An Overview and Assessment of Traffic Signal Operations

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Table of Contents

1.0 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.

2.0 Existing Conditions

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.

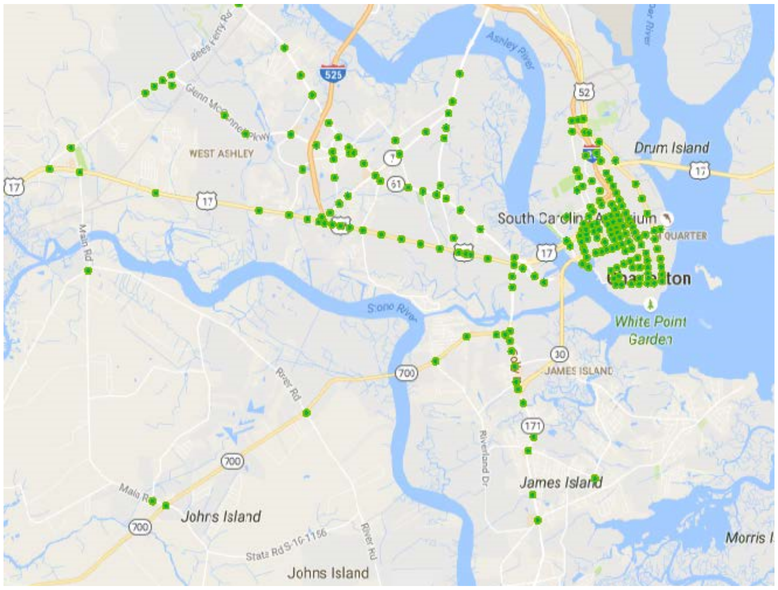
Traffic signal detection is primarily achieved using inductive loops. Most traffic signals in Charleston are equipped with stop-bar loop detection with a few advance loop detectors on Highways US 17 and SC 61. The City has also installed Video Image Vehicle Detection System (VIVDS) cameras at the following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

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.

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 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.

3.0 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 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.

Rockhill, 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 Rockhill include SCDOT, the Rock Hill Fort Mill Area Transportation Study (RFATS), and York County Pennies for Progress.

Table 1: 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.

4.0 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.

4.1 Types of Traffic Signal Operation

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.

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.

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.

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."

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.

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.

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.

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.

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.

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 2: 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 A for a detailed breakdown of the cost opinion.

5.0 Traffic Signal Control Center Evaluation and Recommendations

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).

5.2 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.

5.3 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.

5.4 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 3: 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 A for a detailed breakdown of the cost opinion.

6.0 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.

Appendix A

Appendix A - Charleston Traffic Signal System Upgrades Cost Opinion

Phase	Item	Description	Unit	Approx. Unit Cost	Units required	Cost Estimate	Total
Short Term (12-18 mo)	Controller Upgrades*	Furnish and install Intelight ATC Controllers to remaining intersections (est. 120)	EA	$5,000	120	$600,000	$815,000
	Implement performance measures*	Configure MaxTime for utilization of signal performance measures (install software & server); train staff on intersection configuration and useage	LS	$15,000	1	$15,000	
	Deploy advance detection*	Identify priority corridors for advance detection (assume 20 signals, 2 approaches each)	EA	$5,000	40	$200,000	
Mid-term (2-5 years)	Deploy advance detection*	Complete deployment of advance detection along major corridors (assume 100 signals, 2 approaches each)	EA	$5,000	200	$1,000,000	$1,025,000
	Complete signal performance measures implementation*	Develop signal performance measures utilization & reporting strategy and define procedures for collecting, using, and reporting the data	LS	$25,000	1	$25,000	
Long-term (5+ years)	Install fiber optic cable to traffic signals*	Install fiber optic cable to 90% of signals (assume 190 signals)	EA	$20,000	190	$3,800,000	$4,050,000
	Install wireless communication to traffic signals*	Install wireless communication links to 10% of signals (assume 20)	EA	$5,000	20	$100,000	
	Begin planning future signal system upgrades	Begin development of a concept of operations for future central traffic signal system upgrades using modern technology	LS	$150,000	1	$150,000	

Cost opinion for all phases of development: $5,890,000

Note: Items marked with an asterisk indicate procurement and/or construction tasks. Costs for engineering design services are included in the cost opinion for these items.

Appendix A - Charleston Traffic Signal Control Center (TSCC) Upgrades Cost Opinion

Phase	Item	Description	Unit	Approx. Unit Cost	Units required	Cost Estimate	Total
Short Term (12-18 mo)	Replace video monitors*	Furnish and install 8 40"-48" video monitors for use in the TSCC, including mounting to a video wall board	EA	$7,500	8	$60,000	$220,000
	Add staff position	Fund one full-time position for a TSCC operator	YR	$80,000	1	$80,000	
	Upgrade video server*	Furnish and install one video server to support video wall	EA	$20,000	1	$20,000	
	Add ITS cameras*	Furnish and install up to 5 ITS cameras to improve monitoring capability	EA	$10,000	5	$50,000	
	Utilize high-resolution and travel time data*	Configure MaxTime and travel time software to provide usable data (high-resolution signal data costs shown in signal system upgrade cost opinion)	LS	$10,000	1	$10,000	
Mid-term (2-5 years)	Add additional ITS cameras*	Furnish and install up to 10 ITS cameras to further improve monitoring capability	EA	$10,000	10	$100,000	$650,000
	Add additional fiber optic communication *	Continue to upgrade communication network to fiber optic. The costs shown for this item are related only to ITS devices (such as standalone cameras) and are separate from the signal systems fiber upgrades. Assume 20 devices	EA	$20,000	20	$400,000	
	Add additional travel time stations*	Furnish and install travel time stations on priority corridors (assume 5 corridors, 5 count stations on each)	EA	$6,000	25	$150,000	
Long-term (5+ years)	Add staff position	Fund a second full-time position for continuous staffing of TSCC	YR	$80,000	1	$80,000	$830,000
	Deploy fiber to all ITS elements*	Complete upgrade of communication network to provide fiber to all ITS devices (assume 30 additional devices)	EA	$20,000	30	$600,000	
	Begin planning future TSCC upgrades	Begin development of a concept of operations for future central traffic signal control center upgrades using modern technology	LS	$150,000	1	$150,000	

Cost opinion for all phases of development: $1,700,000

Note: Items marked with an asterisk indicate procurement and/or construction tasks. Costs for engineering design services are included in the cost opinion for these items.