SIGNAL SYSTEM TIMING PHILOSOPHY MANUAL

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RESOURCES AND LINKS

- Improving Traffic Signal Management and Operations: A Basic Service Model
  http://ops.fhwa.dot.gov/publications/fhwahop09055/fhwa_hop_09_055.pdf
- 2012 National Traffic Signal Report Card http://www.ite.org/reportcard/TechnicalReport.pdf
- Traffic Signal Manual http://www.signaltiming.com/The_Signal_Timing_Manual_08082008.pdf
- NCHRP 409: Traffic Signal Retiming Practices in the US
  http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_409.pdf
- NCDOT ITS and Signals Design Manual
  https://connect.ncdot.gov/resources/safety/its%20and%20signals%20resources/its%20and%20signals%20unit%20design%20manual.pdf
- MUTCD http://mutcd.fhwa.dot.gov/
- NCHRP 3-90 "Operation of Traffic Signal Systems in Oversaturated Conditions"
  https://www.nap.edu/catalog/22290/operation-of-traffic-signal-systems-in-oversaturated-conditions-volume-1-practitioner-guidance
- NCHRP Report 812 "Signal Timing Manual Second Edition"
  http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_812.pdf (144.171.11.50)
- FHWA-SA-13-027 (July 2013) Signalized Intersections: Informational Guide
  http://safety.fhwa.dot.gov/intersection/conventional/signalized/fhwasa13027/

Introduction

The North Carolina Department of Transportation (NCDOT) manages a wide range of transportation resources, including pedestrian and bike facilities; arterial, freeway, and interstate routes; passenger rail; and ferry operations. Signalized arterial routes play a significant role in the performance of this comprehensive transportation network. These connections integrate the long distance modes on rail and freeways with more precise destinations. Some of these arterial networks are managed through centralized signal systems that span signalized intersections on multiple corridors, but an even greater number is managed by interconnected coordinated signal systems located on a single corridor.

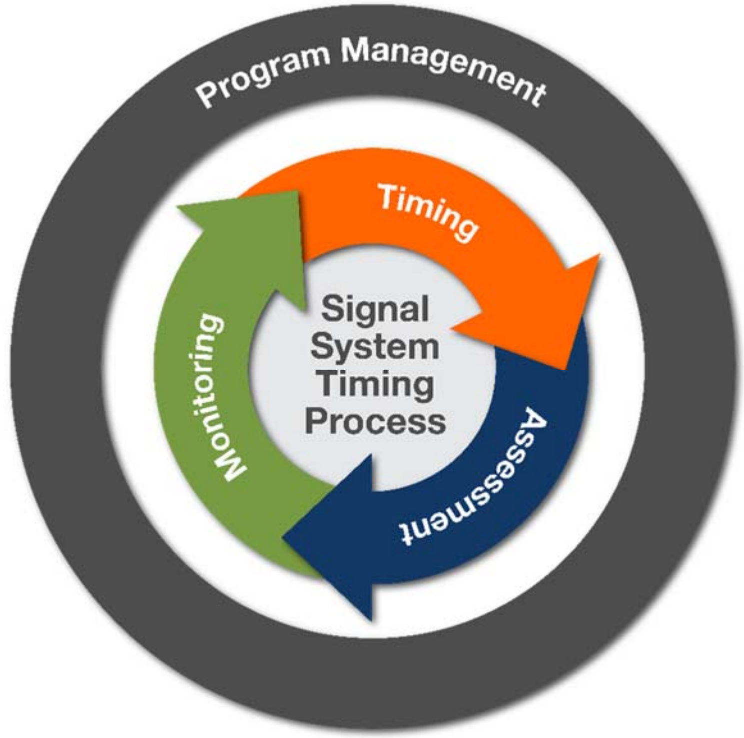


FIGURE 1. SIGNAL SYSTEM TIMING PROCESS

Studies have shown that improving traffic signal coordination plans is one of the most cost effective uses of transportation funds, with a consistent benefit-cost ratio of 40:1. Efficiently coordinating a set of traffic signals within a system with well-designed coordination plans can reduce travel time delays, crashes, fuel consumption, and emissions. North Carolina is fortunate to have a talented pool of expertise both within the Department and in the private sector that can continually optimize these corridors with effective coordination plans. Signal system timing work in North Carolina has given each of these professionals unique experiences and skill sets geared towards two high-level goals:

- Balancing and minimizing congestion
- Promoting smooth flow along a corridor

NCDOT is developing this document as a single repository of signal system timing knowledge integrated with the vision and program objectives of the Department. It is envisioned that this will promote information sharing and best practices to support consistent delivery of signal timing projects within the state. This documentation of procedures and guidelines is intended to help professionals, in both the public and private sectors, to accomplish the following objectives:

- Design appropriately to the prevailing conditions
- Provide versatile solutions that can accommodate a range of conditions
- Prioritize competing objectives for the corridor

The development of this manual is intended to be a collaborative effort facilitated by NCDOT's Central Office System Timing (COST) Section within Transportation Mobility and Safety. The goal is to continue to involve a wide range of experts from across the state and from across both the public and private sector. There are multiple ways to approach signal system timing, and this document will capture the most appropriate methods that address the identified operational objectives for North Carolina. The Department sees this collaborative approach as a successful means to achieving the vision for coordinated signal systems: ***To minimize stops and delays, within the context of safe operation.***

The elements in this manual serve a vast array of purposes, from guiding scope development to providing technical guidance. Each of the elements are presented as standalone guidance documents or tools and are grouped into the four categories present in **Figure 1**.

Catalog

The Philosophy Manual is a collection of guidelines and tools that comprise the catalog outlined below. This catalog of documents is a living library of tools that will be continually revised by the signal timing community as strategies change and new technologies are introduced. They are categorized to streamline user access.

Program Management

- Corridor Selection Process
- Performance Goals
- Data Needs and Applications

Timing

- Signal Timing Project Process
- Context of a Corridor
- Establishing Operational Objectives
- Field Visit Protocol
- Data Collection
- Final Report Recommendations
- "High Priority Ped" Tool for Coordinated Phases (Oasis Software)
- Alternative Timing Plans

Assessment

- Standard Practice for Performing Travel Time Runs
- Cost Benefit Analysis

Monitoring

- Roles and Responsibilities
- Impacts on a Corridor

Strategic Planning / Long Term Topics

In addition to the topics identified in the catalog, other topics have been identified for long range strategic planning efforts and will be integrated into future sections of this manual.

- Continuous Data Options
  - High Resolution Controller Data (HRCD)
  - Bluetooth
  - 3rd Party Probe Data
  - WI-FI
  - Dedicated Short Range Communications (DSRC)
  - System Detectors for Annual Performance Analysis
- Historical Documentation
- Integrated Corridor Management (ICM)
- Diverging Diamond Interchange (DDI)
- Emissions Data

UNDER DEVELOPMENT / FUTURE DOCUMENTATION

- Connected and Automated Vehicles (CAV)
- PEF Evaluation Process
- *Left Turn Phase Reservice*

SUPPORTING DOCUMENTS

- Scope of Services – Retiming of Existing Closed Loop Signals FY 2017

PROGRAM MANAGEMENT

Corridor Selection Process

GOAL

The COST (Central Office Signal Timing) group seeks to select corridors for signal system timing projects that maximize NCDOT's return on investment (ROI). Obtaining this goal will be an evolving process and the COST group will work through several iterations as it moves towards a more refined ROI approach to selecting corridors.

NCDOT is investigating performance metrics and data sources that enable more accurate assessments of a corridor's performance. The chosen performance metrics are closely tied to the value and accuracy of the available data. This identification and evaluation approach will be iterative as NCDOT works through a few alternative approaches.

CURRENT PROCESS

Currently, the COST group issues timing projects on a three-year cycle. A system can be timed with greater frequency in response to citizen complaints, new developments on the corridor, or known changes in traffic patterns that have degraded the performance of the corridor.

Challenges

One observation of the current process is that some of the identified corridors selected for a timing project have limited potential to benefit from a new timing plan. The comprehensive scope of a signal system timing project includes evaluation, design, and implementation. Often the evaluation phase determines that the performance issues with the corridor are not related to the existing timing plan and that capacity or geometric improvements would provide a bigger impact. In addition, the evaluation phase is based on travel time runs for the collection of "before" data. Travel time runs only provide data for a single day of traffic conditions, creating a small sample size of traffic data. The challenges can be easily summarized in two needs:

Evaluation Approach: NCDOT is working through several pilot projects and parallel assessment efforts to evaluate additional corridor performance metrics. Each of these efforts are focused on defining an approach that supports the ability to provide continuous corridor performance statistics and the identification of corridors that will yield the highest ROI with respect to newly implemented signal timing.

Data Sources: NCDOT is currently investigating additional data sources that can provide larger data sets to support the assessment and continuous monitoring of a corridor's performance. These data sources are described in more detail within the *Continuous Data Options* document.

CORRIDOR CATEGORIZATION

In order to optimize the use of resources, the COST Section works closely with Division staff to categorize corridors that include coordinated signal systems. NCDOT has initiated a process that will place corridors into one of three categories that include typical corridors, critical corridors, and non-critical corridors. Analysis for each corridor will be managed as defined below:

Typical Corridors: Typical corridors experience "normal" growth in traffic patterns and assessments at three year intervals are frequent enough to respond to changes in traffic volumes and traffic patterns. This category will include approximately 80% of the coordinated systems currently in place in North Carolina.

Critical Corridors: These corridors will be assessed more frequently at an interval of approximately every 18 months. The existing traffic conditions or projected conditions due to planned development in the vicinity of the corridor create the need for these evaluations to occur more frequently than the typical 3-year time frame. If the need for a revised coordination plan is determined before the 3-year cycle has lapsed, funding could be alternated between the COST Section and Division funding sources.

Non-critical Corridors: These corridors are projected to experience very slow growth in traffic volumes and minimal changes in traffic patterns. They require less frequent assessments and can be evaluated at intervals of possibly 5 to 6 years instead of the typical 3-year interval.

The initial designation of corridors will be established based on available data and the knowledge of the Division and COST section of the corridor's history. A baseline will be established and evaluated as additional data is available. Designations for a corridor can be modified and the process for designating and comparing against baseline values will be refined as the process moves forward.

Existing systems can require revised coordination plans in response to a range of needs. These include a change in traffic patterns, increases in volumes, and complaints from the public. If a corridor is selected as needing analysis and retiming, these needs and the anticipated outcomes should be documented. In response to the quantity of systems that require analysis, the COST section will supplement staffing resources using engineering consultants.

Each year the corridors selected for retiming will be prioritized by the Division based on their needs. Projects will be completed based on available funding from a variety of funding sources, including Safety, Maintenance and/or Construction. Projects may be completed in the following fiscal year if funding is limited.

NEXT STEPS

Each of the current investigative efforts are coordinated to support corridor selection based on the ROI. NCDOT is investigating potential alternatives for accessing before and after performance data. The Department also is looking at what metrics should be evaluated with respect to the operational objectives identified for a corridor. All of these efforts are anticipated to evolve into a process that allows the NCDOT to select projects that yield the highest return on investment with respect to the implementation of new signal timing plans.

CURRENT APPROACH

The COST Section currently is evaluated on a measured improvement of before and after conditions as calculated through Tru-Traffic travel time runs. The metrics are presented in **Table 1**. These values are defined based on a national report for statistics to measure the benefit of signal system timing work: *NCHRP 409: Traffic Signal Retiming Practices in the US* (http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_409.pdf).

TABLE 1. PERFORMANCE GOALS

New Corridors	40% Reduction in Travel Times
Retimed Corridors	20% Reduction in Travel Times

This approach to measuring the outcome presents a few challenges. NCDOT's current process for selecting signal system timing projects is not based on an assessment of the corridor's performance, or the "before" conditions (see "Corridor Selection Process" document in this manual). Therefore, once a project has been identified and the corridor assessed, it is feasible to determine that minimal or no improvements can be realized through signal system retiming. To offset this, the COST Section is evaluated on an average of all the corridors that are retimed within a year.

Additional challenges associated with using travel time reduction as a performance goal include:

- Not effective measures for all operational objectives, like special events, incident management, or ramp queuing on interstate.
- Difficult to perform in saturated conditions, which account for >20% of the projects
- Does not address non-arterial situations
- Small sample size with the number of runs
- Difficult to get runs when there are short timing plans
- Easy to manipulate to achieve higher travel time savings
- No standard for how runs are done (i.e. beginning of queue, back of queue, etc.)
- Does not consider volume
- Requires a lot of manpower time to conduct

This current system prohibits the same measure of effectiveness to be applied to a single corridor. For this reason, PEFs are not held accountable to the same threshold of percent improvement.

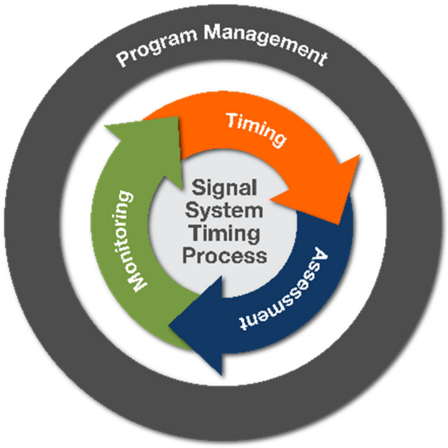
FUTURE UPDATES

In alignment with the corridor selection process, NCDOT is looking to identify corridors that will yield the highest return on investment in response to the implementation of new signal system timing plans. In addition, the identification of operational objectives associated with each corridor selected will be critical to marrying the measure of effectiveness with the defined goals of the signal system timing project.

Future developments in continuous data access, such as high resolution data or probe data, and centralized software for constant monitoring also may expand the realm of achievable performance goals. Additionally, NCDOT is looking to establish performance goals that relate more directly to emissions and fuel consumption.

The results of redefined performance goals will feed into how private engineering firms (PEFs) are evaluated.

Data Needs and Applications



This document defines the signal system timing data needs and the corresponding applications. The data is grouped into three categories that align with the signal system timing process.

TIMING – Designing of signal system timing plans. *Data needs:* turning movement counts, design speed, geometry, and other field collected data (saturation flow rate, lane utilization, distances between the intersections, loss time, mid-block access, surrounding land-use patterns).

ASSESSMENT – Evaluation of the quality of the timing effort by comparing before and after data of the corridor. *Data needs:* travel times, split monitor, volume and occupancy, delay on side streets, cycle length (observation)

MONITORING – Evaluation of the system, over time, to determine at what point "tweaking" of the system is no longer sufficient and a dedicated timing effort is needed. There currently is no criterion in place defining the threshold point for timing. *Data needs:* travel times, split monitor (determine efficiency of the timing plans splits), vehicle speeds (to compare to design speed), and system detector data (Volume and Occupancy).

Data Source	Data Produced	Used for	Advantages	Disadvantages/Limitations
Traffic Counts	Traffic Volumes Turning Movement Counts, Classifications	Timing	Current source of data for retiming Required for capacity analysis	Only 1 typical day of data (normally excludes Mondays, Fridays, rainy days & incidents) Only a snap shot in time
Travel Time Runs (Tru-Traffic)	Travel times, Delay, Stops, LOS, speed, etc.	Timing Assessment	Known method Could be used for monitoring Current source of data for assessment	Labor intensive Limited data points Does not include traffic volumes
Controller and System Detectors	Split Monitor Gap-outs/Max-out Through volumes & occupancy	Assessment Monitoring	Can be collected with current equipment Collected on a limited basis to establish baseline for monitoring Helps with determining the # of timing plans needed, and event scheduling	Labor intensive (without remote access) Currently used informally for assessment Doesn't account for side street volumes Data aggregated in intervals of specified sampling periods (typically 15min intervals)
Blue-tooth	Travel times Speeds	Assessment Monitoring	More data points than travel runs Not as labor intensive Possible use for ICM*	Do not own devices Could be used for ICM assessment Not currently used, investigating
High-Resolution Data	Arrival on green Gap outs Cycle failures Volume & Occupancy	Assessment Monitoring	Time-stamped data Correlates speed, time, volume Some of the data may be useful for design	Would require changing performance measure to "arrival on green" vs. travel time Can be expensive Not currently used
Vehicle Probe data	Speed	Monitoring (?)	May have a use with sub-TMC codes on high volume arterials Possible use for ICM*	Lower probes on low volume roads Not currently being used in this way Not currently used, investigating

*Integrated Corridor Management (ICM) Assessment may include the evaluation of both arterial and interstate traffic.

- Value of having interstate traffic diverted to arterials versus being slowed or stopped due to an incident
- Efficiency of the arterial when traffic is diverted due to an incident on the interstate

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TIMING

Project Process

Context of a Corridor

Identification of a corridor's context provides the background needed to select the appropriate operational objectives. It is encouraged that stakeholders discuss the various characteristics, conditions, and preferences that define a corridor's context to foster a consistent understanding of the existing conditions.

Characteristics & Conditions	Design Considerations
Grid or arterial	Consider cross-coordination for grid network.
Number of lanes	The number of lanes can impact the lane usage. More lanes often balance the distribution or traffic more equally.
Two-way or one-way streets	Offset considerations only apply to two-way streets.
On-street parking	Can drastically reduce free flow speed.
Closely spaced intersections	Want to minimize drivers stopping at consecutive closely spaced intersections.
	Long queues can block upstream intersections.
Land use (retail, office, residential, etc.)	Determines which time-of-day plans may be necessary based on varying traffic impacts of different land uses (e.g., factory shift schedules for industrial areas, holiday schedules for retail areas, or school schedules).
Regional location	Different considerations for coastal or mountainous regions.
	Different considerations for urban or rural areas.
	Different considerations for municipalities.
Interstate performance will take priority over the arterial.	Consideration for freeway ramps along the corridor to determine if queues on the ramps can potentially back-up and impact the freeway.
Railroad preemption will take priority over the corridor.	Consideration for side street delay amount during recovery of the corridor after the railroad preemption has ended.
Undersaturated, saturated, or oversaturated	Can impact the operational objective chosen.
Traffic balanced or directional	Consider if traffic has peak period fluctuations that could affect the time of day plans and give priority to the heavier direction.
Unnecessary delay during light traffic or at night	Consider removing coordination from corridor and allowing to operate in free run conditions.
Pedestrian/bicyclist activity	Consideration for bicycle lanes as well as crosswalk splits. Heavier pedestrian and bike traffic can also impact free flow speeds on the corridor.
Transit considerations	Consider the number of stops along the corridor and whether there is signal pre-emption. Transit stops that do not include their own pull-out can impact the free flow travel speed.
Input from the Division	Considers the different Division goals.
Citizen Complaints	Can impact the goals or operational objectives.

Establishing Operational Objectives

Each stakeholder involved in delivering the signal system timing plan should be involved in the identification of the operational objectives. Identification of the appropriate operational objectives helps to address the specific needs of the corridor as opposed to a blanket approach to implementing signal system timing plans. Once the objectives have been identified, subsequent strategies and tactics can be identified for the signal timing plan development to accomplish the noted operational objective(s) chosen for the corridor.

IDENTIFY OPERATIONAL OBJECTIVES

Operational Objectives: short term quantitative performance goals that align with the Department's vision.

An assessment of the congestion conditions on the corridor can influence the selection of operational objectives. A corridor can perform in undersaturated, saturated, and oversaturated conditions at different times of the day, but the prevailing conditions during the peak period, or the time of day that warrants a revised signal system timing plan, should take precedence while selecting. **Figure 1** is intended to provide the user some guidance on which operational objectives are most appropriate based on the saturation condition for a corridor.

The Division will work with the designer, and others as warranted, to identify the needs of a corridor. These needs can be attributed to many driving factors such as citizen complaints or visual observations of the corridor performance. The needs are not necessarily apples-to-apples to the defined operational objectives, but identifying these needs during the meeting with the Division can support the identification of the desired operational objectives.

Table 1 presents a list of operational objectives and ways the objectives are most commonly used.

TABLE 1. OPERATIONAL OBJECTIVES

Operational Objective	Ways Operational Objectives Are Used
Improve Efficiency of Free Run Ops	Modify an undersaturated individual traffic signal's timing parameters to minimize delay.
Regulate Speeds/Traffic Calming	Restrain vehicles to a desired speed. Examples: Set the progression speed at or below the speed limit. Set offsets to cause planned stops restraining buildup of platoon speeds.
Minimize Cycle Failures	Modify to avoid vehicles not being served due to inadvertent gap-outs.
Improve Travel Times/Minimize Delay	Modification such that the average after travel time run is faster than the average before travel time run from one end of the corridor to the other end of the corridor.
Maximize Throughput	Modification to allow the maximum number of vehicles to traverse the corridor.
Improve Progression	Minimize number of stops.
Improve Safety	Modify corridor/network to reduce vehicle on vehicle, or vehicle on pedestrian/bicycle accidents.
Reduce Citizen Complaints	Address issues raised by the public or politicians.
Reduce Congestion	Minimize the accumulation of vehicles in a specific area, or to minimize the time length of the accumulation.
Minimize Environmental Impacts	Maximize fuel economy, minimize fuel consumption, or minimize pollution (carbon monoxide, mono-nitrogen oxides, and volatile organic compounds) emissions.

Operational Objective	Ways Operational Objectives Are Used
Manage Planned Events	Develop signal system timing plans to accommodate planned events such as concerts and sports events.
Manage Unplanned Incidents	Develop signal system timing plans that can accommodate anticipated oversaturated traffic caused by an incident within the corridor/network or nearby. Example: Given an arterial that parallels an Interstate, develop a signal system timing plan for the arterial that accommodates traffic diverting from an accident on the Interstate.
Queue Management	Modifications to avoid left turn bay spillovers into the through lanes or vehicle queues between closely spaced intersections that reduce the effective green of the through movement.

Establishing Operational Objectives

Operational Objectives — Under-saturated / Saturated / Oversaturated

Strategies	Improve Efficiency of Free Run Ops	Regulate Speeds/Traffic Calming	Minimize Cycle Failures	Improve Travel Times / Minimize Delay	Maximize Throughput	Improve Progression	Improve Safety	Reduce Citizen Complaints	Reduce Congestion	Minimize Environmental Impacts	Manage Planned Events	Manage Unplanned Incidents	Queue Management
Meter Traffic Entering Storage Area													→
Manage Queues													→
Traffic Responsive Operation												→	
Integrated Corridor Management												→	
Flush Plan											→	→	
Provide Left Turn Progression											→		
Progress Certain Side Streets											→		
Reduce Emissions										→			
Reduce Fuel Consumption										→			
Reduce Stops										→			
Increase Percent Arrival on Green									→				
Balance Queues									→				
Optimize Mainline Progression				→		→							
Bi-directional Progression						→							
Transit Progression						→							
Pedestrian Progression						→							
Bicycle progression						→							
Maximize Mainline Capacity				→	→								
Reduce Vehicle Delays				→									
Reduce Transit Delay				→									
Reduce Pedestrian Delay				→									
Reduce Bicycle Delay				→									
Reduce Max Outs (free run)			→										
Reduce Cycle and Split Failures			→										
Reduce Progression ("cut through traffic")		→											
Fine-tune Individual Signal Parameters	→												

Tactics

Strategies	Optimize Cycle Lengths	Long Cycle Length	Short Cycle Length	Half/Double Cycle Length	Alternate Cycle Length	Resonant Cycle Length	Determine Phase Sequence	Phase Reservice	Optimize Offsets	Optimize Max Green Time	Adjust Max and Extension Times	Optimize Gap Time	Optimize Ped/Walk Time	Minimize Number of Transitions	Minimize Duration of Transitions	Determine Permissive Mode
Meter Traffic Entering Storage Area			1													3
Manage Queues							1	3	2							
Traffic Responsive Operation	1								3							
Integrated Corridor Management	1								3							
Flush Plan	1						2									
Provide Left Turn Progression					2		1									
Progress Certain Side Streets									2							
Reduce Emissions																
Reduce Fuel Consumption																
Reduce Stops																
Increase Percent Arrival on Green	1						3		3							
Balance Queues									2							
Optimize Mainline Progression	1	1					3		3					3	3	
Bi-directional Progression				2		1	2		2							
Transit Progression																
Pedestrian Progression													3			
Bicycle progression																
Maximize Mainline Capacity		1					3		3							
Reduce Vehicle Delays	1						3		3							
Reduce Transit Delay																
Reduce Pedestrian Delay																
Reduce Bicycle Delay																
Reduce Max Outs (free run)										1	2	3				
Reduce Cycle and Split Failures	1															
Reduce Progression ("cut through traffic")									1							
Fine-tune Individual Signal Parameters										1	2	3				

Instructions

Identify the desired objective.

Look down the objective's column to → which identifies potential strategies.

From the desired strategy identify the potential tactics by looking at the ranking (1 having the least impact, and 3 being the most impactful).

FIGURE 1. SELECTION OF OBJECTIVES, STRATEGIES, AND TACTICS

IDENTIFY STRATEGIES

Strategy: a high-level method or plan of action to achieve one or more objectives

Refer to **Figure 1** to select strategies that correspond with identified operational objectives. **Table 2** presents descriptions of the strategies listed in **Figure 1** and the associated actions.

TABLE 2. STRATEGIES

Strategies	Action Plan
Meter Traffic Entering Storage Areas	Develop a timing plan (cycle length, splits, offsets, phase order) for an oversaturated corridor/network that restricts vehicles entering a short turn bay or short link between closely spaced intersections and queue the vehicles where there is adequate storage.
Manage Queues	Develop a timing plan for an oversaturated corridor/network that avoids turn bay spillback into through lanes, approach spillback to upstream intersections, and through lane queues blocking entry into turn bays.
Traffic Responsive Operation	Develop and threshold settings to automatically change signal system timing plans based on traffic volume, occupancy and directionality.
Integrated Corridor Management	Develop a group of signal system timing plans for manual implementation.
Flush Plan	Develop a signal system timing plan designed to maximize vehicle throughput for a preferred movement or direction.
Provide Left-turn Progression	Modify a corridor/network that facilitates either 1) a high volume side-street left movement becoming a platoon that travels along a corridor with a minimum of stops/delays at intersections, or 2) minimum delay for left turning vehicles from a platoon with a high proportion of left-turning vehicles to achieve the objective of managing planned events
Progress Certain Side Streets	Modify the network to allow vehicle platoons to travel along a the side street(s) with a minimum of stops/delays at intersections to achieve the objective of managing planned events.
Reduce Emissions	Develop a timing plan with the primary goal of minimizing tailpipe emissions to achieve the objective of minimizing environmental impacts.
Reduce Fuel Consumption	Develop a timing plan with the primary goal of minimizing fuel consumption to achieve the objective of minimizing environmental impacts.
Reduce Stops	Develop a timing plan for a saturated or oversaturated corridor/network to minimize the number of stops on the mainline or for the entire network.
Increase Percent Arrival on Green	Develop a timing plan for a saturated or oversaturated corridor/network that minimizes mainline vehicle platoons arriving at intersections on red indication.
Balance Queues	Develop a timing plan for a saturated or oversaturated corridor/network so that the queues on all approaches are generally the same length with the aim of equitably distributing queues and sharing delay.

Strategies	Action Plan
Optimize Mainline Progression	Develop a timing plan for an undersaturated or saturated corridor/network that allows vehicle platoons to travel along a corridor in the primary direction of traffic flow with a minimum of stops/delays at intersections.
Bi-directional Progression	Develop a timing plan for an undersaturated or saturated corridor that allows vehicle platoons to travel along a corridor in both directions with a minimum of stops/delays at intersections.
Transit Progression	Use of equipment, software and/or timing plans that allow busses priority travel along a corridor with a minimum of stops/delays at intersections.
Pedestrian Progression	Develop a timing plan that allow pedestrians to walk at 3.5 feet per second along the corridor/network with a minimum of waiting at the intersections.
Bicycle progression	Use of equipment or development of timing plans that allow bicyclists to ride along the corridor/network at an average bicycle speed with a minimum of delay at the intersections.
Maximize Mainline Capacity	Develop a timing plan for an undersaturated or saturated corridor that provides as much green time as possible to the mainline through movements.
Reduce Vehicle Delays	Develop a timing plan for an undersaturated or saturated corridor/network to minimize the amount of time vehicles are stopped or traveling below the speed limit.
Reduce Transit Delay	Use of equipment, software and/or timing plans that allow busses to minimize the amount of time they are stopped or traveling below the speed limit.
Reduce Pedestrian Delay	Use of equipment or development of timing plans on a corridor/network to minimize pedestrian wait times at intersections.
Reduce Bike Delay	Use of equipment or development of timing plans on a corridor/network that minimize bicyclists' wait times at intersections.
Reduce Max Outs (free run)	Provide adequate Max Green values for individual traffic signals during undersaturated actuated-uncoordinated operation.
Reduce Cycle and Split Failures	Develop a timing plan for an undersaturated corridor/network to ensure all vehicles are served each cycle.
Reduce Progression ("cut through traffic")	Develop a timing plan for an undersaturated corridor/network that limits vehicle platoon progression speed to the speed limit or below.
Fine-tune Individual Signal Parameters	Modify individual traffic signal timing parameters such as Min Green, gap/extension, Max Green.

IDENTIFY TACTICS

Tactic: an action implemented as one or more specific tasks to achieve a result (strategy). One or more tactics may be available to achieve a specific strategy.

Refer to **Figure 1** to select tactics that correspond with identified strategies. Each tactic also has a rating on a scale of 1 to 3, with 3 being the most effective tactic for achieving the corresponding strategy. **Table 3** presents descriptions of the tactics listed in **Figure 1**.

TABLE 3. TACTICS

Tactics	Actions
Optimize Cycle Lengths	Chosen to best achieve the desired strategy such as minimum corridor or network delay.
Long Cycle Length	Chosen that is longer than optimized to best achieve the desired strategy such as maximum arterial throughput of vehicles along a corridor.
Short Cycle Length	Chosen that is shorter than optimized to best achieve the desired strategy such as limiting the traffic into a short link (metering traffic).
Half/Double Cycle Length	Allows phases to be serviced twice as often as the majority of the other intersections in the coordinated system.
Alternate Cycles Length	A coordinated system that neither matches the system's common cycle length, half cycle, or double cycle. Example: a cycle length that is a 1.5 multiple of the coordinated system's common cycle length.
Resonant Cycle Length	Allows bi-directional progression through evenly spaced intersections on a coordinated arterial.
Determine Phase Sequence	Changing the order of left turn phases (compared with the opposing thru phase) to best accommodate platoons of traffic traveling through the intersection along a corridor.
Lead-Lead Left-Turn Phase Sequence.	This most commonly used phase sequence has both left turn phases displaying left arrows before the respective opposing thru movement phase displays a green ball. Example: Phase 1 (westbound left) leads Phase 2 (eastbound thru), and Phase 5 (eastbound left) leads Phase 6 (westbound thru) on the major roadway.
Lag-Lag Left-Turn Phase Sequence.	This phase sequence has both left turn phases displaying left arrows after the respective opposing thru movement phase displays a green ball. This is the opposite of Lead-Lead and can be useful at an interchange or a pair of closely spaced intersections. Example: Phase 1 (westbound left) lags Phase 2 (eastbound thru), and Phase 5 (eastbound left) lags Phase 6 (westbound thru) on the major roadway.
Lead-Lag Left-Turn Phase Sequence	This phase sequence has one left turn phase display its arrow before the opposing through movement phase displays a green ball, while the other left turn phase displays its arrow after its opposing through movement phase displays a green ball. The Lead-Lag sequence is usually used to accommodate through movement progression along the major roadway. Example: Phase 1 (westbound left) leads Phase 2 (eastbound thru), and Phase 5 (eastbound left) lags Phase 6 (westbound thru) on the major roadway.

Tactics	Actions
Phase Reservice	A controller function that allows a left turn phase to operate before and after its opposing through phase. Example: Use phase reservice for a left turn phase where the average queue exceeds the turn bay length.
Optimize Offsets	Time relationships between traffic signals (offsets) in a network to best achieve the desired strategy such as maximum arterial bandwidth (green band)
Optimize Max Green Time	A phase green time chosen for actuated-uncoordinated operation that provides enough time to serve the average traffic demand plus the majority of fluctuations above average traffic. A general rule-of-thumb is the phase's traffic volume divided by the sum of the critical movements' volumes multiplied by an assumed cycle length multiplied by 1.25 or 1.5. See Critical Movement Analysis/Quick Estimation Method in Chapter 10 of the HCM 2000 for more detail.
Adjust Max and Extension Times	Adjust max green and extension during actuated-uncoordinated operation to minimize green time for movement for light traffic. Extension is also known as passage time, vehicle intervals, gap, passage gap and unit extension.
Optimize Gap Time	Adjust the gap time so that cycle failures do not occur due to long vehicle start up times. Example: Trucks require more time to start moving from a stop than other vehicles.
Optimize Ped/Walk Time	The Ped/Walk time is usually 7 seconds but may be reduced to a minimum of 4 seconds for intersections with low pedestrian volumes, or it may need to be increased to 10 seconds, 15 seconds or higher at intersections with high pedestrian volumes, in school zones or in areas with elderly pedestrians. Note: A change in Walk time may affect the calculation of the flashing don't walk (FDW) time. Reference the current version of the MUTCD and consult with NCDOT prior to modifying the Ped/Walk time.
Minimize Number of Transitions	Develop a signal timing plan that minimizes the potential number of transitions that can occur. Minimizing the number of transitions allows the corridor to perform the defined signal timing plan for longer periods and avoids the time spent in transition. Transitions can introduce the most ineffective period of signal timing on a corridor.
Minimize Duration of Transitions	Transition is the process of entering into a coordinated timing plan or changing between two plans. Timing plans that are flexible enough to accommodate traffic fluctuations can operate longer during the day, thus minimizing transitions between timing plans. Minimizing the actual transition time is determined by the controller's specified transition method. Controllers generally have several methods for transitioning. The fastest method may be determined by reading the controller manual, talking with a signal technician familiar with the specific type of controller, or through experimentation.
Determine Permissive Mode	Periods in the cycle that designate when the next phase that is allowed to be served. Auto – periods calculated automatically; Open – periods open for all phases when the coordinated phase ends; Manual – periods for all phases entered manually.

DETERMINE THE SATURATION CONDITION OF THE CORRIDOR

Determining whether a corridor has undersaturated, saturated, or oversaturated traffic conditions is a combination of observing the context and evaluating the operational performance.

Table 4 includes field observations that should be considered.

TABLE 4. FIELD SYMPTOMS

"Symptoms" in the Field (Traffic)	Description
Cycle failure	Traffic queued at the beginning of green does not clear in one cycle
Residual queues	Queues that continue to build each cycle due to cycle failures
Turn Bay Spillback	Queues from a turn bay spilling back into a through lane
Blocking	Through movement queues blocking entrance to turn bays
Approach Spillback	Queue from one intersection extends to an upstream intersection
Starvation	Demand from an upstream intersection cannot reach downstream intersection to use available capacity
Intersection Blocking	Traffic on one approach queues through an intersection blocking traffic from another approach

Degree of Saturation

Undersaturated Traffic Conditions

Undersaturated conditions is the 'under capacity' of the network and intersections. Volume-to-capacity (v/c) ratios are less than 0.85.

Conditions typically are stable and relatively predictable, but can have the occasional cycle failure of movements. Additionally, the presence of congestion may not indicate that a corridor or individual signal is oversaturated. The corridor or signal may be undersaturated and the congestion could be the result of poor signal system timing parameters such as an excessively long cycle length, insufficient split, or bad offsets.

Saturated Traffic Conditions

Saturated conditions are when the network and intersection are 'at capacity.' There is a clear balance of green time versus queue buildup.

Oversaturated Traffic Conditions

Oversaturated conditions are 'exceeding capacity' along the network or intersections. V/C ratio is greater than 1.0.

Conditions are unstable with excessive delays and expected queue buildup. The severity and impacts of the oversaturation also are critical to note when developing timing plans to mitigate it. For example, oversaturation at an interchange between an arterial and freeway that causes ramp traffic to spillback from the arterial onto the freeway should be treated differently from oversaturation on one approach to an intersection with ample queue storage available.

Considerations for Oversaturation

It is important to define the corridor including the scale of the impacts of oversaturation. The following items should be considered and noted prior to retiming the signal system.

- The number of affected intersection movements/ approaches
- The number of affected intersections
- The number of affected routes
- The direction(s) of travel
- Duration and time periods of oversaturation
- Frequency of oversaturation (recurrent or intermittent)

Additionally, certain scenarios are likely to impact or drive the oversaturation of the corridor. The following potential causal factors also should be noted.

- Planned special events
- Anomalous events
    - Crashes
    - Weather
    - Work zones
- Conflicting modes of travel
- Traffic signal system operations
- Geometrics
- Traffic demand

Field Visit Protocol

When performing field visits for signal system timing work, everyone should follow protocol specified in the project scope. Additional best practices are listed below.

- Coordination
  - Contact the Division prior to any field visit. If the signal is part of a construction project, coordinate with the contractor through the resident engineer.
- Safety (Elements covered in the safety guidelines include: safety vest, moving traffic, multiple people, etc.)
  - Follow all safety guidelines as outlined in the:
    - North Carolina Department of Transportation (NCDOT) Standard Specifications for Roads and Structures (2012 version).
    - NCDOT Workplace Safety Manual, specially SOP#11B-87 and 11B-88[1].
    - NCDOT Safety Policy and Procedure Manual (framework for the NCDOT Occupational Safety and Health (OSH))[2].
    - 2009 version of the Manual of Uniformed Traffic Control Devices (MUTCD)[3].
- Fieldwork
  - Reference all relevant notes from Division meetings.
  - Document any timing changes in the log book in the cabinet.
  - Do not upload signal timing plans after hours when technicians are not available.

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[1] https://connect.ncdot.gov/resources/documents/workplace%20safety%20manual.pdf
[2] https://connect.ncdot.gov/resources/Documents/Safety%20Policy%20and%20Procedure%20Manual.pdf
[3] http://mutcd.fhwa.dot.gov/

Data Collection

Prior to the initial field visit, it is important to assemble certain key documents to aid in data collection. Once in the field, most notes are made on the existing documentation, while others may be noted as necessary within accompanying notes.

There is a certain amount of data collection that can occur before performing the initial field visit. This includes assembling the following, as appropriate for the corridor.

- Google Maps
- Signal Plans
- Existing Timing Plans
- COST Database
- Traffic Counts
- Split Monitor Data (in lieu of traffic counts)
- System Detectors Volumes
- Contact Traffic Generators
- Citizen Complaints

During the initial field visit, the data assembled above should be referenced and integrated with the following field data collection that also is most appropriate for the corridor.

- Upload controller data if communication cannot be established remotely
- Field Observations
    - Verify critical intersections
    - Observe traffic patterns to identify any “surprises” that may not have been identified in the traffic data
    - Verify intersection configuration matches signal design plans
    - Verify the distance between intersections
    - Identify mid-block access
    - Verify Signal Plans have been implemented and match existing conditions
    - Identify any equipment or communication issues that need addressing in the field before design
- Identify Controlling Intersections
- Identify lane utilization
- Determine which intersections to count
    - Identify turning movement counts
- Stop Watch Timing (in lieu of traffic counts)
- Measure Speed (needed for Synchro)
- Measure Saturation Flow (needed for Synchro)
- Meet with Division personnel (training or technical issues)

Final Report Recommendations

As part of the final report, there often is a recommendations section that can be easily extracted for sharing with other individuals and operating units. The recommendations may include feedback on items that are affecting the corridor and signal timing performance such as geometric changes, broken loops, equipment failures, or even the need for additional timing plans. The documentation for the recommendations should be organized as follows.

- Recommendations should be documented in paragraph form.
- The recommendations section of the report should include a checklist with added details as needed (i.e. develop standard check list form to be used with report, with room to add extra details/explanations).

INTERNAL COMMUNICATION

Once received, the recommendations should be extracted and shared with the following NCDOT individuals, as appropriate.

- Regional Traffic Engineer
- Units within Mobility and Safety
    - Signals & ITS
    - Congestion Management
    - Safety
- Division Personnel beyond Traffic Services/Division Traffic Engineer (DTE)/Deputy Division Traffic Engineer (DDTE)

CONSIDERATION FACTORS

Table 1 provides examples of additional recommendations beyond signal system timing improvements. For ease in consideration and sharing with others, they are grouped into specific categories.

TABLE 1. SECONDARY RECOMMENDATIONS FOR IMPROVED CORRIDOR OPERATIONS

Category	Recommendation Factors for Consideration
Geometrics	• Add lanes • Extend lanes • Other type of widening (radius, taper, etc.) • Revise pavement markings • Update pavement markings (repaint faded PM, add arrows, etc.) • Islands (add/delete, Right-In-Right-Out (RIRO), etc.) • Yield (revise/add/delete) • Sight distance • Lane continuity
Signals	• Heads (add/revise/delete/upgrade) • Flashing Yellow Arrows (FYAs) • Pedestrian (heads, crossings, etc.) • Loops (System, Calling (presence/upstream), Queue, Force-Off, etc.) • System detectors assigned • Sight distance
Communication Needs	• Is working • Fiber Optic • Wireless • Phone Drop

Category	Recommendation Factors for Consideration
Phasing	• Lead-lag • Add/delete/revise current phasing • Split side-street (add/delete/revise) • Identify potential/actual yellow-trap situation • Revise protected to Protected-Permissive, or vice versa • Revise permissive to Protected-Permissive/Protected • Correct street coordinated (i.e. main vs. side, equal volumes, traffic patterns changed, etc.) • Pre-timed vs. actuated • Alternative Cycle Length (Required Electrical Detail modification)
Maintenance	• Controller functions • Loops (system, et al) • Detector cards • Wiring • Poles (wood, metal, guys, etc.) • Sight distance (i.e. tree trimming needs)
Additional Timing Plans Needed (i.e. not funded/in scope)	• Weekend • School • Holiday • Hurricane • Incident Management • Shift Work
Signs	• Lane Control • Signal Ahead • Regulatory • Pedestrian

"High Priority Ped" Tool For Coordinated Phases

OASIS SOFTWARE

The "High Priority Ped" tool in the Oasis software package works differently on coordinated phases. Pedestrian clearance times that exceed splits cannot be implemented for coordinated phases the way they can for a minor phase. With current Oasis functionality, it is understood that coordinated phases *will have* enough time to cover the ped times. This document explains a work-around solution for situations where main street ped clearance times are very high. The solution is to force the signal into free run any time the ped phases in question are active.

PROCESS

The "High Priority Ped" work-around solution consists of the following steps:

- The coordination plan uses an alternate timing page with the values for "Don't Walk 1" set to zero. "Walk 1" times remain the same. This will prevent the "Bad Split on Phase X" outcome.
- Inputs 63 and 64 are programmed as "Timing Page = 1" and "Coordination Plan = free".
- A logic step is programmed to activate inputs 63 and 64 when either ped walk or ped FDW is active. This step will tell the signal to go into free run and switch to timing page 1, which has the correct "Don't Walk 1" times. (This logic step must be enabled on the Phase Control page.)
- If you are using an alternate sequence, that sequence must be scheduled by time of day to run concurrently with the coordination plan. This will prevent the signal from switching sequence pages when input 64 (Coordination = free) is active.
- Additionally, on page D-2 (General Communications Configuration), "Comm Fail Return to TOD" must be set to zero. If it is not set to zero, the controller will **ignore the input to go into free run** and generate a "Bad Split" error when the timing page switches.

Sample Programming

For this example it is assumed that both phases 2 and 6 have extremely high ped clearance times.

Yellow Detector Lock	2	6
Active Logic 1 - 16	1	
Active Logic 17 - 32		
Dynamic/Backup		

FIGURE 1. OASIS PHASE CONTROL PAGE

62	Not Enabled		0
63	Change Phase Timing Page (1-4)	1	0
64	Coordination Plan	Free	0

FIGURE 2. OASIS INPUTS PAGE

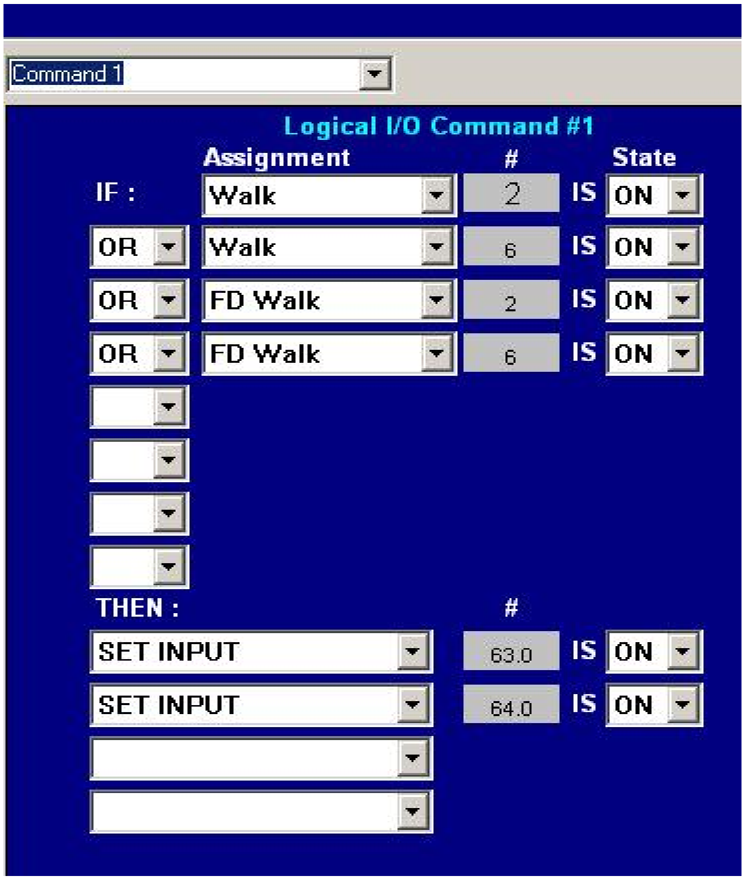

FIGURE 3. OASIS LOGIC PAGE

For an example schedule, consider Plan 1 and assume that it is using Sequence Page 2. That sequence would have to be scheduled to start and end at the same time as the coord plan. See event 16 in
Figure 4:

13	Coordination Plan (1-66)	4-1	L	1	1	12	31	18	30	20	30	
14	Coordination Plan (1-66)	2-1	L	1	1	12	31	20	30	21	30	
15	Coordination Plan (1-66)	Free	L	1	1	12	31	21	30	9	0	
16	Coordination Plan (1-66)	1-1	L	1	1	12	31	9	0	10	30	1
17	Coordination Plan (1-66)	4-1	L	1	1	12	31	10	30	11	45	1
18	Coordination Plan (1-66)	6-1	L	1	1	12	31	11	45	17	0	1
19	Coordination Plan (1-66)	4-1	L	1	1	12	31	17	0	19	0	1
20	Coordination Plan (1-66)	2-1	L	1	1	12	31	19	0	20	30	1

FIGURE 4. OASIS SEQUENCE PAGE 2 (SEE EVENT 16)

Event 44 also requires programming, as shown in **Figure 5**:

39	None			0	0	0	0	0	0	0	0	
40	Change Phase Sequence Page (1-12)	3		1	1	12	31	9	30	14	0	2 3 4 5 6
41	Change Phase Sequence Page (1-12)	3		1	1	12	31	19	0	22	0	2 3 4 5 6
42	Change Phase Sequence Page (1-12)	3		1	1	12	31	7	0	9	30	7
43	Change Phase Sequence Page (1-12)	3		1	1	12	31	18	30	21	30	7
44	Change Phase Sequence Page (1-12)	2		1	1	12	31	9	0	10	30	1
45	Change Phase Sequence Page (1-12)	3		1	1	12	31	10	30	11	45	1
46	Change Phase Sequence Page (1-12)	3		1	1	12	31	17	0	20	30	1
47	None			0	0	0	0	0	0	0	0	

FIGURE 5. OASIS SEQUENCE PAGE 2 (SEE EVENT 44)

Coordination

It is important to alert the Division to implementation of the “High Priority Ped” process.

Alternative Timing Plans

Alternative timing plans can be developed for planned or unplanned incidents or major construction projects. This section addresses guidelines for the following types of alternative timing plans:

- Incident Management Plans
- Hurricane Evacuation Plans
- Temporary Timing Plans
- Special Event Timing Plans

INCIDENT MANAGEMENT PLANS

When a crash or other unplanned incident occurs on the interstate or an access controlled facility, development of signal system timing plans should be considered to account for traffic detours onto surface streets. These timing plans should account for worst case scenario during the peak hour operations. These timing plans are to be developed in conjunction with the regular non-incident management timing plans.

Corridor Parameters

Document a profile of the corridor's incident management process.

- Stakeholders – List of agencies involved and contact information.
- Routes
  - Specific locations of the incidents
  - Details of the detour route
  - Laneage on the detour route (surface street)
  - Number of signals included
- Incident Information
  - Locations – Identify locations of frequent incidents
  - Scope of Impact – Identify the interchanges and intersections impacted
  - Durations – Identify the typical clearance time
- Communications Infrastructure
  - Isolated signals
  - Available communication
  - Type (dial-up/wireless)

Develop Timing Plans

- Cycle Lengths
  - Standard – Incidents are typical and the responses are predictable
  - Non-Standard – Incidents are not typical and the responses may be worst case scenario
  - Maximum green band on the detour route
  - Minimum splits for the side streets and the left turn phases
- Triggers
  - Develop thresholds – Identify measure for activating the incident management plan (examples include: average travel speeds, incident confirmed)
- Define the Activation Protocol
  - Confirm the owner of the signal system.
  - Confirm who will have access for activating incident management timing plans.
  - Standardize incident management timing plan numbers
    - Numbering would be in the 50's (i.e. Plan 51 through Plan 59

- Validation
  - Field test the incident management plan during an off-peak period.
  - Follow-up after first implementation to evaluate plan.

HURRICANE EVACUATION PLANS

The development of hurricane evacuation plans follows the same process as incident management timing plans.

TEMPORARY TIMING PLANS

Phasing of construction projects often can introduce multiple traffic patterns to a corridor. Not only does the final corridor warrant a new signal system timing plan, but the variations on the traffic patterns also can require the need for temporary timing plans to mitigate impacts on traffic. It is important however that the amount of effort expended to develop and implement the temporary timing plans are proportional to the duration of the impacts.

SPECIAL EVENT TIMING PLANS

Signal system timing plans for special events can resemble incident management flush plans, or they can be customized. Examples of special events include:

- Holidays
- Football games
- Major concert or arena events
- U.S. Open

ASSESSMENT

Standard Practice for Performing Travel Time Runs

This document present the NCDOT Standard Practice for performing *Tru-Traffic* Travel Time Runs for the evaluation of traffic signal system timing. This standard practice has been incorporated and referenced in the scopes for projects being initiated for 2017.

SOFTWARE REQUIREMENTS

- *Tru-Traffic Version 10* with a GPS receiver is the only acceptable data collection method for this Standard Practice.

STUDY PERIOD

- Typically, the study period for travel runs are the peak traffic periods by direction.
- Possible peak traffic periods may include:
    - Weekday peak traffic periods (i.e. AM, PM, Noon, etc.)
    - School start/end or class change
    - Seasonal traffic
    - Special events
    - Holidays
    - Incident management scenarios (i.e. detour routes, hurricane evacuations, etc.)
- The study period(s) will be defined by the Department.

DATA COLLECTION STANDARDS

- Travel time runs should be representative of typical trips through the system. Runs skewed by bus stops, trains, crashes, turning traffic, or other obstructions should be discarded.
- Runs should not be performed during the following conditions, (unless the study period has been specifically defined for that condition):
    - Lane closure or active work zone
    - Adverse weather (rain, snow, etc.)
    - On a Monday or Friday
    - During special events
- *Tru-Traffic* must be synced with the appropriate timing plan before beginning run (See Sync Clocks).
- Driving style should be the "floating car" method where the driver "floats" with the traffic by attempting to safely pass as many vehicles as passed the test vehicle.

NUMBER OF RUNS

- Six (6) or more travel runs per direction should be completed for each study period. An exception to this minimum may be granted by the Department.
- Multiple days may be required to complete the minimum number of runs, depending on the length of the corridor.
- Attempt to spread runs so that they are performed in a variety of positions in the queue.

SYNC CLOCKS

- *Sync Tru-Traffic* file to timing plan at the beginning of red of the coordinated phase when there's a call on the subsequent phase.
- Watch one cycle to confirm that the file is synced correctly with the timing plan before beginning travel run.

REPORTING

- Generate reports (Travel Time, Delay, Stops, Speed and LOS) that show the current operational status of the signal system
- *Tru-Traffic Travel Time & Delay Report* that includes:
  - Reports
    - Cumulative Travel Time (CTT)
    - Cumulative Delay (CD)
    - Cumulative Stopped Delay (CStopD)
    - Cumulative Actual Average Speed (CAS)
    - Cumulative Number of Stops in Run (CStops)
    - Levels of Service Delay (LOSDelay)
    - Cumulative Urban Street LOS (CSpeedLOS)
  - Cumulative summaries for each separate direction of coordination and a cumulative summary of both directions together (i.e. "Cumulative Summary of all runs, either direction through the artery") for each/all of the timing plans
  - All trip logs used to generate the reports

Cost Benefit Analysis

NCDOT requires "before" and "after" analyses to measure traffic operational enhancements associated with traffic signal system retiming initiatives. This analysis is normally performed using:

- Model projections from an approved computer-based traffic modeling software such as Synchro Plus SimTraffic, and
- Field measured travel time studies from approved GPS software that will generate a Travel Time & Delay Report such as Tru-Traffic.

The benefits associated with a traffic signal system retiming initiative are typically expressed as travel time savings through reductions in overall system travel time, stops, and delay measurements. These improvements are best evaluated using the Travel Time and Delay Report developed from the travel time study data in Tru-Traffic. In addition to travel time savings, the traffic signal system retiming initiative is expected to yield environmental benefits such as reduced emissions (NO_x, HC, and CO) and fuel usage. When required as part of an analysis, these environmental benefits are best measured in the SimTraffic simulation software.

While travel time savings and adverse environmental reductions are good indicators of the success of the signal system retiming initiative, it is often useful to translate these benefits into monetary savings expressed as part of a cost benefit analysis. To ensure all traffic signal systems retiming initiatives performed for NCDOT are evaluated equally, the methodology herein should be followed to determine the expected benefit cost savings when such an analysis is required as part of a traffic signal system retiming initiative.

DATA ACQUISITION AND EVALUATION

When retiming a traffic signal system, the Engineer is required to collect a wide variety of field data to develop their new timing plans as well as to prepare a "before" and "after" analysis of the system operation. Field data includes, but is not limited to, intersection schematics such a lane configurations and distances between traffic signals; field observations such as posted speed limits; volume data including 24-hour tube counts and 12-hour turning movement counts; existing traffic signal system timing and coordination data as programmed in the field; and travel time and delay data. As part of the existing traffic signal system timing and coordination data, cycle lengths, splits, offsets, sequencing, and time-of-day/day-of-week patterns must be extracted from each local controller during the initial field investigation.

Following field data collection, the Engineer will analyze "before" traffic operational measures and develop new traffic signal system timing plans which will be used for the "after" analysis of the system operations. The new traffic signal system timing plans are to be submitted to NCDOT for review and approval. Following review and approval by NCDOT, the Engineer will implement the new traffic signal system timing plans in the field. During implementation, the Engineer will make cycle length, split, and offset adjustments to fine-tune the new traffic signal system timing plans based on field observations of system operations. Following this fine-tuning of the plans, the Engineer will revise all traffic modeling projections and travel time study databases to reflect actual timing values now operating in the field. This step is critical to ensuring accurate representation of the improvements attained in the cost benefit analyses.

At the completion of field implementation and fine-tuning of the traffic signal system timing plans, the Engineer will evaluate the cost benefit achieved by the retiming initiative when required. To perform the cost benefit, the Engineer will calculate the annual cost benefit resulting from travel time savings and from environmental savings. The total annual cost benefit for the traffic signal system retiming initiative will be the sum of these two savings. The following pages provide detailed information on the required data collection parameters for a cost benefit analysis. They include cost benefit factors and annual cost benefit formulas for the analysis along with those parameters specific to the travel time savings and the environmental savings.

ANNUAL COST BENEFIT ANALYSIS FOR TRAVEL TIME SAVINGS

The Engineer will calculate an annual cost benefit for travel time savings. The travel time savings benefit is comprised of a reduced delay savings and a reduction in stops savings. The following process should be followed to calculate these two components.

Step 1: Peak Hour Volumes – Peak Hour Volumes should be calculated as the sum of the main corridor's approaching movements (Eastbound and Westbound OR Northbound and Southbound).

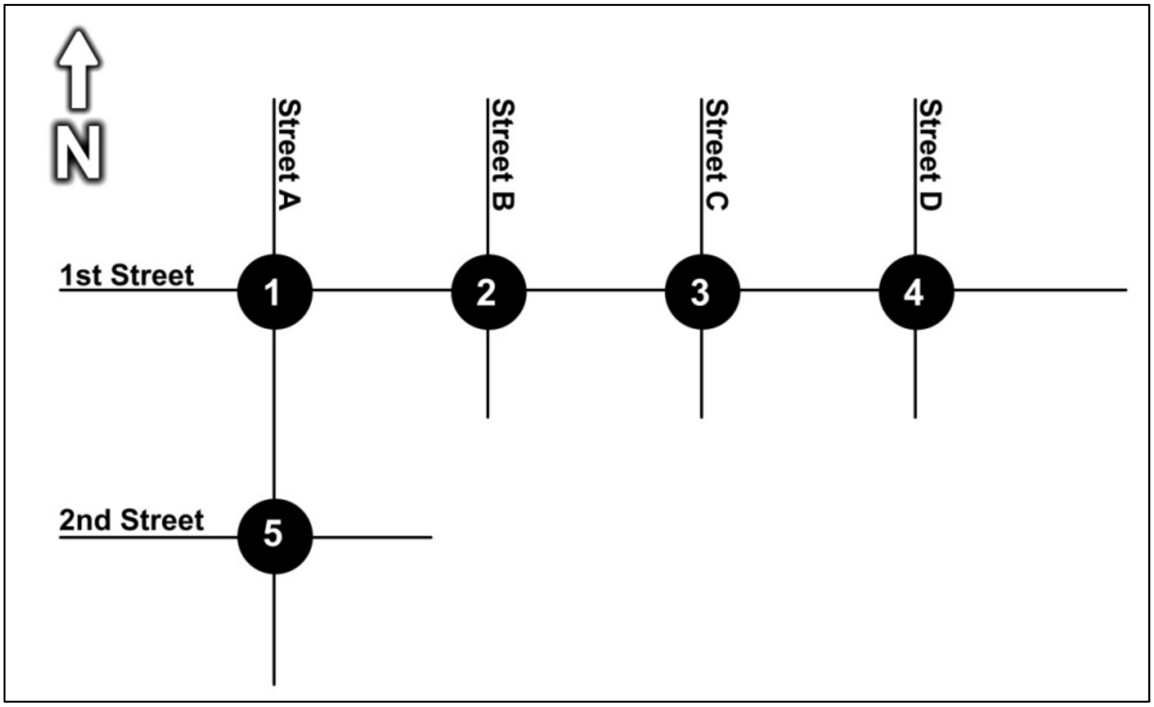

FIGURE 1. SAMPLE SIGNAL SYSTEM LAYOUT

For example, to calculate the peak hour volumes for the above illustrated traffic signal system, confirm which corridor the travel time study was completed along. For this example, assume a travel time study was completed during the peak hours along 1st Street between Intersection 1 and Intersection 4. Because Intersection 5 was not included in the travel time study, its peak hour volumes will not be considered in the annual cost benefit calculation. Use the cumulative eastbound and westbound volumes along 1st Street at Intersection 1, 2, 3, and 4 to determine the system's peak hour volumes as shown in **Table 1**.

TABLE 1. TURNING MOVEMENT COUNTS

Turning Movement Count - AM PEAK

60 Minute Volume Data

Int #	NBL	NBT	NBR	SBL	SBT	SBR	EBL	EBT	EBR	WBL	WBT	WBR
1	41	118	53	44	119	34	63	225	60	54	150	40
2	14	19	27	8	16	3	4	262	22	16	270	15
3	5	4	7	10	4	5	4	301	7	14	286	10
4	85	52	6	13	5	52	204	142	77	7	250	39
							Peak Hour TOTAL - AM Peak					2522

Turning Movement Count - NOON PEAK

60 Minute Volume Data

Int #	NBL	NBT	NBR	SBL	SBT	SBR	EBL	EBT	EBR	WBL	WBT	WBR
1	78	119	67	73	178	37	43	154	43	61	141	57
2	15	14	25	9	16	9	11	257	16	23	296	19
3	6	16	17	11	6	18	11	295	11	20	300	14
4	91	42	6	15	9	54	108	218	105	10	181	14
							Peak Hour TOTAL - NOON Peak					2408

Turning Movement Count - PM PEAK

60 Minute Volume Data

Int #	NBL	NBT	NBR	SBL	SBT	SBR	EBL	EBT	EBR	WBL	WBT	WBR
1	67	232	93	55	277	74	87	251	37	95	237	39
2	24	29	33	8	23	16	2	379	18	22	381	13
3	4	8	12	13	9	7	6	387	21	19	403	4
4	111	54	5	38	2	91	173	368	184	9	198	48
							Peak Hour TOTAL - PM Peak					3381
Sum of Peak Hour TOTALS - All Peaks												8311

Step 2: Travel Time Savings – The change in Travel Delay (seconds/veh) and Cumulative Stops (stops/veh) from "before" to "after" should be calculated by Tru-Traffic and presented in tabular form. **Table 2** is an example of a typical Travel Time & Delay Report generated by Tru-Traffic. The highlighted values are required for the Annual Cost Benefit Analysis and will be used for the example system.

TABLE 2. TRU-TRAFFIC TRAVEL TIME & DELAY REPORT

Cumulative Summary of all runs, either direction through artery

44 Before-type runs, collected Tuesday 9/17/2013 to Tuesday 9/17/2013, over day(s) Tue, with starting times during 7:02:04 AM to 5:49:14 PM

44 After-type runs, collected Thursday 10/3/2013 to Thursday 10/3/2013, over day(s) Thu, with starting times during 6:59:41 AM to 5:59:39 PM

	CTT	CD	CStopD	CBS1T	CStops	DperInt	LOSDelay	CUFFC
to End of Artery								
Average Before (n=44)	140	38	26	28	1.2	7.6	A	0.0
Std Dev Before (n=44)	*35*	*40*	*36*	*34*	*0.9*	*8.1*	*1*	*0.0*
Average After (n=44)	113	9	10	11	0.6	1.8	A	0.0
Std Dev After (n=44)	*17*	*21*	*13*	*13*	*0.7*	*4.2*	*0*	*0.0*
Difference	-27	-29	-17	-16	-0.5	-5.8	0	0.0
Std Dev Difference	*39*	*45*	*38*	*37*	*1.1*	*9.1*	*1*	*0.0*
% Difference	-20%	-76%	-63%	-59%	-45.1%	-76.5%	N/A	N/D

Step 3: Evaluation Parameters – The following parameters should be used for conversion of travel time savings to a monetary value.

A. Cost of Delay – The cost of delay, also referred to as wasted person-time, is the value of the time lost in travel delay. For consistency on all traffic signal system retiming projects, the Engineer should use values found in the North Carolina Statewide Median Hourly Wage for All Occupations for the project year (or closest reported year), as reported by the United States Department of Labor's Bureau of Labor Statistics at:

   http://www.bls.gov/oes/current/oes_nc.htm

   In 2015, the cost of delay is $15.91 per hour and is the value that will be used for the example system.

B. Cost per Stop – The cost per stop is the assumed cost of fuel, oil, tires, general maintenance, and vehicle depreciation as determined by calculations in AASHTO's Manual on Road User Benefit Analysis. This value is currently $0.014 per stop and is the value that will be used for the example system.

C. Analysis Days per Year – In the cost benefit analysis, 250 days per year represents the number of typical weekdays in a year. This is derived from 365/366 days per year less weekends and holidays. This factor is important as Travel Time Savings reported from the Travel Time Study only represent conditions for the weekday peaks.

Step 4: Annual Cost Benefit Formula for Travel Time Savings – Using the calculated peak hour volumes, highlighted travel time savings data, and conversion parameters, calculate the monetary travel time savings as follows.

A. Annual Cost Benefit of Reduced Delay

> [Sum of Peak Hour Volumes (vehicles) *
> Change in Travel Delay (seconds / vehicle) * (1 hour / 3600 seconds)] *
> Cost of Delay ($ / hour) * Analysis Days per Year (days / year)

For the example system, the Annual Cost Benefit of Reduced Delay is:

[8,311 veh * 29 sec/veh* (1 hr/3600 sec)] * $15.91/hr *250 days/yr = $266,293

B. Annual Cost Benefit of Fewer Stops

[Sum of Peak Hour Volumes (vehicles) * Change Cumulative Stops (stops / vehicle)] * Cost per Stop ($ / stop) * Analysis Days per Year (days / year)

For the example system, the Annual Cost Benefit of Fewer Stops is:

[8,311 veh * 0.5 stops / veh] * $0.014 / stop * 250 days / yr = $14,544

TOTAL ANNUAL COST BENEFIT

To determine the Total Annual Cost Benefit for the traffic signal system retiming initiative, the Engineer will add all annual cost benefits from both, travel time and environmental savings.

For the example system, the Total Annual Cost Benefit is:

Annual Cost Benefits from Travel Time Savings:

- Annual Benefit of Reduced Delay - $266,293
- Annual Benefit of Fewer Stops - $14,533

Annual Cost Benefits from Travel Time Savings - $280,837

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MONITORING

Roles and Responsibilities

Maintenance of the state's inventory of coordinated systems will be balanced between the Division staff and the COST Section. Division staff are the owners and maintainers of the systems on a daily basis. The COST Section, with support from private engineering firms, will provide support and guidance on the evaluation and prioritization of the corridors.

DIVISION STAFF

The Division is the primary owner and operator of the coordinated signal systems. They also are the primary contact the public in regards to the performance of the systems. Each Division provides input into prioritizing the corridors for analysis and retiming.

- Owners
- Operations of the signal system
- Maintenance of the signal system
  - Includes individual intersection equipment and communications infrastructure
- Input and feedback to coordination and prioritization of corridors
- Documentation in field diaries when system is modified
- Be available during technician's data download in case signal goes into flash mode
- Note any activity in field notebooks every time the system is touched
- Monitoring (pull in section about data collection)
- Handle citizen's complaints

COST SECTION

The COST Section is tasked with facilitating NCDOT's vision within the state of North Carolina. This includes five regions with 326 closed loop systems and 54 time based systems for a total of 2,360 signalized intersections. The following responsibilities have been defined for the COST Section:

- Current Responsibilities
  - Maintain an inventory of all coordinated signal systems and their coordination plans
  - Oversight and development of coordination plans
  - Coordination for analysis and prioritization of corridor projects
  - Documentation in field diaries when system is modified
  - Oversee the implementation of new approaches to managing coordinated systems (e.g. high resolution data, centralized system)
  - Reviewing final coordination plan with Division after implementation
  - Notification to the Division within 24-48 hours of being on site of a coordinated system
  - Coordinate with Division for scheduling data downloads so technicians can be available if signal goes into flash mode.
  - Note any activity in field notebooks every time the system is touched
  - Assist field personnel in addressing system timing complaints.
- Future Goals
  - Coordinate traffic signal coordination across jurisdictional boundaries
  - Establish a consistent approach to signal timing for the signal systems in NC
  - Investigate the feasibility of requiring professional engineering seals on coordination plans
  - Implement policies or procedures that minimize undocumented field adjustments
  - Technician training on the implementation of coordination plans
  - Establish consistency for signal system timing practices between all engineers and technicians
  - Improve the integration of coordination plans for emergencies, incidents, special events, and during roadwork

- Establish metrics and means for communicating the Program Benefits to agency management, policy makers, elected officials, and the public
  - Travel times savings and reports online
  - Project oriented - Report outlining thought process and meeting with division to explain
  - Future – communication to the public

PRIVATE ENGINEERING FIRMS (PEFS)

PEFs are tasked with providing additional staff to support the COST Section's workload. PEFs will work closely with the COST Section while corridors are assigned and projects are established. Once a project is initiated, the PEF will work closely with the Division with continuous coordination with the COST Section.

- Develop and implement coordination plans
- Work with COST Section and Division to define operational objectives
- Documentation in field diaries when system is modified
- Reviewing final coordination plan with Division after implementation
- Notification to the Division within 24-48 hours of being on site of a coordinated system
- Coordinate with Division for scheduling data downloads so technicians can be available if signal goes into flash mode.
- Note any activity in field notebooks every time the system is touched

Impacts on a Corridor

The timing of signals along a corridor could be affected by a number of impacts. These impacts can be either quick or span over a few months to years. Examples of impacts include road work, construction projects, or new development along the corridor. Each of the impacts affect motorists by changing the traffic patterns from time-to-time and possibly without warning. There is no timing pattern the morotists can rely on until the project has been completed.

ROADWAY WORK AND TEMPORARY TRAFFIC PATTERNS

Road work typically includes short quick turn-arounds. The work performed includes maintenance activities, temporary geometric changes, and utility work. The timing should be adjusted to accommodate back flow or changes in available lanes.

CONSTRUCTION PROJECTS

During construction projects, changes to signal timing could provide temporary relief due to traffic shifts. Also, additional coordination with roadway or congestion management groups would benefit from notification of how timing may be impacted or timing plans may need to be revised during traffic pattern changes throughout the construction project. However, there are some construction projects that are so short in time duration that there may not be any impacts; otherwise the timing should be adjusted.

NEW DEVELOPMENTS ON A CORRIDOR

New developments can impact the performance on a corridor. Developers can be held accountable for geometric improvements, including additional turn lanes or the installation of a new traffic signal, to accommodate additional demand their development may introduce on the corridor. **Table 1** provides a summary of the roles and responsibilities of NCDOT and the Developer.

Additional guidelines will be developed to refine the roles and responsibilities and to integrate the concept of signal system timing into developer mitigation strategies.

TABLE 1. ROLES AND RESPONSIBILITIES

Developer	NCDOT Divisions
• Develop final coordinated signal system timing • Fund signal system timing work for entire affected corridor, not only one signal	• Hold developers accountable for funding signal system timing work for the entire corridor affected by new developments • If necessary, help developer hire a firm that is prequalified by the COST section for timing work, or help coordinate for the central office to do the work • Include coordinated signal system timing for a corridor in project cost estimates • Include traffic engineers in design meetings from the beginning of the project • Include the re-cost of timing signals within the Contract, providing additional Division control

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STRATEGIC PLANNING / LONG TERM TOPICS

Continuous Data Options

The North Carolina Department of Transportation (NCDOT) operates and maintains much of the traffic signals in the state of North Carolina. Currently NCDOT uses travel time runs using GPS devices and Tru-Traffic software to compute and compare performance measures such as travel time, stops, and delay. The performance should be traceable to operational objectives. NCDOT has signal performance objectives they are moving to incorporate into the evaluation of corridor's performance.

It is beneficial for NCDOT to regularly review new options for measuring system performance as newer technologies can demonstrate their ability to monitor and continuously evaluate a corridor's performance. Assessments of newer technology options allow the Department to compare the value of the current process against the accuracy, availability, and applicability of other data collection and analysis approaches. Several states are currently examining some of these methods for performance measures evaluation including: high resolution controller data (HRCD), Bluetooth, probe data, and Wi-Fi. NCDOT has performed initial assessments on probe data and Bluetooth.

HIGH RESOLUTION CONTROLLER DATA (HRCD)

"A high-resolution data system for an intersection captures the location (lane), speed, and turn movement of every vehicle as it approaches and departs an intersection, together with the signal phase. The data is available in real time and archived. Real-time data is used to implement traffic-responsive signal control, including adaptive signal control. Archived data is used to obtain intersection, corridor, and network performance, and to evaluate and design better control strategies."[1]

High Resolution Data in North Carolina

NCDOT is interested in exploring the use of high resolution data for traffic management and will continue to investigate potential uses and implementations. To fully recognize the benefits of the data, the Department has identified certain infrastructure investments that will be required.

NCDOT signal equipment currently collects high resolution data, but the current processing and storage of the data packages and bundles the data into less granular detail. Revising the current data management would require additional infrastructure for processing and storing larger volumes of data. NCDOT aims to conduct a pilot project that will assess specific infrastructure solutions required to support high resolution data. Once this equipment is in place, the Department then can assess how high resolution data can benefit North Carolina.

BLUETOOTH

Bluetooth sensors operate as "active" devices, searching several times per second for a Bluetooth enabled device with which to pair. The sensors can detect the devices as a vehicle passes by and provide point-to-point travel time information specific to the device detected. The Bluetooth reader system records a time stamp for each media access control (MAC) match. The data logs typically have numerous MAC addresses due to the frequent searches and large zone in which a MAC address may be read.[2] Travel times are determined by comparing the MAC addresses recorded at successive sensors along a roadway and comparing the timestamps at each point. Keep in mind the detection range for Bluetooth sensors is approximately 328 feet[3]; if NCDOT decides to use this technology, the devices will need to spaced accordingly in order to obtain accurate information.

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[1] High-res traffic data provides planners with the big picture, *ITS International*, 2015 (http://www.itsinternational.com/categories/detection-monitoring-machine-vision/features/high-res-traffic-data-provides-planners-with-the-big-picture/)

[2] http://utcm.tamu.edu/publications/final_reports/Puckett_09-00-17.pdf

[3] http://www.ops.fhwa.dot.gov/publications/fhwahop13028/ch2.htm

Bluetooth enabled devices are now ubiquitous and include hand held mobile devices, headsets, navigation devices or even the actual vehicles, as this technology is factory installed in more vehicles. For this reason, the data collection via Bluetooth is more easily implementable and can provide an agency with a non-intrusive alternative.

Bluetooth in North Carolina

Bluetooth data collection method is new for NCDOT. Currently, NCDOT does not own any Bluetooth reader devices so the cost of applying this methodology could potentially be higher. Benefits of using Bluetooth for a corridor include access to a larger quantity of data points and the data collection effort is less labor intensive than performing travel time runs. NCDOT has completed their first pilot study to assess the capabilities and potential applicability on other corridors.

3RD PARTY PROBE DATA

Performance measures using vehicle probe data is another rapidly developing technology. This data is collected by third party vendors that process and package the data for specific roadway links. Until recently, probe data was primarily used for freeways and was not considered to be accurate or reliable data source for arterial performance. Improvements in the technology include an increase in the capture rate of probe data and an ability to package the data into smaller roadway segments. These advances are making the use of probe data a more feasible alternative for evaluating arterial performance.

NCDOT's Closed Loop System Retiming projects for 2017 all will have probe data collected for them. These additional data points will provide the ability to compare before and after conditions as measured by both the travel time runs and the available probe data.

Probe Data in North Carolina

Probe data collection for designing, assessing, or monitoring a corridor has not been done in NC. NCDOT is beginning to look at ways to incorporate this type of data collection into their projects. Recently, the NCDOT Safety Unit performed a comparison of probe data received from NCDOT's third-party vendor and travel time runs along three specific corridors. Based on this analysis, NCDOT determined that the probe data demonstrated an acceptable level of accuracy.

WI-FI

Wi-Fi data collection has a very similar protocol to Bluetooth data collection, and in some cases, work with Bluetooth versus independently.

Wi-Fi sensors operate in "passive" mode, waiting for mobile devices to search for wi-fi networks and collecting the device's MAC address in the process. The rate at which mobile devices search for wi-fi networks varies based on the manufacturer, but is roughly every 30 seconds, providing more data points. Depending on the range of the wi-fi sensor and the speed of a vehicle, it is possible that a vehicle could pass in and out of the range of the sensor without being recorded.

One benefit of Wi-Fi data collection over Bluetooth data collection is that nearly all vehicles will contain one or more wi-fi enabled devices and users are more likely to leave wi-fi "on" than to leave Bluetooth in "discoverable" mode, so the number of vehicles detected tends to be much higher using Wi-Fi than Bluetooth.

Wi-Fi in North Carolina

Like Bluetooth, NCDOT does not use Wi-Fi for data collection currently. There would be a huge learning curve within the Department. Also, NCDOT does not own any Wi-Fi devices that could be placed along the corridor, which could potentially increase the cost of using this method.

DEDICATED SHORT RANGE COMMUNICATIONS (DSRC)

Connected vehicle technology uses dedicated short range communication (DSRC) to communicate from vehicle-to-vehicle (V2V) or vehicle-to-infrastructure (V2I). This technology still is in its infancy, however there are vast changes every day regarding the technology. DSRC could be capable of transmissions up to 3280 feet;[4] however, DSRC communication needs line-of-sight to support accurate data transfers.

The USDOT's plan is requesting to have the DSRC transceiver ID to randomly reassign every five-minutes to protect privacy. To locate matching ID's within a corridor, a vehicle would have to pass by at least two devices within this five-minute span. To mitigate this five-minute window challenge, devices would need to be spaced closer together.

It is theorized that "…if the average travel time between transceivers is 3 minutes, a match rate of about 40 percent could be expected. Another theory is "if the system is designed to base calculations on vehicles'' spot speed measurement instead of segment travel times", it could provide a near 100 percent detection rate.[12] As the penetration rate of DSRC technology improves, this technology could provide the largest sample size for calculating performance measures with a high level of accuracy.

[4] http://www.ops.fhwa.dot.gov/publications/fhwahop13028/ch2.htm

SYSTEM DETECTORS FOR ANNUAL PERFORMANCE ANALYSIS

Extraction of system detector data can be used to evaluate the performance of corridor. NCDOT does not have system detectors on all corridors, but they can still provide valuable data where they are in place. **Figure 1** provides the process for using system detector data to evaluate the performance of a corridor.

If this system is prone to experience a variation in volumes due to seasonal demands, the data set should be extracted and saved to the system file more frequently. Similarly, if traffic volumes fluctuate between the weekdays and weekend traffic demands, data extraction also can be considered. The frequency and timing for the data collection should be managed in response to the performance characteristics of the corridor.

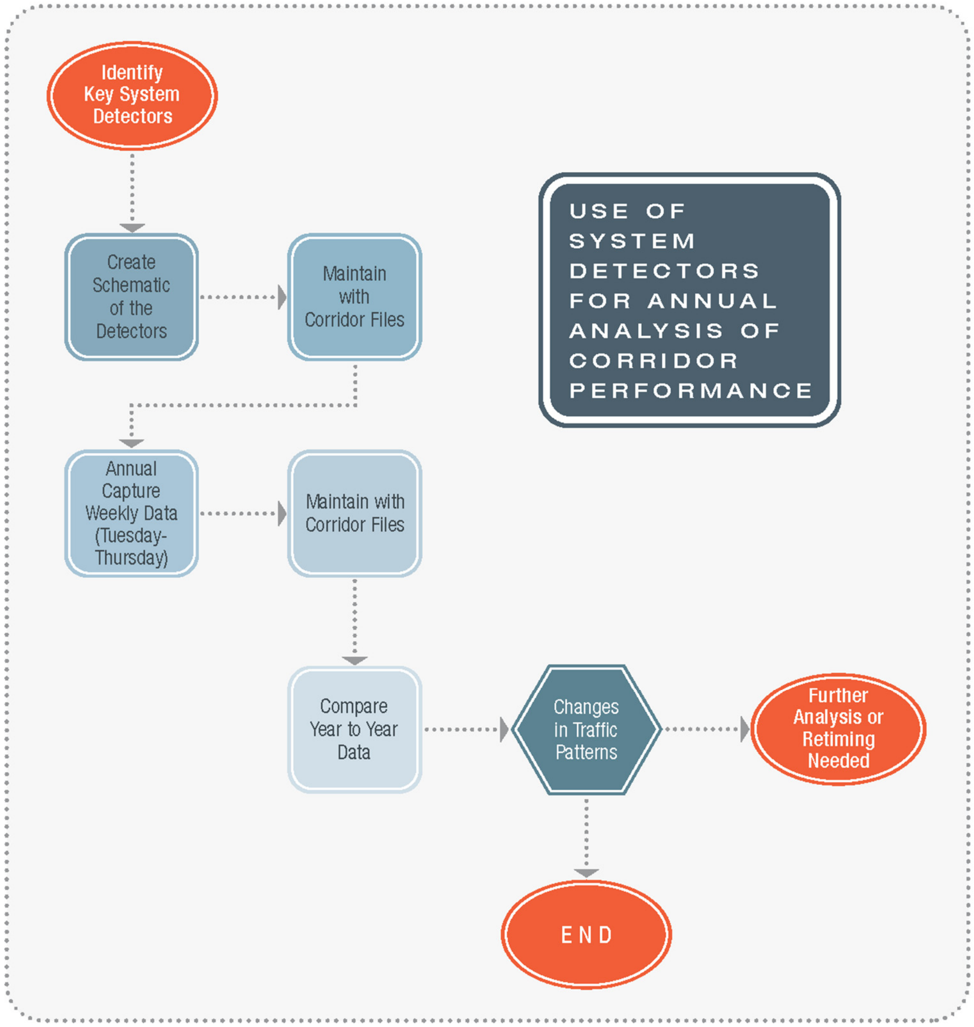

FIGURE 1. USE OF SYSTEM DETECTORS FOR ANALYSIS

Historical Documentation

In 2009, NCDOT launched a program to optimize the timing of signal systems in the state every three years. To date, many of the signal systems have been optimized at least twice since the start of the program. “Before and after” data has been collected each time the systems are re-timed to determine the overall travel time savings (benefit) of the optimization effort. The NCDOT COST group maintains a database of signal systems with system timing histories and signals by inventory ID number. Using this database NCDOT can determine when a system was last timed, who timed it, the number of signals, and the communication type.

The COST Section is partnering with the Safety Unit to perform some analysis using existing historical data for corridors that have been retimed multiple times. This spreadsheet is forming the foundation for how historical data can be more consistently maintained to provide both the history of a specific corridor and the overall recognized benefits of the corridors that have been retimed statewide.

Integrated Corridor Management (ICM)

Integrated Corridor Management (ICM) combines two fundamental concepts: active management and integration. Active management involves monitoring and assessing the performance of the system and dynamically implementing actions in response to fluctuations in demand. In an ICM corridor, all individual facilities must be actively managed so that operational approaches can be altered in real-time in response to an event anywhere on the system.

Integration requires actively managing assets in a unified way so that actions can be taken to benefit the corridor as a whole, not just a particular piece of it. Integration occurs along three dimensions:

- **Institutional Integration** – Involves coordination and collaboration between various agencies and jurisdictions (i.e., transportation network owners) in support of ICM, including the distribution of specific operational responsibilities and the sharing of control functions in a manner that transcends institutional boundaries.
- **Operational Integration** – Involves the implementation of multi-agency transportation management strategies, often in real-time, that promote information sharing and coordinated operations across the various transportation networks in the corridor and facilitate management of the total capacity and demand of the corridor.
- **Technical Integration** – Provides the means (e.g., communication links between agencies, system interfaces, and the associated standards) by which information, system operations, and control functions can be effectively shared and distributed among networks and their respective transportation management systems, and by which the impacts of operational decisions can be immediately viewed and evaluated by the affected agencies. Cannot be accomplished without institutional and operational integration.

NC has approached ICM in 2 different ways to date. The Central Office System Timing (COST) group has led the development of a rural ICM project on the I-40 and I-26 corridors in the Asheville area. Signal Systems were timed, re-timed, and expanded to incorporate a detour for an incident on I-26 west. This concept was coordinated with both Division 13 and 14 and implemented remotely in real time.

The second ICM project is under development. Division 10 and 12 are committed to documenting ICM processes using the I-85 corridor in Gaston and Mecklenburg Counties as an example. This project could be used a pilot project and details applied to other ICM projects around the State. Freeway and arterial integration is a statewide goal and will be addressed along the I-85 / US 74 corridor for this project – the first of its kind in North Carolina. The I-85 study area will begin east of Billy Graham Parkway (Exit 33) and extend west of US 74 (Exit 10).

Next steps are to develop ICM triggers, response plans, performance measures, DMS sign locations, SOPs, signal timing diversion plans, and data collection to support before/after assessment.

INTEGRATED CORRIDOR MANAGEMENT (ICM) IN THE METROLINA REGION

The NCDOT has begun the process of developing an Integrated Corridor Management (ICM) plan for a section of I-85 in Mecklenburg and Gaston Counties, NC. The goal of the ICM plan is to actively manage the transportation corridor to reduce congestion, and improve network performance and reliability. A diverse stakeholder group is meeting to work through the details of TIM, signal system timing, additional ITS infrastructure and other challenges.

Diverging Diamond Interchange (DDI)

Timing signals at or near a diverging diamond interchange (DDI) presents some unique challenges. The traffic signals at the DDI crossovers do not have a “minor” movement but rather alternate between the two directions of mainline traffic. Because of this, it can be difficult to provide two-way progression through the interchange. Depending on the design of the signals at the DDI, the two intersections may run on one controller or on two separate controllers. If the signals operate on a single controller, a ring offset may be used to define the relationship between the intersection. If two controllers are used, this relationship is defined with an offset just as it would be with traditional timing. In that case, it is also important to note which direction serves as the offset reference point. Currently, NCDOT uses two controllers for most DDI timing projects. NCDOT is deploying DDI’s more frequently, but the Department does not have a current standard practice related to 1 versus 2 controllers.

Another unique characteristic of signal system timing within a DDI is related to the clearance intervals. The crossover intersections tend to be very compact, creating a short distance for a vehicle to travel to clear the opposing through movement. However, the distance between the crossover and the downstream left or right turn movements tends to be much longer. When these movements are signalized, the additional time to clear these movements must be accounted for in the signal design. One way to account for this distance is to provide a very long red clearance interval. However, this can result in a loss of efficiency for the signal. Another option to design clearance intervals at the DDI crossover intersections is to provide an overlap to begin the opposing through after a short red interval but hold the conflicting left or right turn movement from the ramp for an additional interval. Currently, NCDOT has not adopted a standard, but commonly uses a dummy phase to hold conflicting movement. The signal system timing plans must properly account for this time.

One of the key factors in developing appropriate timing plans at DDI signals is the travel time between the crossover signals. This time may be difficult to determine prior to construction of the DDI because speeds on the bridge tend to be much lower than the design speed due to the curvature of the road. Once the average travel time between the crossovers is determined, setting the cycle length as a multiple of this time has been found to be a useful rule of thumb for these signals.

Because the DDI crossovers tend to be very closely spaced, keeping the space between the signals clear is a key objective when developing the timing plans. With this in mind, and because DDI signals tend to operate with two or three phases, a low cycle length is generally the best option. Sometimes running the DDI signals at half of the cycle length of other signals on a corridor will enable corridor progression while also optimizing the DDI operations. In some cases, it is also possible to run one crossover signal at half of the cycle length of the other to progress both a left turn movement from a ramp as well as a through movement along the mainline at the downstream crossover.

Because roadway geometry and vehicle speeds are so critical to developing signal system timing plans at a DDI, microsimulation modeling of a signal system timing plan prior to implementation could be a very helpful assessment approach for NCDOT to consider. It currently is not NCDOT’s practice to use microsimulation, but the Department does understand the value of this assessment tool for corridors that include a DDI.

Emissons Data

Collecting and interpreting emissions data to assess signal systems timing work is a long-term objective of NCDOT. Currently, this data is not used for specific analysis of signal timing performance, but the Department has identified emissions data as future performance metric for signal system timing.

Establishing a standard process for equating emissions to dollars will allow NCDOT to analyze the return-on-investment calculation of implementing signal system timing with regard to air quality. NCDOT has conducted this analysis on a few projects, but guidelines for the data analysis have not yet been adopted.

POTENTIAL APPLICATIONS OF EMISSIONS DATA

Environmental benefits can be predicted using the SimTraffic simulation software for a “before” and “after” analysis, as shown in the sample outputs in **Figure 1.**

1st Street – PM PEAK — Existing (Free)

Total Network Performance

Fuel Used (gal)	307.6
Fuel Eff. (mpg)	21.5
HC Emissions (g)	3703
CO Emissions (g)	160456
NOx Emissions (g)	12551

1st Street – PM PEAK — Improved (130s)

Total Network Performance

Fuel Used (gal)	298.9
Fuel Eff. (mpg)	24.0
HC Emissions (g)	3441
CO Emissions (g)	149316
NOx Emissions (g)	12397

FIGURE 1. SAMPLE SIMTRAFFIC "BEFORE" AND "AFTER" RESULTS

Calculations for the assessment of environmental impacts could include:

- Annual Cost Benefit of Reduced HC Emissions
- Annual Cost Benefit of Reduced CO Emissions
- Annual Cost Benefit of Reduced NOx Emissions
- Annual Cost Benefit of Reduced Fuel Usage

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SUPPORTING DOCUMENTS

NCDOT Central Office System Timing (COST) Section

Scope of Services

Retiming of Existing Closed Loop Signals FY 2017

For each of the Projects listed in the Attachment, the Firm shall provide professional engineering services necessary for evaluating the current operation of the Existing Closed Loop Signal Systems (CLS) to develop improved signal timing plans, implement and fine-tune the new plans, and evaluate the final operational benefits associated with work performed on the project. The signal timing plans shall be designed to address all possible traffic needs along the study corridor, including but not limited to:

- Weekday peak/non-peak traffic periods (i.e. AM, PM, Noon, Off-Peak, etc.);
- School/Universities start/end and/or class change peak traffic periods;
- Seasonal traffic patterns;
- Pre-scheduled holiday(s) traffic patterns;
- Incident management traffic patterns (i.e. detour routes, hurricane evacuations, etc.); and
- Other special events traffic patterns.

All work performed under this proposal will be performed under the direct charge of a North Carolina licensed Professional Engineer.

Task 1: Provide Cost Estimate

Submit a detailed Cost Estimate to be reviewed and approved by State Traffic Engineer's Staff Engineer, Dr. Joseph Hummer. Dr. Hummer will advise if negotiations are needed between the Firm and the COST Section. If necessary, the Firm may need to revise the cost estimate and resubmit to Dr. Hummer after negotiations. Once COST Section and Dr. Hummer both approve the Cost Estimate, Dr. Hummer will issue a Notice to Proceed (NTP). The Firm will not be allowed to begin re-timing effort until the date of the NTP.

Prior to completing a cost estimate, the Firm shall discuss with the Division to ascertain their specific timing plan needs. Any information collected from the Division must be provided to the COST Reviewing Engineer prior to submitting a cost estimate. After NTP, minor adjustments to the number of timing plans may be made without affecting the scope, schedule and budget for the projects.

Task 2: Kick Off Meeting

The Firm and the COST Section reviewing Engineer shall meet with Division and /or Municipality and Regional Traffic Engineer's representatives to discuss the scope of the projects in detail, and any additional pertinent information/recommendations before developing new timing plans.
The Firm is required to provide the Division prior notification anytime field work is being performed on the project.

Task 3: Field Data Collection

The Firm shall:

- Provide 13-hour turning movement/directional counts, for the total number of locations identified as critical intersections as agreed upon by the COST Section and/or Division.
  NOTE: Existing count data may be used if count data is 3 years old or less and includes a 3% per year adjustment factor. Existing count data may be found at:
  https://connect.ncdot.gov/resources/safety/Pages/Volume-Class.aspx
  http://www.ncdot.org/doh/preconstruct/traffic/safety/TSI/turning.html
- Field review signalized locations to verify:
  - Existing geometrics and signal phasing
  - Distance and speed limits between intersections
  - All equipment status is in necessary working order: detectors, communication, controllers, etc.
  - Verify programming matches the most recent traffic signal Plan of Record (POR) and note discrepancies
    NOTE: Revisions to existing traffic signal POR beyond field notes and red-lining of the plans are not included in this scope of services. However, any recommendations/suggestions for improvements to traffic safety and efficiency are requested to be included in the Final Report.
- Note issues that will need to be addressed prior to the implementation and report these issues to the Division. Inform the Regional Traffic Engineer (RTE) of any critical safety issues observed in the field. Issues that should be reported to the Division may be:
  - loops not detecting vehicles
  - signal heads rotated or displays out
  - communication issues with local controllers
  - controller screen blank
  - pedestrian push buttons that don't work
  - etc.

Task 4: Evaluation of Existing Traffic Signal System Operations

The Firm shall:

- Create a *Translink32* Database so that the Master asset designation is listed in standard order of Master Asset Number (preceded by 2 digit Division number), System Name @ Division, County, City (ex: MS – 0310312 – US 17 (Ocean Hwy) @ Division 3, Brunswick Co, Leland)
- Upload the existing System data from the field
- Discuss operational objectives with the Division
- Perform "Before Runs" using *Tru-Traffic* software in accordance with the Standard Practice for Travel Time Runs for Evaluation of Signal Timing Plans.
- Perform work in accordance with recognized professional engineering practices

NOTE: any existing files and/or information provided by the Department (including, but not limited to: signal plans, *SYNCHRO* files, timing schedules, *Tru-Traffic* files, etc.) shall be checked for accuracy by the Firm.

Task 4A: Data Review with Division 10 (Division 10 Projects Only)

The Firm shall meet with the Division after data collection and traffic operations review but prior to beginning any signal timing design to discuss and establish consensus on design approach.

Task 5: Develop Traffic Signal System Timing Plans

The Firm shall:

- Ensure intersection geometric and phasing data in *Tru-Traffic* and *SYNCHRO* 9.0 match.
- Develop *SYNCHRO* network model for existing conditions. Interpolation of traffic counts is acceptable for non-critical intersections when count data is not available.
- Develop time-of-day schedules
- Update/develop *Translink32* database
- Update/develop Master Graphics:
  - All new graphics should use photogrammetry and/or signal design plans as a minimum standard
  - Internal *Translink32* default graphics will not be acceptable
  - All graphics shall have a resolution of 1280 pixel x 768 pixel in order for entire graphics screen to be viewed on a laptop without requiring scrolling
  - Intersections and detectors shall be labeled
- Ensure all System Detectors are assigned and the detector data is logging in field
- Coordinate the number of timing plans with the Division and COST Section.

Task 6: Preliminary Submittal

The Firm shall:

- Submit electronic preliminary timing plan report and supporting documentation to the COST Reviewing Engineer for review, using the DOT File Transfer System (FTS), including:
  - TransLink32 Databases
  - Synchro
  - Tru-Traffic
  - Traffic Counts
- Use the following report format:

  Section 1 - Executive Summary
  Section 2 - Study Area
    - Intersections and a map
    - Existing signal system zones
    - Special signal timing requirements (pedestrian phases, FYAs, railroad preemption, etc.)

- Facility Type
- Purpose of Route

Section 3 - Turning Movement Counts

- Map and location of existing and new counts
- Methodology of developing volumes for intersections without turning movement counts
- Identify Traffic Flow Characteristics
- Table showing counts, who did them, date and peak periods counted

Section 4 - Existing Timing Plans

- Existing TOD Schedule
- Discrepancies between Translink32 & signal plans
- Discrepancies between signal plan and current conditions
- Day and time of “Before” travel time runs
- Refer back to Translink32 database

Section 5 – Field Observations of Corridor

- Observations from “Before” travel time runs – including any issues related to deficiencies/safety issues with geometrics/pavement marking/signal heads, etc.
- Summary of Division concerns
- Citizen complaints

Section 6 - Proposed Timing Plans

- Identify Performance Measures
- Define Prioritization
- Define Operational Objectives
- Changes to Zones
- Identify Critical Intersections
- Cycle lengths for each plan
- Special timing (half cycle, uncoordinated intersections, lead/lag, etc.)

Section 7 - Proposed TOD/DOW Schedule

Section 8 - Proposed Implementation Schedule

Section 9 - Appendices

- Traffic routing methodology and results (If explanation is needed)
- Additional information
- Hard Copies (if requested)

- Allow three (3) weeks for review, comments, and preliminary approval process to be completed by the COST Section
- Wait to implement until all review comments have been addressed and the preliminary submittals have been approved by the COST Section
- Receive initial project ratings after preliminary review approval is completed.

Task 7: Field Implementation & Fine-Tuning of New Timing Plans

The Firm shall:

- Implement timing plans in accordance with the COST Section’s requirements
- Ensure all TOD scheduled events are operational in both the Master and local controller(s)
- Observe new traffic operations at the intersections and along corridors and drive the system with Tru-Traffic synced with the system time

- Fine-tune traffic as necessary. (For estimating purposes, on complex projects this task may be limited to an agreed upon maximum number of days.)

<u>Task 8</u>: Evaluation of Traffic Signal System Operations

The Firm shall:

- Perform "After Runs" using *Tru-Traffic* software in accordance with the Standard Practice for Travel Time Runs for Evaluation of Signal Timing Plans.

<u>Task 9</u>: Final Submittal & Final Report

The Firm shall:

- Submit Final Report, timing plans, and all supporting documentation to the COST Reviewing Engineer a minimum of one (1) month in advance of the deadline of the project to provide adequate time for to review, evaluate, and approve (see ***Schedule*** below).
  - One (1) electronic copy to COST Reviewing Engineer
  - One (1) electronic copy to the Division
  - All *SYNCHRO*, *Tru-Traffic* Reports and data, *Translink32* database files (cleaning up the schedule, removing unused timing plans, etc.), traffic counts, and any other pertinent information.
- Prepare a <u>Final Report</u> using the following format:

  Section 1 - Executive Summary
  Section 2 - Study Area
    - Intersections and a Map
    - Final signal system zones with any changes
    - Special signal timing requirements (noteworthy changes or special programing to note for future)

  Section 3 - Turning Movement Counts
    - Summary and refer back to Preliminary submittal

  Section 4 - Implemented Timing Plans
    - Date Implemented
    - Cycle lengths for each plan
    - Special programming changed because of field conditions

  Section 5 - Implemented TOD/DOW Schedule
  Section 6 - Travel Time Run Comparison
    - Dates and Times of “Before” and “After” runs
    - Tables summarizing “Before” and “After” run results

  Section 7 - Recommendations
    - Separate the signal operations comments from the remaining comments
    - Classify recommendations by their added benefit to operation or safety (i.e. high, medium, or low)

  Section 8 - Appendices
    - Additional information
    - Hard Copies (if requested)

- Notify COST Section if System re-timing effort does not provide an improvement/benefit to the current System operations. COST Section, Division, and Firm will meet to discuss result and agree on further actions and/or recommendations. If agreement between COST Section and Firm is that improvement/benefit to the System operations cannot be accomplished through the System re-timing effort then written justification should be included in the Final Report.
- Email Section 7 - Recommendations to Jennifer Portanova once the Final Report has been accepted by the COST Reviewing Engineer.
- Receive final project ratings after Final Report and accompanying documents are received and approved.

Task 10: Meet with Division Personnel

The Firm shall meet with Division and Regional Traffic Engineer's personnel for up to 1/2 business days to review and explain all work done.

Work Standards

The Firm will prepare plans in accordance with current edition of the following, if applicable:

- Traffic Systems Operations' Project Special Provisions - (*Special Provisions for the Preparation of Coordinated Traffic Signal System Timing Plans* – Version 2011.1)
- *NCDOT Traffic Management and Signal Systems Unit Design Manual*
- *The Manual on Uniform Traffic Control Devices (MUTCD)*, 2003 Edition.
- *North Carolina Supplement to the MUTCD*
- Plan preparation and CADD conventions, customary practices and formats of the NCDOT ITS and Signals Unit

The Firm shall be responsible for responding to any operational issues related to the final signal timing plans for up to one (1) month after final signal timing plans have been reviewed and approved without additional cost to the Department.

Invoices

The Firm shall:

- Include *Summary of Progress* and a *Percent Completion* on all Invoice submittals
- Expect remittance of the Final Invoice after the Post implementation Observation Period has ended.
- Submit invoices to Dr. Hummer for payment.

Schedule

The Firm shall commence work in conjunction with receiving the Notice to Proceed (NTP) from the Dr. Hummer and complete project by **September 30, 2017 or sooner.**

Reasonable extensions of time for unforeseen delays may be allowed as agreed to by mutual consent by and between the Firm and the COST Section.

Reference

Regional Traffic Engineers - https://apps.ncdot.gov/dot/directory/authenticated/UnitPage.aspx?id=9685

Traffic Count Information
https://connect.ncdot.gov/resources/safety/TrafficSafetyResources/Price%20List%20-%202015-2018.pdf
https://connect.ncdot.gov/resources/safety/Pages/Traffic-Data.aspx

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