilize performance measures, identify needs for detection upgrades, and deploy advanced detection along the highest priority corridors.

Mid-term (2-5 years) recommendations include deployment of advanced detection at all locations identified during the short-term evaluation and development of a long-term strategy for utilizing performance measures.

Long-term (5+ years) recommendations include the complete deployment of modern communication technologies and the development of a conceptual plan for operations and deployment for future upgrades.

1.2.4 Traffic Signal Control Center Evaluation

The City's existing Traffic Signal Control Center (TSCC), sometimes referred to as a Transportation Management Center (TMC), was constructed in the early 2000's and includes a video monitor wall which has reached the end of its useful life and is largely non-operational. New workstations and servers for running the traffic management software were installed in 2015.

The City's traffic signal system is operated and maintained by ten (10) staff—a systems manager, a signal supervisor, and several signal and electrical technicians. Several agencies with similar sized traffic signal maintenance and operational responsibilities to that of Charleston, South Carolina were reviewed to provide insight into how those systems are managed. Peer cities in Texas, North Carolina, and elsewhere in South Carolina with signal systems ranging from 122 to 236 signals were contacted to provide information pertaining to the types of signal control, communication, cameras, and operations centers within their jurisdictions. Details of the peer cities responsibilities, operations, and staffing are described in subsequent sections of this report.

1.2.5 Traffic Signal Control Center Recommendations

Short-term (12-18 months) recommendations include replacing the existing video monitors, adding at least one (1) staff position to monitor and operate the TSCC, installing three (3) – five (5) ITS cameras at key locations, beginning to utilize the high-resolution data from the controllers, and begging to evaluate travel time data.

Mid-term (2-5 years) recommendations include continuing to evaluate five (5) – ten (10) additional locations for ITS camera coverage, continuing to replace older communication equipment with fiber optic cable, and deployment of additional travel time stations.

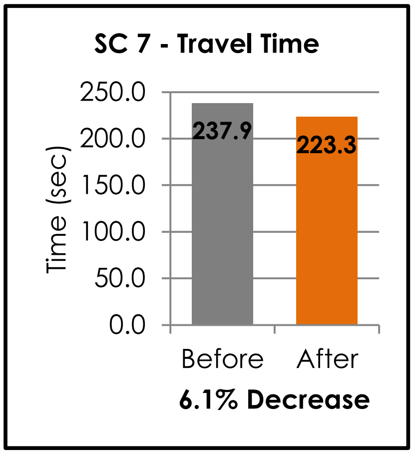
Long-term (5+ years) recommendations include creating two (2) new full-time positions to operate the TSCC Monday-Friday, 7AM-7PM, deploying fiber optic interconnectivity to all signals and ITS devices, and developing a detailed plan for the next generation of TMC.

The most important resource available to any transportation management system is the people who operate it. The value of a dedicated, knowledgeable, and fully trained staff is immeasurable. The City should consider deeper investment into its staff to ensure that the transportation system is led with experience and wisdom as this iconic City writes the next chapters in its long history.

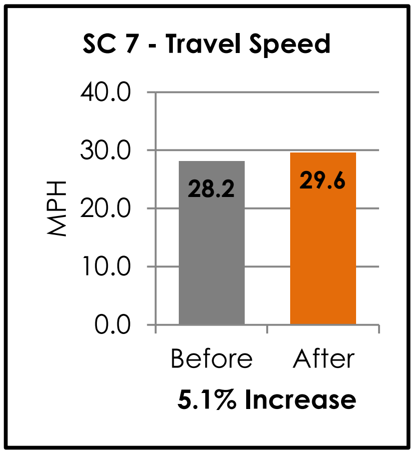
2.0 NORTHBRIDGE CORRIDOR

The consultant team, under contract with the City of Charleston, recently completed a project to develop and implement new coordinated signal timings for eight (8) signals along SC 7 (Sam Rittenberg Boulevard) and SC 171 (Old Towne Road) in the City of Charleston, Charleston County, South Carolina.

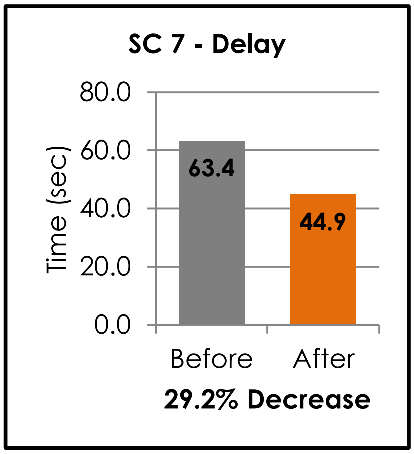
To determine the effectiveness of the new signal timing plans, travel time studies were performed using GPS for the SC 7 (Sam Rittenberg Boulevard) and SC 171 (Old Towne Road) corridors to evaluate and document the results of the timing plan development process. This report presents the results of the "before" and "after" studies that were conducted along the eight (8) intersections included in this project. The approximate lengths of the SC 7 (Sam Rittenberg Boulevard) and SC 171 (Old Towne Road) corridors are 1.8 miles and 1.4 miles, respectively. The travel time studies were conducted on typical weekdays during three (3) time periods of the day: AM Peak (7:00-9:00), Midday (11:00-13:00), and PM Peak (16:00-18:00). The following charts show the average improvements in travel time, travel speed, delay, and emissions experienced along SC 7 (Sam Rittenberg Boulevard) and SC 171 (Old Towne Road) for both directions of travel during all three (3) time periods. Charts summarizing the detailed results by each timing plan are presented in subsequent sections of this report.


SC 7 - Travel Time

6.1% Decrease

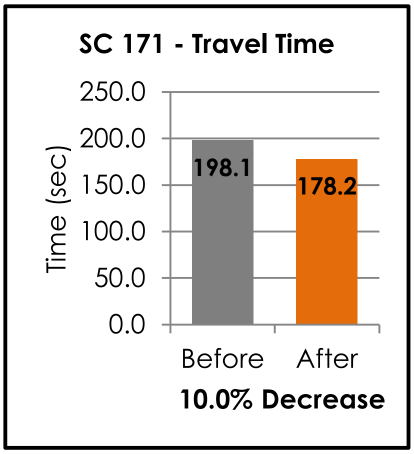

SC 7 - Travel Speed

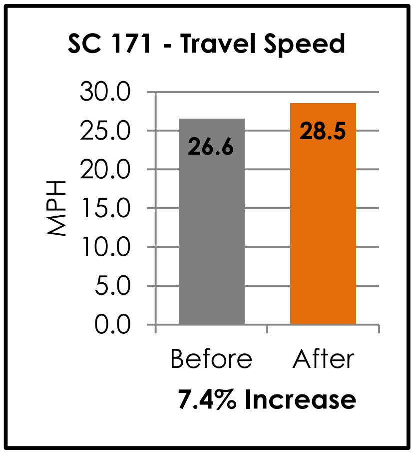
5.1% Increase

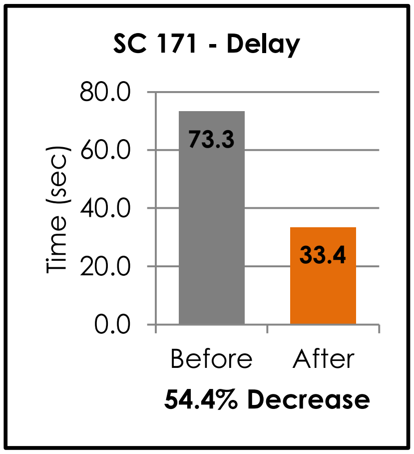

SC 7 - Delay

29.2% Decrease

As evident in the graphs above, improvements were shown in travel time, speed, and delay for the SC 7 (Sam Rittenberg Boulevard) corridor.

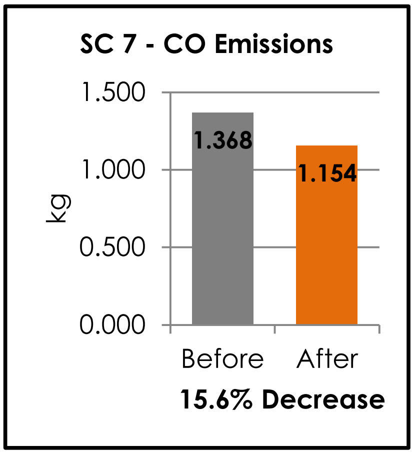


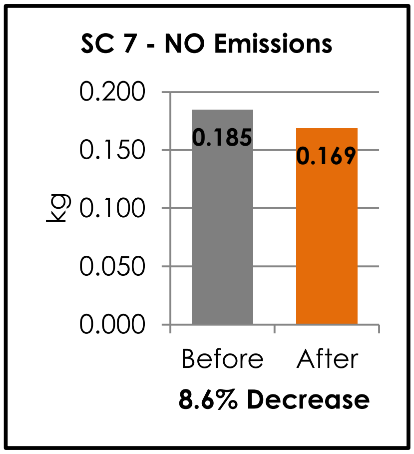


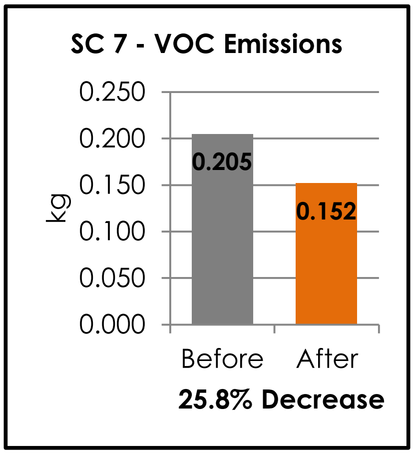


As evident in the graphs above, improvements were shown in travel time, speed, and delay for the SC 171 (Old Towne Road) corridor.

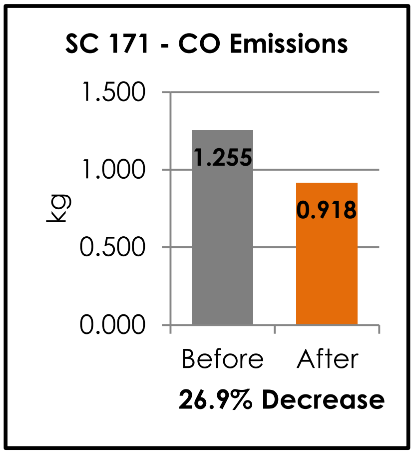
Carbon monoxide (CO), oxides of nitrogen (NOx), and volatile organic compounds (VOC) are three (3) types of vehicle emissions regulated by federal law. The following charts show the average improvements experienced along SC 7 (Sam Rittenberg Boulevard) and SC 171 (Old Towne Road) for both directions of travel during all three (3) time periods. Charts summarizing the detailed results by each timing plan are presented in subsequent sections of this report.

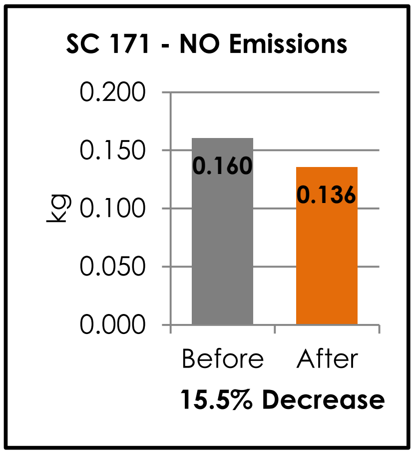


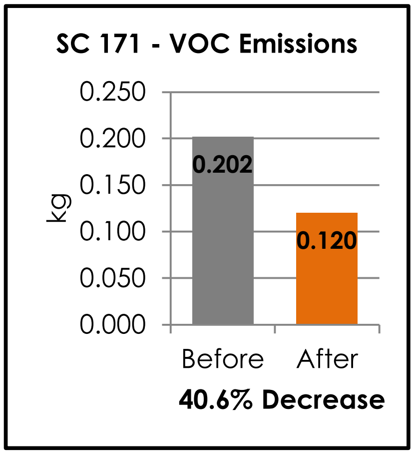




As evident in the graphs above, improvements were shown in the carbon monoxide, oxides of nitrogen, and volatile organic compound emissions along SC 7 (Sam Rittenberg Boulevard).







As evident in the graphs above, improvements were shown in the carbon monoxide, oxides of nitrogen, and volatile organic compound emissions along SC 171 (Old Towne Road).

Delay incurs direct costs upon motorists in the form of increased fuel consumption and the value of their time wasted while waiting in traffic. Motorists using SC 7 (Sam Rittenberg Boulevard) and SC 171 (Old Towne Road) during the AM, Midday, and PM peak periods will save an estimated 27,937 hours each year because of the improved traffic flow due to the new timing plans.

Conservatively assuming a vehicle occupancy of 1.2 persons/vehicle, $12.00 per hour for the value of motorists' time, and $2.38 per gallon for gasoline, annual savings to motorists along SC 7 (Sam Rittenberg Boulevard) and SC 171 (Old Towne Road) will be an estimated $402,289 in the form of reduced delay and $1,545 decrease in cost due to decreased fuel consumption, for an estimated total annual savings of $403,834.

Based on equivalent annual cost of designing, implementing, and documenting signal timing plan improvements, the benefit to cost ratios for interest rates ranging from 4% to 8% were calculated to be between 21.8:1 and 23.0:1 for the SC 7 (Sam Rittenberg Boulevard) and SC 171 (Old Towne Road) corridors.

2.1 INTRODUCTION

This document describes the development of timing plans by Stantec for eight (8) intersections along and near SC 7 (Sam Rittenberg Boulevard) and SC 171 (Old Towne Road) in the City of Charleston, Charleston County, South Carolina. The intersections are listed in **Table 1**. The purpose of this project is to develop and implement traffic signal timing plans for the following intersections:

Table 1 - Project Intersections

#	Signal ID	Intersection
1	143	SC 7 (Sam Rittenberg Boulevard) & Durham Place/Poston Road
2	144	SC 7 (Sam Rittenberg Boulevard) & Orange Grove Road
3	145	SC 7 (Sam Rittenberg Boulevard) & SC 171 (Old Towne Road)
4	146	SC 171 (Old Towne Road) & Charlestowne Drive
5	147	SC 171 (Old Towne Road) & Charlestowne Landing
6	148	SC 7 (Sam Rittenberg Boulevard) & Dickens Street/Charlestowne Drive
7	149	SC 7 (Sam Rittenberg Boulevard) & Ashley Hall Road
8	150	Ashley Hall Road & Orange Grove Road

South of their intersection, SC 7 (Sam Rittenberg Boulevard) and SC 171 (Old Town Road) are four-lane arterial highways divided by a flush median with exclusive left- and right-turn lanes at most intersections. To the south, these highways provide connections to residential areas of West Ashely while also carrying commuter traffic. North of their intersection, the routes merge and continue toward the Ashley River and Interstate 26 as a six-lane principal arterial highway with exclusive left and right-turn lanes at major intersections. While the adjacent land use is typically residential, there is significant commercial and retail development near the intersection of SC 7 (Sam Rittenberg Boulevard) and SC 171 (Old Town Road), as shown below in **Figure 1**.

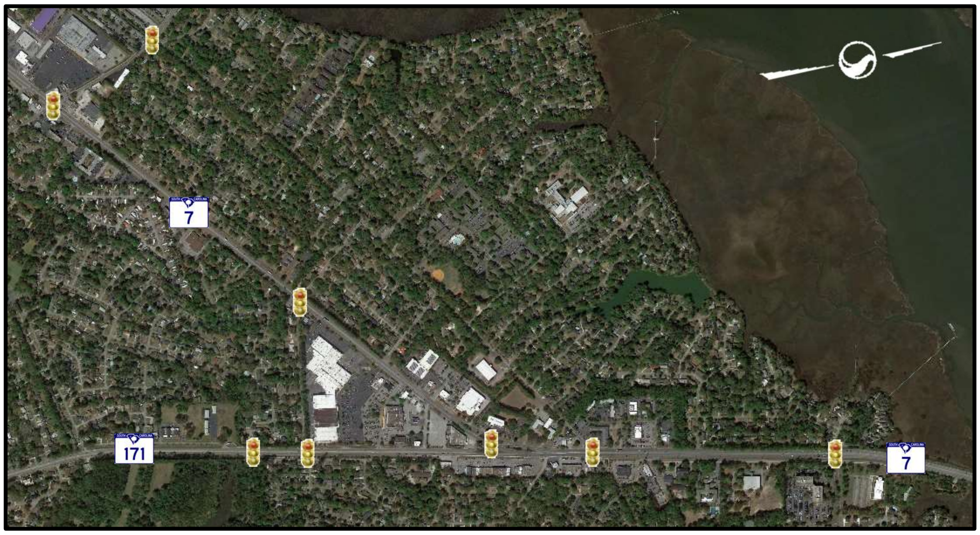


Figure 1 – Project Location

2.2 INVENTORY & DATA COLLECTION

2.2.1 Inventory

Stantec staff completed an inventory of each of the project intersections. Information obtained consists of the intersection configuration, signing and marking configurations, signal phasing, pedestrian crossing dimensions, communication status, and detector status. The inventory limits were approximately 500-feet from the intersection along the mainline. The completed form for each intersection is provided in **Appendix A**.

2.2.2 Data Collection

Stantec collected a combination of four-day 24-hour bi-directional tube counts and peak hour turning movement counts at signalized intersections. **Table 2** lists the 24-hour count locations while the turning movement counts were conducted during weekday AM, weekday midday, weekday PM, and weekend peak hours at the study corridor intersections shown previously in **Table 1**. The count program is also depicted on **Figure 2**.

Table 2 – 24-Hour Bi-Directional Tube Count Locations

#	Location	Direction of Travel
A	SC 7 (Sam Rittenberg Boulevard) west of Dickens Street	Eastbound and Westbound
B	SC 171 (Old Towne Road) south of Old Town Plantation Road	Northbound and Southbound
C	SC 7 (Sam Rittenberg Boulevard) north of Poston Road	Northbound and Southbound

The 24-hour bi-directional tube counts were graphed, as shown on **Figures 3 and 4**, to show the traffic volumes throughout the day. The existing and proposed time-of-day (TOD) schedules are shown for reference on the Figures. The turning movement count (TMC) data was collected after obtaining the tube counts and determining the peaks in two-hour increments. The TMC's were collected and the peak hour was determined; this count data is included in **Appendix B** and **Appendix C**.

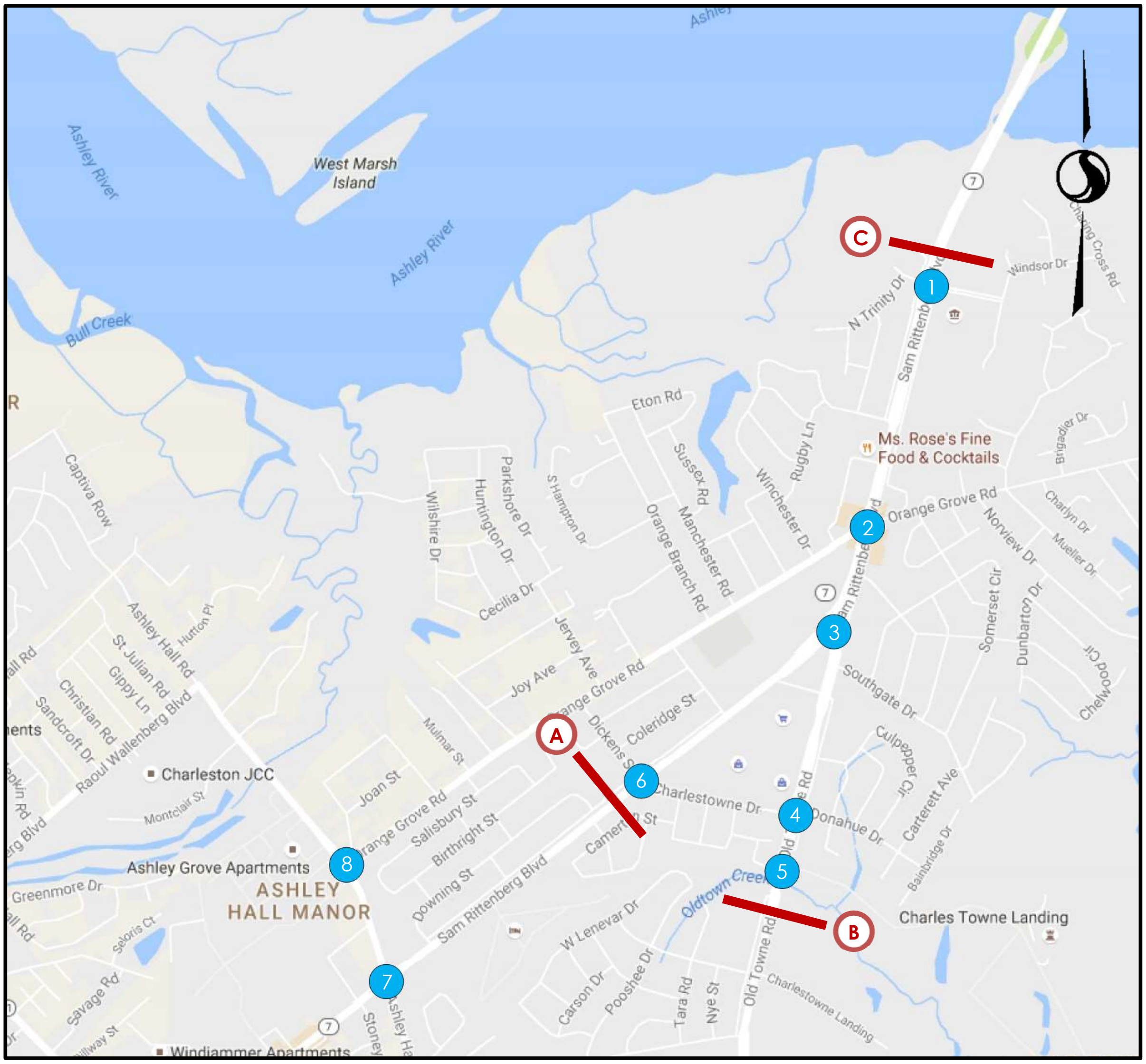


Figure 2 - Count Program

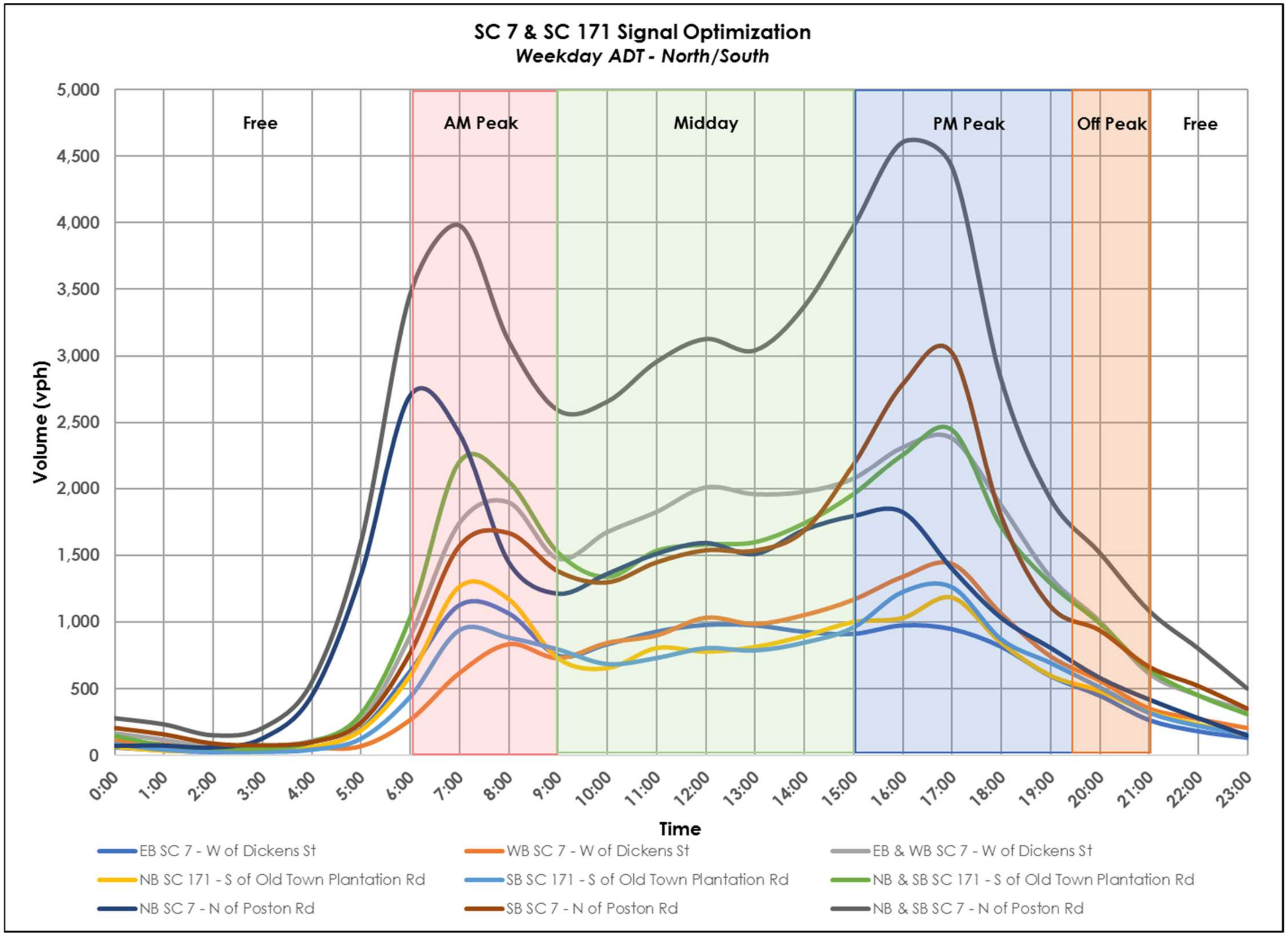


Figure 3 – Weekday Traffic Volumes

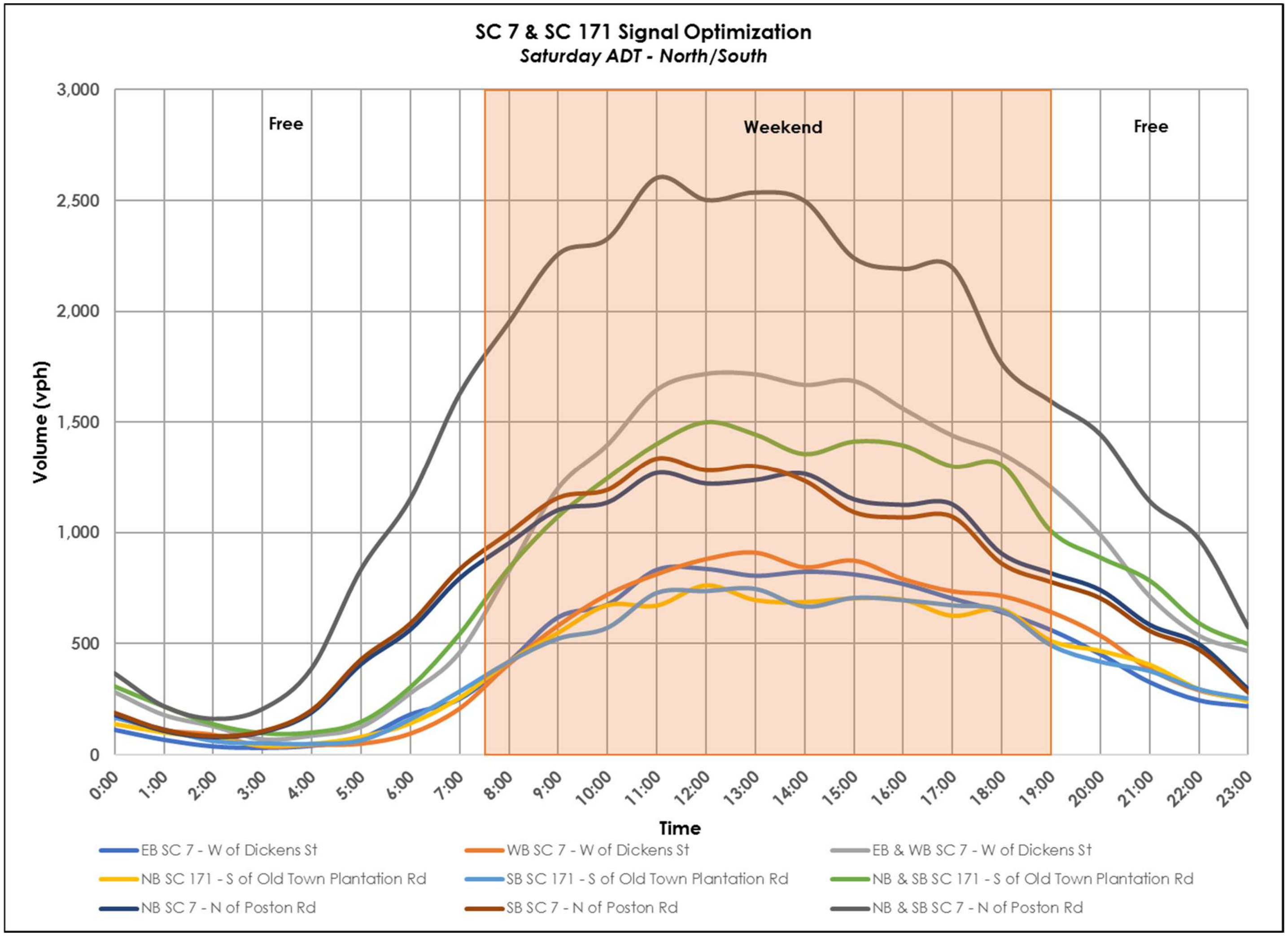


Figure 4 – Weekend Traffic Volumes

2.3 LOCAL TIMING PARAMETERS

Local controller timings were developed for each of the eight (8) intersections in this project. **Table 3** details the methods used to develop the controller values that will be used for each intersection. Clearance calculations for each intersection are shown in **Appendix D**.

Table 3 – Local Timing Parameters

<table>
<tr><th>Parameter</th><th colspan="2">Value</th></tr>
<tr><td colspan="3">PEDESTRIAN INTERVAL</td></tr>
<tr><td>Pedestrian Change Interval</td><td colspan="2">((Curb to Curb Distance) / (Walking Speed))</td></tr>
<tr><td>Walking Speed</td><td colspan="2">3.5 Feet per Second</td></tr>
<tr><td>Walk</td><td colspan="2">7 Seconds – Also calculated (Push button to far curb distance) / (walking speed of 3.0fps). If this number was greater than the calculated Pedestrian Change Interval then the difference was added to the Walk time.</td></tr>
<tr><td>Buffer Interval</td><td colspan="2">Following the pedestrian change interval, a buffer interval consisting of a steady UPRAISED HAND (symbolizing DON'T WALK) signal indication shall be displayed for at least 3 seconds prior to the release of any conflicting vehicular movement</td></tr>
<tr><td colspan="3">VEHICLE INTERVAL</td></tr>
<tr><td>Yellow Interval</td><td>t + (V/(2A + 64.4g))
Minimum of 3 seconds. Rounded up to nearest half second.
Left turn clearance calculations based on 20-MPH</td><td rowspan="12">t = perception reaction time (1 second)
V = posted speed in feet/second (25 mph for left turn clearances)
A = deceleration rate (10 feet/second/second)
W = intersection width measured from stop bar to the far edge of the last conflict lane (or crosswalk when the crosswalk is greater than 20' from the intersection)
L = length of vehicle (assume 20 feet)
g = The average of two field measured approach grades:
• At the stop bar
• At the setback loop (if present)
n = detection distance / 20
N = number of lanes</td></tr>
<tr><td>All Red Interval</td><td>(W + L) / V
Minimum of 1.5 seconds. Rounded up to nearest half second</td></tr>
<tr><td>Minimum Green</td><td>Maintained existing</td></tr>
<tr><td>Volume Density</td><td>Maintained existing</td></tr>
<tr><td>Minimum Cycle Length</td><td>90 seconds</td></tr>
<tr><td>Maximum Cycle Length</td><td>180 Seconds</td></tr>
<tr><td>Offset Reference</td><td>End of Green</td></tr>
<tr><td>Offset Seeking</td><td>Short Way</td></tr>
<tr><td>Free Operation</td><td>Overnight hours</td></tr>
<tr><td>Lead/Lag by TOD?</td><td>No</td></tr>
<tr><td>Traffic Responsive Operation</td><td>No</td></tr>
<tr><td>Special Events</td><td>No</td></tr>
<tr><td colspan="3">CONTACT INFORMATION</td></tr>
<tr><td>Signal Systems Manager</td><td colspan="2">Troy Mitchell, City of Charleston</td></tr>
<tr><td>Law Enforcement</td><td colspan="2">City of Charleston Police Department</td></tr>
</table>

2.4 COORDINATION PARAMETERS

The objective of the proposed signal timing is to minimize delay for all vehicles within the system and provide improved progression at the posted speed limit through the signal system for the mainline while minimizing side-street delay.

The turning movement count inventory data was entered into Synchro 9.1 using the following guidelines:

- All movements were coded as they appear in the field.
- Signing and marking restrictions were coded as they appear in the field.
- A saturated flow rate of 1,900 vehicles per hour was used.
- Posted speed limits were used for progression speeds.

Multiple runs of Synchro 9.1 were completed to determine the most appropriate combination of cycle length, splits, and offsets for each signal in the system. The existing plans are contrasted with the existing and proposed plans developed as summarized in **Table 4** and **Table 5**, respectively. Synchro timing reports are included in **Appendix E** and time-space diagrams are included in **Appendix F**.

Table 4 – Time-of-Day/Day-of-Week Schedule

Plan Day	Day	HH:MM (Start Time)	Plan #	Cycle (Sec)	Directional Bias
EXISTING					
1	Saturday-Sunday	00:00	14	Free	-
1	Saturday-Sunday	06:30	24	Free +Max 2	-
1	Saturday-Sunday	07:30	5	130	-
1	Saturday-Sunday	22:00	14	Free	
2	Monday-Friday	00:00	14	Free	-
2	Monday-Friday	06:00	1	140	-
2	Monday-Friday	09:30	2	90	-
2	Monday-Friday	13:30	3	140	-
2	Monday-Friday	19:30	4	120	-
2	Monday-Friday	22:00	14	Free	-
IMPLEMENTED					
1	Saturday-Sunday	00:00	14	Free	-
1	Saturday-Sunday	07:30	4	90	Balanced
1	Saturday-Sunday	19:00	14	Free	-
2	Monday-Friday	00:00	14	Free	-
2	Monday-Friday	06:00	1	130	Northbound
2	Monday-Friday	09:00	2	90	Balanced
2	Monday-Friday	15:00	3	130	Southbound
2	Monday-Friday	19:30	2	90	Balanced
2	Monday-Friday	21:00	14	Free	-

2.4.1 Proposed Timing Plans

The existing corridor utilizes coordinated timing plans with cycle lengths that range from 90-140 seconds. The AM and PM implemented timing plans operate with a 130 second cycle length. The Midday implemented timing plan operates with a 90 second cycle length. Saturday and Sunday daytime plans utilize the Midday timings once again at 90 seconds in length.

The existing AM plan has a 140 second cycle length and runs from 06:00 to 09:30. This plan was replaced with a 130 second cycle length plan that runs from 06:00 to 09:00 during the peak seen in the 24-hour counts. As discussed in section 5.2, the implemented AM plan reduced the delay at four (4) of the eight (8) signals in coordination and improved or maintained the level of service at all eight (8) intersections.

The existing Midday plan runs a 90 second cycle length from 09:30 to 13:30. The implemented Midday plan maintained the 90 second cycle length but runs from 09:00 to 15:00. As discussed in section 5.2, the implemented Midday plan reduced the delay at three (3) of the eight (8) signals in coordination. The implemented Midday plan maintained the level of service at six (6) of the eight (8) intersections.

The existing PM plan runs from 13:30 to 19:30 and has a cycle length of 140 second and the PM off-peak plan runs from 19:30 to 22:00 and has a cycle length of 120 second. These plans were replaced with a 130 second cycle length plan that runs from 15:00 to 19:30 and a 90 second cycle length that runs from 19:30 to 21:00. As discussed in section 5.2, the implemented PM plan maintained the level of service at seven (7) of the eight (8) intersections and reduced delay at one (1) intersection.

The existing weekend plan runs from 07:30 to 22:00 and has a 130 second cycle length. The implemented plan runs from 07:30 to 19:00 with a decreased cycle length of 90 seconds.

2.5 OPERATIONAL ANALYSIS

2.5.1 Methodology for Before and After Studies

The travel time, average speed, and delay studies were conducted in accordance with the procedures given in the *Manual of Transportation Engineering Studies*, published by the Institute of Transportation Engineers. Travel time, average speed, and delay studies were conducted in both the northbound and southbound directions on SC 7 (Sam Rittenberg Boulevard) and SC 171 (Old Towne Road) during the AM peak, Midday peak, and PM peak periods. A minimum of six (6) runs was made in each direction. The "floating car" technique was used, whereby the driver passes as many cars as pass the driver. The four (4) following routes were determined along the Northbridge system:

- Route 1: SC 7 (Sam Rittenberg Boulevard), southbound from Durham Place/Poston Road to Ashley Hall Road
- Route 2: SC 7 (Sam Rittenberg Boulevard), northbound from Ashley Hall Road to Durham Place/Poston Road
- Route 3: SC 171 (Old Towne Road)/SC 7 (Sam Rittenberg Boulevard), southbound from Durham Place/Poston Road to Charlestowne Landing
- Route 4: SC 171 (Old Towne Road)/SC 7 (Sam Rittenberg Boulevard), northbound from Charlestowne Landing to Durham Place/Poston Road

The study vehicle was unmarked and operated as inconspicuously as possible. The operator recorded the stops and travel time experienced during each run. All Traffic Data was subcontracted to collect the travel time data. The "before" runs were collected on August 30, 2016 and the "after" runs were collected on April 18 and 20, 2017. Travel run data was collected using Qstar Logger and was processed with Trav-time. The tables below summarize the "before" and "after" travel time, delay, average speed, and number of stops, as well as atmospheric pollutants carbon monoxide, oxides of nitrogen, and volatile oxygen compounds (hydrocarbons), which are vehicle emissions regulated by federal law. The data below is shown for each corridor, time period, and direction of travel. The travel time reports from All Traffic Data are included in **Appendix G**.

Table 5 – Average Travel Time (sec)

SC 7 (Sam Rittenberg Boulevard)

	AM		Midday		PM	
Direction of Travel	**SB**	**NB**	**SB**	**NB**	**SB**	**NB**
Before	187.8	256.8	204.6	228.0	256.8	293.4
After	212.4	254.4	195.6	198.0	241.2	238.2
% Difference	**13.1%**	**-0.9%**	**-4.4%**	**-13.2%**	**-6.1%**	**-18.8%**

SC 171 (Old Towne Road)

	AM		Midday		PM	
Direction of Travel	**SB**	**NB**	**SB**	**NB**	**SB**	**NB**
Before	156.0	222.0	139.8	190.2	216.6	264.0
After	180.0	216.6	151.2	156.6	168.6	196.2
% Difference	**15.4%**	**-2.4%**	**8.2%**	**-17.7%**	**-22.2%**	**-25.7%**

Table 6 – Average Delay (sec)

SC 7 (Sam Rittenberg Boulevard)

	AM		Midday		PM	
Direction of Travel	**SB**	**NB**	**SB**	**NB**	**SB**	**NB**
Before	22.2	59.4	35.4	46.2	70.2	108.6
After	44.4	69.6	25.8	19.8	46.8	63.0
% Difference	**100.0%**	**17.2%**	**-27.1%**	**-57.1%**	**-56.9%**	**-42.0%**

SC 171 (Old Towne Road)

	AM		Midday		PM	
Direction of Travel	**SB**	**NB**	**SB**	**NB**	**SB**	**NB**
Before	14.4	88.8	9.0	60.0	68.4	133.8
After	43.8	33.0	14.4	21.0	24.6	63.6
% Difference	**204.2%**	**-62.8%**	**60.0%**	**-65.0%**	**-81.6%**	**-52.5%**

Table 7 – Average Speed (mph)

SC 7 (Sam Rittenberg Boulevard)						
	AM		Midday		PM	
Direction of Travel	**SB**	**NB**	**SB**	**NB**	**SB**	**NB**
Before	34.65	25.65	31.98	28.86	25.40	22.46
After	30.88	25.76	33.36	33.08	27.03	27.50
% Difference	**-10.9%**	**0.4%**	**4.3%**	**14.6%**	**6.4%**	**22.4%**
SC 171 (Old Towne Road)						
	AM		Midday		PM	
Direction of Travel	**SB**	**NB**	**SB**	**NB**	**SB**	**NB**
Before	32.09	22.56	36.01	26.46	23.11	19.09
After	27.80	23.08	33.10	31.91	29.73	25.52
% Difference	**-13.4%**	**2.3%**	**-8.1%**	**20.6%**	**28.7%**	**33.7%**

Table 8 – Average Number of Stops

SC 7 (Sam Rittenberg Boulevard)						
	AM		Midday		PM	
Direction of Travel	**SB**	**NB**	**SB**	**NB**	**SB**	**NB**
Before	1.14	3.14	1.43	1.43	2.00	3.17
After	1.43	2.43	1.50	1.62	2.43	2.29
% Difference	**25.4%**	**-22.6%**	**4.9%**	**13.3%**	**21.5%**	**-27.8%**
SC 171 (Old Towne Road)						
	AM		Midday		PM	
Direction of Travel	**SB**	**NB**	**SB**	**NB**	**SB**	**NB**
Before	1.14	2.14	0.43	1.86	2.17	1.17
After	1.43	1.71	0.88	1.62	2.00	1.86
% Difference	**25.4%**	**-20.1%**	**104.7%**	**-12.9%**	**-7.8%**	**59.0%**

Table 9 – Average Carbon Monoxide Emissions (kg)

SC 7 (Sam Rittenberg Boulevard)						
	AM		Midday		PM	
Direction of Travel	**SB**	**NB**	**SB**	**NB**	**SB**	**NB**
Before	0.909	1.458	1.076	1.234	1.538	1.992
After	1.072	1.431	0.939	0.902	1.297	1.286
% Difference	**18.0%**	**-1.8%**	**-12.7%**	**-26.9%**	**-15.7%**	**-35.5%**
SC 171 (Old Towne Road)						
	AM		Midday		PM	
Direction of Travel	**SB**	**NB**	**SB**	**NB**	**SB**	**NB**
Before	0.709	1.556	0.611	1.214	1.368	2.075
After	0.951	1.173	0.676	0.768	0.835	1.103
% Difference	**34.1%**	**-24.6%**	**10.8%**	**-36.7%**	**-39.0%**	**-46.8%**

Table 10 – Average Oxides of Nitrogen Emissions (kg)

SC 7 (Sam Rittenberg Boulevard)						
	AM		Midday		PM	
Direction of Travel	**SB**	**NB**	**SB**	**NB**	**SB**	**NB**
Before	0.134	0.200	0.152	0.171	0.204	0.247
After	0.159	0.201	0.141	0.140	0.186	0.185
% Difference	**18.8%**	**0.7%**	**-7.5%**	**-18.3%**	**-8.5%**	**-25.0%**
SC 171 (Old Towne Road)						
	AM		Midday		PM	
Direction of Travel	**SB**	**NB**	**SB**	**NB**	**SB**	**NB**
Before	0.109	0.189	0.096	0.155	0.176	0.238
After	0.137	0.174	0.105	0.114	0.124	0.158
% Difference	**26.2%**	**-8.2%**	**10.4%**	**-26.0%**	**-29.6%**	**-33.6%**

Table 11 – Average Volatile Organic Compound Emissions (kg)

SC 7 (Sam Rittenberg Boulevard)						
	AM		Midday		PM	
Direction of Travel	**SB**	**NB**	**SB**	**NB**	**SB**	**NB**
Before	0.112	0.219	0.146	0.178	0.239	0.335
After	0.135	0.204	0.114	0.104	0.180	0.175
% Difference	**20.1%**	**-6.8%**	**-21.8%**	**-41.3%**	**-24.9%**	**-47.9%**

SC 171 (Old Towne Road)						
	AM		Midday		PM	
Direction of Travel	**SB**	**NB**	**SB**	**NB**	**SB**	**NB**
Before	0.085	0.266	0.067	0.194	0.222	0.377
After	0.129	0.158	0.077	0.096	0.108	0.152
% Difference	**51.0%**	**-40.8%**	**14.3%**	**-50.6%**	**-51.4%**	**-59.6%**

As shown in the tables above, travel time, delay, average speed, number of stops, and emissions were all improved throughout the day along the SC 7 (Sam Rittenberg Boulevard) and SC 171 (Old Towne Road) corridors with several exceptions.

The southbound direction of travel along both corridors in the AM peak and along SC 171 (Old Towne Road) during the Midday peak experienced undesirable changes to travel time, average speed, number of stops, and emissions. However, the predominate northbound movement showed improvement in all categories for both corridors during the AM peak period with two (2) exceptions. SC 7 (Sam Rittenberg Boulevard) showed an increase in delay of 17.2% and emission of oxides of nitrogen by 0.7% for the northbound direction of travel during the AM peak period.

The northbound direction of travel for both corridors showed improvement across all categories throughout the day with few exceptions. The northbound direction of travel along SC 171 (Old Towne Road) during the PM peak experienced the greatest improvement in all categories except delay, which was reduced by 52.5%, and number of stops, which increased by 59.0%.

The southbound direction of travel for both corridors experienced improvements in all categories during the PM peak period with one (1) exception. SC 7 (Sam Rittenberg Boulevard) showed an increase in number of stops by 21.5% for the southbound direction of travel during the PM peak period.

2.5.2 LOS and Delay Analysis

Synchro 9.1 was also used to prepare an evaluation of intersection operations to determine the Level of Service (LOS) and average delay of the existing condition (existing geometry, existing signal timings, and existing traffic volumes), the proposed condition (existing geometry, proposed signal timings, and existing traffic volumes), and the final condition (existing geometry, implemented signal timings, and existing traffic volumes). This capacity analysis methodology is based on the *2010 Highway Capacity Manual* (HCM), a standard guidance for capacity analysis, which defines LOS at signalized intersections in terms of average control delay per vehicle, which is composed of initial deceleration delay, queue move-up time, stopped delay, and final acceleration delay. LOS ranges from A to F, with LOS A indicating operations with very low control delay and LOS F describing operations with extremely high average control delay. In the comparison between existing, proposed, and final timings, the LOS and delay should improve for the overall corridor, but may increase or decrease at individual intersections depending on what was running before.

Currently, the corridor has very directional peak hour traffic. The primary goal for timing the SC 7 (Sam Rittenberg Boulevard) and SC 171 (Old Towne Road) corridors was to increase efficiency along the routes during all peaks. The volume-to-capacity (V/C) ratios were also included in the analysis to measure capacity demand of each intersection since delay on side streets can sometimes skew an intersection delay even if the respective queues are under capacity. Overall, corridor offsets were adjusted to reduce queuing and delay.

The results of the existing, proposed, and final conditions are shown in **Table 12**. Synchro LOS and Delay outputs are included in **Appendix E**. Although some of LOS and delays results under the final plans yielded worse values than the existing models, the signal timings have been optimized to accommodate improved progression and capacity efficiency throughout the system. Meanwhile, all LOS results remain at ‘D’ or better with several intersections expected to perform with even better results.

The LOS, delay, and V/C ratios varied in the field upon implementation of the proposed timing plans. Overall, the SC 7 (Sam Rittenberg Boulevard) and SC 171 (Old Towne Road) systems have driveways and stop-controlled intersections that were not modeled in the analysis. Consequently, varying speeds, geometric constraints, and volume additions and subtractions between the study intersections contributed various results that can affect the overall progression and flow of the corridor. Adjustments to the splits and offsets were incorporated in the field during fine tuning upon observation of actual driver behavior.

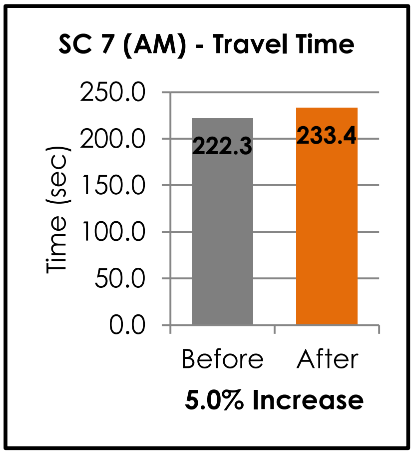
Table 12 – Existing and Proposed Level of Service and Average Delay

#	Intersection	Existing		Proposed		Implemented	
		LOS	Control Delay (sec/veh)	LOS	Control Delay (sec/veh)	LOS	Control Delay (sec/veh)
AM PEAK PERIOD							
1	SC 7 & Poston Road	B	17.3	B	10.5	B	13.7
2	SC 7 & Orange Grove Road	D	49.1	D	46.5	D	47.5
3	SC 7 & SC 171	C	22.2	B	18.6	B	12.9
4	SC 171 & Charlestowne Drive	A	7.2	A	6.2	A	7.3
5	SC 171 & Charlestowne Landing	A	2.4	A	2.4	A	2.4
6	SC 7 & Dickens/Charlestowne Drive	C	24.2	B	17.5	B	16.2
7	SC 7 & Ashley Hall Road	C	30.1	D	43.0	C	34.0
8	Ashley Hall Road & Orange Grove Road	B	10.7	B	18.2	B	15.5
MID PEAK PERIOD							
1	SC 7 & Poston Road	A	5.4	A	5.1	A	4.9
2	SC 7 & Orange Grove Road	C	21.3	C	23.1	C	22.9
3	SC 7 & SC 171	B	11.8	B	11.7	B	10.6
4	SC 171 & Charlestowne Drive	A	5.2	A	3.5	A	4.0
5	SC 171 & Charlestowne Landing	A	2.4	A	2.4	A	2.8
6	SC 7 & Dickens/Charlestowne Drive	A	7.1	A	8.2	B	12.4
7	SC 7 & Ashley Hall Road	C	20.6	C	21.4	C	21.8
8	Ashley Hall Road & Orange Grove Road	A	9.6	B	10.8	B	10.1
PM PEAK PERIOD							
1	SC 7 & Poston Road	B	13.2	B	13.1	B	16.5
2	SC 7 & Orange Grove Road	C	33.6	D	37.9	C	34.2
3	SC 7 & SC 171	B	14.0	B	15.9	B	12.0
4	SC 171 & Charlestowne Drive	A	7.2	A	8.0	A	8.3
5	SC 171 & Charlestowne Landing	A	4.0	A	4.3	A	4.4
6	SC 7 & Dickens/Charlestowne Drive	B	13.0	B	10.1	B	16.3
7	SC 7 & Ashley Hall Road	C	33.9	C	32.4	D	36.7
8	Ashley Hall Road & Orange Grove Road	C	23.1	C	21.8	C	25.3

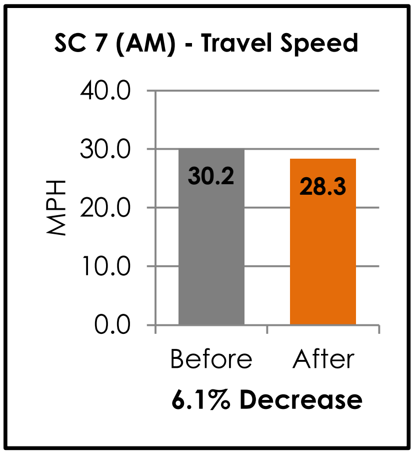
2.6 RESULTS SUMMARY

2.6.1 AM Peak Plan

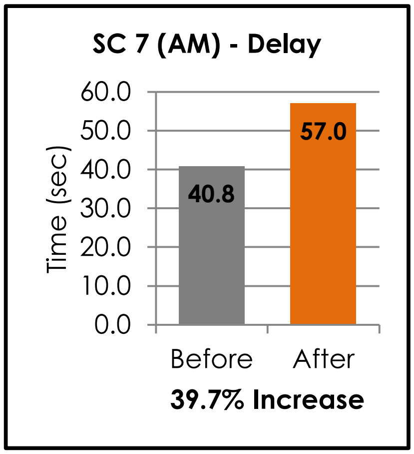
The existing AM plan has a 140 second cycle length and runs from 06:00 to 09:30, Monday – Friday. This plan was replaced with a 130 second cycle length plan that runs weekdays from 06:00 to 09:00 during the peak seen in the 24-hour counts. The predominant flow of traffic is northbound toward Interstate 26 with approximately 50% of the northbound traffic coming from each route. As shown in the charts below, the implemented AM plan improved the cumulative delay along the SC 171 (Old Towne Road) corridor. The implemented AM plan resulted in increased travel time and decreased travel speed for both corridors with a change of less than 7% when compared to the before travel runs. The combined averages for these metrics appear less desirable in the after conditions due to bias for the peak direction of travel. When examined individually, the northbound direction of travel experienced improvement in most categories while the lower-volume southbound movement experienced less desirable change. The changes experienced by the northbound routes affect nearly twice as many vehicles as the southbound routes during the AM peak, and are therefore considered favorable.



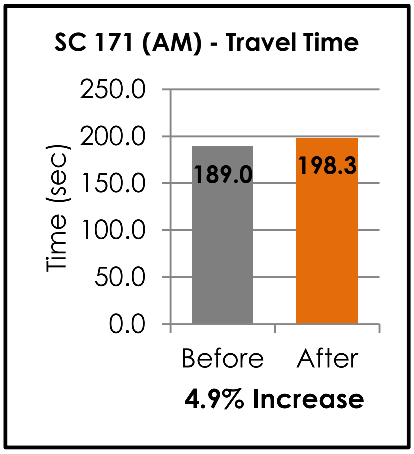
5.0% Increase



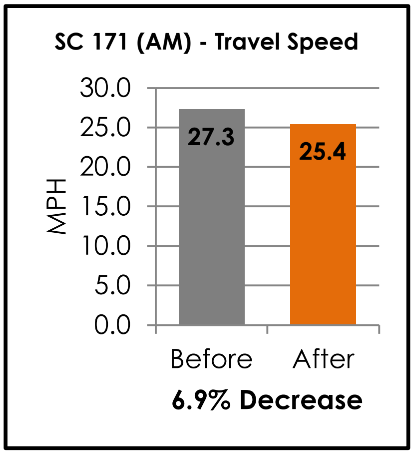
6.1% Decrease



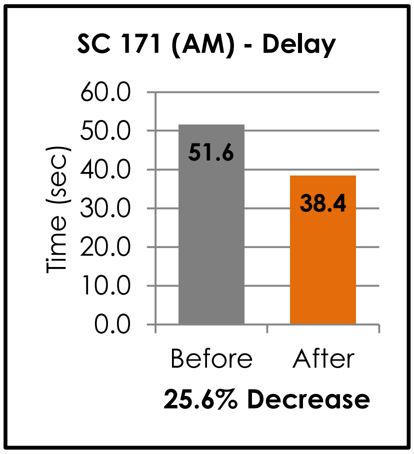
39.7% Increase



4.9% Increase



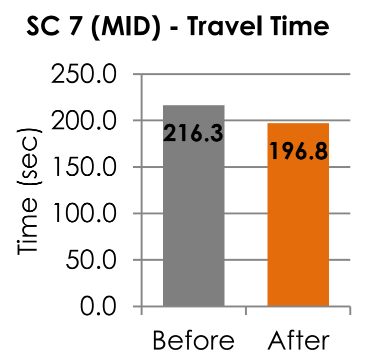
6.9% Decrease



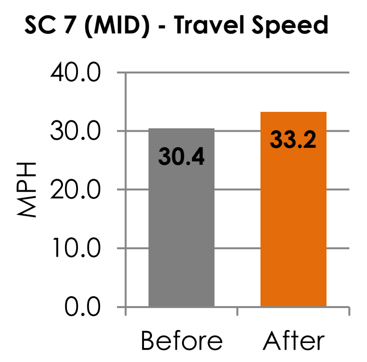
25.6% Decrease

2.6.2 Midday Plan

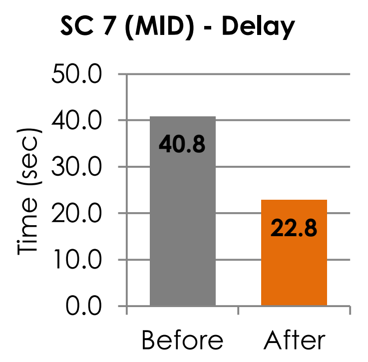
The existing Midday plan has a 90 second cycle length and runs from 09:30 to 13:30, Monday – Friday. The implemented Midday plan also uses a 90 second cycle length and runs weekdays from 09:00 to 15:00. Traffic volumes are directionally balanced during the Midday peak. As shown in the charts below, the implemented Midday plan improved the cumulative travel time, travel speed, and delay along the corridor. Delay for both corridors was reduced by more than 40%.


SC 7 (MID) - Travel Time

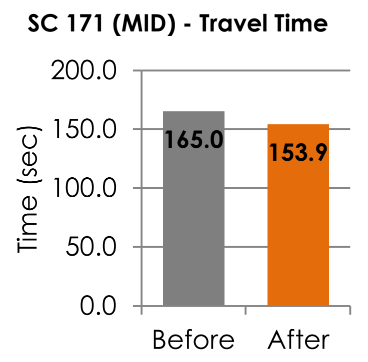
9.0% Decrease


SC 7 (MID) - Travel Speed

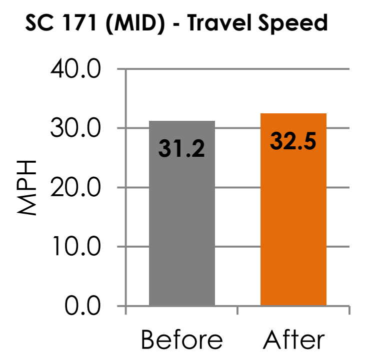
9.2% Increase


SC 7 (MID) - Delay

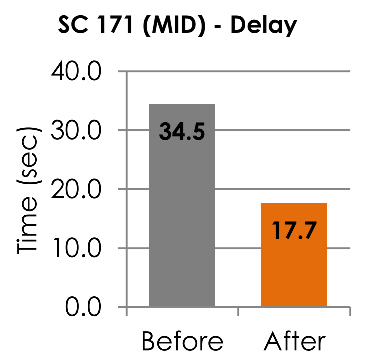
44.1% Decrease


SC 171 (MID) - Travel Time

6.7% Decrease


SC 171 (MID) - Travel Speed

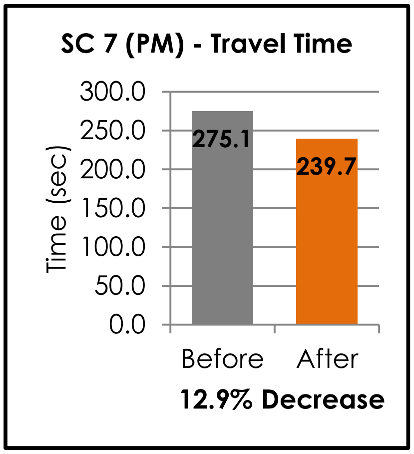
4.1% Increase


SC 171 (MID) - Delay

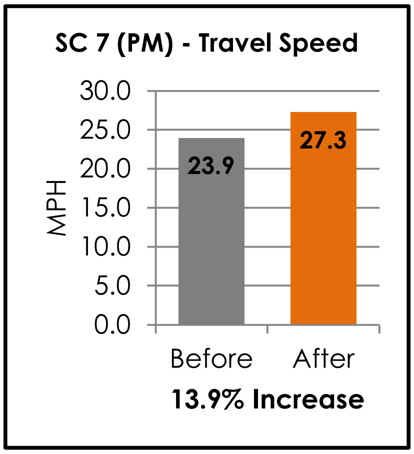
48.7% Decrease

2.6.3 PM Peak Plan

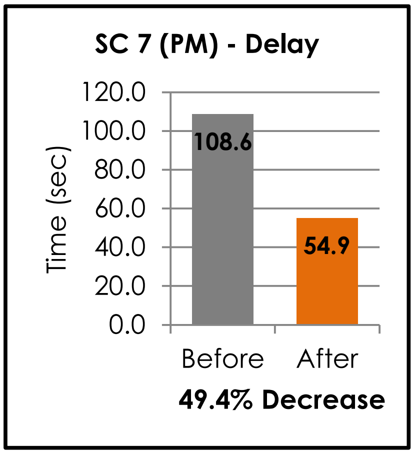
The existing PM plan has a 140 second cycle length and runs from 13:30 to 19:30, Monday – Friday. This plan was replaced with a 130 second cycle length that runs weekdays from 15:00 to 19:30. During the PM peak period the predominant flow of traffic is southbound into West Ashley with approximately 50% of the southbound traffic continuing along each corridor. As shown in the charts below, the implemented PM plan improved the cumulative travel time, travel speed, and delay along the corridor. The implemented PM plan reduced delay by 49% or more for both corridors, improved travel speeds by more than 13%, and reduced travel time by more than 12%.


SC 7 (PM) - Travel Time

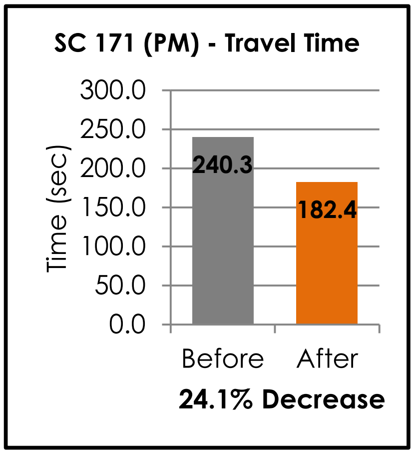
12.9% Decrease


SC 7 (PM) - Travel Speed

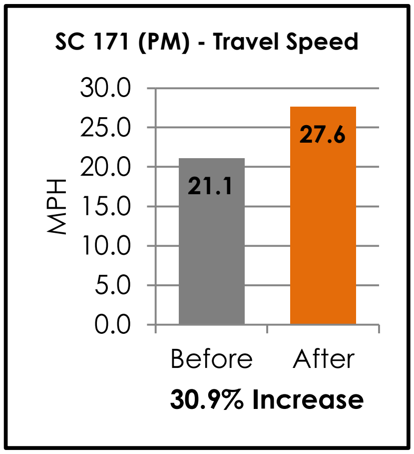
13.9% Increase


SC 7 (PM) - Delay

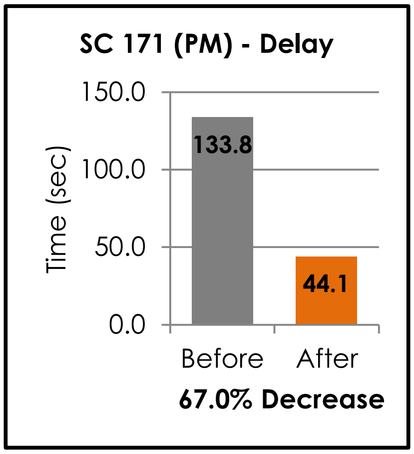
49.4% Decrease


SC 171 (PM) - Travel Time

24.1% Decrease


SC 171 (PM) - Travel Speed

30.9% Increase


SC 171 (PM) - Delay

67.0% Decrease

2.6.4 Weekend Plans

The existing weekend plan runs from 07:30 to 22:00, Saturday – Sunday, and has a 130 second cycle length. The implemented weekend peak plan runs from 07:30 to 19:00, Saturday – Sunday, and uses a 90 second cycle length. Before and after travel time, average speed, and delay studies were not performed for the weekend plan. Weekend operations were observed during implementation and splits and offsets were adjusted to ensure that queueing and delay were within acceptable ranges.

2.7 EFFECTIVENESS EVALUATION

Improvements in traffic signal timing can also be measured using a cost versus benefit ratio. If the financial benefits to the drivers outweigh the financial cost of the project over its lifespan, then the project is worth the investment. The financial benefit to the drivers is seen through decreased driving time and fuel consumption due to improved traffic flow from the signal timing plans.

The signal timing plans will last until changes in volume or roadway characteristics decrease the efficiency of the signal system to move traffic. Development in the area can increase the volume and cause the need for roadway expansion. In order to determine the cost/benefit ratio for this report, the life span of the new signal timing plans was assumed to be 2 years.

2.7.1 Annual Costs

The cost of designing, implementing, and recording the timing plans and the interest associated with the capital invested are all factors involved in calculating the equivalent annual cost.

The formulas used to determine the project's costs are:

$$E=R \times C$$

Where:
E = Equivalent Cost
R = Capital Recovery Cost
C = Initial Cost

$$R = i(1+i)^n / ((1+i)^n - 1)$$

Where:
R = Capital Recovery Cost
i = Annual Interest Rate
n = Useful Life of Timing Plans

The equivalent annual costs, as calculated, using the above formulas, for SC 7 (Sam Rittenberg Boulevard) and SC 171 (Old Towne Road) are shown in **Table 13**. The table shows interest rates ranging from 4% to 8%, which are assumed to be reasonable rates for the current market. As stated previously, the useful life of the timing plans was assumed to be 2 years. Based on contracted fees for traffic data collection, development of timing plans, implementing and field tuning of timing plans, the total cost was $33,065.39.

Table 13 - Equivalent Annual Cost of Timing Plans

Annual Interest Rate	Capital Recovery Factor	Equivalent Annual Cost
4%	0.5302	$17,531
5%	0.5378	$17,783
6%	0.5454	$18,035
7%	0.5531	$18,288
8%	0.5608	$18,542

* $33,065.39 Initial Cost and 2-year Service Life

2.7.2 Benefits

Many benefits can be derived from the improved signal timing, including vehicular emissions, reduced vehicular crashes, time savings, and fuel savings. Unfortunately, it is hard to put a dollar value on the public health benefits received by decreased vehicular emissions. Also, this study did not include a crash analysis; therefore, a dollar value for potential decreased vehicular crashes due to improved traffic flow was not included. However, it is possible to assign a dollar value to the time motorists save due to decreased travel time and the decreased fuel usage. The time saved can be measured by a dollar value using the following formula.

$S = R \times V \times D \times O \times C$

Where:
S = Dollars Saved
R = Travel Time Reduction
V = Volume
D = Days Timing in Effect
O = Average Vehicle Occupancy
C = Cost of Delay per Person Hour

The days the timings are in effect is assumed to be 250 days. The average vehicle occupancy is assumed to be 1.2, and the cost of delay per person is assumed to be $12.00 per person-hour.

The values for fuel consumption were obtained from travel run data collected using Qstar Logger and processed with Trav-time for the existing timing plans and the final timing plans. The cost of fuel is assumed to be $2.34 per gallon. **Table 14** shows the annual dollar value of the SC 7 (Sam Rittenberg Boulevard) and SC 171 (Old Towne Road) signal timing improvements for the three (3) analyzed peak periods.

Table 14 - Annual Travel Time and Fuel Consumption Cost Savings

Time Period	Volume (veh)	Annual Improvement				
		Travel Time (Veh-Hrs)	Value	Fuel Consumption (gallons)	Value	Total
SC 7 (Sam Rittenberg Boulevard)						
AM – NB	1,959	327	$4,702	1,841	$4,309	$9,011
AM - SB	1,304	(2,228)	$(32,078)	(231)	$(542)	$(32,620)
MIDDAY - NB	1,352	2,817	$40,560	(744)	$(1,740)	$38,820
MIDDAY - SB	1,552	970	$13,968	171	$399	$14,367
PM - NB	1,524	5,842	$84,125	(267)	$(624)	$83,501
PM - SB	2,534	2,745	$39,530	63	$148	$39,679
Subtotal	**10,225**	**10,473**	**$150,806**	**834**	**$1,951**	**$152,757**
SC 171 (Old Towne Road)						
AM – NB	2,404	902	$12,982	(6)	$(14)	$12,968
AM - SB	1,481	(2,468)	$(35,544)	144	$338	$(35,206)
MIDDAY - NB	1,388	3,239	$46,637	(49)	$(114)	$46,523
MIDDAY - SB	1,277	(1,011)	$(14,558)	(57)	$(134)	$(14,692)
PM - NB	1,869	8,800	$126,718	(271)	$(634)	$126,084
PM - SB	2,401	8,003	$115,248	54	$126	$115,374
Subtotal	**10,820**	**17,464**	**$251,483**	**(185)**	**$(432)**	**$251,051**
Total	**21,045**	**27,937**	**$402,289**	**649**	**$1,519**	**$403,808**

Note: Values shown in parentheses represent a negative value.

2.7.3 Cost/Benefit Analysis

The benefit to cost ratio is a measure of effectiveness for the new signal timing plans. It validates the time and money spent to improve the timing along the corridor. The ratio for the SC 7 (Sam Rittenberg Boulevard) and SC 171 (Old Towne Road) corridors was obtained by dividing the value of the annual benefits (reduced travel time and fuel consumption) by the equivalent annual cost. A benefit to cost ratio greater than one indicates the project's benefits outweigh the costs.

The total value of the benefits received by the motorists on SC 7 (Sam Rittenberg Boulevard) and SC 171 (Old Towne Road) is $403,808. The equivalent annual cost of designing, implementing, and documenting the improved signal timing plans ranges from $17,531 at 4% interest to $18,542 at 8% interest. **Table 15** shows the benefit to cost ratios for the interest rates ranging from 4% to 8%.

Table 15 - Cost/Benefit Analysis

Costs		Benefits			Benefit/ Cost Ratio
Interest Rate	Equivalent Annual Cost	Reduced Delay	Reduced Fuel Consumption	Total	
4%	$17,531	$402,289	$1,519	$403,808	23.0
5%	$17,783	$402,289	$1,519	$403,808	22.7
6%	$18,035	$402,289	$1,519	$403,808	22.4
7%	$18,288	$402,289	$1,519	$403,808	22.1
8%	$18,542	$402,289	$1,519	$403,808	21.8

As evident in **Table 15**, the benefit to cost ratio ranges from 21.8:1 to 23.0:1. The benefits calculated are only for the AM, Midday, and PM peaks.

2.8 CONCLUSIONS

Stantec, under contract with the City of Charleston, recently completed a project to develop and implement new coordinated signal timings for eight (8) signals along SC 7 (Sam Rittenberg Boulevard) and SC 171 (Old Towne Road) in the City of Charleston, Charleston County, South Carolina.

To determine the effectiveness of the new signal timing plans, travel time studies were performed using Qstar Logger and were processed with Trav-time to evaluate and document the results of the "before" and "after" studies that were conducted along the eight (8) intersections included in this project. The approximate lengths of the SC 7 (Sam Rittenberg Boulevard) and SC 171 (Old Towne Road) corridors are 1.8 miles and 1.2 miles, respectively. The travel time studies were conducted on typical weekdays during three (3) time periods of the day: AM Peak (7:00-9:00), Midday (11:00-13:00), and PM Peak (16:00-18:00).

The new signal timing plans implemented for the AM peak, Midday peak, and PM peak show improvements along SC 7 (Sam Rittenberg Boulevard) and SC 171 (Old Towne Road). The new timing plans have decreased the travel time and delay and increased the speeds throughout both corridors. The improvements in traffic flow are expected to decrease the carbon monoxide, oxides of nitrogen, and volatile organic compound emissions.

Delay incurs direct costs upon motorists in the form of increased fuel consumption and the value of their time wasted while waiting in traffic. Motorists using SC 7 (Sam Rittenberg Boulevard) and SC 171 (Old Towne Road) during the AM, Midday, and PM peak periods can be expected to save an estimated 27,937 hours each year because of the improved traffic flow due to the new timing plans.

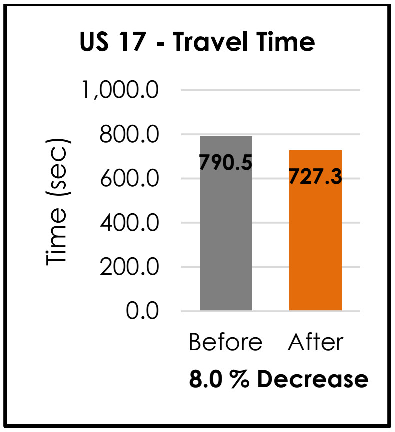
Conservatively assuming a vehicle occupancy of 1.2 persons/vehicle, $12.00 per hour for the value of motorists' time, and $2.34 per gallon for gasoline, annual savings to motorists along SC 7 (Sam Rittenberg Boulevard) and SC 171 (Old Towne Road) are estimated to be $402,289 in the form of reduced delay and $1,519 decrease in cost due to decreased fuel consumption, for an estimated total annual savings of $403,808.

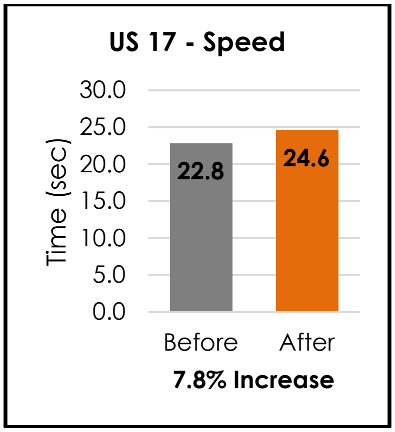
The Benefit to Cost ratio is between 21.8:1 and 23.0:1 for the SC 7 (Sam Rittenberg Boulevard) and SC 171 (Old Towne Road) corridors.

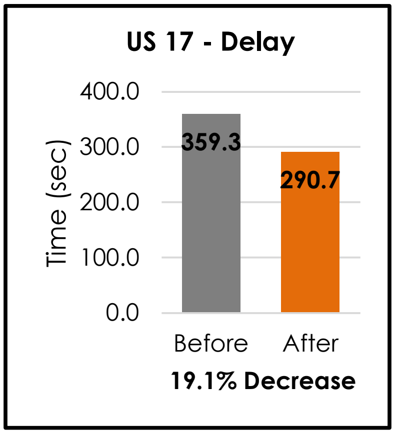
3.0 US 17 (SAVANNAH HIGHWAY) CORRIDOR

The project team, under contract to the City of Charleston, recently completed a project to develop and implement new coordinated signal timings for twenty-two (22) signals along and surrounding US 17 (Savannah Highway) in the City of Charleston, Charleston County, South Carolina. Travel time studies were only conducted for the seventeen (17) signals along the US 17 (Savannah Highway) corridor. The before and after results for the remaining five (5) signals are discussed later in this report.

To determine the effectiveness of the new signal timing plans, travel time studies were performed using GPS for the seventeen (17) signals along the US 17 (Savannah Highway) corridor to review and document the results of the timing plan development process. This report presents the results of the "before" and "after" studies that were conducted along the seventeen (17) intersections included in this project. The length of the corridor is approximately 4.5 miles. The travel time studies were conducted on typical weekdays during three time periods of the day: AM Peak (07:00-09:00), Midday (11:00-13:00), and PM Peak (16:00-18:00). The following charts show the average improvements experienced along US 17 (Savannah Highway) for both directions of travel during all three (3) time periods. Charts summarizing the detailed results by each timing plan are presented later in the report.

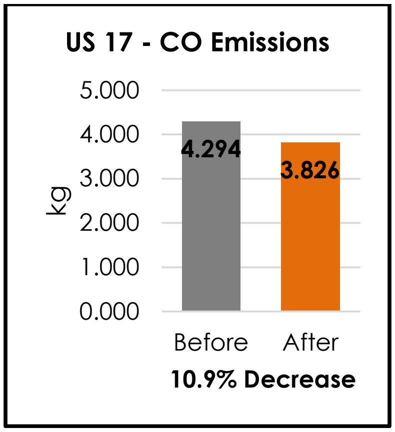




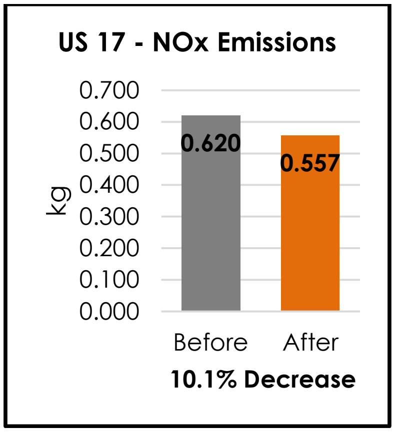


As evident in the graphs above, improvements were shown in travel time, delay and speed for the US 17 (Savannah Highway) corridor.

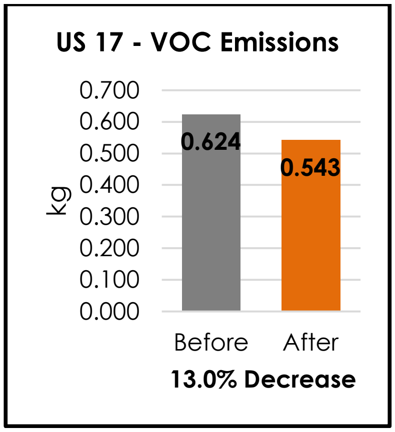
Carbon monoxide (CO), oxides of nitrogen (NOx), and volatile organic compounds (VOC) are three (3) types of vehicle emissions regulated by federal law. The following charts show the average improvements experienced along US 17 (Savannah Highway) for both directions of travel during all three (3) time periods. Charts summarizing the detailed results by each timing plan are present in subsequent sections of this report.



10.9% Decrease



10.1% Decrease



13.0% Decrease

As evident in the graphs above, improvements were shown in the carbon monoxide, oxides of nitrogen, and volatile organic compound emissions along US 17 (Savannah Highway).

Delay incurs direct costs upon motorists in the form of increased fuel consumption and the value of their time wasted while waiting in traffic. Motorists using US 17 (Savannah Highway) during the AM, Midday, and PM peak periods will save 98,878 hours each year because of the improved traffic flow due to the new timing plans.

Conservatively assuming a vehicle occupancy of 1.2 persons/vehicle, $12.00 per hour for the value of motorists' time, and $2.34 per gallon for gasoline, annual savings to motorists along US 17 (Savannah Highway) will be $1,423,843 in the form of reduced delay and $10,921 decrease in cost due to decreased fuel consumption, for a total annual savings of $1,434,764.

Other benefits not considered in this analysis include lower driver frustration levels and a potential reduction of accidents. All of the improvements mentioned in the report are for six (6) hours a day for each weekday during the AM, MD, and PM peak periods. New signal timing plans were also implemented during the off-peak and weekend hours. However, because benefit/cost "before" and "after" studies were not conducted during these time periods, additional savings could not be quantified during these periods.

Based on equivalent annual cost of designing, implementing, and documenting signal timing plan improvements, the benefit to cost ratios for interest rates ranging from 4% to 8% were calculated to be between 37.0:1 and 39.2:1 for this portion of the project.

3.1 INTRODUCTION

The purpose of this study was to improve traffic signal timing along the US 17 (Savannah Highway), which in turn reduces fuel consumption, vehicle emissions, driver delay, and driver stops / starts. The purpose of this report is to briefly summarize the data collection efforts and the existing conditions analysis for these intersections, as well as to identify options for improving intersection operation at these locations.

US 17 (Savannah Highway) is a four-lane, north-south roadway with a two-way-left-turn lane and a speed limit of 45 mph in the vicinity of the site. Based on 2015 South Carolina Department of Transportation (SCDOT) average annual daily traffic volumes, US 17 (Savannah Highway) carries 50,100 vehicles per day (vpd) in the vicinity of the project. US 17 (Savannah Highway), in the project limits, travels in an east-west direction.

Table 16 details each of the twenty-two (22) intersections, including each intersection's identification number, and **Figure 5** depicts the intersections and corridor.

Table 16 - Project Intersections

#	Intersection
125	US 17 (Savannah Highway) & Dobbin Road
124	US 17 (Savannah Highway) & Savage Road
192	US 17 (Savannah Highway) & Ashley Town Center Drive
123	US 17 (Savannah Highway) & SC 7 (Sam Rittenberg Boulevard)
119	US 17 (Savannah Highway) & I-526 Off Ramp
118	US 17 (Savannah Highway) & Skylark Drive
117	US 17 (Savannah Highway) & Orleans Road
116	US 17 (Savannah Highway) & Dupont Road
115	US 17 (Savannah Highway) & Wappoo Road
114	US 17 (Savannah Highway) & White Oak Circle
113	US 17 (Savannah Highway) & Markfield Drive
112	US 17 (Savannah Highway) & Wateree Drive / Parkwood Estates Drive
111	US 17 (Savannah Highway) & Farmfield Avenue / W Oak Forest Drive
110	US 17 (Savannah Highway) & Coburg Road
109	US 17 (Savannah Highway) & Magnolia Road / Avondale Avenue
99	US 17 (Savannah Highway) & Parish Road
97	US 17 (Savannah Highway) & Wesley Drive
207	SC 7 (Sam Rittenberg Boulevard) & Dupont Road
120	SC 7 (Sam Rittenberg Boulevard) & Orleans Road
246	Hazelwood Drive & Orleans Road
121	SC 7 (Sam Rittenberg Boulevard) & Skylark Drive
122	SC 7 (Sam Rittenberg Boulevard) & I-526 Off Ramp

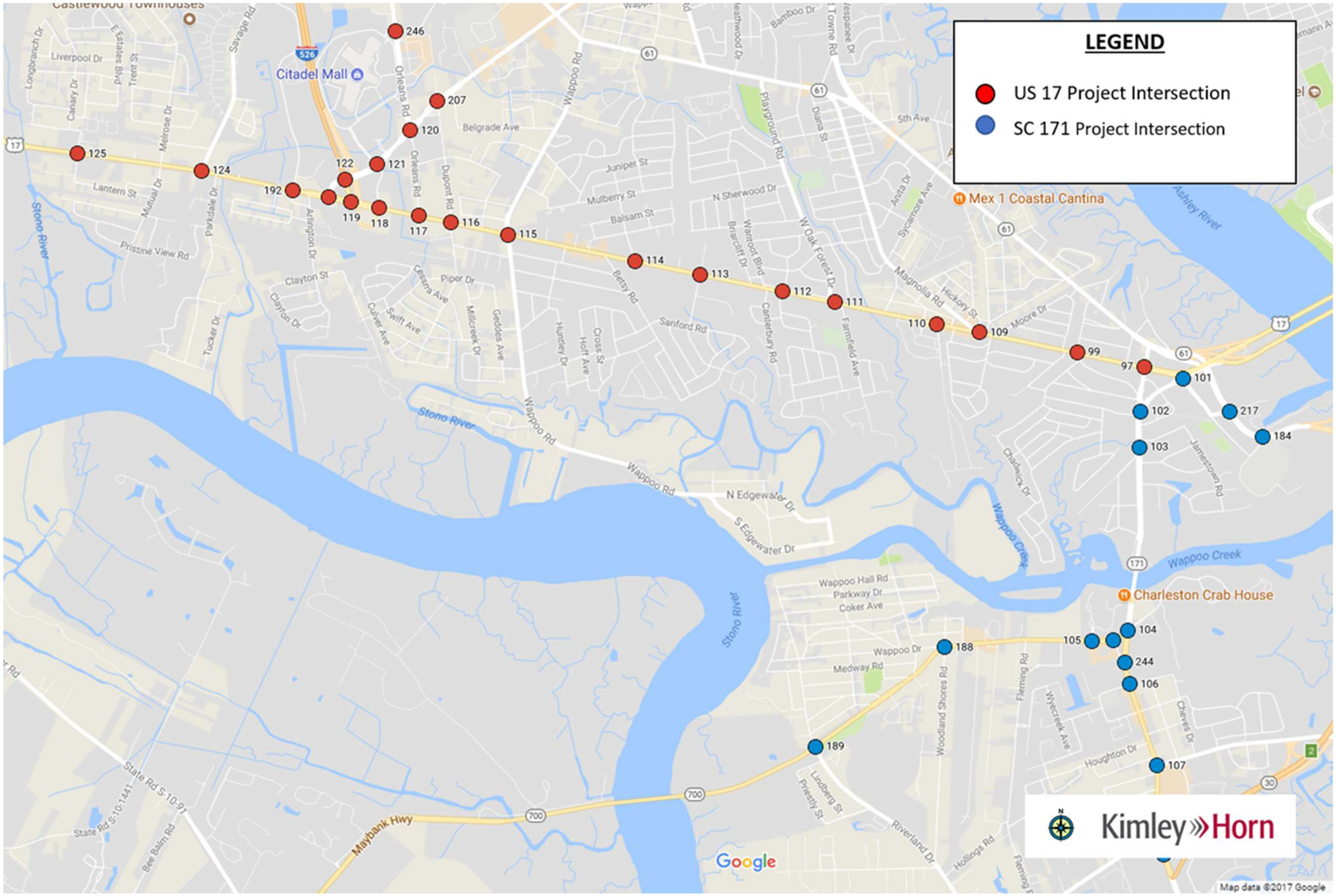


Figure 5 – Project Intersections

3.2 INVENTORY & DATA COLLECTION

3.2.1 Inventory

The project team completed an inventory of each of the project intersections. Information obtained consists of the intersection configuration, signing and marking configurations, signal phasing, pedestrian crossing dimensions, communication status, and detector status. The inventory limits were approximately 500-feet from the intersection along the mainline. The completed form for each intersection is provided in **Appendix A**.

3.2.2 Data Collection

Two (2) types of traffic volume data were used for this study. Average daily traffic (ADT) volumes and turning movement counts (TMC) and were used for the model development and time-of-day schedule. The ADT and TMC volume data is located in **Appendix B** and **Appendix C**, respectively.

ADT volumes were collected throughout April 2016 utilizing automatic traffic recorders (ATR) and consisted of four-day 24-hour bi-directional tube counts at three (3) locations. **Table 17** lists the 24-hour count locations. The count program is also depicted on **Figure 6**.

Table 17 – 24-Hour Bi-Directional Tube Count Locations

#	Location	Direction of Travel	Month of Counts
A	US 17 (Savannah Highway) East of Savage Road	Eastbound and Westbound	April
B	US 17 (Savannah Highway) East of Parish Road	Eastbound and Westbound	April
C	SC 7 (Sam Rittenberg Boulevard) North of Orleans Road	Northbound and Southbound	April

The 24-hour bi-directional tube counts were graphed, as shown on **Figures 7 and 8**, to show the traffic volumes throughout the day. The proposed TOD schedules are shown for reference on the Figures.

TMC data was collected at each signalized intersection on a weekday (Tuesday, Wednesday, or Thursday) during the following time frames: AM peak (07:00 – 09:00); Midday (MD) peak (11:00 – 13:00); and PM peak (16:00 – 18:00).

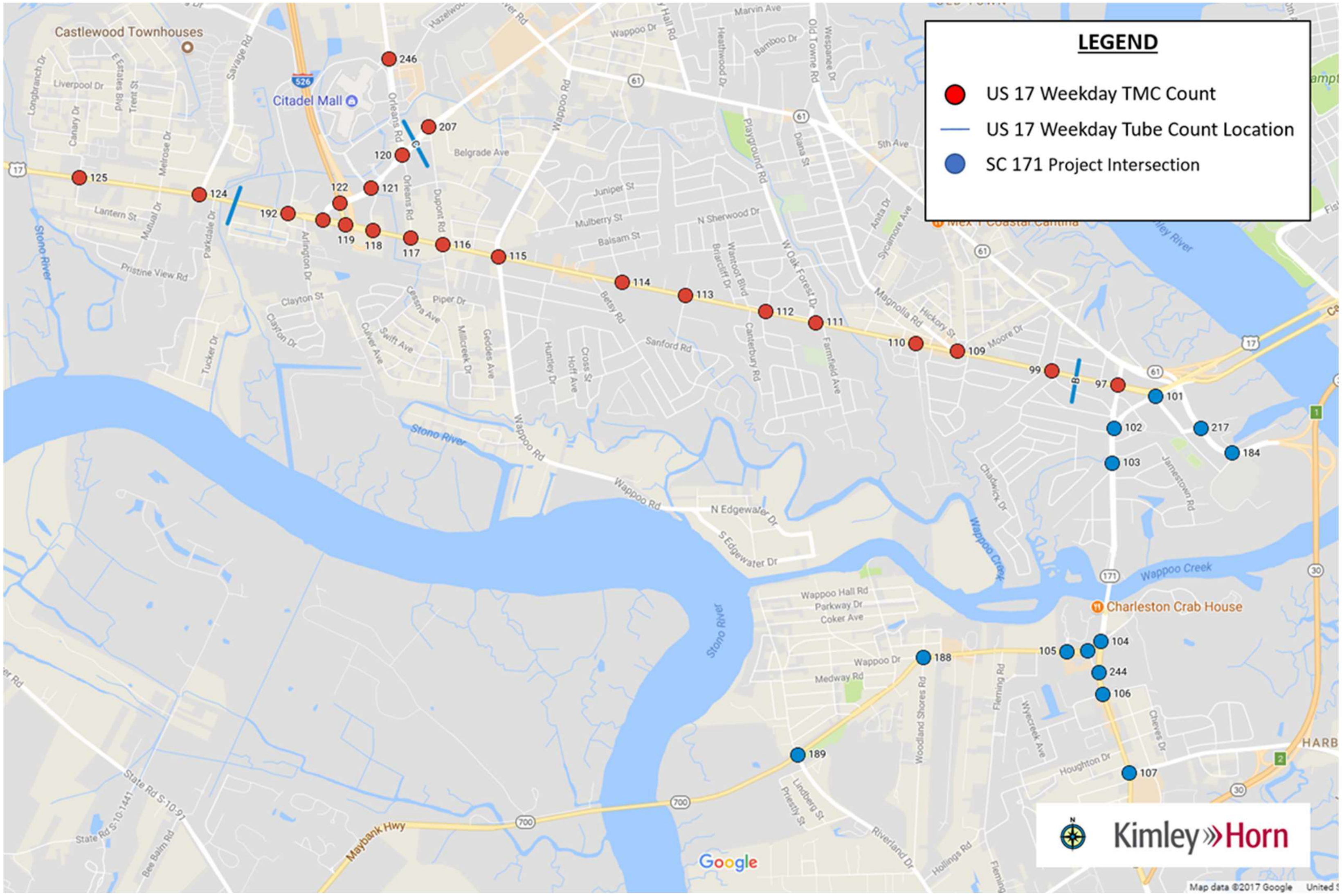


Figure 6 - Count Program

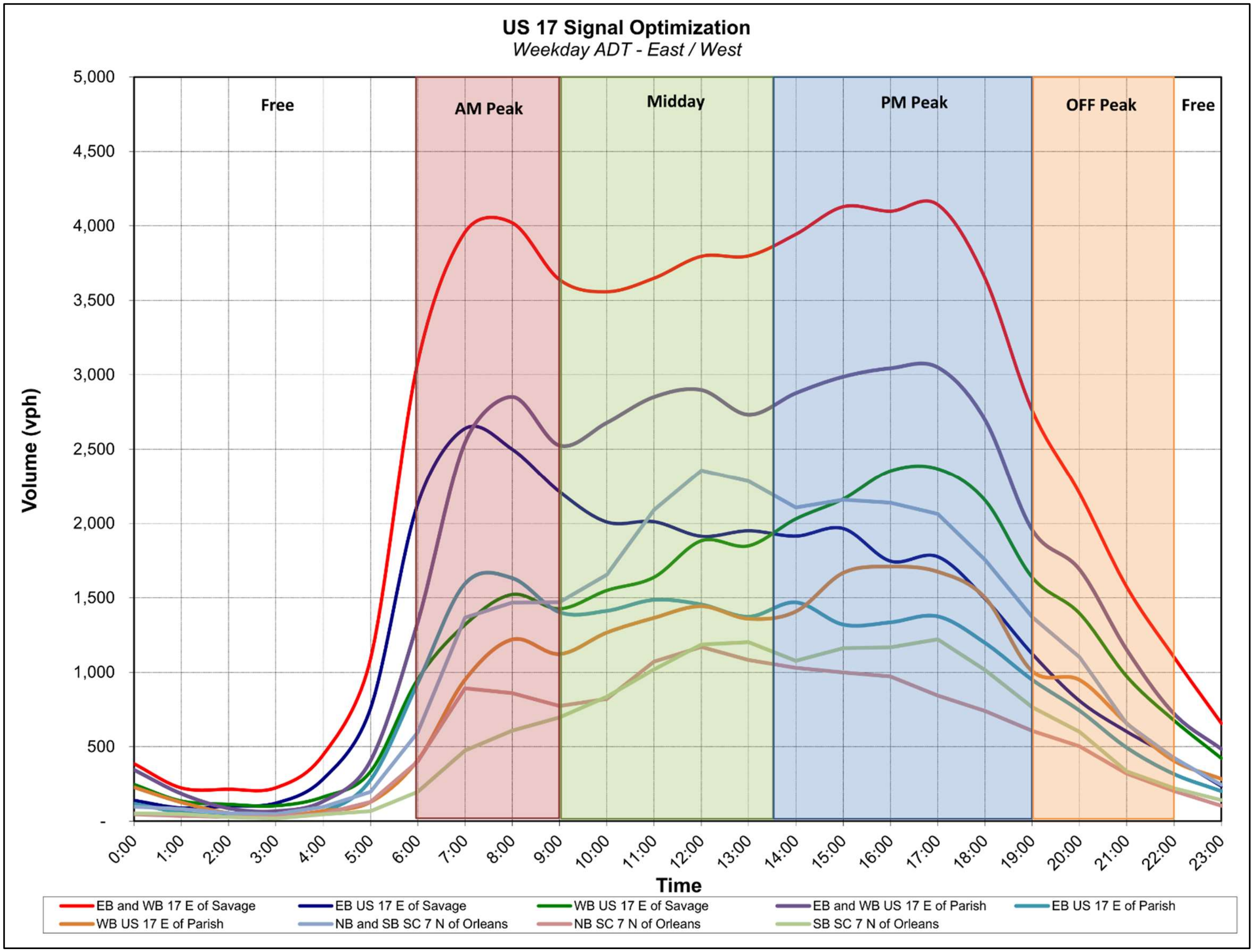


Figure 7 – Weekday Traffic Volumes

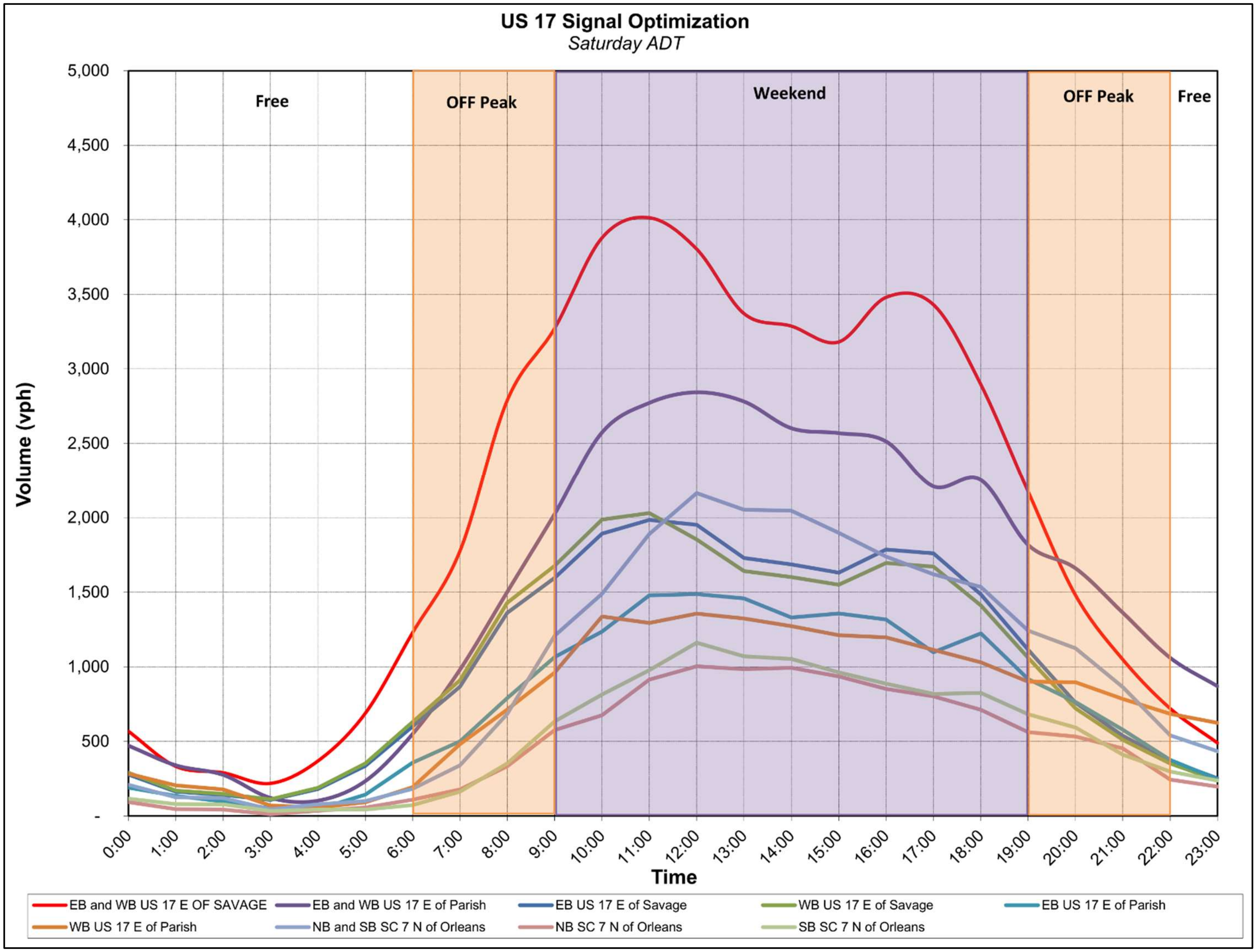


Figure 8 – Weekend Traffic Volumes

3.3 LOCAL TIMING PARAMETERS

Local controller timings were developed for each of the project intersections. **Table 18** details the methods used to develop the controller values that were used for each intersection. The clearance calculations were completed using the *SCDOT Clearance Time Calculations Spreadsheet Rev 2015-01-12* for each intersection. The clearance interval change sheets along with the clearance calculation are located in **Appendix D**.

Table 18 – Local Timing Parameters

<table>
<tr><th>Parameter</th><th colspan="2">Value</th></tr>
<tr><td colspan="3">PEDESTRIAN INTERVAL</td></tr>
<tr><td>Pedestrian Change Interval</td><td colspan="2">((Curb to Curb Distance) / (Walking Speed))</td></tr>
<tr><td>Walking Speed</td><td colspan="2">3.5 Feet per Second</td></tr>
<tr><td>Walk</td><td colspan="2">7 Seconds – Also calculated (Push button to far curb distance) / (walking speed of 3.0fps). If this number was greater than the calculated Pedestrian Change Interval then the difference was added to the Walk time.</td></tr>
<tr><td>Buffer Interval</td><td colspan="2">Following the pedestrian change interval, a buffer interval consisting of a steady UPRAISED HAND (symbolizing DON'T WALK) signal indication shall be displayed for at least 3 seconds prior to the release of any conflicting vehicular movement</td></tr>
<tr><td colspan="3">VEHICLE INTERVAL</td></tr>
<tr><td>Yellow Interval</td><td>t + (V/(2A + 64.4g))
Minimum of 3 seconds. Rounded up to nearest half second.
Left turn clearance calculations based on 20-MPH</td><td rowspan="12">t = perception reaction time (1 second)
V = posted speed in feet/second (25 mph for left turn clearances)
A = deceleration rate (10 feet/second/second)
W = intersection width measured from stop bar to the far edge of the last conflict lane (or crosswalk when the crosswalk is greater than 20' from the intersection)
L = length of vehicle (assume 20 feet)
g = The average of two field measured approach grades:
• At the stop bar
• At the setback loop (if present)
n = detection distance / 20
N = number of lanes</td></tr>
<tr><td>All Red Interval</td><td>(W + L) / V
Minimum of 1.5 seconds. Rounded up to nearest half second</td></tr>
<tr><td>Minimum Green</td><td>Maintained existing</td></tr>
<tr><td>Volume Density</td><td>Maintained existing</td></tr>
<tr><td>Minimum Cycle Length</td><td>90 seconds</td></tr>
<tr><td>Maximum Cycle Length</td><td>180 seconds</td></tr>
<tr><td>Offset Reference</td><td>End of Green</td></tr>
<tr><td>Offset Seeking</td><td>Short Way</td></tr>
<tr><td>Free Operation</td><td>Overnight hours</td></tr>
<tr><td>Lead/Lag by TOD?</td><td>Yes</td></tr>
<tr><td>Traffic Responsive Operation</td><td>No</td></tr>
<tr><td>Special Events</td><td>No</td></tr>
<tr><td colspan="3">CONTACT INFORMATION</td></tr>
<tr><td>Signal Systems Manager</td><td colspan="2">Troy Mitchell, City of Charleston</td></tr>
<tr><td>Law Enforcement</td><td colspan="2">City of Charleston Police Department</td></tr>
</table>

3.4 COORDINATION PARAMETERS

The timing plan development process for each intersection was developed with three (3) key objectives: (1) to progress all through movements on the primary arterial routes; (2) to favor progression in the predominant direction; and (3) to minimize overall system vehicular delay at all signalized intersections.

The timing plan development process includes five (5) distinct tasks:

- Cycle length determination
- Split allocation
- Offset manipulation / optimization
- Phase operation / sequencing
- Time-of-day clock development

The following subsections describe the methodology and tools used in each of the components of the timing plan development process.

3.4.1 Timing Plan Development

As discussed earlier, there were a number of field observations, traffic counts, signal settings, and miscellaneous data collection efforts undertaken to collect all of the data needed to evaluate the existing conditions of the corridors. This data was compiled in *Synchro 9,* which is a signal timing/optimization/simulation software package accepted in the industry. The existing and proposed *Synchro* timing reports are included in **Appendix E** and time-space diagrams are included in **Appendix F**.

3.4.1.1 Cycle Length Determination

The project team created *Synchro* network files for the AM, Midday (MD), PM, Off-Peak (OP), and Weekend (WKND) peak periods. The traffic counts, signal settings, and geometric characteristics from the field survey notes were coded into the *Synchro*. These characteristics included the following items for each intersection approach:

- Number of lanes
- Lane configurations (left, through, right or shared use)
- Storage bay lengths to the nearest five (5) ft increment
- Approach percent grades
- Link speeds (posted speed limits)

- Saturation flow rate of 1,900 vehicles per hour

Each peak period was evaluated using *Synchro* analysis tools and observations of existing characteristic. The cycle lengths were evaluated for a range of 110 seconds to 200 seconds at 10-second intervals.

The existing corridor utilizes coordinated timing plans with cycle lengths that range from 70 seconds to 140 seconds, utilizing half-cycle lengths at some intersections. The AM and PM implemented timing plans operate with a 170 second cycle length and 85 second half-cycle length at some intersections. The Midday and Weekend implemented timing plans operates with a 150 second cycle length and 75 second half cycle length at some intersections. The Off-peak implemented timing plan operates with a 130 second cycle length and 65 second half cycle length at some intersections.

3.4.1.2 Split Allocation and Offset Manipulation / Optimization

Once cycle lengths and clearance intervals were determined, each intersection was evaluated to determine the optimal vehicle split allocations. Split allocations were determined based upon the calculated time per movement and the minimum vehicle splits and pedestrian timing requirements. The chosen splits were then input into the proposed Synchro models and simulated in SimTraffic to identify any queuing issues or storage by spillovers prior to implementation of the timing plans.

The optimization task was then performed on the Synchro models for each timing plan by determining the optimal offset per intersection in order to optimize traffic progression along the corridor. Progression of traffic along the heavier direction of travel was favored during heavy inbound and outbound periods of the day. Dual progression (equal allotments of green band widths in both directions) was the goal during the Midday and Off-peak timing plans.

3.4.1.3 Phasing Operation / Sequencing

While developing the optimized timing plans, each intersection was analyzed for potential changes to the phase operation or sequencing. In particular, intersections with leading protected-only left turns were analyzed to determine if a lagging permissive-protected left turn phase could be utilized instead. Generally, lagging permissive-protected left turns are preferred, because left turning vehicles are able to use the gaps in oncoming traffic to complete their movement. This means that left-turn split times can be reduced and more time can be given to through movements.

3.4.1.4 Time of Day Clock Development

A time-of-day (TOD) analysis was performed based upon the ADT hourly volumes along the corridors. Existing TOD schedule for surrounding signals were also taken into consideration when developing recommendations. The existing TOD schedule and cycle lengths varied between the project intersections however, the most common TOD schedule is shown in **Table 19**. The standard TOD schedule and cycle lengths that were proposed and implemented along US 17 (Savannah Highway) and the surrounding intersections is also shown in **Table 19.**

Table 19 – Time-of-Day/Day-of-Week Schedule

Day	HH:MM (Start Time)	Plan #	Cycle (Sec)	Decription
EXISTING				
Saturday-Sunday	00:00	14		Free
Saturday-Sunday	06:00	24		Free + Max 2
Saturday-Sunday	08:00	3	130	OP
Saturday-Sunday	22:00	14		Free
Monday-Friday	00:00	14		Free
Monday-Friday	05:45	21		Free + Max 2
Monday-Friday	06:00	1	140	AM
Monday-Friday	09:00	3	130	MD
Monday-Friday	13:30	2	140	PM
Monday-Friday	19:00	3	120, 130	OP
Monday-Friday	22:00	14		Free
IMPLEMENTED				
Saturday-Sunday	00:00	14		Free
Saturday-Sunday	06:00	5	130	OP
Saturday-Sunday	09:00	6	150	WKND
Saturday-Sunday	19:00	5	130	OP
Saturday-Sunday	22:00	14		Free
Monday-Friday	00:00	14		Free
Monday-Friday	06:00	1	170	AM
Monday-Friday	09:00	2	150	MD
Monday-Friday	13:30	3	170	PM
Monday-Friday	19:00	4	130	OP
Monday-Friday	21:00	14		Free

3.5 OPERATIONAL ANALYSIS

3.5.1 Methodology for Before and After Studies

The travel time, average speed, and delay studies were conducted in accordance with the procedures given in the *Manual of Transportation Engineering Studies*, published by the Institute of Transportation Engineers. Travel time, average speed, and delay studies were conducted in both the westbound and eastbound directions on US 17 (Savannah Highway) during the weekday AM peak (07:00-09:00), Midday peak (11:00-13:00), and PM peak (16:00-18:00) periods. A minimum of five (5) runs was made in each direction. The "floating car" technique was used, whereby the driver passes as many cars as pass the driver. Travel times were performed along the follow two (2) sections of the US 17 (Savannah Highway) system:

- Route 1: US 17 (Savannah Highway) westbound from Dobbin Road to Wesley Drive
- Route 2: US 17 (Savannah Highway) eastbound from Wesley Drive to Dobbin Road

The study vehicle was unmarked and operated as inconspicuously as possible. The operator recorded the stops and travel time experienced during each run. The weekday "before" runs were collected for US 17 (Savannah Highway) October 18 and 19, 2016. The weekday "after" runs were collected for US 17 (Savannah Highway) on April 18, 19, and 20, 2017. The GPS travel run data was collected using Qstar Logger and was processed with Trav-time. The tables below summarize the "before" and "after" travel time, average speed, delay, and number of stops, as well as atmospheric pollutants carbon monoxide (CO), oxides of nitrogen (NOx), and volatile organic compounds (VOC), which are vehicle emissions regulated by federal law. The data below is shown for each time period and direction of travel. The travel time reports are included in **Appendix G**.

Table 20 – Average Travel Time (sec)

US 17 (Savannah Highway)						
	AM		Midday		PM	
Direction of Travel	**WB**	**EB**	**WB**	**EB**	**WB**	**EB**
Before	535.8	1181.4	622.8	671.4	1033.8	697.8
After	476.4	985.8	613.2	680.4	996.0	612.0
% Difference	**-11.1%**	**-16.6%**	**-1.5%**	**1.3%**	**-3.7%**	**-12.3%**

Table 21 – Average Delay (sec)

US 17 (Savannah Highway)						
	AM		Midday		PM	
Direction of Travel	**WB**	**EB**	**WB**	**EB**	**WB**	**EB**
Before	104.40	779.40	177.00	236.40	607.20	251.40
After	54.00	547.80	165.60	214.80	594.60	167.40
% Difference	**-48.3%**	**-29.7%**	**-6.4%**	**-9.1%**	**-2.1%**	**-33.4%**

Table 22 – Average Speed (mph)

US 17 (Savannah Highway)						
	AM		Midday		PM	
Direction of Travel	**WB**	**EB**	**WB**	**EB**	**WB**	**EB**
Before	31.11	14.14	26.81	24.83	16.12	23.94
After	34.99	16.95	27.17	24.55	16.74	27.30
% Difference	**12.5%**	**19.9%**	**1.3%**	**-1.1%**	**3.8%**	**14.0%**

Table 23 – Average Number of Stops

US 17 (Savannah Highway)						
	AM		Midday		PM	
Direction of Travel	**WB**	**EB**	**WB**	**EB**	**WB**	**EB**
Before	3.71	20.67	4.14	5.43	17.00	5.67
After	1.88	13.14	5.57	4.88	14.67	5.00
% Difference	**-49.3%**	**-36.4%**	**34.5%**	**-10.1%**	**-13.7%**	**-11.8%**

Table 24 – Average Carbon Monoxide Emissions (kg)

US 17 (Savannah Highway)						
	AM		Midday		PM	
Direction of Travel	**WB**	**EB**	**WB**	**EB**	**WB**	**EB**
Before	2.414	7.343	2.933	3.464	5.959	3.652
After	1.988	5.954	2.836	3.358	5.726	3.092
% Difference	**-17.7%**	**-18.9%**	**-3.3%**	**-3.1%**	**-3.9%**	**-15.3%**

Table 25 – Average Oxides of Nitrogen Emissions (kg)

US 17 (Savannah Highway)						
	AM		Midday		PM	
Direction of Travel	**WB**	**EB**	**WB**	**EB**	**WB**	**EB**
Before	0.373	1.007	0.451	0.509	0.849	0.531
After	0.319	0.819	0.440	0.503	0.815	0.449
% Difference	**-14.6%**	**-18.6%**	**-2.6%**	**-1.3%**	**-3.9%**	**-15.5%**

Table 26 – Average Volatile Organic Compound Emissions (kg)

US 17 (Savannah Highway)						
	AM		Midday		PM	
Direction of Travel	**WB**	**EB**	**WB**	**EB**	**WB**	**EB**
Before	0.289	1.183	0.371	0.473	0.918	0.512
After	0.209	0.936	0.355	0.455	0.879	0.426
% Difference	**-27.7%**	**-20.9%**	**-4.4%**	**-3.9%**	**-4.2%**	**-16.9%**

During the AM peak period approximately 60 percent of the traffic is traveling eastbound along US 17 (Savannah Hwy) from the I-526 Ramps toward downtown Charleston. The westbound and eastbound directions of travel experienced great improvement during the AM peak period. The eastbound travel time was reduced by 16.6 percent, average speed was increased by 19.9 percent, delay was reduced by 29.7 percent, and the number of stops was reduced by 36.4 percent. The westbound travel time was reduced by 11.1 percent, average speed was increased by 12.5 percent, delay was reduced by 48.3 percent, and the number of stops was reduced by 49.3 percent.

During the MD peak period the traffic flow is approximately balanced between the eastbound and westbound directions with many turning movement patterns in the middle of the corridor. The middle of the US 17 (Savannah Highway) corridor includes many shopping centers and restaurants. During the MD peak these shopping areas are destinations for vehicles along the corridor and create turning traffic flow patterns rather than end-to-end progression. The focus of reducing overall delay during this balanced volume period is illustrated by the slight change in travel time but greater reduction in delay. The eastbound travel time was increased by 1.3 percent while delay was reduced by 9.1 percent. The westbound travel time was reduced by 1.5 percent while delay was reduced by 6.4 percent.

During the PM peak period approximately 55 percent of the traffic is traveling westbound and approximately 45 percent of the traffic is traveling eastbound along US 17 (Savannah Highway). The heavy left turn movements from northbound SC 171 (Folly Road) and heavy left- and right-turn movements from the I-526 ramps during the PM peak were balanced with corridor end-to-end progression. For example, the new signal timings included progression of the heavy southbound right-turn movement from SC 7 (Sam Rittenberg Boulevard) onto westbound US 17 (Savannah Highway), as well as the heavy eastbound left-turn movement from US 17 (Savannah Highway) onto SC 7 (Sam Rittenberg Boulevard). The new signal timings included progression of the heavy northbound left-turn movement from SC 171 (Folly Road) onto westbound US 17 (Savannah Highway) to reduce queuing at signals upstream of the intersection. The eastbound travel time was reduced by 12.3 percent, average speed was increased by 14 percent, delay was reduced by 33.4 percent, and the number of stops was reduced by 11.8 percent. The westbound travel time was reduced by 3.7 percent, average speed was increased by 3.9 percent, delay was reduced by 2.1 percent, and the number of stops was reduced by 13.7 percent.

3.5.2 LOS and Delay Analysis

Synchro 9.1 was also used to prepare an evaluation of intersection operations to determine the Level of Service (LOS) and average delay of the existing condition (existing geometry, existing signal timings, and existing traffic volumes), the proposed condition (existing geometry, proposed signal timings, and existing traffic volumes), and final condition (existing geometry, implemented signal timings, and existing traffic volumes). This capacity analysis methodology is based on the *2010 Highway Capacity Manual (HCM)*, a standard guidance for capacity analysis, which defines LOS at signalized intersections in terms of average control delay per vehicle, which is composed of initial deceleration delay, queue move-up time, stopped delay, and final acceleration delay. LOS ranges from A to F, with LOS A indicating operations with very low control delay and LOS F describing operations with extremely high average control delay. In the comparison between existing, proposed, and final timings, the LOS and delay should improve for the overall corridor, but may not increase or decrease at individual intersections depending on what was running before.

The primary goal for timing the US 17 (Savannah Highway) corridor was to increase efficiency along the routes during all peaks for all major movements not just end-to-end progression. The volume-to-capacity (V/C) ratios were also included in the analysis to measure capacity demand of each intersection since delay on side streets can sometimes skew an intersection delay even if the respective queues are under capacity. Overall, corridor offsets were adjusted to reduce queuing and delay.

The results of the existing, proposed, and final conditions are shown in **Table 27**. Synchro LOS and Delay outputs are included in **Appendix E**. Although some of LOS and delays results under the final plans yielded worse values than the existing modules, the signal timings have been optimized to accommodate improved progression and capacity efficiency throughout the system. Meanwhile, all LOS results remain at 'D' or better with several intersections expected to perform with even better results.

The LOS, delay and V/C ratios varied in the field upon implementation of the proposed timing plans. Overall, the US 17 (Savannah Highway) system has driveways and stop-controlled intersections that were not modeled in the analysis. Consequently, varying speeds, geometric constraints, and volume additions and subtractions between the study intersections contributed various results that can affect the overall progression and flow of the corridor. Adjustments to the splits and offsets were incorporated in the field during fine tuning upon observation of actual driver behavior.

Table 27 – Existing, Proposed, and Implemented Level of Service and Average Delay

#	Intersection	Existing		Proposed		Implemented	
		LOS	Control Delay (sec/veh)	LOS	Control Delay (sec/veh)	LOS	Control Delay (sec/veh)
AM PEAK PERIOD							
125	US 17 (Savannah Hwy) & Dobbin Rd	A	9.5	B	12.8	B	12.3
124	US 17 (Savannah Hwy) & Savage Rd	B	16.2	C	28.1	C	21.2
192	US 17 (Savannah Hwy) & Ashley Town Center Dr	D	37.8	C	27.5	C	29.8
123	US 17 (Savannah Hwy) & SC 7 (Sam Rittenberg Blvd)	B	10.4	B	15.0	B	10.9
119	US 17 (Savannah Hwy) & I-526 Off Ramp	B	16.7	B	13.0	B	13.9
118	US 17 (Savannah Hwy) & Skylark Dr	A	8.2	A	7.3	A	9.9
117	US 17 (Savannah Hwy) & Orleans Rd	B	18.4	A	8.8	B	13.5
116	US 17 (Savannah Hwy) & Dupont Rd	B	14.1	B	15.0	B	15.4
115	US 17 (Savannah Hwy) & Wappoo Rd	C	31.4	D	43.2	D	44.4
114	US 17 (Savannah Hwy) & White Oak Cir	B	11.7	A	9.3	B	15.2
113	US 17 (Savannah Hwy) & Markfield Dr	B	13.0	B	18.0	B	11.6
112	US 17 (Savannah Hwy) & Wateree Dr / Parkwood Estates Dr	A	2.6	A	7.9	A	2.9
111	US 17 (Savannah Hwy) & Farmfield Ave / W Oak Forest Dr	B	12.5	B	14.3	B	10.7
110	US 17 (Savannah Hwy) & Coburg Rd	B	13.0	C	22.5	C	21.3
109	US 17 (Savannah Hwy) & Magnolia Rd / Avondale Ave	B	8.2	B	13.3	B	15.9
99	US 17 (Savannah Hwy) & Parish Rd	B	18.5	B	19.3	C	24.8
97	US 17 (Savannah Hwy) & Wesley Dr	E	79.5	F	111.2	E	73.0
207	SC 7 (Sam Rittenberg Blvd) & Dupont Rd	B	11.3	B	10.3	B	10.2
120	SC 7 (Sam Rittenberg Blvd) & Orleans Rd	C	22.7	D	38.4	C	31.5
246	Hazelwood Dr & Orleans Rd	A	8.2	B	18.4	B	11.4
121	SC 7 (Sam Rittenberg Blvd) & Skylark Dr	B	14.5	B	16.7	B	16.2
122	SC 7 (Sam Rittenberg Blvd) & I-526 Off Ramp	C	24.4	B	15.3	B	18.4

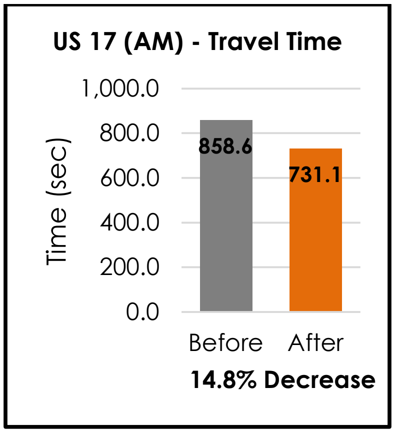
MID PEAK PERIOD							
125	US 17 (Savannah Hwy) & Dobbin Rd	A	4.6	A	5.9	A	5.4
124	US 17 (Savannah Hwy) & Savage Rd	B	17.6	B	12.9	B	15.2
192	US 17 (Savannah Hwy) & Ashley Town Center Dr	C	29.0	C	33.2	C	31.9
123	US 17 (Savannah Hwy) & SC 7 (Sam Rittenberg Blvd)	B	12.0	C	21.1	B	14.6
119	US 17 (Savannah Hwy) & I-526 Off Ramp	A	9.7	A	6.7	A	7.8
118	US 17 (Savannah Hwy) & Skylark Dr	B	12.7	A	9.5	A	8.5
117	US 17 (Savannah Hwy) & Orleans Rd	B	12.3	B	19.7	C	20.1
116	US 17 (Savannah Hwy) & Dupont Rd	B	12.3	B	14.9	B	17.1
115	US 17 (Savannah Hwy) & Wappoo Rd	C	22.3	C	27.4	C	31.5
114	US 17 (Savannah Hwy) & White Oak Cir	B	10.9	A	8.7	A	10.0
113	US 17 (Savannah Hwy) & Markfield Dr	B	15.4	B	14.8	B	15.2
112	US 17 (Savannah Hwy) & Wateree Dr / Parkwood Estates Dr	A	3.5	A	7.0	A	3.0
111	US 17 (Savannah Hwy) & Farmfield Ave / W Oak Forest Dr	A	8.6	B	15.8	B	14.1
110	US 17 (Savannah Hwy) & Coburg Rd	C	25.0	C	28.6	C	26.8
109	US 17 (Savannah Hwy) & Magnolia Rd / Avondale Ave	B	10.0	B	13.8	C	20.2
99	US 17 (Savannah Hwy) & Parish Rd	A	7.6	C	21.3	B	10.9
97	US 17 (Savannah Hwy) & Wesley Dr	D	49.8	D	38.2	D	38.4
207	SC 7 (Sam Rittenberg Blvd) & Dupont Rd	B	14.3	B	17.0	B	14.4
120	SC 7 (Sam Rittenberg Blvd) & Orleans Rd	D	38.6	D	44.5	D	36.1
246	Hazelwood Dr & Orleans Rd	C	24.1	C	31.5	C	28.0
121	SC 7 (Sam Rittenberg Blvd) & Skylark Dr	B	20.0	B	19.6	B	17.1
122	SC 7 (Sam Rittenberg Blvd) & I-526 Off Ramp	C	24.3	C	29.6	C	32.3

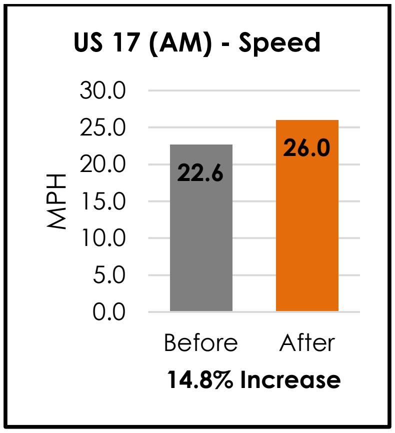
PM PEAK PERIOD							
125	US 17 (Savannah Hwy) & Dobbin Rd	A	3.7	A	4.5	A	4.1
124	US 17 (Savannah Hwy) & Savage Rd	B	16.9	C	21.8	C	22.2
192	US 17 (Savannah Hwy) & Ashley Town Center Dr	C	28.6	C	29.9	C	25.6
123	US 17 (Savannah Hwy) & SC 7 (Sam Rittenberg Blvd)	B	12.5	B	15.9	B	15.0
119	US 17 (Savannah Hwy) & I-526 Off Ramp	B	12.7	B	16.6	B	14.2
118	US 17 (Savannah Hwy) & Skylark Dr	B	10.9	B	13.0	B	18.4
117	US 17 (Savannah Hwy) & Orleans Rd	B	14.8	C	26.7	C	22.4
116	US 17 (Savannah Hwy) & Dupont Rd	B	18.4	C	20.7	C	21.1
115	US 17 (Savannah Hwy) & Wappoo Rd	C	24.9	D	39.2	C	34.5
114	US 17 (Savannah Hwy) & White Oak Cir	B	14.3	B	10.0	A	9.4
113	US 17 (Savannah Hwy) & Markfield Dr	B	11.5	B	15.2	B	16.5
112	US 17 (Savannah Hwy) & Wateree Dr / Parkwood Estates Dr	A	5.3	A	4.3	A	4.2
111	US 17 (Savannah Hwy) & Farmfield Ave / W Oak Forest Dr	B	10.5	B	19.5	B	16.0
110	US 17 (Savannah Hwy) & Coburg Rd	C	30.9	C	27.9	C	21.8
109	US 17 (Savannah Hwy) & Magnolia Rd / Avondale Ave	A	8.8	B	12.3	D	48.3
99	US 17 (Savannah Hwy) & Parish Rd	C	25.6	C	23.3	C	26.7
97	US 17 (Savannah Hwy) & Wesley Dr	F	89.2	E	71.4	E	59.1
207	SC 7 (Sam Rittenberg Blvd) & Dupont Rd	B	12.8	B	18.1	B	19.1
120	SC 7 (Sam Rittenberg Blvd) & Orleans Rd	D	35.9	D	35.2	D	49.3
246	Hazelwood Dr & Orleans Rd	C	28.3	C	26.8	C	23.6
121	SC 7 (Sam Rittenberg Blvd) & Skylark Dr	B	19.7	B	17.5	B	18.5
122	SC 7 (Sam Rittenberg Blvd) & I-526 Off Ramp	C	20.6	B	17.3	B	17.2

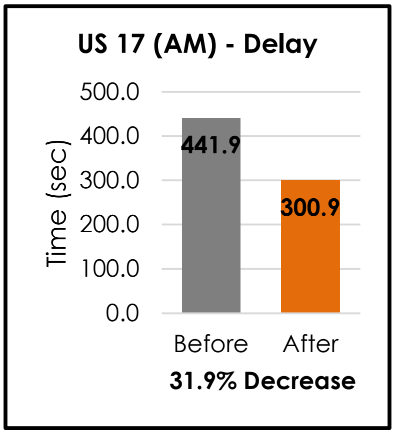
3.6 RESULTS SUMMARY

3.6.1 AM Peak Plan

The existing AM plan had a 140 second cycle length and ran from 06:00 to 09:00, Monday – Friday, at the majority of the intersections. The remaining intersection had a 70 second half-cycle length. This plan was replaced with a 170 second cycle length or 85 second half-cycle length that runs weekdays from 06:00 to 09:00 during the peak seen in the 24-hour counts. The predominant flow of traffic is eastbound toward downtown Charleston, with approximately 45 percent of the eastbound traffic onto I-526. As shown in the charts below, the implemented AM plan improved the combined averages of travel time, travel speed, and delay along the corridor. Along the corridor travel time, was reduced by nearly 15 percent, speed was increased by almost 15 percent, and delay was reduced by more than 31 percent.

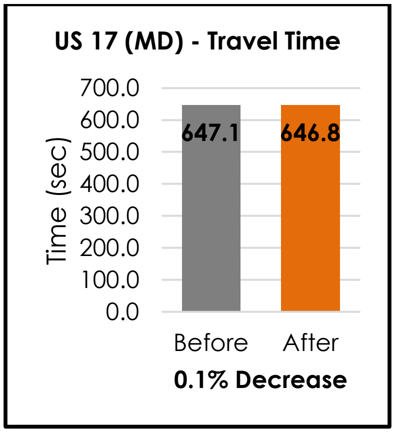




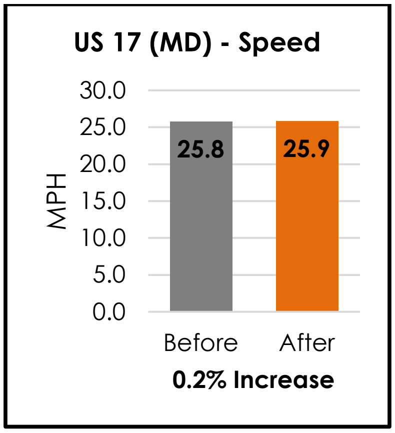


3.6.2 Midday Plan

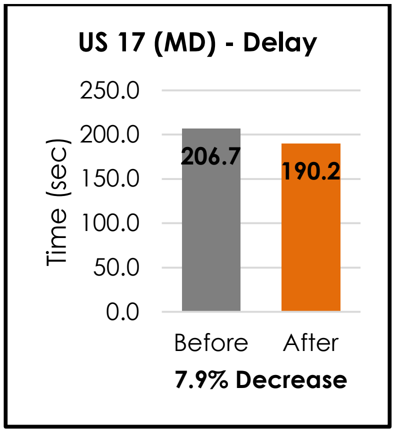
The existing Midday plan had a 130 second cycle length and ran from 09:00 to 13:30, Monday – Friday, at the majority of the intersections. The remaining intersections had a 65 second half-cycle length. This plan was replaced with a 150 second cycle length or 75 second half-cycle length that runs weekdays from 09:00 to 13:30 during the peak seen in the 24-hour counts. The traffic volumes are approximately balanced in both directions during the Midday peak. The implemented plans were focused on reducing the overall delay on the corridor, not necessarily the through progression along the corridor. As shown on the charts below, the implemented Midday plans provided slight improvements in the combined averages of travel time and in travel speed, while having greater benefits in the overall delay of the corridor. Along the corridor delay was reduced by nearly 8 percent.



0.1% Decrease



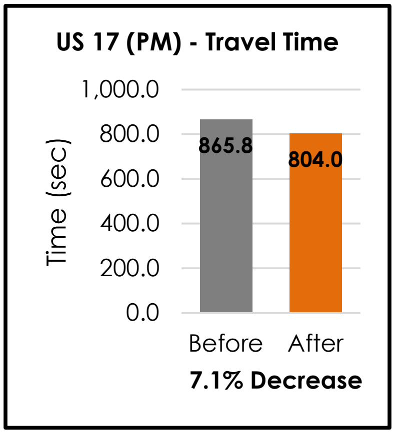
0.2% Increase



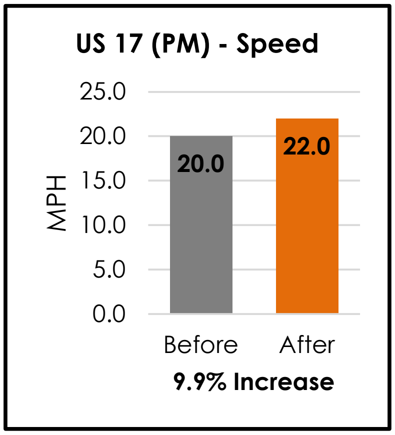
7.9% Decrease

3.6.3 PM Peak Plan

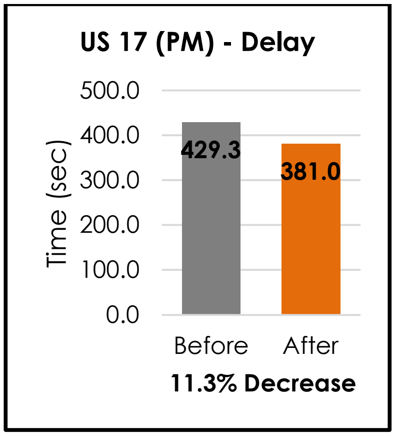
The existing PM plan had a 140 second cycle length and ran from 13:30 to 19:00, Monday – Friday, at the majority of the intersections. The remaining intersections operated with a 70 second half-cycle length. This plan was replaced with a 170 second cycle length or 85 second half-cycle that runs weekdays from 13:30 to 19:00 during the peak seen in the 24-hour counts. The predominant flow of traffic is westbound away from downtown Charleston, with approximately 35 percent of the westbound traffic tuning left from SC 171 (Folly Road). The secondary flow of traffic is eastbound from I-526 with approximately 45 percent of the traffic along US 17 (Savannah Highway). The implemented plans focused on the major turning movements as discussed previously to reflect the traffic flow patterns of the corridor. As shown in the charts below, the implemented PM plan improved the combined averages of travel time, travel speed, and delay for end-to-end progression along the corridor. Along the corridor travel time was decreased by over 7 percent, speed was increased by nearly 10 percent, and delay was decreased by over 11 percent.



7.1% Decrease



9.9% Increase



11.3% Decrease

3.6.4 Weekend Plans

The existing Weekend plan had a 130 second cycle length and ran from 08:00 to 22:00, Saturday and Sunday, at the majority of the intersections. The remaining intersections had a 65 second half-cycle length. This plan was replaced with a 150 second cycle length plan or 75 second half-cycle length runs weekends from 09:00 to 19:00 during the peak seen in the 24-hour counts. The traffic volumes are approximately balanced in both directions during the weekend peak. Weekend operations were observed during implementation and splits and offsets were adjusted to ensure that queuing and delay were within acceptable ranges.

3.7 EFFECTIVENESS EVALUATION

Improvements in traffic signal timing can also be measured using a cost versus benefit ratio. If the financial benefits to the drivers outweigh the financial cost of the project over its lifespan, then the project is worth the investment. The financial benefit to the drivers is seen through decreased driving time and fuel consumption due to improved traffic flow from the signal timing plans.

The signal timing plans will last until changes in volume or roadway characteristics decrease the efficiency of the signal system to move traffic. Development in the area can increase the volume and cause the need for roadway expansion. In order to determine the cost/benefit ratio for this report, the life span of the new signal timing plans was assumed to be 2 years.

3.7.1 Annual Costs

The cost of designing, implementing, and recording the timing plans and the interest associated with the capital invested are all factors involved in calculating the equivalent annual cost.

The formulas used to determine the project's costs are:

$E=R \times C$

Where:
E = Equivalent Cost
R = Capital Recovery Cost
C = Initial Cost

$R = i(1+i)^{n} / ((1+i)^{n} - 1)$

Where:
R = Capital Recovery Cost
i = Annual Interest Rate
n = Useful Life of Timing Plans

The equivalent annual costs, as calculated, using the above formulas, for US 17 (Savannah Highway) are shown in **Table 28**. The table shows interest rates ranging from 4% to 8%, which are assumed to be reasonable rates for the current market. As stated previously, the useful life of the timing plans was assumed to be 2 years. Based on contracted fees for traffic data collection, development of timing plans, implementing and field tuning of timing plans, the total cost was $69,070.40.

Table 28 - Equivalent Annual Cost of Timing Plans

Annual Interest Rate	Capital Recovery Factor	Equivalent Annual Cost
4%	0.5302	$36,621
5%	0.5378	$37,146
6%	0.5454	$37,674
7%	0.5531	$38,202
8%	0.5608	$38,733

* $69,070.40 Initial Cost and 2-year Service Life

3.7.2 Benefits

Many benefits can be derived from the improved signal timing, including vehicular emissions, reduced vehicular crashes, time savings, and fuel savings. Unfortunately, it is hard to put a dollar value on the public health benefits received by decreased vehicular emissions. Also, this study did not include a crash analysis; therefore, a dollar value for potential decreased vehicular crashes due to improved traffic flow was not included. However, it is possible to assign a dollar value to the time motorists save due to decreased travel time and the decreased fuel usage. The time saved can be measured by a dollar value using the following formula.

$$S = R \times V \times D \times O \times C$$

Where:
S = Dollars Saved
R = Travel Time Reduction
V = Volume
D = Days Timing in Effect
O = Average Vehicle Occupancy
C = Cost of Delay per Person Hour

The days the timings are in effect is assumed to be 250 days. The average vehicle occupancy is assumed to be 1.2, and the cost of delay per person is assumed to be $12.00 per person-hour.

The values for fuel consumption were obtained from travel run data collected using Qstar Logger and processed with Trav-time for the existing timing plans and the final timing plans. The cost of fuel is assumed to be $2.34 per gallon. **Table 29** shows the annual dollar value of the US 17 (Savannah Highway) signal timing improvements for the three analyzed peak periods.

Other benefits not considered in this analysis include lower driver frustration levels and a potential reduction of accidents. All of the improvements mentioned in the report are for six (6) hours a day for each weekday during the AM, MD, and PM peak periods along US 17 (Savannah Highway).

Table 29 - Annual Travel Time and Fuel Consumption Cost Savings

Time Period	Volume (veh/hr)	Annual Improvement				
		Travel Time (Veh-Hrs)	Value	Fuel Consumption (gallons)	Value	Total
US 17 (Savannah Highway)						
AM – WB	1,451	11,971	$172,382	693	$1,622	$174,004
AM - EB	2,091	56,806	$818,006	5,259	$12,306	$830,312
MIDDAY - WB	1,672	2,229	$32,098	(322)	$(753)	$31,345
MIDDAY - EB	1,765	(2,206)	$(31,766)	(1,253)	$(2,932)	$(34,698)
PM - WB	1,968	10,332	$148,781	(128)	$(300)	$148,481
PM - EB	1,657	19,746	$284,342	418	$978	$285,320
Total	**10,604**	**98,878**	**$1,423,843**	**4,667**	**$10,921**	**$1,434,764**

Note: Values shown in parentheses represent a negative value.

3.7.3 Cost/Benefit Analysis

The benefit to cost ratio is a measure of effectiveness for the new signal timing plans. It validates the time and money spent to improve the timing along the corridor. The ratio for the US 17 (Savannah Highway) corridor was obtained by dividing the value of the annual benefits (reduced travel time and fuel consumption) by the equivalent annual cost. A benefit to cost ratio greater than one indicates the project's benefits outweigh the costs.

The total value of the benefits received by the motorists on US 17 (Savannah Highway) is $1,434,764. The equivalent annual cost of designing, implementing, and documenting the improved signal timing plans ranges from $36,621 at 4% interest to $38,733 at 8% interest. **Table 30** shows the benefit to cost ratios for the interest rates ranging from 4% to 8%.

Table 30 - Cost/Benefit Analysis

Costs		Benefits			Benefit/ Cost Ratio
Interest Rate	Equivalent Annual Cost	Reduced Delay	Reduced Fuel Consumption	Total	
4%	$36,621	$1,423,843	$10,921	$1,434,764	39.2
5%	$37,146	$1,423,843	$10,921	$1,434,764	38.6
6%	$37,674	$1,423,843	$10,921	$1,434,764	38.1
7%	$38,202	$1,423,843	$10,921	$1,434,764	37.6
8%	$38,733	$1,423,843	$10,921	$1,434,764	37.0

As evident in **Table 30**, the benefit to cost ratio ranges from 37.0:1 to 39.2:1. The benefits calculated are only for the AM, MD, and PM peaks.

3.8 CONCLUSIONS

New coordinated signal timings were developed and implemented for twenty-two (22) signals along and surrounding US 17 (Savannah Highway) in the City of Charleston, Charleston County, South Carolina.

To determine the effectiveness of the new signal timing plans, travel time studies were performed using Qstar Logger and processed with Trav-time to evaluate and document the results of the timing plan development process. The report presents the results of the “before” and “after” studies that were conducted along the seventeen (17) intersections included in the travel time studies along the US 17 (Savannah Highway) corridor. The length of the corridor is approximately 4.5 miles. The travel time studies were conducted on typical weekdays during three (3) time periods of the day: AM Peak (07:00-09:00), Midday (11:00-13:00), and PM Peak (16:00-18:00).

The new signal timing plans implemented for the AM peak, Midday peak, and PM peak show improvements along US 17 (Savannah Highway). The new timing plans have decreased travel time and delay and increased the speeds through the corridor. The improvements in traffic flow are expected to decrease carbon monoxide, oxides of nitrogen, and volatile organic compound emissions.

Delay incurs direct costs upon motorists in the form of increased fuel consumption and the value of their time wasted while waiting in traffic. Motorists using US 17 (Savannah Highway) during the AM, Midday, and PM peak periods will save hours each year because of the improved traffic flow due to the new timing plans.

Conservatively assuming a vehicle occupancy of 1.2 persons/vehicle, $12.00 per hour for the value of motorists’ time, and $2.34 per gallon for gasoline, annual savings to motorists along US 17 (Savannah Highway) will be $1,423,843 in the form of reduced delay and $10,921 due to decreased fuel consumption, for a total annual savings of $1,434,764.

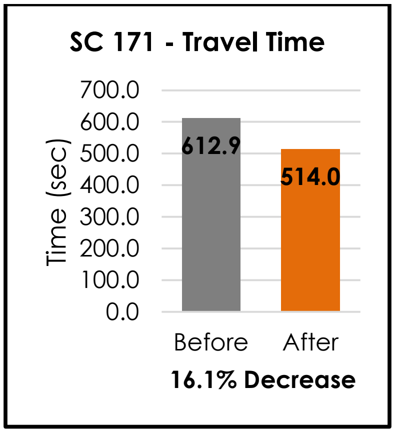
Other benefits not considered in this analysis include lower driver frustration levels and a potential reduction of accidents. All of the results mentioned in the report are for six (6) hours a day for each weekday during the AM, MD, and PM peak periods, along US 17 (Savannah Highway). New signal timing plans were also implemented at five (5) additional intersections in addition to the new timing plans at all project intersections during Off-peak and weekend hours. However, because benefit/cost “before” and “after” studies were not conducted during these time periods, additional savings could not be quantified during these periods.

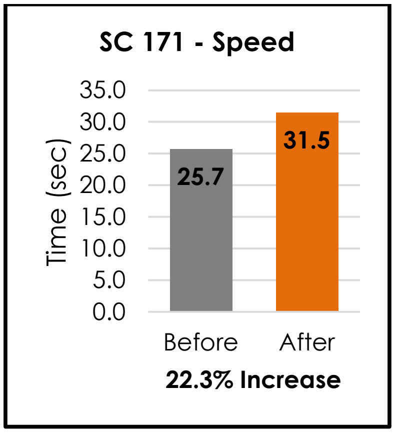
The Benefit to Cost ratio is between 37.0:1 and 39.2:1 for the US 17 (Savannah Highway) corridor.

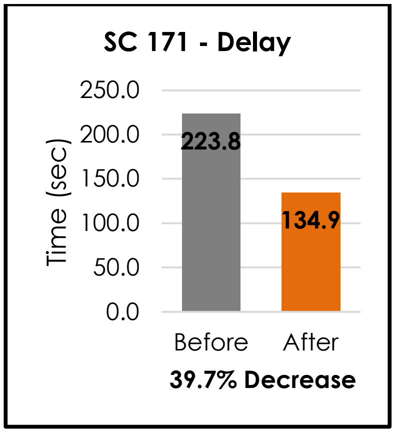
4.0 SC 171 (FOLLY ROAD) CORRIDOR

The consultant team, under contract to the City of Charleston, recently completed a project to develop and implement new coordinated signal timings for twenty (20) signals along and surrounding SC 171 (Folly Road) in the City of Charleston, Charleston County, South Carolina. Travel time studies were only conducted for the thirteen (13) signals along the SC 171 (Folly Road) corridor. The before and after results for the remaining seven (7) signals are discussed later in this report.

To determine the effectiveness of the new signal timing plans, travel time studies were performed using GPS for the thirteen (13) signals along the SC 171 (Folly Road) corridor to review and document the results of the timing plan development process. This report presents the results of the "before" and "after" studies that were conducted along the thirteen (13) intersections included in this project. The length of the corridor is approximately 4.5 miles. The travel time studies were conducted on typical weekdays during three (3) time periods of the day: AM Peak (07:00-09:00), Midday (11:00-13:00), and PM Peak (16:00-18:00). The following charts show the average improvements experienced along SC 171 (Folly Road) for both directions of travel during all three time periods. Charts summarizing the detailed results by each timing plan are presented later in the report.

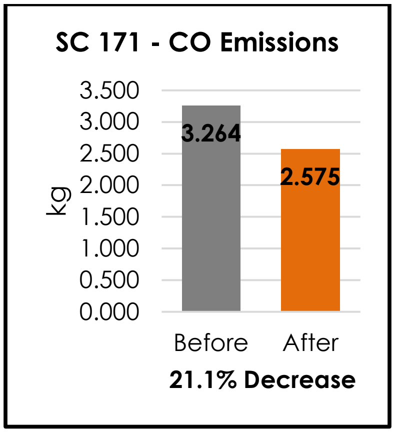


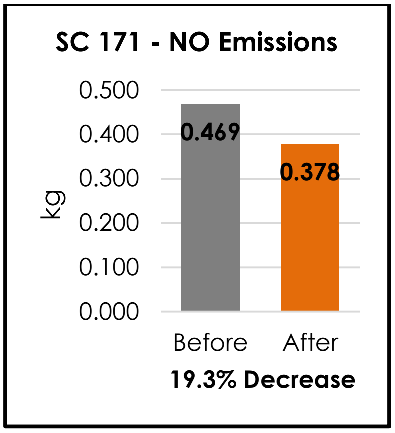


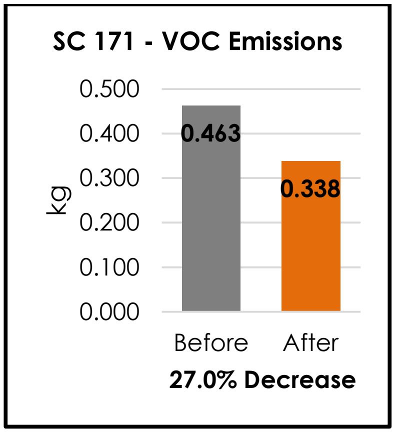


As evident in the graphs above, improvements were shown in travel time, delay and speed for the SC 171 (Folly Road) corridor.

Carbon monoxide (CO), oxides of nitrogen (NOx), and volatile organic compounds (VOC) are three (3) types of vehicle emissions regulated by federal law. The following charts show the average improvements experienced along SC 171 (Folly Road) for both directions of travel during all three (3) time periods. Charts summarizing the detailed results by each timing plan are present in subsequent sections of this report.







As evident in the graphs above, improvements were shown in the carbon monoxide, oxides of nitrogen, and volatile organic compound emissions along SC 171 (Folly Road).

Other benefits not considered in this analysis include lower driver frustration levels and a potential reduction of accidents. All of the improvements mentioned in the report are for six (6) hours a day for each weekday during the AM, MD, and PM peak periods. New signal timing plans were also implemented during the off-peak and weekend hours. However, because benefit/cost "before" and "after" studies were not conducted during these time periods, additional savings could not be quantified during these periods.

Delay incurs direct costs upon motorists in the form of increased fuel consumption and the value of their time wasted while waiting in traffic. Motorists using SC 171 (Folly Road) during the AM, Midday, and PM peak periods will save 146,626 hours each year because of the improved traffic flow due to the new timing plans.

Conservatively assuming a vehicle occupancy of 1.2 persons/vehicle, $12.00 per hour for the value of motorists' time, and $2.34 per gallon for gasoline, annual savings to motorists along SC 171 (Folly Road) will be $2,111,414 in the form of reduced delay and $19,204 decrease in cost due to decreased fuel consumption, for a total annual savings of $2,130,618.

Based on equivalent annual cost of designing, implementing, and documenting signal timing plan improvements, the benefit to cost ratios for interest rates ranging from 4% to 8% were calculated to be between 67.7:1 and 71.6:1 for this portion of the project.

4.1 INTRODUCTION

The purpose of this study was to improve traffic signal timing along the SC 171 (Folly Road) corridor, which in turn reduces fuel consumption, vehicle emissions, driver delay, and driver stops / starts. The purpose of this report is to briefly summarize the data collection efforts and the existing conditions analysis for these intersections, as well as to identify options for improving intersection operation at these locations.

SC 171 (Folly Rd) is a four-lane roadway with a posted speed limit of 40 mph north of 171 (Folly Road) at Central Park Road / Harbor Cave Lane and 45 mph south of the intersection and a 2016 South Carolina Department of Transportation (SCDOT) Average Annual Daily Traffic (AADT) of 25,200 vehicles per day (vpd) north of the James Island Connector, and 39,900 vpd south of the James Island Connector.

Table 31 details each of the twenty (20) intersections, including each intersection's identification number, and **Figure 9** depicts the intersections and corridor.

Table 31 - Project Intersections

#	Intersection
101	SC 700 (Folly Road Boulevard) & Albemarle Road
102	SC 171 (Folly Road) & Windermere Boulevard
103	SC 171 (Folly Road) & Yeamans Road / Formosa Road
104	SC 171 (Folly Road) & SC 700 (Maybank Highway)
243	SC 700 (Maybank Highway) & Old Folly Road
105	SC 700 (Maybank Highway) & Wappoo Creek Drive
188	SC 700 (Maybank Highway) & Woodland Shores Drive
189	SC 700 (Maybank Highway) & Riverland Drive
244	SC 171 (Folly Road) & Old Folly Road
106	SC 171 (Folly Road) & Cross Creek Drive
107	SC 171 (Folly Road) & Harbor View Road
108	SC 171 (Folly Road) & Central Park Road / Harbor Cave Lane
185	SC 171 (Folly Road) & SC 30
186	SC 171 (Folly Road) & Oak Point Road / Ellis Oak Drive
187	SC 171 (Folly Road) & River Point Row / Eugene Gibbs Street
224	SC 171 (Folly Road) & Camp Road
225	SC 171 (Folly Road) & George L. Griffith Boulevard
226	SC 171 (Folly Road) & Fort Johnson Road
217	SC 61 & Croghan Spur / Ashley Point Drive
184	SC 61 & Ashley River Drive

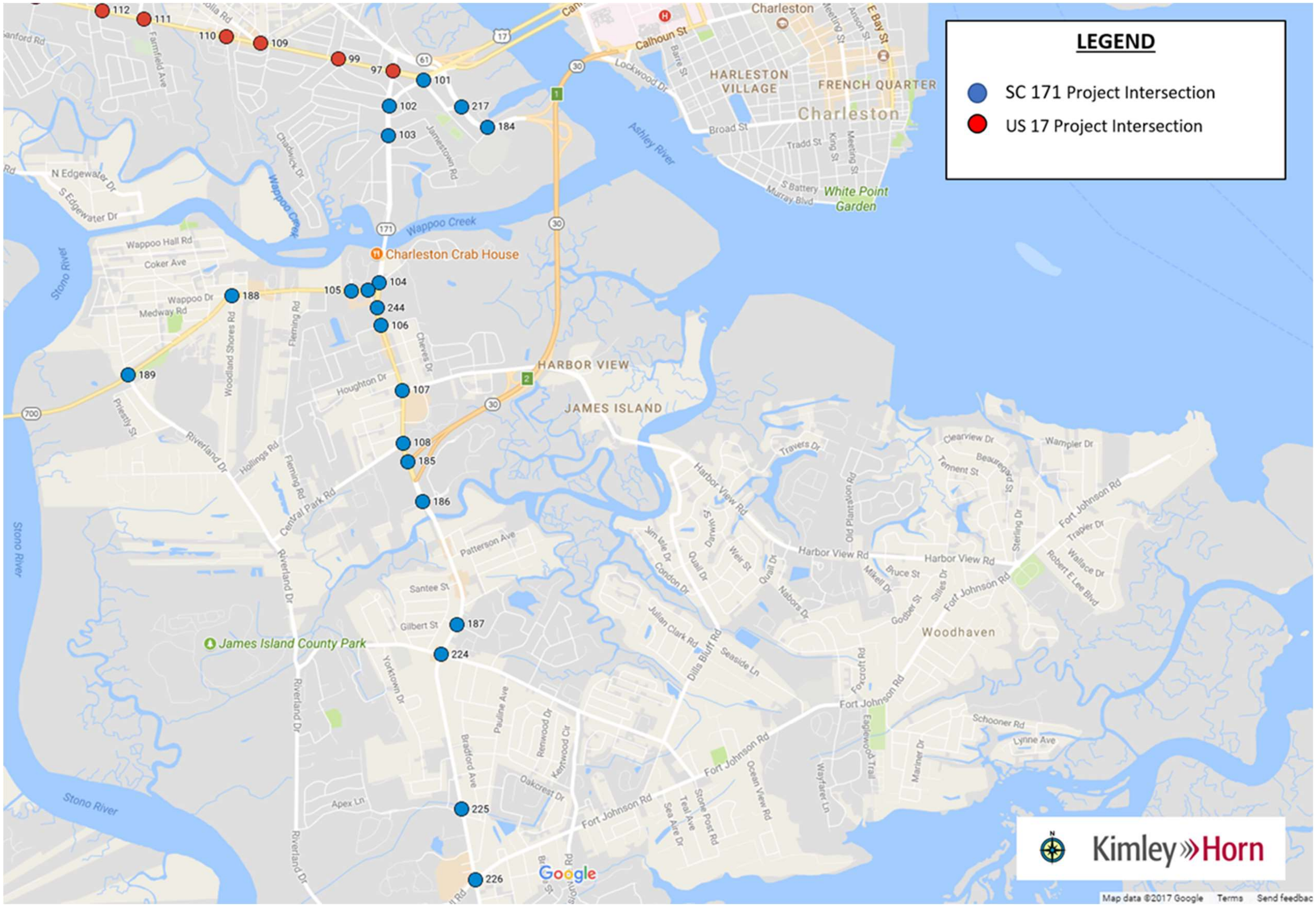


Figure 9 – Project Intersections

4.2 INVENTORY & DATA COLLECTION

4.2.1 Inventory

The project team completed an inventory of each of the project intersections. Information obtained consists of the intersection configuration, signing and marking configurations, signal phasing, pedestrian crossing dimensions, communication status, and detector status. The inventory limits were approximately 500-feet from the intersection along the mainline. The completed form for each intersection is provided in **Appendix A**.

4.2.2 Data Collection

Two (2) types of traffic volume data were used for this study. Average daily traffic (ADT) volumes and turning movement counts (TMC) and were used for the model development and time-of-day schedule. The ADT and TMC volume data is located in **Appendix B** and **Appendix C**, respectively.

ADT volumes was collected throughout April 2016 utilizing automatic traffic recorders (ATR) and consisted of four-day 24-hour bi-directional tube counts at three (3) locations. Additional ADT data was collected in June 2016. The weekend ATR counts consisted of one-day 24-hour volumes at two (2) locations. **Table 32** lists the 24-hour count locations. The count program is also depicted on **Figure 10**.

Table 32 – 24-Hour Bi-Directional Tube Count Locations

#	Location	Direction of Travel	Month of Counts
A	SC 171 (Folly Rd) North of Yeamans Rd / Formosa Rd	Northbound and Southbound	April
B	SC 171 (Folly Rd) South of Camp Rd	Northbound and Southbound	April and June
C	SC 171 (Folly Rd) North of Cross Creek Dr	Northbound and Southbound	June

The 24-hour bi-directional tube counts were graphed, as shown on **Figures 11 and 12**, to show the traffic volumes throughout the day. The proposed TOD schedules are shown for reference on the Figures.

TMC data was collected by ATD at each signalized intersection on a weekday (Tuesday, Wednesday, or Thursday) during the following time frames: AM peak (07:00 – 09:00); Midday (MD) peak (11:00 – 13:00); and PM peak (16:00 – 18:00). Additional TMC data was collected in June 2016 at seven (7) locations along SC 171 (Folly Road) corridor. The weekend TMC data was counted on a Saturday during the following time frames: MD peak (10:00) and PM peak (14:00 – 18:00).

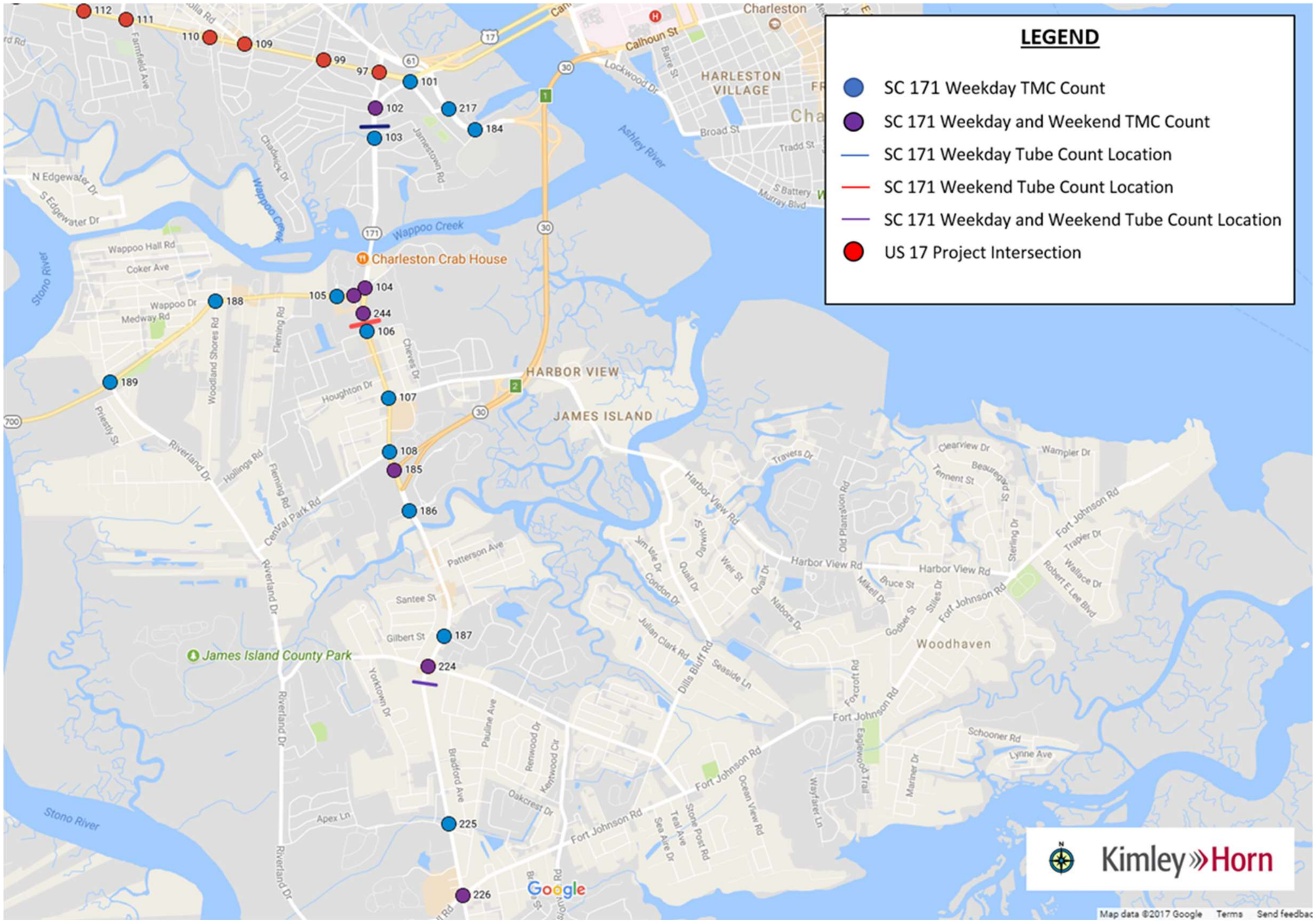


Figure 10 - Count Program

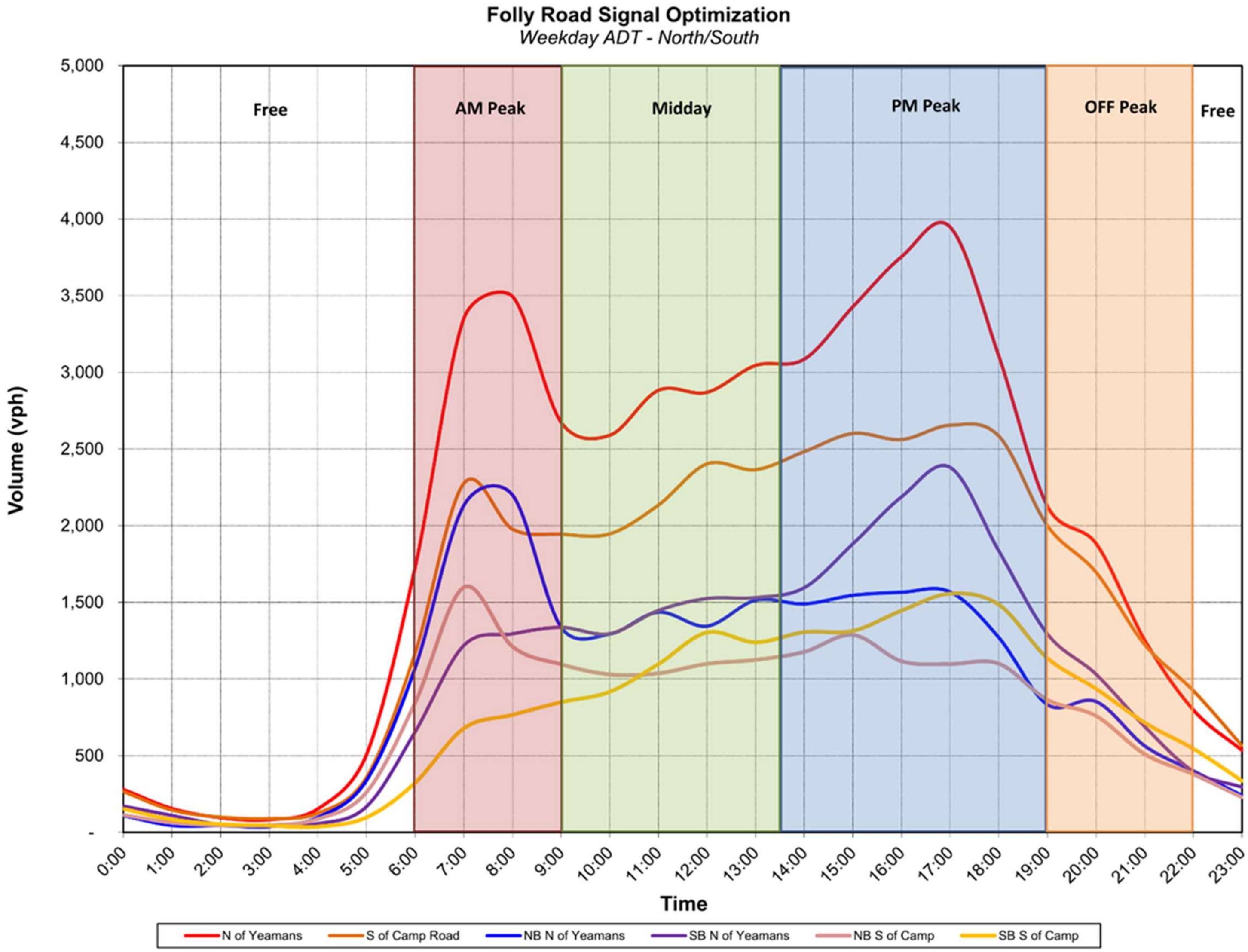


Figure 11 – Weekday Traffic Volumes

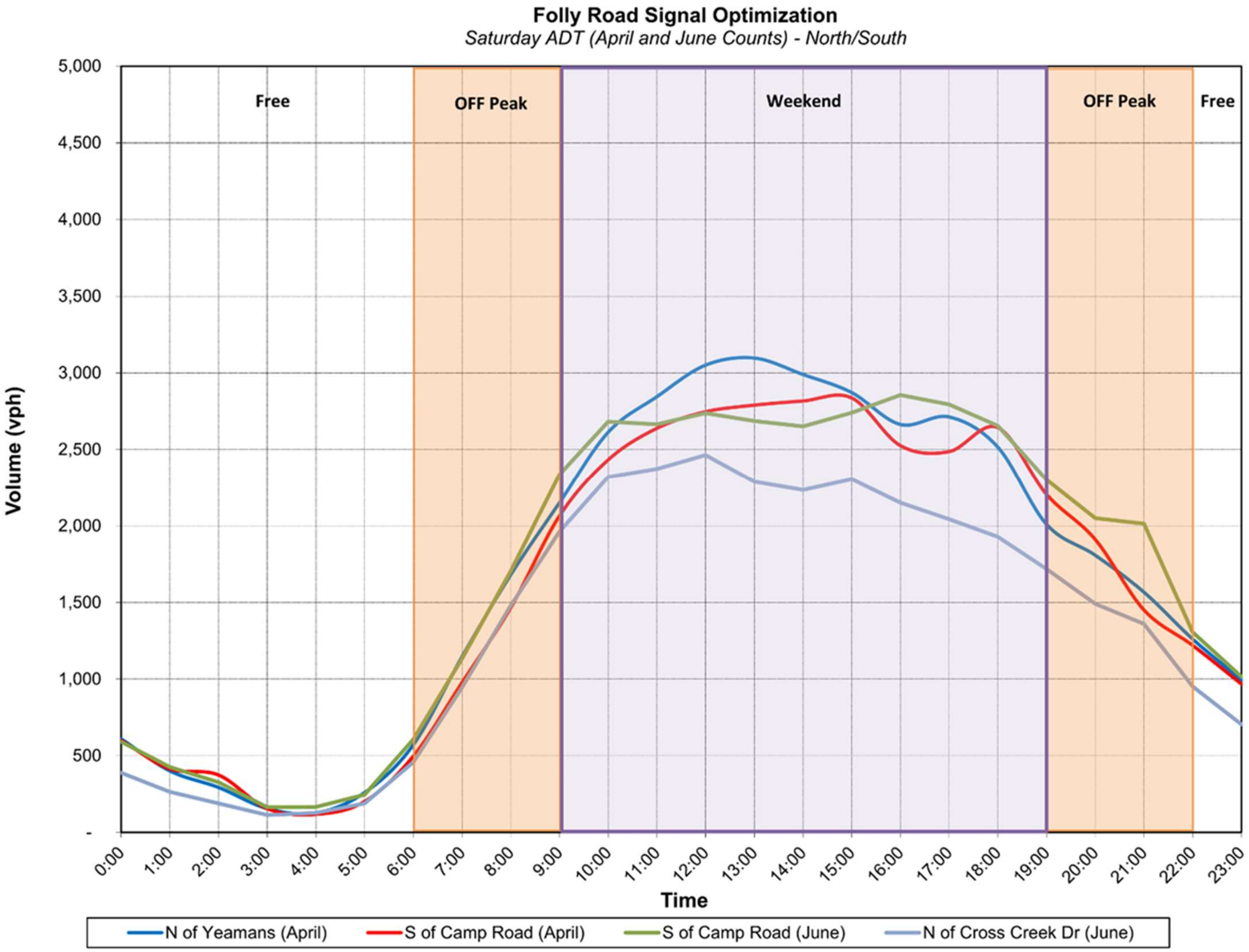


Figure 12 – Weekend Traffic Volumes

4.3 LOCAL TIMING PARAMETERS

Local controller timings were developed for each of the project intersections. **Table 33** details the methods used to develop the controller values that were used for each intersection. The clearance calculations were completed using the *SCDOT Clearance Time Calculations Spreadsheet Rev 2015-01-12* for each intersection. The clearance interval change sheets along with the clearance calculation are located in **Appendix D**.

Table 33 – Local Timing Parameters

<table>
<tr><th>Parameter</th><th colspan="2">Value</th></tr>
<tr><td colspan="3">PEDESTRIAN INTERVAL</td></tr>
<tr><td>Pedestrian Change Interval</td><td colspan="2">((Curb to Curb Distance) / (Walking Speed))</td></tr>
<tr><td>Walking Speed</td><td colspan="2">3.5 Feet per Second</td></tr>
<tr><td>Walk</td><td colspan="2">7 Seconds – Also calculated (Push button to far curb distance) / (walking speed of 3.0fps). If this number was greater than the calculated Pedestrian Change Interval then the difference was added to the Walk time.</td></tr>
<tr><td>Buffer Interval</td><td colspan="2">Following the pedestrian change interval, a buffer interval consisting of a steady UPRAISED HAND (symbolizing DON'T WALK) signal indication shall be displayed for at least 3 seconds prior to the release of any conflicting vehicular movement</td></tr>
<tr><td colspan="3">VEHICLE INTERVAL</td></tr>
<tr><td>Yellow Interval</td><td>t + (V/(2A + 64.4g))
Minimum of 3 seconds. Rounded up to nearest half second.
Left turn clearance calculations based on 20-MPH</td><td rowspan="13">t = perception reaction time (1 second)
V = posted speed in feet/second (25 mph for left turn clearances)
A = deceleration rate (10 feet/second/second)
W = intersection width measured from stop bar to the far edge of the last conflict lane (or crosswalk when the crosswalk is greater than 20' from the intersection)
L = length of vehicle (assume 20 feet)
g = The average of two field measured approach grades:
• At the stop bar
• At the setback loop (if present)
n = detection distance / 20
N = number of lanes</td></tr>
<tr><td>All Red Interval</td><td>(W + L) / V
Minimum of 1.5 seconds. Rounded up to nearest half second</td></tr>
<tr><td>Minimum Green</td><td>Maintained existing</td></tr>
<tr><td>Volume Density</td><td>Maintained existing</td></tr>
<tr><td>Minimum Cycle Length</td><td>90 seconds</td></tr>
<tr><td>Maximum Cycle Length</td><td>180 seconds</td></tr>
<tr><td>Offset Reference</td><td>End of Green</td></tr>
<tr><td>Offset Seeking</td><td>Short Way</td></tr>
<tr><td>Free Operation</td><td>Overnight hours</td></tr>
<tr><td>Lead/Lag by TOD?</td><td>Yes</td></tr>
<tr><td>Traffic Responsive Operation</td><td>No</td></tr>
<tr><td>Special Events</td><td>No</td></tr>
<tr><td colspan="3">CONTACT INFORMATION</td></tr>
<tr><td>Signal Systems Manager</td><td colspan="2">Troy Mitchell, City of Charleston</td></tr>
<tr><td>Law Enforcement</td><td colspan="2">City of Charleston Police Department</td></tr>
</table>

4.4 COORDINATION PARAMETERS

The timing plan development process for each intersection was developed with three (3) key objectives: (1) to progress all through movements on the primary arterial routes; (2) to favor progression in the predominant direction; and (3) to minimize overall system vehicular delay at all signalized intersections.

The timing plan development process includes five (5) distinct tasks:

- Cycle length determination
- Split allocation
- Offset manipulation / optimization
- Phase operation / sequencing
- Time of day clock development

The following subsections describe the methodology and tools used in each of the components of the timing plan development process.

4.4.1 Timing Plan Development

As discussed earlier, there were a number of field observations, traffic counts, signal settings, and miscellaneous data collection efforts undertaken to collect all of the data needed to evaluate the existing conditions of the corridors. This data was compiled in *Synchro 9,* which is a signal timing/optimization/simulation software package accepted in the industry. The existing and proposed *Synchro* timing reports are included in **Appendix E** and time-space diagrams are included in **Appendix F**.

4.4.1.1 Cycle Length Determination

The project team created *Synchro* network files for the AM, MD, PM, Off-Peak (OP), and Weekend (WKND) peak periods. The traffic counts, signal settings, and geometric characteristics from the field survey notes were coded into the *Synchro*. These characteristics included the following items for each intersection approach:

- Number of lanes
- Lane configurations (left, through, right or shard use)
- Storage bay lengths to the nearest five (5) ft increment
- Approach percent grades
- Link speeds (posted speed limits)

- Saturation flow rate of 1,900 vehicles per hour

Each peak period was evaluated using *Synchro* analysis tools and observations of existing characteristic. The cycle lengths were evaluated for a range of 110 seconds to 200 seconds at 10-second intervals.

The existing corridor utilizes coordinated timing plans with cycle lengths that range from 60 seconds to 140 seconds, utilizing half-cycle lengths at some intersections. The AM and PM implemented timing plans operate with a 170 second cycle length and 85 second half-cycle length at some intersections. The Midday and Weekend implemented timing plans operates with a 150 second cycle length and 75 second half cycle length at some intersections. The off-peak implemented timing plan operates with a 130 second cycle length and 65 second half cycle length at some intersections.

4.4.1.2 Split Allocation and Offset Manipulation / Optimization

Once cycle lengths and clearance intervals were determined, each intersection was evaluated to determine the optimal vehicle split allocations. Split allocations were determined based upon the calculated time per movement and the minimum vehicle splits and pedestrian timing requirements. The chosen splits were then input into the proposed *Synchro* models and simulated in *SimTraffic* to identify any queuing issues or storage by spillovers prior to implementation of the timing plans.

The optimization task was then performed on the *Synchro* models for each timing plan by determining the optimal offset per intersection in order to optimize traffic progression along the corridor. Progression of traffic along the heavier direction of travel was favored during heavy inbound and outbound periods of the day. Dual progression (equal allotments of green band widths in both directions) was the goal during the MD and off-peak timing plans.

4.4.1.3 Phasing Operation / Sequencing

When developing the optimized timing plans, each intersection was analyzed for potential changes to the phase operation or sequencing. In particular, intersections with leading protected-only or leading permissive protected flashing yellow arrow left turns were analyzed to determine if lead/lag left turn sequencing could be utilized.

The phasing and sequencing were modified for the intersection of SC 171 (Folly Road) at Windermere Boulevard to allow better progression for northbound SC 171 (Folly Road) as well as provide additional throughput and progression along northbound and southbound SC 171 (Folly Road). The changes included renumbering the phases, modifying overlap phasing, changing the phase sequencing, and changing the coordinated phases to northbound and southbound SC 171 (Folly Road) from westbound Folly Road. These changes required rewiring of the signal cabinet and modifying the controller programming settings and were implemented in April 2017, after the initial field implementation. The fine-tuning of the signal timings for the new configuration were completed after the travel time data collection was completed.

4.4.1.4 Time of Day Clock Development

A time-of-day (TOD) analysis was performed based upon the ADT hourly volumes along the corridors. Existing TOD schedule for surrounding signals were also taken into consideration when developing recommendations. The existing TOD schedule and cycle lengths varied between the project intersections however, the most common TOD schedule is shown in **Table 34**. The standard TOD schedule and cycle lengths that was implemented along SC 171 (Folly Road) and the surrounding intersections is also shown below in **Table 34.**

Table 34 – Time-of-Day/Day-of-Week Schedule

Day	HH:MM (Start Time)	Plan #	Cycle (Sec)	Decription
EXISTING				
Saturday-Sunday	00:00	14		Free
Saturday-Sunday	06:00	24		Free + Max 2
Saturday-Sunday	07:00	5	90, 130	OP
Saturday-Sunday	09:00	2	90, 140	WKND
Saturday-Sunday	18:30	5	90, 130	OP
Saturday-Sunday	21:00	24		Free + Max 2
Saturday-Sunday	22:00	14		Free
Monday-Friday	00:00	14		Free
Monday-Friday	05:45	21		Free + Max 2
Monday-Friday	06:00	1	90, 140	AM
Monday-Friday	09:00	5	90, 130	MD
Monday-Friday	13:30	3	90, 140	PM
Monday-Friday	18:30	4	90, 120	OP
Monday-Friday	22:00	14		Free
IMPLEMENTED				
Saturday-Sunday	00:00	14		Free
Saturday-Sunday	06:00	5	130	OP
Saturday-Sunday	09:00	6	150	WKND
Saturday-Sunday	19:00	5	130	OP
Saturday-Sunday	22:00	14		Free
Monday-Friday	00:00	14		Free
Monday-Friday	06:00	1	170	AM
Monday-Friday	09:00	2	150	MD
Monday-Friday	13:30	3	170	PM
Monday-Friday	19:00	4	130	OP
Monday-Friday	21:00	14		Free

4.5 OPERATIONAL ANALYSIS

4.5.1 Methodology for Before and After Studies

The travel time, average speed, and delay studies were conducted in accordance with the procedures given in the *Manual of Transportation Engineering Studies*, published by the Institute of Transportation Engineers. Travel time, average speed, and delay studies were conducted in both the northbound and southbound directions on SC 171 (Folly Road) during the weekday AM peak (07:00-09:00), Midday peak (11:00-13:00), and PM peak (16:00-18:00) periods and Weekend peak (11:00-13:30 and 16:00-18:00) periods. A minimum of five (5) runs was made in each direction. The “floating car” technique was used, whereby the driver passes as many cars as pass the driver. Travel times were performed along the following two (2) sections of the SC 171 (Folly Road) system:

- Route 1: SC 171 (Folly Road) Northbound from Fort Johnson Road to Windermere Boulevard
- Route 2: SC 171 (Folly Road) Southbound from Windermere Boulevard to Fort Johnson Road

The study vehicle was unmarked and operated as inconspicuously as possible. The operator recorded the stops and travel time experienced during each run. The weekday “before” runs were collected for SC 171 (Folly Road) October 18 and 19, 2016. The weekday “after” runs were collected for SC 171 (Folly Road) on April 19 and 20, 2017. The weekend “before” runs were collected for SC 171 (Folly Road) on Saturday, June 4, 2016. The weekend “after” runs were collected for SC 171 (Folly Road) on Saturday, August 6, 2016. The GPS travel run data was collected using Qstar Logger and was processed with Trav-time. The tables below summarize the “before” and “after” travel time, average speed, delay, and number of stops, as well as atmospheric pollutants carbon monoxide (CO), oxides of nitrogen (NOx), and volatile organic compounds (VOC), which are vehicle emissions regulated by federal law. The data below is shown for each time period and direction of travel. The travel time reports are included in **Appendix G**.

Table 35 – Average Travel Time (sec)

SC 171 (Folly Road)						
	AM		Midday		PM	
Direction of Travel	**NB**	**SB**	**NB**	**SB**	**NB**	**SB**
Before	746.4	502.8	578.4	661.2	658.2	530.4
After	768.0	387.0	476.4	541.2	454.8	456.6
% Difference	**2.9%**	**-23.0%**	**-17.6%**	**-18.2%**	**-30.9%**	**-13.9%**

Table 36 – Average Delay (sec)

SC 171 (Folly Road)						
	AM		Midday		PM	
Direction of Travel	**NB**	**SB**	**NB**	**SB**	**NB**	**SB**
Before	352.8	100.8	192.6	271.2	296.4	129.0
After	361.2	15.6	113.4	157.2	91.2	70.8
% Difference	**2.4%**	**-84.5%**	**-41.1%**	**-42.0%**	**-69.2%**	**-45.1%**

Table 37 – Average Speed (mph)

SC 171 (Folly Road)						
	AM		Midday		PM	
Direction of Travel	**NB**	**SB**	**NB**	**SB**	**NB**	**SB**
Before	21.42	31.78	26.34	23.03	23.09	28.72
After	20.82	41.19	31.88	28.13	33.42	33.36
% Difference	**-2.8%**	**29.6%**	**21.0%**	**22.2%**	**44.7%**	**16.2%**

Table 38 – Average Number of Stops

SC 171 (Folly Road)						
	AM		Midday		PM	
Direction of Travel	**NB**	**SB**	**NB**	**SB**	**NB**	**SB**
Before	7.57	3.00	4.86	6.71	7.20	3.60
After	7.11	0.22	2.25	3.25	2.83	3.00
% Difference	**-6.1%**	**-92.7%**	**-53.7%**	**-51.6%**	**-60.7%**	**-16.7%**

Table 39 – Average Carbon Monoxide Emissions (kg)

SC 171 (Folly Road)						
	AM		Midday		PM	
Direction of Travel	**NB**	**SB**	**NB**	**SB**	**NB**	**SB**
Before	4.239	2.471	2.914	3.612	3.879	2.472
After	4.154	1.548	2.553	2.870	2.258	2.064
% Difference	**-2.0%**	**-37.4%**	**-12.4%**	**-20.5%**	**-41.8%**	**-16.5%**

Table 40 – Average Oxides of Nitrogen Emissions (kg)

SC 171 (Folly Road)						
	AM		Midday		PM	
Direction of Travel	**NB**	**SB**	**NB**	**SB**	**NB**	**SB**
Before	0.589	0.360	0.433	0.517	0.533	0.379
After	0.606	0.254	0.357	0.405	0.331	0.316
% Difference	**2.7%**	**-29.3%**	**-17.5%**	**-21.7%**	**-37.9%**	**-16.7%**

Table 41 – Average Volatile Organic Compound Emissions (kg)

SC 171 (Folly Road)						
	AM		Midday		PM	
Direction of Travel	**NB**	**SB**	**NB**	**SB**	**NB**	**SB**
Before	0.649	0.324	0.390	0.523	0.585	0.310
After	0.595	0.137	0.354	0.408	0.289	0.246
% Difference	**-8.3%**	**-57.7%**	**-9.3%**	**-21.9%**	**-50.6%**	**-20.5%**

As shown in the tables above, travel time, average speed, delay, number of stops, and emissions were all improved throughout the day along the SC 171 (Folly Road) corridor with one exception.

The northbound direction of travel showed improvement across all categories throughout the day with one exception. The northbound direction of travel in the AM peak experienced undesirable changes to travel time, average speed, number of stops, and emissions. The northbound direction of travel experienced a 2.9 percent increase in travel time and 2.3 percent increase in delay during the AM peak. However, the additional phasing and sequence changes at SC 171 (Folly Road) at Windermere Boulevard were not captured during the after travel times analysis, due to the required hardware installations and signal cabinet wiring. These changes included reprogramming the coordinated phases to northbound and southbound SC 171 (Folly Road) to allow for the unused time on the minor approaches to provide additional throughput and progression in the northbound and southbound directions These changes were observed in the field to show additional reduction in travel time and delay along SC 171 (Folly Road), specifically in the AM peak period. The northbound direction of travel experienced the greatest improvement in all categories during the PM peak. During the PM peak travel time was reduced by 30.9 percent, delay was reduced by 69.2 percent, average number of stops was reduced by 60.7 percent, and the average speed was increased by 44.7 percent.

The southbound direction of travel showed improvement in all categories throughout the day. The southbound direction experienced the greatest improvement during the AM peak period. During the AM peak travel time was reduced by 23 percent, delay was reduced by 84.5 percent, average number of stops was decreased by 92.7 percent, and average speed was increased by 29.6 percent. The phasing and sequence changes made at SC 171 (Folly Road) at Windermere Boulevard were observed to provide additional benefit in travel time and delay along southbound SC 171 (Folly Road), that was not captured in the travel time analysis.

4.5.2 LOS and Delay Analysis

Synchro 9.1 was also used to prepare an evaluation of intersection operations to determine the Level of Service (LOS) and average delay of the existing condition (existing geometry, existing signal timings, and existing traffic volumes), the proposed condition (existing geometry, proposed signal timings, and existing traffic volumes), and final condition (existing geometry, implemented signal timings, and existing traffic volumes). This capacity analysis methodology is based on the *2010 Highway Capacity Manual* (HCM), a standard guidance for capacity analysis, which defines LOS at signalized intersections in terms of average control delay per vehicle, which is composed of initial deceleration delay, queue move-up time, stopped delay, and final acceleration delay. LOS ranges from A to F, with LOS A indicating operations with very low control delay and LOS F describing operations with extremely high average control delay. In the comparison between existing, proposed, and final timings, the LOS and delay should improve for the overall corridor, but may not increase or decrease at individual intersections depending on what was running before.

Currently, the corridor has very directional peak hour traffic. During the AM peak period the predominant flow of traffic is northbound toward downtown Charleston, with approximately 45 percent of the northbound traffic tuning left from SC 700 (Maybank Highway). During the PM peak period the predominant flow of traffic is southbound away from downtown Charleston, with approximately 45 percent of the southbound traffic tuning right onto SC 700 (Maybank Highway). During the Midday peak period the traffic flow is approximately equal between the northbound and southbound directions. The primary goal for timing the SC 171 (Folly Road) corridor was to increase efficiency along the routes during all peaks. The volume-to-capacity (V/C) ratios were also included in the analysis to measure capacity demand of each intersection since delay on side streets can sometimes skew an intersection delay even if the respective queues are under capacity. Overall, corridor offsets were adjusted to reduce queuing and delay.

The results of the existing, proposed, and final conditions are shown in **Table 42**. Synchro LOS and delay outputs are included in **Appendix E**. Although some of LOS and delays results under the final plans yielded worse values than the existing modules, the signal timings have been optimized to accommodate improved progression and capacity efficiency throughout the system. Meanwhile, all LOS results remain at 'D' or better with several intersections expected to perform with even better results.

The LOS, delay and V/C ratios varied in the field upon implementation of the proposed timing plans. Overall, the SC 171 (Folly Road) system has driveways and stop-controlled intersections that were not modeled in the analysis. Consequently, varying speeds, geometric constraints, and volume additions and subtractions between the study intersections contributed various results that can affect the overall progression and flow of the corridor. Adjustments to the splits and offsets were incorporated in the field during fine tuning upon observation of actual driver behavior.

Table 42 – Existing, Proposed, and Implemented Level of Service and Average Delay

#	Intersection	Existing		Proposed		Implemented	
		LOS	Control Delay (sec/veh)	LOS	Control Delay (sec/veh)	LOS	Control Delay (sec/veh)
AM PEAK PERIOD							
101	SC 700 (Folly Road Blvd) & Albemarle Rd	C	24.1	C	20.2	C	27.4
102	SC 171 (Folly Rd) & Windermere Blvd	B	18.1	B	15.5	B	12.6
103	SC 171 (Folly Rd) & Yeamans Rd / Formosa Rd	F	73.3	B	7.8	B	10.7
104	SC 171 (Folly Rd) & SC 700 (Maybank Hwy)	E	58.4	E	57.6	D	48.2
243	SC 700 (Maybank Hwy) & Old Folly Rd	B	11.3	A	6.9	A	7.3
105	SC 700 (Maybank Hwy) & Wappoo Creek Dr	A	6.5	A	3.8	B	10.1
188	SC 700 (Maybank Hwy) & Woodland Shores Dr	C	22.0	C	34.5	C	28.3
189	SC 700 (Maybank Hwy) & Riverland Dr	D	43.9	E	65.2	C	30.8
244	SC 171 (Folly Rd) & Old Folly Rd	B	19.5	B	11.8	B	11.5
106	SC 171 (Folly Rd) & Cross Creek Dr	A	7.5	B	15.9	B	13.6
107	SC 171 (Folly Rd) & Harbor View Rd	C	21.1	C	25.4	C	24.3
108	SC 171 (Folly Rd) & Central Park Rd / Harbor Cove Ln	B	19.8	C	28.7	C	27.2
185	SC 171 (Folly Rd) & SC 30	B	19.3	C	22.8	C	23.1
186	SC 171 (Folly Rd) & Oak Point Rd / Ellis Oak Dr	E	55.3	D	43.4	D	36.9
187	SC 171 (Folly Rd) & River Point Row / Eugene Gibbs St	A	9.0	A	9.4	A	9.9
224	SC 171 (Folly Rd) & Camp Rd	D	49.9	E	63.2	E	61.8
225	SC 171 (Folly Rd) & George L. Griffith Blvd	A	6.7	A	9.9	A	9.6
226	SC 171 (Folly Rd) & Fort Johnson Rd	C	21.6	D	42.8	D	40.6
217	SC 61 & Croghan Spur / Ashley Point Dr	A	3.5	A	7.4	A	7.1
184	SC 61 & Ashley River Dr	B	16.4	B	18.8	C	22.4

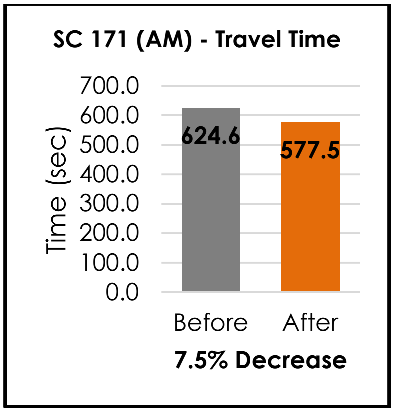
MID PEAK PERIOD							
101	SC 700 (Folly Road Blvd) & Albemarle Rd	B	11.4	B	12.9	A	6.8
102	SC 171 (Folly Rd) & Windermere Blvd	C	21.7	C	21.1	B	17.7
103	SC 171 (Folly Rd) & Yeamans Rd / Formosa Rd	B	10.9	A	7.1	A	6.9
104	SC 171 (Folly Rd) & SC 700 (Maybank Hwy)	C	26.1	C	24.3	C	22.9
243	SC 700 (Maybank Hwy) & Old Folly Rd	B	13.6	B	10.4	A	9.0
105	SC 700 (Maybank Hwy) & Wappoo Creek Dr	B	12.6	B	11.5	B	11.2
188	SC 700 (Maybank Hwy) & Woodland Shores Dr	B	15.1	B	14.0	B	10.7
189	SC 700 (Maybank Hwy) & Riverland Dr	B	16.0	B	18.1	B	18.7
244	SC 171 (Folly Rd) & Old Folly Rd	C	20.9	C	27.5	C	27.3
106	SC 171 (Folly Rd) & Cross Creek Dr	A	7.5	B	13.9	B	10.9
107	SC 171 (Folly Rd) & Harbor View Rd	B	14.4	B	16.1	B	17.0
108	SC 171 (Folly Rd) & Central Park Rd / Harbor Cove Ln	B	19.2	C	21.2	B	16.2
185	SC 171 (Folly Rd) & SC 30	B	18.6	B	18.6	C	20.1
186	SC 171 (Folly Rd) & Oak Point Rd / Ellis Oak Dr	C	31.6	D	38.8	D	40.5
187	SC 171 (Folly Rd) & River Point Row / Eugene Gibbs St	B	10.2	B	10.6	B	10.2
224	SC 171 (Folly Rd) & Camp Rd	D	35.1	D	40.0	D	36.3
225	SC 171 (Folly Rd) & George L. Griffith Blvd	A	7.8	B	11.5	A	9.5
226	SC 171 (Folly Rd) & Fort Johnson Rd	C	20.9	B	17.5	B	16.4
217	SC 61 & Croghan Spur / Ashley Point Dr	A	6.1	A	8.0	A	5.6
184	SC 61 & Ashley River Dr	A	9.1	B	12.8	B	13.1

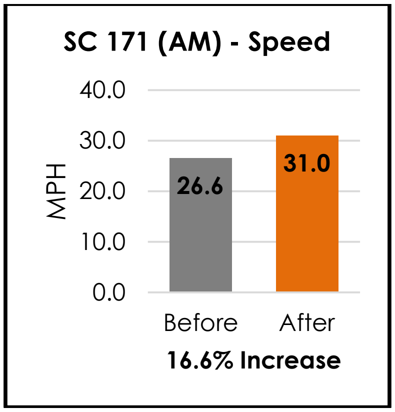
PM PEAK PERIOD							
101	SC 700 (Folly Road Blvd) & Albemarle Rd	C	22.3	C	22.1	B	18.0
102	SC 171 (Folly Rd) & Windermere Blvd	B	10.8	C	24.3	C	21.4
103	SC 171 (Folly Rd) & Yeamans Rd / Formosa Rd	C	20.8	A	6.8	A	6.7
104	SC 171 (Folly Rd) & SC 700 (Maybank Hwy)	B	10.3	D	37.4	C	34.5
243	SC 700 (Maybank Hwy) & Old Folly Rd	B	10.3	B	14.8	B	13.4
105	SC 700 (Maybank Hwy) & Wappoo Creek Dr	B	19.8	B	16.5	B	11.1
188	SC 700 (Maybank Hwy) & Woodland Shores Dr	B	17.3	C	25.5	B	12.9
189	SC 700 (Maybank Hwy) & Riverland Dr	C	21.5	C	25.5	C	22.0
244	SC 171 (Folly Rd) & Old Folly Rd	B	17.8	B	15.8	B	19.5
106	SC 171 (Folly Rd) & Cross Creek Dr	A	7.0	A	8.5	A	7.8
107	SC 171 (Folly Rd) & Harbor View Rd	B	16.5	B	19.8	B	18.6
108	SC 171 (Folly Rd) & Central Park Rd / Harbor Cove Ln	C	30.3	D	40.6	D	39.2
185	SC 171 (Folly Rd) & SC 30	E	62.7	D	47.0	D	47.4
186	SC 171 (Folly Rd) & Oak Point Rd / Ellis Oak Dr	C	32.3	C	31.3	D	35.1
187	SC 171 (Folly Rd) & River Point Row / Eugene Gibbs St	B	19.1	B	17.6	B	11.4
224	SC 171 (Folly Rd) & Camp Rd	D	47.0	D	41.2	D	44.0
225	SC 171 (Folly Rd) & George L. Griffith Blvd	A	8.3	A	9.8	A	9.8
226	SC 171 (Folly Rd) & Fort Johnson Rd	C	26.4	D	49.6	D	42.2
217	SC 61 & Croghan Spur / Ashley Point Dr	A	9.1	A	8.6	B	12.6
184	SC 61 & Ashley River Dr	B	11.3	C	21.5	B	15.4

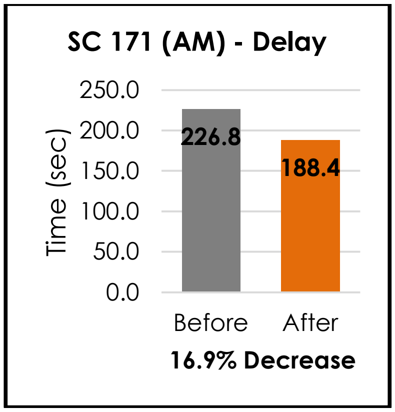
4.6 RESULTS SUMMARY

4.6.1 AM Peak Plan

The existing AM plan had primarily a 140 second cycle length and ran from 06:00 to 09:00, Monday – Friday, at the majority of the intersections. The remaining intersections had a 70 second half cycle length or 90 second cycle length. This plan was replaced with a 170 second cycle length, or 85 second half cycle length, that runs weekdays from 06:00 to 09:00 during the peak seen in the 24-hour counts. The predominant flow of traffic is northbound toward downtown Charleston, with approximately 45 percent of the northbound traffic tuning left from SC 700 (Maybank Highway). As shown in the charts below, the implemented AM plan improved the combined averages of travel time, travel speed, and delay along the corridor. Along the corridor travel time was reduced by more than 5 percent, speed was increased by more than 15 percent, and delay was reduced by more than 15 percent.

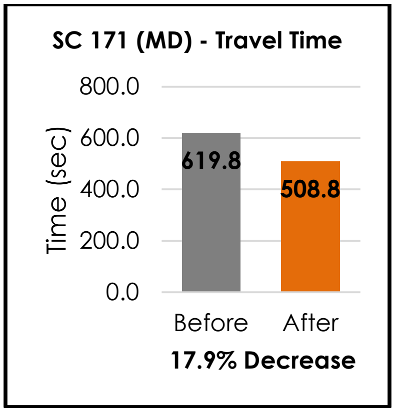




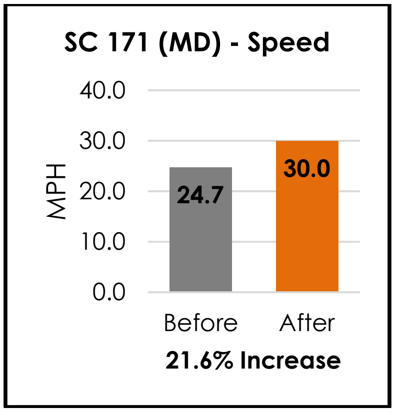


4.6.2 Midday Plan

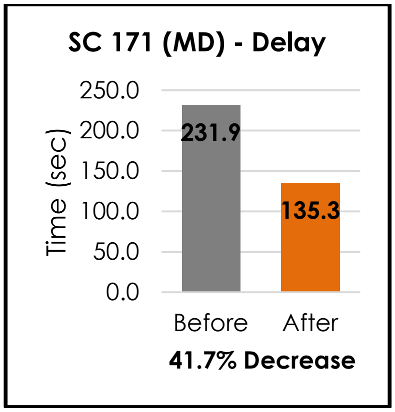
The existing Midday plan had a 130 second cycle length and ran from 09:00 to 13:30, Monday – Friday, at the majority of the intersections. The remaining intersections had a 65 second half-cycle length or a 90 second cycle length. This plan was replaced with a 150 second cycle length plan, or 75 second half-cycle length, that runs weekdays from 09:00 to 13:30 during the peak seen in the 24-hour counts. The traffic volumes are approximately balanced in both directions during the midday peak. As shown on the charts below, the implemented Midday plans improved the combined averages of travel time, travel speed, and delay along the corridor. Along the corridor travel time was decreased by over 15 percent, speed was increased by over 20 percent, and delay was reduced by over 40 percent.


SC 171 (MD) - Travel Time

17.9% Decrease


SC 171 (MD) - Speed

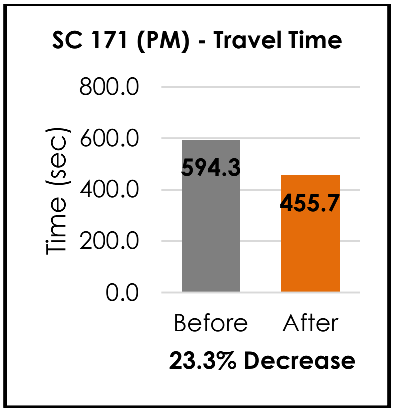
21.6% Increase


SC 171 (MD) - Delay

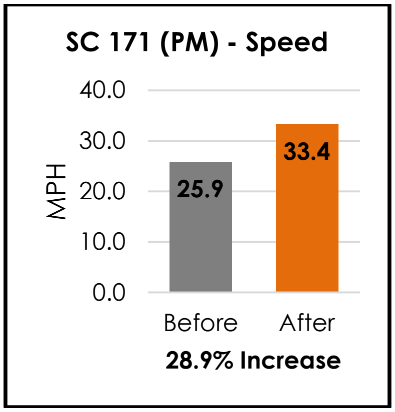
41.7% Decrease

4.6.3 PM Peak Plan

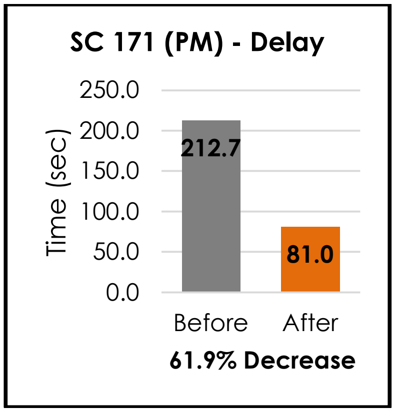
The existing PM plan had a 140 second cycle length and ran from 13:30 to 18:30, Monday – Friday, at the majority of the intersections. The remaining intersections had a 70 second half-cycle length or 90 second cycle length. This plan was replaced with a 170 second cycle length, or 85 second half-cycle length, that runs weekdays from 13:30 to 19:00 during the peak seen in the 24-hour counts. The predominant flow of traffic is southbound away from downtown Charleston, with approximately 45 percent of the southbound traffic tuning right onto SC 700 (Maybank Highway). As shown in the charts below, the implemented PM plan improved the combined averages of travel time, travel speed, and delay along the corridor. Along the corridor travel time was decreased by over 20 percent, speed was increased by over 25 percent, and delay was decreased by over 60 percent.


SC 171 (PM) - Travel Time

23.3% Decrease


SC 171 (PM) - Speed

28.9% Increase

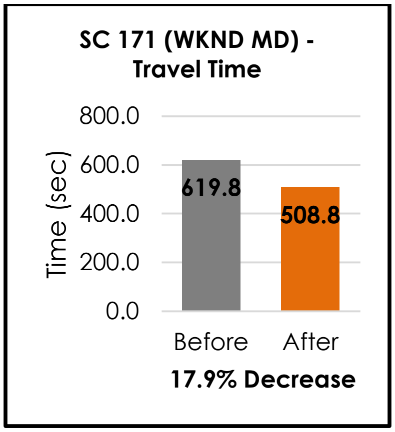

SC 171 (PM) - Delay

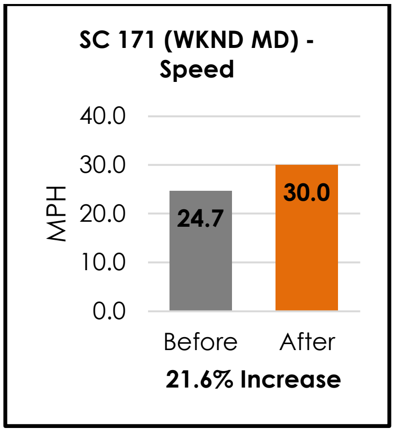
61.9% Decrease

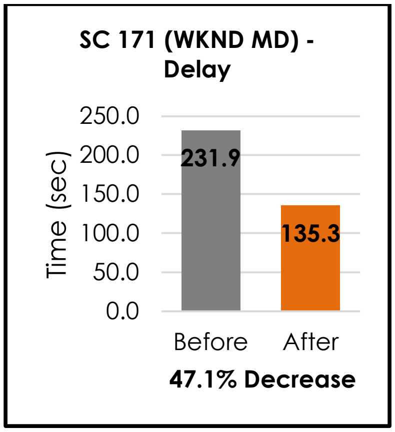
4.6.4 Weekend Plans

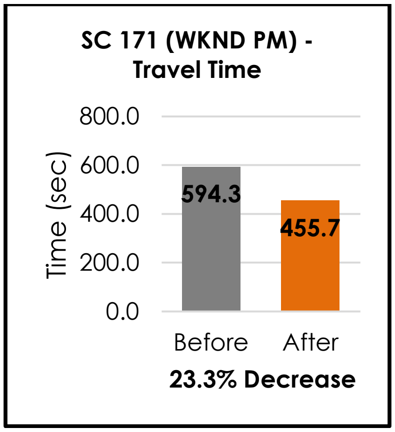
The existing Weekend plan had a 130 second cycle length and ran from 09:00 to 18:30, Saturday and Sunday, at the majority of the intersections. The remaining intersections had a 65 second half-cycle length or 90 second cycle length. This plan was replaced with a 150 second cycle length, or 75 second half-cycle length, that runs weekends from 09:00 to 19:00 during the peak seen in the 24-hour counts.

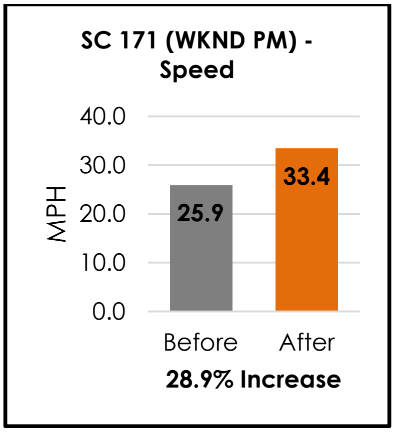
During the summer beach season the 130 second cycle length was replaced with a 140 second cycle length. The traffic volumes are approximately balanced in both directions during the weekend peak, along with southbound and northbound directions alternating directional peaks during the summer beach season. Although not included in the benefit to cost analysis for the project, "before" and "after" travel time runs were collected for the Weekend summer beach season timings during two (2) time periods of the day: Midday peak (11:00-13:30), and PM peak (16:00-18:00). As shown on the charts below, the implemented summer beach season Weekend plans improved the combined averages of travel time, travel speed, and delay along the corridor. Along the corridor during the Weekend Midday peak travel time was decreased by over 15 percent, speed was increased by over 20 percent, and delay was reduced by over 40 percent. Along the corridor during the Weekend PM peak travel time was decreased by over 20 percent, speed was increased by over 25 percent, and delay was reduced by over 45 percent. Along the corridor during the Weekend peak travel time was decreased by 20 percent, speed was increased by over 25 percent, and delay was reduced by over 50 percent.

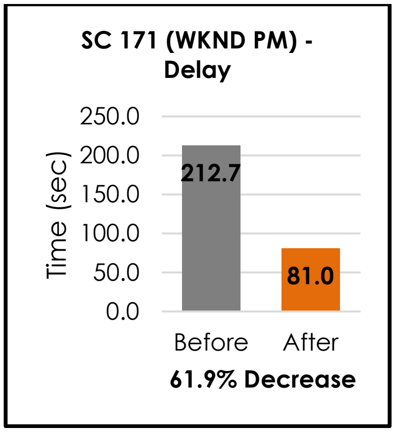


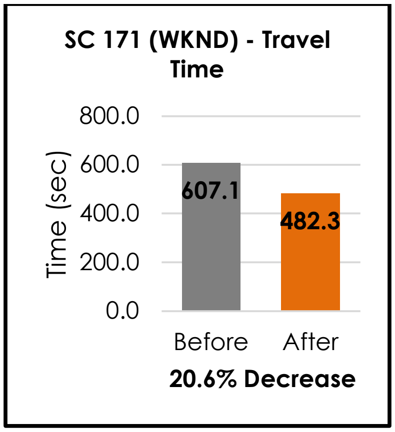


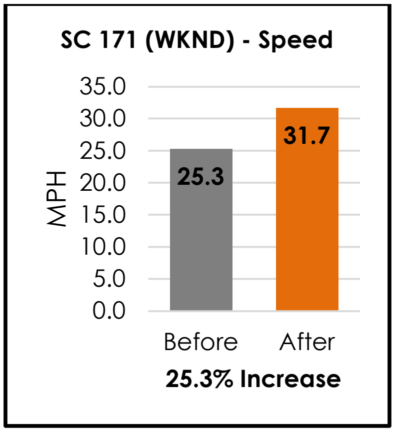


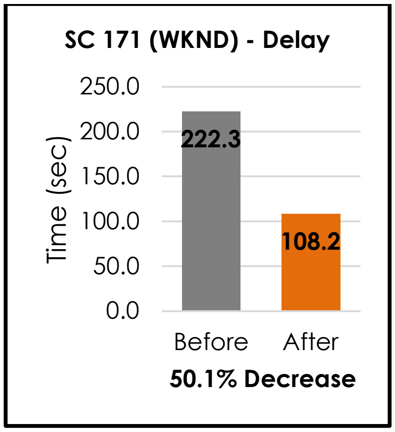

SC 171 (WKND PM) - Travel Time
800.0
600.0
400.0
200.0
0.0
Time (sec)
594.3
455.7
Before
After
23.3% Decrease


SC 171 (WKND PM) - Speed
40.0
30.0
20.0
10.0
0.0
MPH
25.9
33.4
Before
After
28.9% Increase


SC 171 (WKND PM) - Delay
250.0
200.0
150.0
100.0
50.0
0.0
Time (sec)
212.7
81.0
Before
After
61.9% Decrease


SC 171 (WKND) - Travel Time
800.0
600.0
400.0
200.0
0.0
Time (sec)
607.1
482.3
Before
After
20.6% Decrease


SC 171 (WKND) - Speed
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
MPH
25.3
31.7
Before
After
25.3% Increase


SC 171 (WKND) - Delay
250.0
200.0
150.0
100.0
50.0
0.0
Time (sec)
222.3
108.2
Before
After
50.1% Decrease

4.7 EFFECTIVENESS EVALUATION

Improvements in traffic signal timing can also be measured using a cost versus benefit ratio. If the financial benefits to the drivers outweigh the financial cost of the project over its lifespan, then the project is worth the investment. The financial benefit to the drivers is seen through decreased driving time and fuel consumption due to improved traffic flow from the signal timing plans.

The signal timing plans will last until changes in volume or roadway characteristics decrease the efficiency of the signal system to move traffic. Development in the area can increase the volume and cause the need for roadway expansion. In order to determine the cost/benefit ratio for this report, the life span of the new signal timing plans was assumed to be 2 years.

4.7.1 Annual Costs

The cost of designing, implementing, and recording the timing plans and the interest associated with the capital invested are all factors involved in calculating the equivalent annual cost.

The formulas used to determine the project's costs are:

$E=R \times C$

Where:
E = Equivalent Cost
R = Capital Recovery Cost
C = Initial Cost

$R = i(1+i)^n / ((1+i)^n - 1)$

Where:
R = Capital Recovery Cost
i = Annual Interest Rate
n = Useful Life of Timing Plans

The equivalent annual costs, as calculated, using the above formulas, for SC 171 (Folly Road) are shown in **Table 43**. The table shows interest rates ranging from 4% to 8%, which are assumed to be reasonable rates for the current market. As stated previously, the useful life of the timing plans was assumed to be 2 years. Based on contracted fees for traffic data collection, development of timing plans, implementing and field tuning of timing plans, the total cost was $56,119.70.

Table 43 - Equivalent Annual Cost of Timing Plans

Annual Interest Rate	Capital Recovery Factor	Equivalent Annual Cost
4%	0.5302	$29,754
5%	0.5378	$30,181
6%	0.5454	$30,610
7%	0.5531	$31,039
8%	0.5608	$31,470

* $56,117.70 Initial Cost and 2-year Service Life

4.7.2 Benefits

Many benefits can be derived from the improved signal timing, including vehicular emissions, reduced vehicular crashes, time savings, and fuel savings. Unfortunately, it is hard to put a dollar value on the public health benefits received by decreased vehicular emissions. Also, this study did not include a crash analysis; therefore, a dollar value for potential decreased vehicular crashes due to improved traffic flow was not included. However, it is possible to assign a dollar value to the time motorists save due to decreased travel time and the decreased fuel usage. The time saved can be measured by a dollar value using the following formula.

$$S = R \times V \times D \times O \times C$$

Where:
S = Dollars Saved
R = Travel Time Reduction
V = Volume
D = Days Timing in Effect
O = Average Vehicle Occupancy
C = Cost of Delay per Person Hour

The days the timings are in effect is assumed to be 250 days. The average vehicle occupancy is assumed to be 1.2, and the cost of delay per person is assumed to be $12.00 per person-hour.

The values for fuel consumption were obtained from travel run data collected using Qstar Logger and processed with Trav-time for the existing timing plans and the final timing plans. The cost of fuel is assumed to be $2.34 per gallon. **Table 44** shows the annual dollar value of the SC 171 (Folly Road) signal timing improvements for the three (3) analyzed peak periods.

Other benefits not considered in this analysis include lower driver frustration levels and a potential reduction of accidents. All of the improvements mentioned in the report are for six (6) hours a day for each weekday during the AM, MD, and PM peak periods along SC 171 (Folly Road). New signal timing plans were also implemented at seven (7) additional intersections in addition to the new timing plans at all project intersections during off-peak and weekend hours. However, because benefit/cost "before" and "after" studies were not conducted during these time periods, additional savings could not be quantified during these periods.

Table 44 - Annual Travel Time and Fuel Consumption Cost Savings

Time Period	Volume (veh/hr)	Annual Improvement				
		Travel Time (Veh-Hrs)	Value	Fuel Consumption (gallons)	Value	Total
SC 171 (Folly Road)						
AM – SB	1,045	16,807	$242,021	1,019	$2,384	$244,405
AM - NB	1,918	(5,754)	$(82,858)	1,093	$2,558	$(80,300)
MIDDAY - SB	1,373	22,883	$329,515	1,545	$3,615	$333,130
MIDDAY - NB	1,251	17,723	$255,211	1,220	$2,855	$258,066
PM - SB	1,959	54,852	$789,869	1,303	$3,049	$792,918
PM - NB	1,420	40,115	$577,656	2,027	$4,743	$582,399
Total	**8,966**	**146,626**	**$2,111,414**	**8,207**	**$19,204**	**$2,130,618**

Note: Values shown in parentheses represent a negative value.

4.7.3 Cost/Benefit Analysis

The benefit to cost ratio is a measure of effectiveness for the new signal timing plans. It validates the time and money spent to improve the timing along the corridor. The ratio for the SC 171 (Folly Road) corridor was obtained by dividing the value of the annual benefits (reduced travel time and fuel consumption) by the equivalent annual cost. A benefit to cost ratio greater than one indicates the project's benefits outweigh the costs.

The total value of the benefits received by the motorists on SC 171 (Folly Road) is $2,130,618. The equivalent annual cost of designing, implementing, and documenting the improved signal timing plans ranges from $29,754 at 4% interest to $31,470 at 8% interest. **Table 45** shows the benefit to cost ratios for the interest rates ranging from 4% to 8%.

Table 45 - Cost/Benefit Analysis

Costs		Benefits			Benefit/ Cost Ratio
Interest Rate	Equivalent Annual Cost	Reduced Delay	Reduced Fuel Consumption	Total	
4%	$29,754	$2,111,414	$19,204	$2,130,618	71.6
5%	$30,181	$2,111,414	$19,204	$2,130,618	70.6
6%	$30,610	$2,111,414	$19,204	$2,130,618	69.6
7%	$31,039	$2,111,414	$19,204	$2,130,618	68.6
8%	$31,470	$2,111,414	$19,204	$2,130,618	67.7

As evident in **Table 45**, the benefit to cost ratio ranges from 67.7:1 to 71.6:1. The benefits calculated are only for the AM, Midday, and PM peaks.

4.8 CONCLUSIONS

New coordinated signal timings were developed and implemented for twenty (20) signals along and surrounding SC 171 (Folly Road) in the City of Charleston, Charleston County, South Carolina.

To determine the effectiveness of the new signal timing plans, travel time studies were performed using Qstar Logger and processed with Trav-time to evaluate and document the results of the timing plan development process. The report presents the results of the "before" and "after" studies that were conducted along the thirteen (13) intersections included in the travel time studies along the SC 171 (Folly Road) corridor. The length of the corridor is approximately 4.5 miles. The travel time studies were conducted on typical weekdays during five (5) time periods of the day: AM Peak (07:00-09:00), Midday (11:00-13:00), and PM Peak (16:00-18:00) and Weekend peaks (11:00-13:30 and 16:00-18:00).

The new signal timing plans implemented for the AM peak, Midday peak, PM peak, and Weekend peaks show improvements along SC 171 (Folly Road). The new timing plans have decreased travel time and delay and increased the speeds through the corridor. The improvements in traffic flow are expected to decrease carbon monoxide, oxides of nitrogen, and volatile organic compound emissions.

Delay incurs direct costs upon motorists in the form of increased fuel consumption and the value of their time wasted while waiting in traffic. Motorists using SC 171 (Folly Road) during the AM, Midday, and PM peak periods will save 146,626 hours each year because of the improved traffic flow due to the new timing plans.

Conservatively assuming a vehicle occupancy of 1.2 persons/vehicle, $12.00 per hour for the value of motorists' time, and $2.34 per gallon for gasoline, annual savings to motorists along SC 171 (Folly Road) during the AM, MD and PM peaks will be $2,111,414 in the form of reduced delay and $19,204 decrease in cost due to decreased fuel consumption, for a total annual savings of $2,130,618.

The Benefit to Cost ratio is between 67.1:1 and 71.6:1 for the SC 171 (Folly Road) corridor.

5.0 TRAFFIC SIGNAL OPERATIONS OVERVIEW AND ASSESSMENT

5.1 INTRODUCTION & PURPOSE

The City of Charleston, South Carolina is experiencing rapid population and economic growth which is exerting growing pressure on its transportation infrastructure. Founded in 1670, Charleston is the oldest city in South Carolina, with a population estimated at 132,609 in 2015, and a metro area population of over 725,000. Charleston is a city which can boast three and a half centuries worth of history, architecture, and culture – priceless cross sections of American history which draw visitors from all over the world.

However, the unique character of the City also presents unique challenges to its leaders, particularly with respect to its transportation infrastructure. In the downtown peninsula, narrow rights-of-way run between centuries-old historical sites, leaving no room for roadway expansion. In the suburbs of Charleston, the daily ebb and tide of commuter traffic across fixed-width bridges leads to major congestion issues. All over the City, upgrading transportation infrastructure to meet today's travel demands are hindered by limited rights-of-way and densely packed utility corridors.

The City of Charleston recently retained Stantec to upgrade its traffic signal timings for its 207 traffic signals in downtown, West Ashley, James Island, and Johns Island. As an additional task in this project, the City asked Stantec to evaluate its current traffic signal system and make recommendations as to whether other types of signal control would be more appropriate for more efficiently moving traffic. Related to that task, Stantec also evaluated the City's current Traffic Signal Control Center (TSCC). This report documents Stantec's work related to both the traffic signal control and the Traffic Signal Control Center evaluations. Stantec was the lead on both of these tasks while Kimley-Horn and Associates, Inc. provided peer city analysis and collaborated in the recommendations.

5.2 EXISTING CONDITIONS

5.2.1 Traffic Signal System

The City of Charleston Traffic & Transportation Department currently operates 207 signalized intersections within its jurisdictional boundaries. The department also operates approximately 70 school zone flashers.

The City is in the process of upgrading its traffic signal controller hardware. The legacy system consisted of Model 170 controllers, which many have been in place for over 20 years. These controllers are becoming outdated; therefore, the City has begun to deploy the upgraded replacement traffic signal controllers as budget and schedule allow. The replacement controllers selected by the City are Intelight Advance Traffic Controllers (ATCs). As of September 2016, approximately 90 of the City's 207 signals have been upgraded to the Intelight ATC.

Traffic signal detection is primarily achieved using inductive loops. Most traffic signals in Charleston are equipped with stop-bar loop detection with a few advance loop detectors on Highways US 17 and SC 61. The City has also installed Video Image Vehicle Detection System (VIVDS) cameras at the following locations:

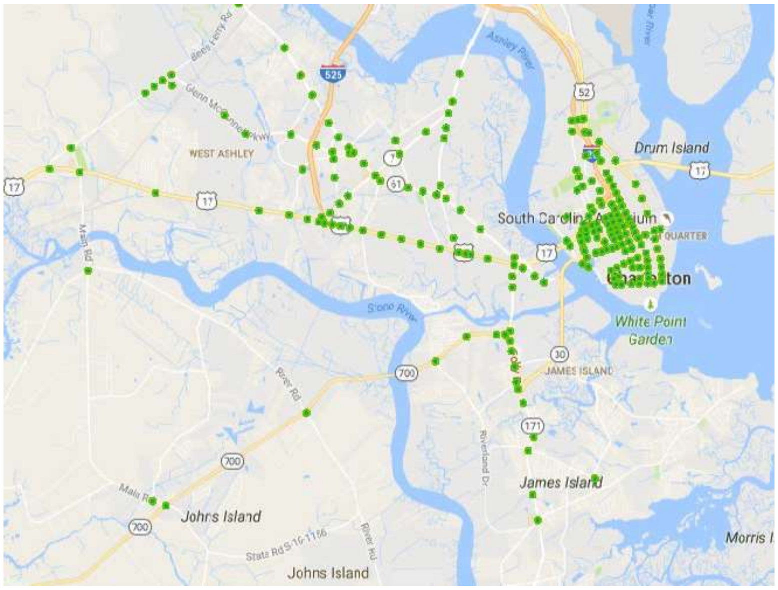
- Septima Clark Parkway ("The Crosstown")
- Calhoun Street & Elizabeth Street
- I-526 & Paul Cantrell Boulevard

To some extent, the traffic patterns in Charleston are predictable. Typically the morning peak hour brings an influx of traffic from the suburban areas toward the downtown peninsula, and generally a reversal of that pattern in the afternoon. These daily commuting patterns particularly congest the following corridors:

- US 17 (Savannah Highway), SC 61 (Ashley River Road), and SC 171 (Folly Road) converge in a single interchange on the west side of the Ashley River. Eastbound traffic headed to downtown Charleston in the morning must use either the US 17 bridge or the nearby 4-lane James Island Expressway bridge to access the downtown peninsula. These bridges are not easily expanded and cause a bottleneck for traffic headed onto the peninsula.
- Traffic from North Charleston typically uses I-26, but also is served by Meeting Street and King Street, for access to and from the peninsula.
- The only convenient access to downtown Charleston from Mount Pleasant to the east is across the Arthur Ravenel Jr. (US 17) Bridge.

Charleston's specific circumstances have introduced some variability in the directional distribution of traffic. Due to its popularity as a tourist destination, Charleston always has a baseline traffic demand which is inherently unpredictable – vacationers do not typically adhere to the same travel patterns as work commuters. Although the tourist season is highest in the spring, summer, and early fall, Charleston's warm climate boosts its popularity during the cooler months as well. In addition to the seasonal tourism, Charleston also experiences a large amount of event-specific tourism that regularly occur each year, including the Spoleto Festival USA, the Southeastern Wildlife Exposition, the Mojo Arts Festival, etc.

Another challenge being faced by Charleston's Department of Traffic and Transportation is the presence of several schools, including The Citadel, the College of Charleston, and the Medical University of South Carolina, as well as several trade schools and primary school campuses. These schools introduce unpredictability for traffic demand, as students often have different schedules than would be expected for the population in general. Schools also introduce high demand for pedestrian accommodations.



The downtown peninsula is not the only area of Charleston with heavy traffic congestion. West Ashley is a vibrant suburb with a heavily residential neighborhood. Its primary arteries include SC 7 (Sam Rittenberg Boulevard), US 17 (Savannah Highway), and SC 61 (Ashley River Road), Interstate 526 (Mark Clark Expressway), and city arterial streets Glenn McConnell Parkway and Paul Cantrell Boulevard. Owing to the daily commuter traffic into the downtown area, these roadways are predictably congested at the AM and PM peak periods.

Additionally, Charleston's popularity with beachgoers causes heavy traffic headed south toward the oceanfront on Highway SC 171 (Folly Road). This road extends through James Island and terminates at Folly Island on the Atlantic Coast. Since the beach traffic demand on Folly Road is influenced heavily by weather conditions, it is less predictable than other Charleston roadways. Also adding to the unpredictable nature of this corridor is the potential for the draw bridge on Folly Road at Wappoo Creek to open at various times.

Compounding all of these issues is the fact that Charleston is an old city, with long-established rights-of-way and historic buildings on nearly every block. The City's ability to physically expand its transportation network is extremely limited. Therefore, city planners and managers must evaluate all available technologies to ensure the traffic system is being operated as efficiently as possible.

The City's Department of Traffic and Transportation is also challenged by hurricane evacuations. These events cause large amounts of traffic demand, sometimes with only a few hours notice.

Since hurricane events are largely unpredictable, it is important that the City has the ability to monitor traffic conditions in real-time along all major roadways and be able to adjust traffic control systems to accommodate shifting demand. Oversight for hurricane evacuations is also performed by SCDOT, which makes interconnectivity between the City and the SCDOT of critical importance.

All of Charleston's traffic signals currently operate in either isolated or time-based mode. The only exception to this is Glenn McConnell Parkway, Paul Cantrell Boulevard, and SC 61 (Ashley River Road), where SCDOT is currently implementing a traffic responsive signal system. For its time-based coordinated operation, the City typically uses a 90-second cycle length in its coordinated patterns. Some locations, particularly in the downtown area, operate on a "half-cycle" of 45-seconds. At about 20 intersections along US 17 (Savannah Highway), the cycle length is set to 140-seconds to accommodate large platoons headed to and from downtown Charleston.

The traffic signal timing currently in place was last updated in 2008/2009 and has become outdated. The City has a project currently underway to deploy updated traffic signal timing plans city-wide.

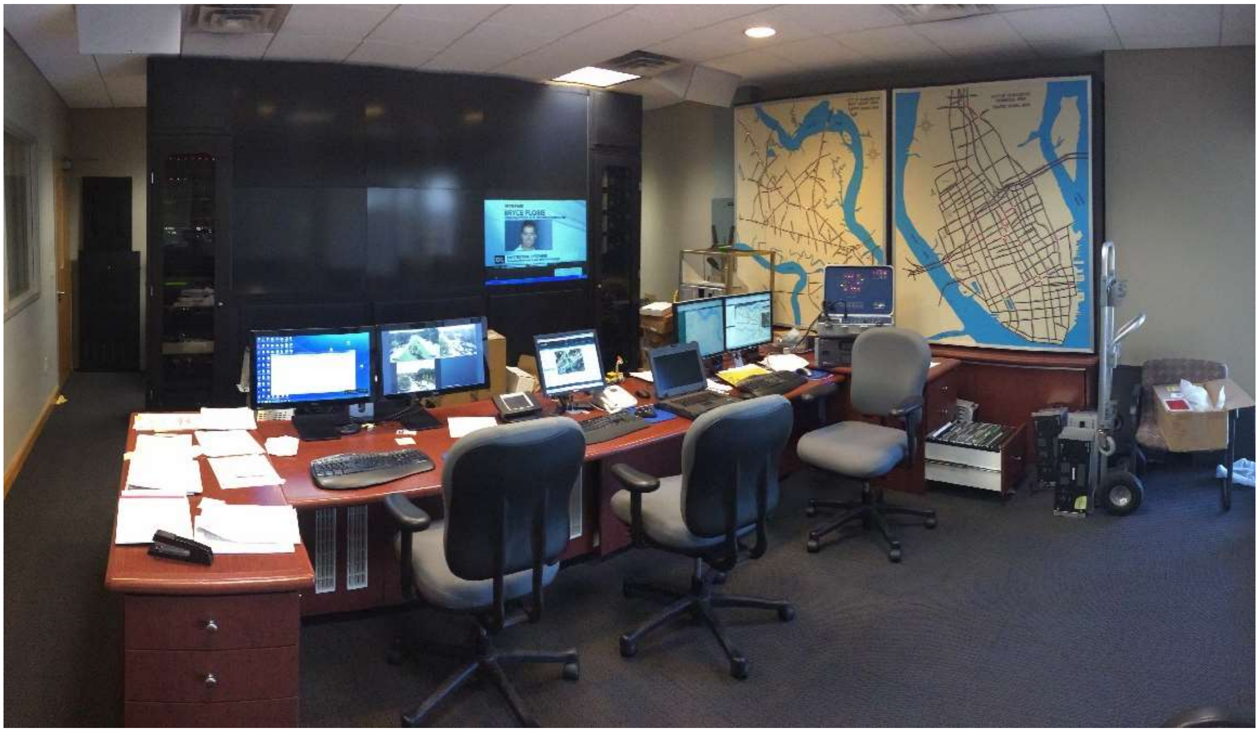
5.2.2 Traffic Signal Control Center

The City's Traffic Signal Control Center (TSCC), sometimes referred to as a Transportation Management Center (TMC), was constructed in the early 2000's. The existing TSCC hardware consists of an operator console with room for three operators, a video monitor wall with six monitors, and a video distribution switch. The TSCC also contains workstations and servers which run its existing traffic management software. These workstations and servers are modern systems which were installed in 2015.

Currently, the City operates two Advanced Traffic Management System (ATMS) software packages in parallel:

- Intelight-ITS MaxView, which provides the TSCC with an interface to manage the Intelight ATC units which are in the process of being deployed city-wide.
- McCain Quicnet, which provides management and control of the City's legacy model 170 traffic signal controllers.

The existing video board has reached the end of its useful life. All monitors on the board except for one are non-operational. The original design of the board was intended to support older monitors with specific dimensions and operating requirements. These monitors are no longer commercially available, which means that when one malfunctions, no replacement parts can be procured to repair it.



The TSCC also has a legacy system light board which was used in past years to monitor the City's signal system. This light board is no longer in service for traffic management purposes, although it is still functional as a display piece.

The City has Bluetooth travel time stations along two corridors (US 17 and SC 61). These stations can transmit travel time data to the TSCC and provide operators with a snapshot of the travel conditions along these two corridors.

The City's transportation communication network is in the process of being upgraded. Currently, the City uses a mix of twisted-pair copper, dial-up modems, fiber-optic cable, cellular modems, and wireless radios to provide connectivity to their traffic signals. The legacy equipment (twisted pair, dial-up modems) is being replaced with modern communication equipment. The City's long-range goals include the upgrade of all communication links to fiber-optic cable. This will allow video monitoring capabilities of the city from the TSCC, with the ability to detect and respond to incidents in real-time. This full fiber network will support the ability to share video data between the TSCC and SCDOT. The City has already deployed fiber-ready Ethernet switches in many of its signal controller cabinets, which will smooth the road toward a full fiber deployment.

A full fiber network will also support the expansion of the City's transportation system monitoring ability. The City currently operates approximately five Closed Circuit TV (CCTV) and 35 video detection cameras which aid staff in monitoring the conditions along Charleston's most critical roadways. As deployment of the fiber network becomes more widespread, the City will have the ability to add more cameras to the network to allow the TSCC operators to monitor more of the City's traffic operations in real-time.

5.2.3 Existing Staff

Charleston's signal system is operated and maintained by the following staff:

- 2 electronics technicians who perform any work inside controller cabinets
- 3 – 2 person crews (one senior traffic signal technician and one traffic signal technician) for construction and maintenance tasks
- 1 traffic signal supervisor to oversee line crews
- 1 signal systems manager

The City has also requested one additional staff position to be added to the department for signal maintenance duties. Until this position is created and filled, the work of the traffic department is performed by ten (10) people. At the time of this report, the three traffic signal technician positions are vacant.

The City's signs and pavement marking are deployed and maintained by the following staff:

- 7 field technicians
- 2 fabricators
- 1 signs and markings supervisor

In all, the City's traffic department is staffed by 20 personnel, with one position pending approval.

5.3 REVIEW OF SIMILAR SIZED AGENCIES

This section provides a review of cities with similar sized traffic signal maintenance and operational responsibility to that of Charleston, South Carolina. This section provides some level of insight into how other agencies manage their traffic signal systems. There are varying approaches to traffic signal management throughout the United States and this provides a sampling of how some similar communities address their needs.

Cary, North Carolina

The Town of Cary has 195 traffic signals in their signal system. The majority of those signals are owned by NCDOT, but all are maintained by the Town of Cary with partial reimbursement of maintenance expenses by NCDOT. The signals on Town maintained roads are owned and maintained by the Town. The Town also has 38 CCTVs with a project underway to add 70 more. The Town previously implemented traffic adaptive traffic signal control on Walnut Street, a major commuter and retail corridor in the area. They were not satisfied with the resulting operations and subsequently removed the adaptive system. All coordinated signals now use time-based coordination. Most of the signals and all the CCTVs are connected via fiber-optic cable to the Town's Traffic Management Center (TMC).

The Cary TMC is shown below. It is housed in the Cary Town Hall. It includes a small office for the signal system engineer and a small server room behind the video wall.

The TMC is staffed by one engineer and two specialists and operates from 7:00 AM – 6:00 PM on weekdays. Outside of normal hours of operation, the Cary 911 system has access to the system, as does the NCDOT Statewide TMC. Field personnel consist of four teams of two technicians each that are overseen by a supervisor and manager. Each team is assigned one geographic region of the Town with on-call rotations for overnight or after-hours emergencies. This adds up to 13 total engineering and maintenance personnel.

Wilmington, North Carolina

The City of Wilmington has 213 traffic signals in their system and 36 CCTVs. The equipment is connected to their TMC via 61 miles of fiber optic cable. No traffic responsive or adaptive strategies are in place or planned in Wilmington. NCDOT owns the majority of signals in the City of Wilmington and the City maintains the signals with partial reimbursement of maintenance costs by NCDOT.

The TMC, shown above, is staffed by a signal system management engineer, a senior ITS analyst, and half of an engineering technician (this position is shared with the Traffic Signs and Markings group). Field personnel include an ITS maintenance supervisor, an ITS master technician, three senior ITS technicians, and three ITS technicians. One senior ITS technician is exclusively tasked with underground utility location responsibilities and one exclusively with electronic repair responsibilities.

This results in 10.5 total personnel including engineering and maintenance staff.

Plano, Texas

The City of Plano currently has 236 traffic signals and 187 school zone flashers. The school flashers operate on local time clocks and do not communicate with a central system. One hundred of the signals operate on Ethernet with wireless Cambium backhaul that is managed by the IT department. The remaining 136 signals operate on RS-232 Serial over 900mHz Spread Spectrum (MDS) radio.

Plano currently only uses time based coordination but has a plan to deploy adaptive control in a business park area where new development is under way. Plano coordinates with other neighboring cities such as Frisco and Richardson as well as regional stakeholders such as TxDOT, the North Texas Tollway Authority (NTTA), and North Central Texas Council of Government (NCTCOG). The TMC operates 7:00 AM – 6:00 PM on weekdays.

The City of Plano TMC engineering staff includes two senior engineers and one TMC technician. Field operations staff includes one manager, one signals supervisor, five signal technicians, and five signal construction crew personnel. This results in a total of 15 personnel including both engineering and maintenance staff.

Frisco, Texas

The City of Frisco currently has 122 traffic signals, 175 school zone flashers, 116 CCTVs with PTZ capabilities and 400 fixed focal cameras. The City is currently installing a trial adaptive system on a primary thoroughfare adjacent to a major shopping mall but primarily relies on frequently updated time-based coordination plans.

A small portion of the traffic signals are connected via fiber-optic cable but roughly 99% use wireless radio communication. A recent communications master plan has identified a major upgrade to the communications network using a backbone of fiber-optic cable.

The City TMC is in a shared space within the Emergency Operations Center (EOC). The Center has five overhead displays for the video wall. There are two TMC operators on shifts from 6:30 AM – 6:30 PM. The City has one ITS Engineer and eight signal technicians in addition to the two operators, for a total of 11 engineering and maintenance staff.

Frisco coordinates frequently with the neighboring cities of Plano, McKinney, and Little Elm as well as regional stakeholders such as TxDOT, the North Texas Tollway Authority (NTTA), and North Central Texas Council of Governments (NCTCOG).

Greenville, South Carolina

The City of Greenville currently has 202 traffic signals, of which 186 are SCDOT signals, 15 are City signals, and one is a County signal. Greenville also has 37 school zone flashers. The City does not have a TMC. SCDOT currently utilizes time-based coordination and is in the process of implementing traffic adaptive control in the Greenville area in the near future. Most of the signals in the City are connected via twisted pair copper and fiber optic cable. Communication via radio is planned for a short corridor and cell modems are planned for several other corridors.

Greenville has two engineers, one engineering technician, one administrative assistant, and 11 maintenance personnel, for a total of 15 staff members.

Rock Hill, South Carolina

The City of Rock Hill currently has 128 traffic signals and 40 school zone flashers. The City does not have a TMC but does have a central system that connects to 90 signalized intersections. The City has tried traffic responsive traffic signal operation previously but had detection issues and did not have good results. They do intend to try a traffic responsive system again in the future. Fiber optic cable is used to connect the signals to the central system.

The City has two technicians, one helper, and one supervisor and contracts work to an engineering firm. Coordination partners with Rock Hill include SCDOT, the Rock Hill Fort Mill Area Transportation Study (RFATS), and York County Pennies for Progress.

Table 46 – Traffic Signal Operations Peer City Analysis

	Cary, NC	**Wilmington, NC**	**Plano, TX**	**Frisco, TX**	**Greenville, SC**	**Rock Hill, SC**	**Charleston, SC**
Number of Signals	195	213	236	122	202	128	207
Traffic Staffing	13	10.5	15	11	15	4[1]	10 (Not including sign & pavement marking staff)
Communication	Fiber-Optic	Fiber-Optic	Ethernet / Radio	Fiber-Optic/ Radio	Twisted-Pair Copper/ Fiber-Optic	Fiber-Optic	Twisted-Pair Copper/ Fiber-Optic/ Cellular/ Radio
Cameras	38	36	-	516	-	-	40
Traffic Signal Control	Time-Based	Time-Based	Time-Based	Time-Based/ Adaptive	Time-Based/ Adaptive	-	Time-Based/ Adaptive
Traffic Center Operation Times	7AM-6PM	-	7AM-6PM	6:30AM-6:30PM	-	-	As needed

1 – Also supported by Engineering Firm Staffing

Austin, Texas

Although the City of Charleston is not yet as large as Austin, Texas, the Charleston metro area is on a similar scale. The City of Austin currently has 974 traffic signal, 50 pedestrian hybrid beacons, 370 school zone flashers, and over 561 flasher beacons. The City also has 285 CCTV cameras, 13 DMS, and 139 Bluetooth readers. Austin is using adaptive signal timing on several corridors. For time-based coordination, the City retimes most signals ever five years but is actively moving to a performance-based system for arterial retiming.

Approximately 90% of the signals are communicating via fiber optic cable; the remainder are using wireless communication. The Arterial Management TMC includes a main operator area, several offices, a conference room, equipment room, and a larger server room. There are three concentrated operator workstations that observe four large display monitors.

The TMC is staffed through a consultant contract with four engineers responsible for traffic signal operations, seven TMC operators (three on duty at a time), and four administration staff positions. Field personnel include 19 technician positions (five of which are currently unfilled). This gives a total of 34 budgeted engineering and maintenance staff. The Austin TMC actively coordinates with all regional partners including TxDOT, the Central Texas Regional Mobility Authority (CTRMA), and Capital Metro Transit.

5.4 TRAFFIC SIGNAL SYSTEM EVALUATION AND RECOMMENDATIONS

Traffic signal operations have evolved over the years. For the most part, traffic signals that are fairly well separated from other signals and operate as an isolated signal control or they are more closely spaced, such as along a corridor or downtown grid, and operate as a system. While there is no set number as to whether a signal should operate as isolated versus in a system, it depends on whether there is sufficient distance to maintain a “platoon” of vehicles as the upstream signal releases.

The primary purpose of this section of the report is to discuss the different “state-of-the-practice” signal controls for those signals that are in a system and require coordination. Basically, there are three types of signal system coordination and they are described below along with isolated signal operation.

5.4.1 Types of Traffic Signal Operation

5.4.1.1 Isolated Intersection Operation

Isolated traffic signals operate based on current demand and local controller settings. This option is ideal for intersections that are not located near other traffic signals. One rule of thumb is that spacing greater than half of a mile would warrant consideration to use isolated operation, though this distance could vary based on type of roadway facility, land use patterns, and traffic volumes. For example, on a two-lane rural road it is more difficult to provide progression over a long distance than on an access controlled multi-lane roadway.

5.4.1.2 Time-Based Coordination

Time-based coordination is the predominant technique used in achieving coordinated flow along a corridor. This method involves setting the cycle lengths for a series of signals to the same, or compatible values for the purposes of providing progression along a primary route. Progression is achieved by establishing a fixed relationship between each of the signals on the route using an offset, or number of seconds between a set point in the coordinated phase. Providing coordination can decrease travel time, stops and delay, improve safety, and decrease emissions when done well. At an individual intersection level, coordination generally results in some loss of flexibility and efficiency due to the need to use a fixed-cycle length and a reduction in dilemma zone protection due to holding one or more phases for a set window of time rather than terminating those phases based on vehicle detections. For these reasons, the potential decrease in individual intersection performance must be evaluated against the potential gain in corridor performance to determine when coordination is appropriate.

Time-based coordination plans typically need to be updated every three to five years. Corridors with rapidly changing land uses and traffic patterns will need more frequent adjustments; generally, every 18 months. The level of effort required to develop or modify timing plans can vary widely based on the amount of data available or needed, the number of distinct travel patterns observed on the corridor, and the amount of fine-tuning desired. One rule of thumb is to budget approximately one week of effort per traffic signal to be coordinated.

5.4.1.3 Traffic Responsive Control

Traffic responsive control involves the use of real-time data to select from a library of timing plans developed off-line. Generally, a larger number of timing plans would be developed for a traffic responsive system than for a time-based coordination system. In addition to the timing plan development, up front effort is needed to determine appropriate triggers for each timing plan. Real-time communication and detection is needed to allow the system to pick and implement each timing plan, so maintenance of communications and detection infrastructure is critical to the success of a traffic responsive system. In the absence of real-time data, generally the system will default back to a time-based coordination schedule.

The use of a traffic responsive system provides the ability to account for temporal shifts in traffic patterns, such as fluctuations in the beginning and ending times of a commuter peak. For very sharp peaks, such as school traffic, the responsive system may not react quickly enough to implement the correct plan and a scheduled plan would be more effective.

While the use of a traffic responsive system can improve the longevity of a series of timing plans, over time as travel patterns change, the plans will still need to be updated periodically.

5.4.1.4 Traffic Adaptive Control

Traffic adaptive control involves the use of optimization algorithms and extensive real-time data collection to develop timing plans for each traffic signal on a cycle-by-cycle basis. Similar to traffic responsive systems, maintenance of detection and communications infrastructure is critical to the performance of traffic adaptive systems. Some studies have found that traffic adaptive systems perform approximately as well as recently optimized time-based coordination plans, once they are properly calibrated. This type of control should provide a more rapid response to changing traffic conditions than traffic responsive and has the added benefit of being able to accommodate unanticipated traffic patterns. This capability could eliminate or reduce the frequency of the need to retime traffic signals on a regular basis.

A wide variety of proprietary adaptive control systems have been developed and each has a particular set of detection and initial calibration needs. The cost of the system depends on which system is selected, but in general, adaptive systems will cost 5-10 times that of a time-based system.

The National Cooperative Highway Research Program (NCHRP) released report #14364 in 2010. This report discusses the (then current) state-of-the practice and recommendations for adaptive traffic signal timing. A few items of note from this report are shown below:

- “There is a need for expertise for successful ATCS implementation. Although many agencies implement ATCS’s to reduce labor-intensive maintenance of signal timing plans, survey respondents indicated that ATCS’s are only tools for traffic management, and they need to be supervised and controlled by skilled engineering staff.”
- “A majority of the ATCS users rely on in-house expertise, which is more an indication of the inadequate resources available to hire outside support than that ATCS users are trained to fully control and operate their systems. Most ATCS agencies do not have financial resources to acquire comprehensive training for ATCS and most are short-staffed.”
- “Detection requirements for ATCS are somewhat higher than those for conventional traffic-actuated control systems. Most ATCS users are satisfied with the way their systems handle minor detector malfunctions. ATCS users still struggle sometimes with handling ATCS-specific hardware; however, this is primarily an issue that can be resolved with better training of the technical staff.”
- “The survey results showed that ATCS installation costs per intersection are about US$ 65,000, which is higher than reported previously. Interestingly, results showed that ATCS’s require less money than conventional traffic signals for physical maintenance. This finding contradicts the common belief within the traffic signal community that ATCS’s are known for costly maintenance of their detectors and communications.”
- “The benefits of ATCS deployments are not easily observable in oversaturated traffic conditions. Although ATCS users have found that their systems may delay the start of oversaturation and reduce its duration, ATCS’s are not recognized as a cure-all for oversaturated traffic conditions. However, modifications of ATCS’s to reduce oversaturation is often beyond the ability of ATCS operational users; therefore, there is little evidence that can be used to draw conclusions about ATCS’s performances in instances of oversaturation.”

5.4.1.5 System Measurement / Measures of Effectiveness

Travel time and delay runs using the floating car method are a common tool in assessing traffic signal system timing performance. Travel time runs can be conducted using only basic tools such as a stopwatch or using software and GPS units specially made for this purpose. Off-the-shelf software packages can measure and report Measures of Effectiveness (MOE's) such as stops, delay, average speed, and many other arterial performance measures and identify specific locations of concern.

One issue with travel time runs is the difficulty in achieving a sample size that would produce statistically significant results. The use of newer technologies such as Bluetooth, wi-fi, and probe data have allowed for data collection methods that produce much larger sample sizes of arterial performance data.

New ATC controllers, such as the Intelight ATCs the City is currently installing, now provide the ability to log high resolution traffic signal controller data. This log provides a summary of every single thing the traffic signal controller is doing, at 1/10 second resolution. This log can then be downloaded into a central database and queried to measure the performance of individual intersection approaches, an entire intersection, a corridor, network, and the entire traffic signal system. This approach of Automated Traffic Signal Performance Measures (ATSPM's) is an incredible improvement in traffic signal management as now agencies can accurately measure system performance, where as in the past they could only model and estimate how the systems were functioning. ATSPM's can be managed via a standalone system that would run in parallel with the current central signal management system, or incorporated into that system via vendor plug-ins. The standalone software was developed by Utah DOT through a pooled fund study and is available at no cost via the US Department of Transportation, Federal Highway Administration Open Source Application Development Portal, and includes an interactive website for managing queries. Many of the central system vendors are incorporating the ATSPM's into their commercial, off-the-shelf software as well, though they may not provide every performance measure provided via the FHWA software.

ATSPM's include detailed information, depending on detector placements, on approach delay, approach volumes, split monitor, coordination effectiveness, arrivals on red, travel time (with Bluetooth or other similar type detection), phase termination, red light violations, arrival on green, and many other performance measures. Again, this is the first time, in the history of traffic signal operation, that through the use of high-resolution data, an agency can accurately measure what they could only previously model and estimate. Automated reports can help system operators determine when system performance is being degraded and timing changes are needed.

5.4.1.6 Special Considerations

For corridors that may experience non-typical heavy volumes of traffic due to emergency evacuation, incidents on parallel routes, or special events, it may be advisable to develop additional timing plans specifically designed to "flush" traffic through the corridor. These plans generally include a high-cycle length with most of the time allocated to the key route. For special events, these plans may be scheduled to run on a time-of-day schedule. For an emergency evacuation or in response to an incident on a parallel route, ideally these plans would be able to be implemented remotely via communications with the corridor.

5.4.2 Recommendations for Charleston

As of December 2016, the City of Charleston is in the midst of a project to re-time its traffic signal system. As part of this timing upgrade, the City is considering several techniques to improve traffic flow within the City.

As described above, traditional time-based traffic signal timing plans are by far the most commonly used technique for achieving coordinated traffic flow along a corridor. When it is possible to predict the traffic volumes with a reasonable amount of accuracy throughout the day, coordination plans can be designed to accommodate the anticipated traffic patterns. Typically these conditions will apply to commuter routes which bring traffic into and out of the Central Business District (CBD) each day – for example, US 17 (Savannah Highway). For most of Charleston's roadway network, time-based signal timing is the best choice.

Techniques such as traffic responsive timing and adaptive timing work well in very specific circumstances. There is a misconception that responsive and adaptive timing can solve congestion problems where time-based operation fails. In general, this is not true – these techniques are designed to solve the specific problem of unpredictable, but gradually changing, traffic patterns. Careful evaluation is needed to determine whether a responsive or adaptive system can succeed in a particular scenario.

In addition, responsive and adaptive systems require substantial effort to deploy, and constant maintenance to keep them running efficiently. As traffic patterns continue to change, the timing parameters and inputs must be tuned to allow the systems to perform well.

This report will detail the short-, mid-, and long-term goals recommended for the City in the following sections. For the City of Charleston, the following general upgrades are recommended:

1. Continue to deploy Intelight ATC traffic signal controllers as replacements for legacy McCain 170 controllers as rapidly as budget and schedule allow. The ATC controllers provide state-of-the-art performance capability and ensure compatibility with all modern traffic signal timing techniques and communication protocols.

2. Continue to design, deploy, tune, and maintain updated time-based coordination traffic signal timing plans along most routes within the City. The traffic patterns are largely consistent, and lend themselves well to this approach. SC 171 (Folly Road) should be considered for traffic responsive operation. While the traffic volumes can be accommodated by time-based coordinated operation, time-of-day fluctuations due to weather impacts can be more quickly addressed in a traffic responsive system. At this

time, it is not recommended to pursue adaptive signal control as there does not appear to be a candidate corridor that would benefit from the significant financial and staffing resources required to establish the operation. The benefit received from making an investment such as adaptive control would not outweigh the significant financial and labor resource cost needed.

3. Begin implementation, collection, and evaluation of traffic signal performance measures-based signal timing. This can be done through the MaxTime system the City has in place. One advantage of the deployment of Intelight ATC controllers city-wide is that these modern controllers can provide valuable performance metrics for the City's signal system. This data will allow Charleston's traffic engineering team to evaluate their system in real-time and make decisions based on extremely precise information. Implementation of an ATSPM's approach will allow the City traffic engineering team to evaluate the effectiveness of signal timing plans without the need for detailed traffic modeling; allowing the staff to implement timing improvements based on need rather than an assumed calendar schedule.

5.4.2.1 Short-Term Recommendations (12-18 Months)

1. Complete upgrade of traffic signal controllers city-wide to Intelight controllers.

2. Configure the MaxTime system to start evaluating the operation of corridors using the Automated Traffic Signal Performance Measures along key corridors within the City. Establish a procedure for how the system will be monitored to evaluate operations and develop a baseline for corridor operation.

3. Identify priority listing of detection upgrades needed. This can be identified through the ATSPMs system as the performance measures will show those locations where detection is not working. This should also include locations where advance detection should be added to utilize the system performance measures of evaluating the effectiveness of coordination.

4. Deploy advance detection at intersections along highest priority corridors to effectively utilize all of the functionality of the Intelight controllers and MaxTime system.

5.4.2.2 Mid-Term Recommendations (2-5 Years)

1. Deploy upgraded detection needs as identified in the short-term recommendations, to support full use of the Intelight controllers, MaxTime system, and Automated Traffic Signal Performance Measures functionality.

2. Develop a long-term strategy for utilizing the ATSPMs functionality to manage signal operations and support resource management for the traffic engineering department. This should include regular reports to department heads and City Council, generated by the ATSPMs system, on the health of the signal system, improvements made over the

course of a set timeframe, such as quarterly or annually, and support needs for additional resources needed to deploy further detection, traffic responsive systems, or staff resources to manage the signal system in the most efficient manner.

5.4.2.3 Long-Term Recommendations (5+ years)

1. Complete deployment of modern communication technologies. Most infrastructure should be composed of fiber-optic cable, with outlying areas and remote intersections communicating via wireless Ethernet radio to a nearby fiber-optic hub.

2. Begin to develop a concept of operations and deployment plan for future upgrades. Beginning this process early ensures that the plans will be comprehensive in scope. Particularly, pay attention to identification of funding mechanisms (such as bond elections).

Table 47 – Traffic Signal System Recommendations

Period	Recommendation	Opinion of Probable Costs
Short-Term (12-18 Months)	• Complete upgrade of controllers • Configure MaxTime and utilize performance measures • Identify detection upgrade needs • Deploy advanced detection at highest priority corridors	$815,000
Mid-Term (2-5 Years)	• Deploy all advanced detection identified in the short-term recommendations • Develop a long-term strategy for utilizing performance measures	$1,025,000
Long-Term (5+ Years)	• Complete deployment of modern communication technologies • Develop concept of operation and deployment plan	$4,050,000
Opinion of Traffic Signal System Upgrade Costs		**$5,890,000**

Staff position upgrade recommendation carries a yearly recurring cost. Refer to **Appendix H** for a detailed breakdown of the cost opinion.

5.5 TRAFFIC SIGNAL CONTROL CENTER EVALUATION AND RECOMMENDATIONS

5.5.1 Discussion of Possible Elements of a TSCC and Active ITS Center

The heart of the City of Charleston's TSCC will consist of three systems which work together to provide operators the ability to retrieve data from the transportation network, evaluate its operation, and send needed instructions to devices or personnel in the field:

- Communication subsystem – allows video, audio, and other data to be transmitted between the TSCC, field devices, personnel, and other agencies.
- Video monitoring subsystem – the "eyes" of the transportation system. Video data provides irreplaceable information to operators about the current status of the transportation system and allows quick evaluation of potential or existing issues that need resolution. This subsystem includes the video processors, monitors, and/or projection devices that deliver video from the field to the operator.
- Computing subsystem – the servers, workstations, and transportation management system software that allows operators to design and implement solutions to problems, either as a matter of ongoing maintenance of the transportation system or in response to specific events.

For a fully functional TSCC, the following capabilities should be in place and available:

1. Command and control of City traffic signals – using the City's existing MaxView ATMS central software, staff manages, maintains, and operates existing traffic signals which have communication links to the TSCC.
2. Command and control of City Intelligent Transportation System (ITS) video monitoring cameras – as described above, the City currently operates five pan-tilt-zoom cameras and 35 fixed cameras along its street network. The TSCC facility currently provides adequate space for the existing video distribution servers for management of the video display wall. These servers and monitor display wall are to be placed in the space currently occupied by this legacy equipment.
3. Retrieval of video data – data from existing ITS cameras, including PTZ cameras described above and potentially VIVDS detector cameras that are connected to the City network, should be capable of being routed to video servers in the TSCC for distribution to traffic staff and other stakeholders.
4. Display of video from the City's cameras – TSCC operators and staff will use the video retrieved from the City's ITS network to monitor the transportation network in real-time, as well as make decisions about special event and/or incident responses. Video data is critical to making decisions based upon the most complete information possible; the

TSCC shall be equipped with large-format video displays to allow easy and detailed viewing of the video feeds. Typically this is achieved with wide-screen HD monitors. Additionally, the TSCC shall be equipped with at least one display available for viewing news and weather reports for staff information during traffic or weather events.

The TSCC shall provide the ability to display video on a variety of devices. At a minimum, the video shall be available on any City-connected workstation or laptop with appropriate software and user privileges, as well as monitors within the TSCC. Staff shall have the ability to access and view the video on mobile devices, including laptop computers, smart phones, and tablets.

5. Transmission of video to other stakeholders – the Charleston Police and Fire Departments will find great benefit from viewing the video monitoring feeds from the roadway network. This video will provide critical information for use in the coordination and deployment of appropriate emergency response teams, as well as enhance overall safety by allowing the first responders to assess the situation before they arrive at the scene. Other potential stakeholders who would benefit from the video provided by the City of Charleston TSCC include the SCDOT, CHATS (the local MPO), adjacent municipalities, and local news stations.

   Additionally, the TSCC staff is uniquely positioned to provide real-time assistance to Police and Fire Department first responders when responding to incidents. Traffic congestion often delays the arrival of responders to the scene of an incident. TSCC staff will be equipped with the resources necessary to allow for use of real-time traffic information to provide dynamic rerouting information to dispatchers, minimizing response times.

6. Remote operation of the transportation network – the City does not anticipate 24/7 staffing of the TSCC; therefore, for quick response capability after-hours, or for remote TSCC monitoring and operation directly from the field, remote access for TSCC staff is required. This functionality must be supported by the City's IT department.

7. Data repository – the TSCC serves as the primary repository of traffic signal network data. The City of Charleston will store this data in computerized databases (interfaced with the transportation management system) and have the option to maintain hard copies as backup. The TSCC must be provided with adequate rack space and shelf space to accommodate storage of this data. The IT department should provide backups of the data residing on TSCC servers.

8. Serve as a backup Incident Command Center for the Charleston Police and Fire Departments – during an event such as a hurricane, it is often useful for Incident Commanders from the Police or Fire Departments to use the TSCC as a command center to direct response teams. The TSCC may then help the City progress in its abilities to fulfill the Incident Command System (ICS) component of the National Incident Management System (NIMS), which is managed by the Federal Emergency Management Agency (FEMA).

5.5.2 Short-Term Recommendations (12 – 18 Months)

The short-term recommendations of the TSCC upgrade should include the following items:

1. Replace existing video monitors in the TSCC. The existing monitor board has reached the end of its useful life, and all of the monitors are non-operational.

   The replacement monitors should meet the criteria shown below. These criteria have been developed with performance, cost effectiveness, and system longevity in mind.

1920 x 1080 resolution: This allows staff to take advantage of 1080i or 1080p video clarity available modern ITS cameras. Although higher camera resolutions are available, they consume considerably more data across the network, and do not provide significantly higher performance for transportation network surveillance. Therefore, investing in 3840 x 2160 "4K" monitors is unlikely to justify their additional cost.

Available off-the-shelf: This will prolong the useful life of the system by ensuring that replacement parts may be obtained quickly and economically.

Standard dimensions: The City should procure monitors that can be replaced in the future with monitors of the same size, without regard to manufacturer.

Minimum Input Capabilities:

- 2 – HDMI
- 1 – USB
- 1 – Composite (RCA)

The design of the monitor wall should accommodate slight variances (< 1 inch) in the thickness of monitors to be installed without negatively affecting the display quality.

The size of the existing TSCC is sufficient to accommodate a 2 x 4 array of 40 to 48 inch flat screen monitors. Each monitor may be split into four separate displays by the video distribution software, thereby allowing for up to 32 separate video feeds to be displayed simultaneously.

2. Add at least one staff position to monitor and operate the TSCC. The TSCC is currently staffed only on an as-needed basis by the City's Traffic Signal Systems Manager. The City should consider adding at least one position to operate the TSCC during at least the AM and PM peak traffic periods.

   One solution for this short-term staffing need is to hire a part-time intern, ideally a student of engineering at a local college or university. Part-time positions are not as expensive as a full-time professional level position, and the City will likely find it to be a valuable resource for the identification of talented young engineers who are interested in a career in transportation engineering. The young engineers who are selected to fill the position gain invaluable experience in the industry and are better prepared to enter the professional work force upon graduation. Additionally, if the City decides to create a full-time position for the operation of the TSCC, a young engineer with on-the-job experience from an internship is an ideal candidate.

3. Replace the existing video server with a modern system that will meet the needs of the TSCC. The video server should be able to process up to 32 simultaneous video feeds and provide at least eight outputs to the monitor board. The server should be paired with a video distribution software package that is capable of routing video to the monitors in any compatible way desired by the TSCC operator, including single, dual, and quad views on each monitor.

4. Installation of 3-5 ITS cameras at key locations within the City. Locations which should be considered for ITS camera installations include:

    - Bees Ferry Road & Glenn McConnell Parkway
    - Magwood Drive & Glenn McConnell Parkway
    - Maybank Highway & River Road

5. Begin retrieving, analyzing and using the high-resolution data that is currently available in the new ATC controllers that are currently deployed to develop baseline traffic signal performance measures. The City's project to install modern traffic signal controllers will allow engineers at the TSCC to collect and analyze traffic signal performance measure data from intersections. These performance measures are powerful tools and allow engineers to monitor and adjust the transportation network in real-time. The data collection and analysis may be done through the City's existing MaxView central traffic software, or through a standalone software developed by the Utah DOT and distributed through the Federal Highway Administration website. This standalone software is available at no cost to the City other than the labor and computing resources required to install it.

6. Retrieve and evaluate travel time data transmitted from the City's existing Bluetooth travel time stations along Highways US 17 and SC 61 utilizing the ATSPMs functionality. Travel time data provides an extremely useful snapshot of the current traffic conditions along the City's roadways, which is presented in a format that is understandable at a glance. This information is also easily understandable by non-engineers, making it perfect for sharing with local news stations and the public.

5.5.3 Mid-Term Recommendations (2 – 5 Years)

The mid-term recommendations for the TSCC upgrades should include the following:

1. Continue to evaluate the need for ITS camera coverage and installation of 5-10 additional cameras at key locations.
2. Continue to replace legacy communication technology with high-bitrate and low-latency fiber optic cable. Priority corridors for this upgrade include:
    - Replacement of twisted-pair copper on Meeting Street
    - Replacement of spread-spectrum radios on Glenn McConnell Parkway
3. Deploy additional travel time stations as budget allows. Based upon current traffic loading conditions, candidate corridors for travel time stations include Folly Road, East Bay Street, Calhoun Street, Glenn McConnell Parkway, and Ashley River Road. Once travel time data is available for these corridors, it may be used in the TSCC and possibly shared with the public to provide a useful "at-a-glance" snapshot of current travel conditions.

5.5.4 Long-Term Recommendations (5+ Years)

In the long-term, the City will continue to adapt to growth and changing traffic patterns. With the TSCC upgrades completed in the short- and mid-term phases, the City's transportation engineers will be well equipped to respond to these changing conditions. To optimize the effectiveness of the City's upgraded TSCC, the following tasks should be considered long-term goals:

1. Create and fill two full-time staff positions to allow the TSCC to operate between the hours of 7:00 AM and 7:00 PM, Monday through Friday, plus special events as needed. These two staff positions may be supplemented by part-time intern level staff as needed.
2. Deploy fiber to all of the City's traffic signals and ITS devices, with an emphasis on connecting CCTV cameras. Broad coverage of fiber across the City provides benefits to traffic management by allowing reliable, low latency access to high resolution video and traffic signal data.
3. Develop a detailed plan for the next generation Transportation Management Center. By this point in the City's growth, it is anticipated that the existing TSCC will be reaching the end of its design life in terms of space and capability.

Table 48 – Traffic Signal Control Center Recommendations

Period	Recommendation	Opinion of Probable Costs
Short-Term (12-18 Months)	• Replace existing video monitors • Add at least one staff position to monitor and operate the TSCC • Replace the existing video server with a modern system • Install 3-5 ITS cameras at key locations • Begin retrieving, analyzing and using the high resolution data from the controllers • Retrieve and evaluate travel time data utilizing ATSPMs functionality	$220,000
Mid-Term (2-5 Years)	• Continue to evaluate the need for ITS camera coverage of 5-10 additional key locations • Continue to replace legacy communication with fiber-optic cable • Deploy additional travel time stations	$650,000
Long-Term (5+ Years)	• Create and fill two full-time staff positions to operate between 7AM-7PM, Monday through Friday • Deploy fiber to all signals and ITS devices • Develop detailed plan for the next generation TMC	$830,000
Opinion of Traffic Signal Control Center Upgrade Costs		**$1,700,000**

Staff position upgrade recommendation carries a yearly recurring cost. Refer to **Appendix H** for a detailed breakdown of the cost opinion.

5.6 SUMMARY

The City of Charleston's transportation network is approaching its capacity. Thoughtful solutions will be needed to keep traffic moving as the City continues to write its history. Although Charleston has limited ability to physically expand its transportation facilities, the City's leaders are wisely evaluating advanced technologies to optimize the efficiency of its assets.

In addition to the ongoing deployment of upgraded signal timing and hardware, the City is contemplating alternative timing technologies such as adaptive signal control. Although these technologies have their place in the traffic engineer's toolkit, careful evaluation is needed to select corridors where they will be successful. These systems represent large investments of resources and require ongoing maintenance to be successful.

Performance measures based management of the traffic signal system is a rapidly growing technology. Charleston already has much of the needed infrastructure to put this data into use. Given Charleston's need to optimize the efficiency with which it operates the transportation network, these performance measures can provide invaluable information about the health of the City's system.

The most important resource available to any transportation management system is the people who operate it. The value of a dedicated, knowledgeable, and fully trained staff is immeasurable. The City should consider deeper investment into its staff to ensure that the transportation system is led with experience and wisdom as this iconic city writes the next chapters in its long history.