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Traffic Signal Operation, Optimization, Maintenance and Management Practices in the Southeast US

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Abstract: *Adequately designed, managed, operated, and maintained traffic signal systems provide substantial operational, environmental, economic, and safety benefits. While technological advancements can enable improvements in traffic signal operation, optimization, maintenance and management (TSOOMM); such benefits cannot be realized unless transportation authorities are ready to embrace the new technologies and adopt them. In order to understand the needs and opportunities for intervention in TSOOMM, it is important to examine the current practices and document the facilitators and barriers that drive those practices. Along these lines, this study developed and conducted a comprehensive survey of traffic signal operation, optimization and management practices in the Southeast United States. Twenty representatives of transportation agencies that operate various-sized traffic signal systems in six states in the Southeast responded to the survey. The study team aggregated the responses by agency size and used the results to document the state-of-practice. Also, current barriers were identified including limitations in available resources (such as funding and staffing levels), and lack of efficient trigger data for retiming signals. The analysis of the survey results highlighted opportunities for refining and improving current practices through the use of emerging data collection and modeling options.*

Keywords: *Survey of practice; traffic signal control; signal optimization; signal management; signal timing; data; new technologies.*

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I. INTRODUCTION

Traffic congestion is an issue of increasing concern in the United States. Across the country, drivers spend on average 97 hours trapped in congestion every year while the annual cost of congestion is estimated at $87 billion or an average of $1,348 per driver [1]. Outdated traffic signal control, lack of signal optimization, and/or poor signal management are responsible for 5 percent of overall total congestion and more that 11% of recurring congestion [2]. Furthermore, poorly designed, located, operated, and maintained traffic signals lead to negative impacts on air quality and increase in fuel consumption. An estimated 4.3 billion dollars can be saved annually nationwide should well-managed, optimized, and controlled traffic signal systems were in place. Moreover, according to the U.S. Department of Transportation's Intelligent Transportation Systems Joint Program Office the benefits of investments in signal timing outweigh the costs by 40:1 or more [3].

In recent years, new data collection technologies are emerging that can assist in improved traffic signal operation, optimization, maintenance and management (TSOOMM). These include high resolution controller data; advanced detection technologies such as video image detection, automatic-vehicle based identification technologies; third party crowdsourcing data; connected vehicles, and connected automated vehicles data. Moreover, advances in signal optimization methods and models offer new tools that can be used to improve TSOOMM, leading into significant benefits in system performance. However, potential gains can be realized only if the transportation agencies embrace the advanced technologies and tools, and choose to utilize them for traffic signal systems in their regions.

This study conducted a comprehensive survey of practice that aimed at documenting current practices that operating agencies responsible for traffic signal control in small, medium, and large size cities in the Southeast United States currently use to manage, and optimize traffic control in their regions. The findings reported in this paper provide valuable insights about a) current operating, signal retiming, and management practices of agencies, b) the reasons that drive those practices; and c) opportunities and barriers for adopting new approaches to improve the current state-of-the-art through the use of emerging data collection sources and advanced signal optimization options.

II. PREVIOUS SURVEY EFFORTS ON TRAFFIC SIGNAL OPERATION, OPTIMIZATION, MAINTENANCE AND MANAGEMENT (TSOOMM)

The first systematic effort to assess the state of traffic signal operation in the United States took place in 2005, when the National Transportation Operations Coalition (NTOC) conducted a self-assessment survey (SAS) of agencies operating traffic signals across the United States. The goal was to bring attention to the state of signal operation, to create awareness of the congestion-reducing benefits of good traffic signal operation, and to make a case for additional investment in traffic signal operation. The survey responses were used to develop the first National Traffic Signal Report Card [4]. A total of 378 agency representatives from 49 states fully completed the survey. Respondents were asked to rate (on a scale of 1 to 5) each question based on the performance of their agency. Six topics were explored in the questionnaire, namely signal operation in coordinated systems, signal operation at individual intersections, specialized operation for traffic signals, detection systems, management, and maintenance of traffic signals. Based on the responses received, the overall national performance of traffic signal systems was graded as D- receiving a score of 62 out of 100. The report concluded that the rating was not surprising and pointed to limited funding and staff, poor management, delayed re-timing signal plan, and lack of adequate data for traffic signal timing plans as some of the fundamental issues resulting in this performance rating.

In 2007, a second self-assessment survey was carried out across the United States and Canada by NTOC and a total of 417 agencies responded. These agencies operated various-sized traffic signal systems representing 47 states and 45 percent of the nation's traffic signals [5]. Similarly to the 2005 survey, the second survey effort was intended to assess the state of traffic signal management and operation practice, identify deficiencies in traffic signal systems and highlight ways to improve operations. The questionnaire used contained precisely the same six sections as the first SAS; however, questions were improved to provide more clarity and some of the questions within the self-assessment were rearranged. Besides, the scoring methodology was included; thus, respondents could determine their score and associated letter grade. The responses from the 2007 SAS reaffirmed the findings of the 2005 survey and resulted to a National Traffic Signal Report Card score of 65 out of 100 points (equivalent to a D letter grade). According to the 2007 survey findings, one-third of the respondents stated having minimal or no management of traffic signal operations, and almost one-half reported not having enough staff or resources committed to monitor or manage traffic signal operations on a regular basis. In addition, traffic monitoring and data collection received the lowest score ratings, irrespectively of the type of agency or signal system size. The findings confirmed that agencies had limited resources and thus were forced into difficult choices about how to utilize them. A proactive, integrated program management approach that includes the principles of continuous improvement, asset life-cycle costs and resource allocation for traffic signal operations was seldom seen as an option [5].

Subsequently, NTOC undertook a third SAS in 2011, which collected responses from 241 agencies of various sizes across the US and Canada (representing approximately 39 percent of all traffic signals in the US) [6]. The results and findings from the third SAS were used to determine the scores for the 2012 National Traffic Signal Report Card. The survey used the same methodology as the earlier SAS tools but further improvements were made to remove some irrelevant questions, add details to some of the questions, modify and expand the summary information, describe the scoring methodology, and connect the questions more to the outcomes of objectives-based traffic signal operations programs. Topic areas covered in the 2011 SAS included management, traffic signal operations, signal timing practices, traffic monitoring, and data collection, and maintenance. The results showed a slight improvement in terms of management, signal timing practices, and maintenance leading to a 2012 National Traffic Signal Report Card score of 69 out of 100, which is equivalent to a D+ letter grade [6].

The three NTOC SAS efforts discussed above provided a broad overview of the state of practice in traffic control across the USA and Canada in an aggregated manner. However, the survey findings were not categorized based on agency size or population nor provided details about the unique issues and barriers for TSOOMM at the regional or state levels. These issues are essential to characterize the current state of traffic signal operations and draw conclusions regarding effective countermeasures to address needs at the local and regional levels and need further consideration.

In other noteworthy efforts, Gordon at al. conducted a survey of traffic signal operations and maintenance practices across the USA in 2008 for the purpose of developing a formal guideline to estimate the staffing and resources required to operate and maintain traffic signal systems effectively [7]. Responses from 7 agencies operating traffic signals including cities, counties, and state DOTs were received and analyzed. The main subject areas covered in the survey included the classification of signal system characteristics, redundancy characteristics of system traffic detection, timing plan characteristics, operations characteristics, maintenance practices, and staff size and qualifications. The overarching issues of concern revealed by the survey responses were the qualifications of staff, lack of utilization of advanced technologies, failure of signal retiming on a regular basis, and inadequate funds. Although the questionnaire covered a wide variety of subjects, the limited number of survey responses and the heterogeneity of those responses did not allow for a comprehensive analysis of findings and performance of meaningful comparisons and assessments.

In 2010, Gordon led an NCHRP Synthesis study [8] that documented findings from a comprehensive literature review and a series of project case studies. As part of this effort, the authors carried out a survey to document practices that states were using to re-evaluate the timing of signalized intersections. The survey solicited additional statistical and anecdotal information from agencies involved in the case studies that were not addressed in prior surveys. The questions asked revolved around retiming tools and personnel qualifications, field implementation of timing plans, resource appropriation for retiming, evaluation of signal timing performance, and management issues of signal timing. A total of 17 agencies were approached, 7 of which provided responses. According to the survey results, around half of the transportation agencies reported that they did not routinely collect and analyze traffic data for signal timing, and that existing traffic data collection programs did not evaluate the quality of data collected. Also, detector data were often not used routinely to determine the need for retiming. Besides, the appropriate number of timing plans were deemed inadequate for the requirement [8]. While the NCHRP Synthesis report provide valuable information regarding traffic signal retiming practices, the survey conducted as part of this effort was limited in scope focusing only on signal retiming. Furthermore, it drew conclusions from a limited number of responses; thus, overall, cannot provide a broad picture for signal control, optimization, and management practices.

The earlier studies summarized above focused on national wide surveys and had not been updated recently to consider new and emerging data collection methods and the availability of new software for signal timing optimization. Moreover, regional differences were not considered. To address these gaps, this study developed a new questionnaire survey tool and used it to document current practices, existing limitations and needs, and future considerations of agencies located in the Southeast United States and are responsible for TSOOMM. The research team identified transportation agency representatives responsible for TSOOMM in six states in the Southeast (i.e., Georgia, North Carolina, Tennessee, South Carolina, Alabama, and Florida) and distributed the survey to them in 2019. The following sections discuss the study methodology, results, and conclusions from this effort.

III. METHODOLOGY

In order to obtain information about transportation agencies' current practices related to TSOOMM in the Southeast United States, the project team developed a survey questionnaire in accordance with the Institute of Transportation Engineers (ITE) Manual on Transportation Engineering Studies [9] using the Qualtrics platform. The survey questions focused on the number and type of signals managed by the agency, practices related to the signal retiming process, tools and methods employed in signal optimization, data used for evaluation of signal performance, and plans for using emerging technologies for enhancing current practices in the future. More specifically, the questionnaire survey included 16 questions that solicited information on the following topics:

- Characteristics of agencies participating in the survey (e.g., type, size and location of agency, and the number and types of traffic signals managed by an agency)
- Signal retiming practices (e.g., retiming frequency and triggers used to initiate the retiming process)
- Resources used in support of signal control optimization and management (e.g., use of formal guidelines and use of simulation, analysis, and/or optimization software)
- Data collection strategies (e.g., types of data used for signal timing and utilization of emerging data sources).

Moreover, the survey participants were asked about the adequacy of available resources (such as funding, staffing, training, etc.) in support of their work and were given an opportunity to provide comments using an open-ended question format.

The Qualtrics Research Core tool was used to prepare the questionnaire as it provided a user-friendly platform. Several capabilities of the survey tool were utilized, including closed-ended, multiple-choice, checkbox, open-ended, demographic, and rating scale questions.

After the survey questionnaire was developed, it was pretested and fine-tuned prior to use to ensure that it was easy for survey participants to understand the questions and provide answers. Then, an approval was obtained from the Institutional Review Board (IRB) for Human Use to proceed with the survey. Upon approval, the questionnaire survey was emailed to representatives of selected state, county, and local transportation and public works departments in the Southeast region that owned and operated traffic signals along with a request to provide feedback regarding current practices of their agency. Care was placed into soliciting input from jurisdictions of different sizes ranging from large (i.e., serving a population greater than 450,000) to small (i.e., less than 65,000).

Returned responses were carefully screened and incomplete and/or duplicate responses were discarded. Details about the responses obtained, and study findings and conclusions are presented next.

IV. RESULTS AND INTERPRETATION

Twenty detailed responses were received from representatives of the surveyed transportation agencies that operate various-sized traffic signal systems in six states in the Southeast (namely Georgia, North Carolina, Tennessee, South Carolina, Alabama, and Florida). Inspection of the responses indicated that three of the responses were duplicates and had to be omitted. After discarding these three responses, seventeen detailed responses were utilized for further analyses. These responses represent six large, six medium and five small city agencies managing collectively over 9,600 traffic signals. Large city agencies were considered as those with jurisdiction size greater than 450,000 people, whereas medium and small agencies refer to those with jurisdiction size between 65,000 and 450,000 and less than 65,000, respectively. The following paragraphs present summaries of the survey results organized in table format for easy reference. The responses were aggregated by jurisdiction size and subtotals were provided, when appropriate. Survey responses are anonymous except for survey respondents' comments.

4.1 Characteristics of Agencies Participating in the Survey

Based on the survey responses, the total number and percentage of coordinated signals, isolated signals, and signals connected to central software that are managed by responding agencies are shown in Table 1.

Table 1: System Network Characteristic

Population	Agency Type	Coordinated Signals		Isolated Signals		Signals Connected to Central Software
		Total Number Reported	Percent[1]	Total Number Reported	Percent[1]	Total Number Reported
> 450,000	Large	5350	75.54%	1732	24.46%	6175
65K-450K	Medium	932	63.02%	547	36.98%	1296
< 65,000	Small	447	83.24%	90	16.76%	173
	Total	**6729**	**73.96%**	**2369**	**26.04%**	**7644**

Notes: [1] Shows the percent of coordinated or isolated signals by agency type.

As can be seen, nearly three quarters of the signals managed by the agencies responding to the survey are coordinated while isolated signals account for the rest (26%). Moreover, the study participants representing large and medium-size agencies reported that the vast majority of their signals are connected to central software (over 85%) while small agencies reported only one out of every 3 traffic signals being connected centrally.

Table 2 illustrates the number and percent of different types of traffic controllers used (namely fixed time, actuated, traffic responsive, adaptive) by jurisdiction size. It can be observed that actuated signals are by far the most common type of signals used by agencies represented in this survey, regardless of agency size (81.95%). On the other hand, traffic responsive and adaptive signals have a small share (4.94% and 5.57%, respectively) across all agency sizes combined.

Recently, many state-of-the-art signal strategies have been introduced and implemented by various agencies across the United States. Examples include special plans for special events management, arterial incidents response, and freeway incidents response. According to the survey responses from agencies in the Southeast, advanced signal strategies utilized by agencies are summarized in Table 3.

Table 2: Type of Traffic Controllers

Agency Type	Fixed time		Actuated		Traffic responsive		Adaptive		Total Number of Signals Reported
	Total Number Reported	Percent[1]	Total Number Reported	Percent[1]	Total Number Reported	Percent[1]	Total Number Reported	Percent[1]	
Large	361	4.93%	6365	86.97%	102	1.39%	491	6.71%	**7319**
Medium	267	15.01%	1177	66.16%	335	18.83%	0	0.00%	**1779**
Small	99	18.20%	360	66.18%	39	7.17%	46	8.46%	**544**
Total	**727**	**7.54%**	**7902**	**81.95%**	**476**	**4.94%**	**537**	**5.57%**	**9642**

Notes: [1]Shows the percent of the fixed time, actuated, traffic responsive or adaptive by agency type

Table 3: Advanced Signal Strategies Employed by Agencies

Advanced signal strategies	Agency Type, Total Number of Agencies Reporting			Total, n=17
	Large, n=5	Medium, n=6	Small, n=6	
Transit signal priority	4	1	1	**6**
Freight signal priority	1	-	-	**1**
Railroad-highway grade crossing signal priority	4	3	1	**8**
Emergency vehicle preemption	4	5	5	**14**
Special plans for special events management	5	4	4	**13**
Special plans for arterial incidents response	3	-	1	**4**
Special plans for freeway incidents response	3	-	3	**6**
Other (Requested details)	3	-	1	**4**

The findings summarized in Table 3 indicate that emergency vehicle preemption and special plans for special events management are the most prevalent strategies used by agencies in the Southeast, regardless of the justification size. In addition, some large agencies reported utilizing drawbridge preemption and reversible-lane control, which were entered in the "Other" category.

4.2 Signal Retiming Practices

A broad literature review conducted as part of this study revealed that retiming traffic signals improves mobility and contributes significant benefits in terms of reduced delay, fuel consumption, and emissions (Gordon et al. [7], Tarnoff and Ordonez [10], Gordon [8], Skabardonis [11], Chien et al. [12], Sunkari [13]). Koonce et al. [14] suggested that signal retiming should take place every 3 to 5 years, and even more often should there be considerable shifts in traffic volumes or any changes in roadway conditions. Therefore, this survey of practice solicited information about agency current practices with respect to signal retiming. The reported responses are provided in Table 4.

Table 4: Traffic Signals Retiming Frequency

Frequency	Percentage by Agency Type			Total (All Agencies Combined)
	Large	Medium	Small	
Every year	0.0%	16.7%	16.7%	**11.8%**
Every 2 years	0.0%	16.7%	0.0%	**5.9%**
Every 3-5 years	20.0%	16.7%	50.0%	**29.4%**
Every 5 years or more	40.0%	33.3%	0.0%	**23.5%**
When getting feedback from travelers	20.0%	16.7%	16.7%	**17.6%**
Other (Requested details)	20.0%	0.0%	16.7%	**11.8%**

The survey responses revealed that the majority of large and mid-size agencies in the Southeast that responded to the survey retime their traffic signals every five years or more. One of the large agencies reported that they retime the traffic signals when it is needed. It can also be seen from Table 4, that half of the small agencies retime their signals every 3 to 5 years.

Table 5 summarizes the factors considered by agencies in the Southeast when deciding on retiming traffic signals. Some of these factors include a review of available data, field observations, feedback from travelers, and retiming based on a regular schedule.

Table 5: Main Factors of Retiming Signals

Factors	Percentage by Agency Type			Total (All Agencies Combined)
	Large	Medium	Small	
Based on the review of data (requested the data source)	20.0%	33.3%	20.0%	**23.8%**
Based on field observations (requested details)	0.0%	16.7%	30.0%	**19.0%**
Based on feedback from travelers	20.0%	0.0%	20.0%	**14.3%**
Retiming is scheduled at regular intervals	20.0%	16.7%	20.0%	**19.0%**
Other (Requested details)	40.0%	33.3%	10.0%	**23.8%**

Two large agencies, two mid-size, and one small agency reported that they combine several of the factors listed in Table 5, when making signal retiming decisions. Also, the survey requested participants to specify the data source considered if they base their decisions on the review of data. Based on the participants' answers, the reviewed data includes traffic counts, origin and destination (OD) data, Metropolitan Planning Organization (MPO) travel time studies, Automated Traffic Signal Performance Measures (ATSPMs), and intersection movement counts. Furthermore, agencies that reported making decisions about signal retiming based on field observations, were asked to elaborate. The following comments were made by the agencies in response to this request for details:

- Observation of general congestion
- Date of last timing update
- The agency is required to re-evaluate all signals over a set period. If through observation, it determines that a signal needs timing updates, then the signal is re-timed. The agency also evaluates the signals if it receives feedback from travelers, but this occurs less frequently
- Observation of traffic flow

Table 6 summarizes different types of triggers used by the agencies to retime the signals. These triggers include geometric changes, traffic demand changes, installation of new traffic signals in the area, and new development in the area. Changes in traffic demand are the most common trigger, followed closely by installation of new traffic signals in the area, geometric changes, and new development.

Table 6: Triggers Used to Initiate the Retiming Process

Triggers	Number by Agency Type			
	Large, n=5	Medium, n=6	Small, n=6	Total, n=17
Geometric changes	2	5	6	**13**
Traffic demand changes	5	5	6	**16**
Installation of new traffic signals in the area	5	6	3	**14**
New development in the area	4	4	5	**13**
Other (Requested details)	1	0	1	**2**

4.3 Resources Used in Support of Signal Control Optimization and Management

The survey participants were also asked if their agencies use formal guidelines for signal control optimization and management. Their responses are summarized in Table 7. It can be seen that the majority of agencies surveyed (58.8%) rely on national or statewide guidance. Only a small number of agencies reported having their own guidelines, but 17.6% of the agencies expressed an interest in developing a set of guidelines in the future.

Table 7: Deployed formal guidelines for signal control optimization and management

Options	Percentage by Agency Type			Total (All Agencies Combined)
	Large	Medium	Small	
Yes, my agency has established guidelines and/or manuals for signal control optimization & management	0.0%	0.0%	16.7%	**5.9%**
Yes, my agency has some guidelines and/or are currently in the process of developing a set of guidelines	0.0%	16.7%	0.0%	**5.9%**
My agency uses national or statewide guidance	80.0%	50.0%	50.0%	**58.8%**
No, my agency has no guidelines but is using national guidelines	0.0%	16.7%	0.0%	**5.9%**
No, my agency has no guidelines but is interested in developing a set of guidelines	20.0%	16.7%	16.7%	**17.6%**
No, my agency has no guidelines and/or is not interested in developing guidelines	0.0%	0.0%	16.7%	**5.9%**

Furthermore, the survey requested information regarding current practices with respect to the use of signal optimization software or techniques. A summary of the responses obtained from representatives of agencies in the Southeast responsible for TSOOMM is provided in Table 8.

Table 8: Utilized Signal Optimization Software or Technique

Type of Software or Techniques	Number by Agency Type Large, n=5	Medium, n=6	Small, n=6	Total, n=17
SYNCHRO	5	5	5	**15**
TRANSYT-7F	0	0	0	**0**
PASSER-V	0	0	0	**0**
MAXBAND	0	0	0	**0**
Tru-Traffic	3	0	1	**4**
My agency performs optimization based on high-resolution controller data	1	2	1	**4**
My agency uses manual time-space diagrams	2	1	1	**4**
My agency uses manual fine-tuning for retiming	3	4	3	**10**
Other (Requested details)	1	0	1*	**2**

Note: * HCM-based method/tool

It is clear from the responses received that SYNCHRO is the most popular software for signal optimization in the Southeast, with 15 out of 17 responding agencies reporting using the software at the time of the survey. Ten agencies also reported engaging in manual fine-tuning and two reported using the Highway Capacity Manual methodologies for signal optimization. It was interesting to see that none of the agencies that responded to the survey utilized TRANSYT-7F, PASSER-V, and MAXBAND at present. Once very popular for signal optimization use, these software packages are no longer mainstream and have been replaced by other options.

The survey participants were also asked to report on their use of simulation or computational models in support of signal control optimization and management. Table 9 clearly shows that SimTraffic is the most widely used computational model with 10 out of 17 agencies surveyed reporting using it. Highway Capacity Software (HCS) and VISSIM/VISUM were used by 5 and 4 agencies, respectively. There is no use of TSIS/CORSIM and AIMSUN, and only one large agency reported the use Transmodeler. In addition, two mid-size and two small responding agencies indicated they do not use any simulation models as part of their practice.

Table 9: Used simulation or computational models in support of signal control optimization and management

Simulation or Computational Models	Number by Agency Type Large, n=5	Medium, n=6	Small, n=6	Total, n=17
TSIS/CORSIM	0	0	0	**0**
VISSIM/VISUM	1	1	2	**4**
SimTraffic	5	4	1	**10**
Highway Capacity Software (HCS)	1	2	2	**5**
AIMSUN	0	0	0	**0**
Transmodeler	1	0	0	**1**
Other (Requested details)	0	0	0	**0**
No, my agency does not use any simulation models	0	2	2	**4**

4.4 Data Collection Strategies

The survey solicited information regarding the types and sources of data currently used for evaluating signal performance. As illustrated in Table 10, agencies responding to the survey use a variety of data types for evaluating signal performance. Intersection crash data and results from simulation or computational tools are the most prevalent data types considered. Some of the large and mid-size agencies report using travel time measurements/delays based on third-party vendors (INRIX, HERE, TomTom, etc.), whereas none of the small size agencies surveyed reported the utilization of such data. Furthermore, one large agency reported that they use travel time runs/field observations, and two small size agencies stated that they use "manual observations of the corridor and individual signal performance (delays, queuing, etc.)" and "Manual counts and HCS procedures."

Table 10: Data employed for evaluating signal performance

Data Types	Number by Agency Type			Total, n=17
	Large	Medium	Small	
High-resolution controller/ATSPMs	3	2	2	**7**
Travel time measurements/ delays based on Bluetooth/Wi-Fi	3	1	3	**7**
Travel time measurements/ delays based on third party vendor (INRIX, HERE, TomTom, etc.)	2	1	0	**3**
Intersection crash data	4	3	2	**9**
Simulation or HCS models	3	3	2	**8**
Other (Requested details)	2	0	2	**4**

In addition, the survey participants were asked if their agency implemented emerging data collection strategies such as high-resolution controller data in support of signal control optimization and management. Table 11 summarizes the answers received.

Table 11: Emerging data collection strategies

Options	Percentage by Agency Size			Total (All Agencies Combined)
	Large	Medium	Small	
Yes, full scale implementation	0.0%	16.7%	0.0%	**5.9%**
Yes, on few intersections	20.0%	16.7%	33.3%	**23.5%**
Planned, not implemented yet	20.0%	16.7%	0.0%	**11.8%**
Not planned, being considered	60.0%	33.3%	0.0%	**29.4%**
Not planned, or not aware	0.0%	16.7%	50.0%	**23.5%**
Not planned, or not interested in implementing	0.0%	0.0%	16.7%	**5.9%**

As seen from Table 11, the majority of large and mid-size agencies responded that the use of emerging data collection practices in support of signal optimization is not currently done but it is being considered for the future. However, the majority of small size agencies reported that they have no plans for using emerging data collection options, or their agencies are not aware of such practices and/or not interested in implementing.

To understand motivations and obstacles associated with the use of new sources of data in support of signal timing and optimization, survey participants were asked their opinion on whether or not it is worth to invest on emerging technologies for signal optimization (such as high-resolution controller data and connected vehicle data) in their regions. The responses summarized in Table 12 indicate that representatives of large agencies are extremely supportive of such investment. Mid-size agencies are also in support with two thirds of the reporting agencies embracing investment on emerging technologies in support of signal optimization. Small-size agencies are more cautious but are still overall supportive.

Table 12: Perceived value of the investment in emerging technologies for signal optimization (such as high-resolution controller data and connected vehicle data)

Options	Percentage by Agency Size			Total (All Agencies Combined)
	Large	Medium	Small	
Yes	100.0%	66.7%	50.0%	**70.6%**
Somehow	0.0%	33.3%	33.3%	**23.5%**
No	0.0%	0.0%	16.7%	**5.9%**

Survey participants were also asked if their agency has sufficient resources at present (e.g., technical staff and an adequate budget) or not in order to meet signal optimization and management needs. The respondents' opinions are summarized in Table 13.

Table 13. Agency resources to meet signal optimization and management needs

Options	Percentage by Agency Size			Total (All Agencies Combined)
	Large	Medium	Small	
Yes, my agency has sufficient resources to meet current and future needs	0.0%	16.7%	33.3%	**17.6%**
My agency has limited resources; additional resources will be needed in order to adequately meet future needs	80.0%	50.0%	66.7%	**64.7%**
No, my agency does not have sufficient resources; lack of resources hinders efforts to improve signal optimization and management at the present time	20.0%	33.3%	0.0%	**17.6%**

According to Table 13, the majority of agencies representatives surveyed think that their agency has limited resources. About 20% of representatives of large agencies and 33.3% of representatives of mid-size agencies feel that their agency does not have sufficient resources and that the lack of resources hinders efforts to improve signal optimization and management at present. They also feel that additional resources will be needed in order to adequately meet future needs.

To gain a more in depth understanding about the resources needed and agency priorities, the survey further asked: “If your agency needs additional resources, please rank the following resources based on need from highest priority to lowest priority ”. The responses obtained from representatives of large, medium, and small size agencies are depicted in Figures 1, 2, and 3, respectively.

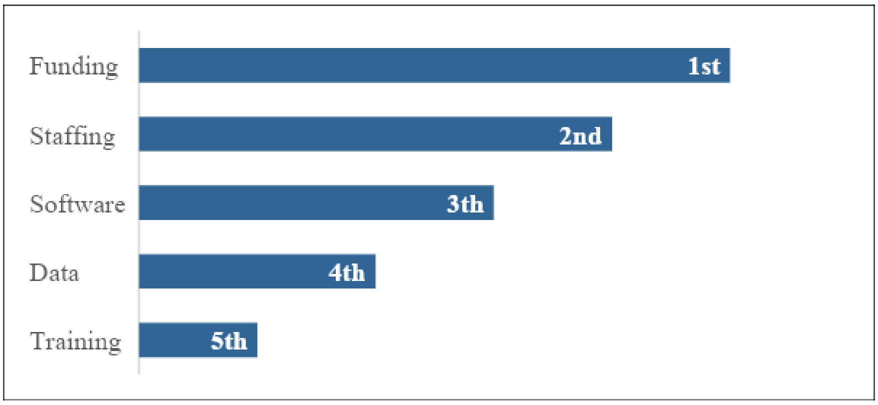

Figure 1: Large agencies’ participant opinion, ranking from highest priority to lowest priority

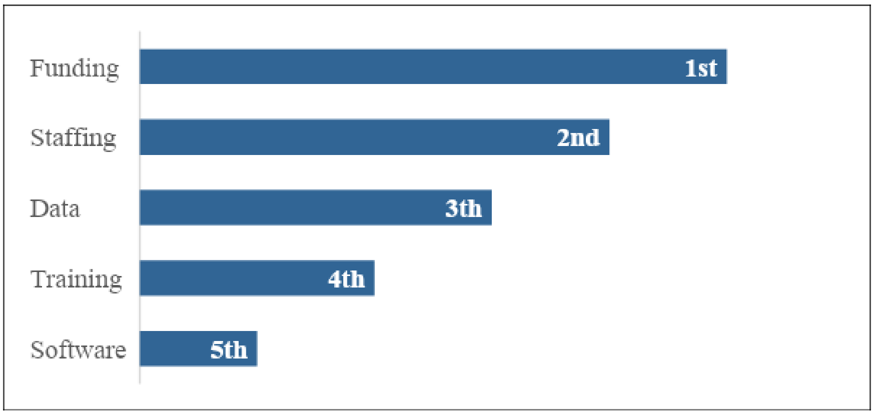

Figure 2: Mid-size agencies’ participant opinion, ranking from highest priority to lowest priority

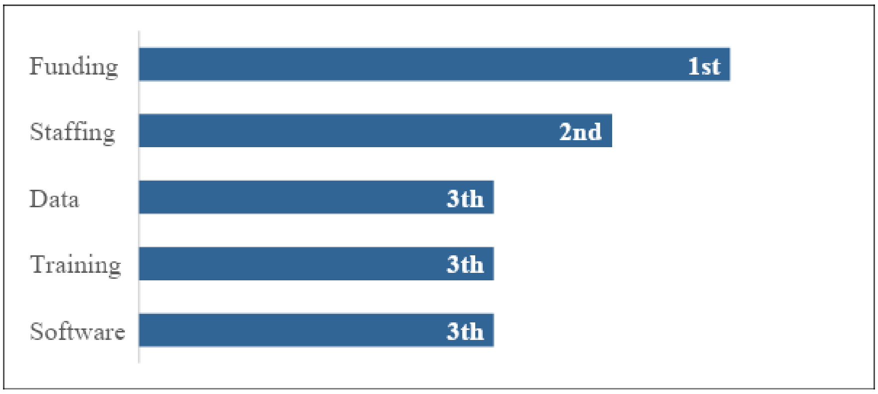

Figure 3: Small agencies' participant opinion, ranking from highest priority to lowest priority

The results in Figures 1 through 3 show that funding and staffing are ranked as the top two priority issues regardless of agency size. This is consistent with earlier findings from nationwide surveys that reported resource limitations related to funding and staff as being the most significant factors contributing to suboptimal signal retiming and optimization [6], [7].

V. CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

This study collected and analyzed questionnaire survey responses from 17 transportation agencies responsible for TSOOMM of over 9,600 traffic signals in the Southeast US. The findings shed light on current signal timing practices and software resources used for signal control optimization and management. Moreover, the survey results document types and sources of data used for evaluating signal performance along with stated preferences related to the value of the investment in emerging technologies for signal optimization and the adequacy of resources. The following conclusions can be given based on the analysis of the responses to the survey conducted in this study:

- The responding agencies reported that nearly 74% of the traffic signals that they manage are coordinated. Large and mid-size agencies surveyed also reported that the majority of their signals are connected to the central controller (87%).
- Large majorities of the signals managed by the agencies surveyed are actuated/semi actuated. The numbers of traffic responsive and adaptive signal controls are still relatively low.
- Most of the agencies surveyed have implemented emergency vehicle preemption and special plans for special event management. Furthermore, large agencies reported that they utilize drawbridge preemption, and reversible-lane control. Eight out of the 17 agencies surveyed reported using railroad-highway grade crossing signal priority.
- Most of large and mid-size agencies retime their traffic signals every five years or more while half of the small agencies retime their signals more frequently, typically every three to five years.
- The agencies surveyed reported making signal retiming decisions based on review of data, field observations, feedback from travelers, or they retime at regular intervals. One-third of the agencies reported combining several of the above mentioned considerations.
- The majority of agencies use national or statewide guidelines for signal optimization and management, irrespective of agency size.
- SYNCHRO is a very popular signal optimization software utilized by 15 out of 17 agencies surveyed. None of the 17 agencies that responded to the survey currently utilizes TRANSYT-7F, PASSER-V, and MAXBAND.
- SimTraffic is the most used simulation model by survey participants, irrespective of agency size. VISSIM/VISUM and Highway Capacity Software (HCS) are also utilized but to a much lesser extent.
- Agencies reported using a variety of data types for evaluating signal performance with intersection crash data and outputs from simulation models being the most prevalent data type used.
- The majority of large and mid-size agencies reported that even though they do not currently utilize emerging data collection strategies such as high-resolution controller data in support of signal control optimization and management, such strategies are being considered for future use. On the contrary, the majority of small size agencies indicated that their agencies are not planning and/or are not aware or interested in such data collection strategies.
- Large agencies reported being much more interested in investing resources toward emerging technologies for signal optimization (such as high-resolution controller data and connected vehicle data) in their regions than small agencies.

- The majority of agencies surveyed feel that they have limited resources (e.g., technical staff and budget) in order to properly handle signal optimization and management needs. They also stated that additional resources will be needed in order to adequately meet future needs. Such results are in agreement with those from previous survey efforts [4]–[8] that also identified lack of funding as the biggest issue of concern that almost all types of agencies involved in TSOOMM are facing.

The consensus of survey participants regarding limited finding resources may also explain why some agencies have limited ability to collect data, invest in software and emerging technologies, retime signals more frequently, and increase staffing. The findings also heighten the importance of well-managed traffic signal operations as a means for optimizing traffic operations and reducing related congestion.

According to the scope of the study, the results from this survey of practice focused on agencies engaged in TSOOMM in the Southeastern States. While this was done by survey design, it may also be viewed as a limitation of this study. In terms of future work, it is recommended to expand the scope of this research and conduct a comprehensive survey of practice soliciting feedback from transportation agencies responsible of TSOOMM across the nation. Analysis of responses on a region-by-region basis (West, Midwest, Northwest, Southeast, and Southwest) is recommended to facilitate a better understanding of potential similarities and differences in current practices based on geographical region. In addition, in future work, it is suggested to include self-assessment as part of the survey instrument. The self-assessment would allow agencies to benchmark their own performance and compare their practices with those of other agencies as well as with commonly accepted best practices. Finally, further research can focus on the integration of traditional and emerging data from different sources for signal timing optimization purposes. It is recommended that a framework be developed considering the variations in the capability, maturity and resources available to different agencies.

The work presented in this paper was the first study documenting TCOOMM practices in the Southeast in the era of emerging technologies. One valuable contribution of the study is that transportation agencies can use the findings of the survey to compare their practices with other agencies in the Southeast and gain useful knowledge that will assist them in improving signal timing, optimization, and management in the future. Moreover, the survey identified current gaps and barriers that may be addressed through additional research and training to further assist agencies in taking full advantage of existing and new data and technology resources in the future

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