Use of Data to Prioritize Traffic Signal Retiming
Task 2017-08

FINAL REPORT

Prepared by the Center for Transportation Research at
The University of Texas at Austin
for the City of Austin

COA/CTR Interlocal Agreement
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Introduction

The City of Austin (CoA) Transportation Department is charged with retiming one third of the city's 1,151 traffic signals every year, with the goal of ensuring the signals are timed to optimize safety and performance. Currently, signals are selected for retiming based on a three-year fixed schedule. The purpose of CTR's Task 2017-08 was to explore methodologies that use data to identify traffic signal corridors for which retiming is most critical in a given year. The project resulted in the development of a data-driven, needs-based ranking method for prioritizing traffic signal retiming operations. Transitioning from a schedule-based system to a needs-based system will lead to increased operational efficiency and improved system performance for travelers in Austin.

This report details the steps involved in the completion of Task 2017-08, which include reviewing the existing processes used by the CoA and other agencies, exploring the literature and potential data sources, the development of performance measures, and the eventual implementation of a ranking methodology. Additionally, a literature review of adaptive signal control techniques was performed as exploration of a possible extension of this work in the future.

Existing Signal Retiming Process

The CoA develops its signal retiming schedule by grouping traffic signals into corridors. There are ninety corridors divided into three groups to create a rotating three-year schedule for retiming.

The effectiveness of retiming operations is assessed using probe vehicle travel time runs. The CoA conducts the timed runs in a consistent manner, at carefully chosen times before and after a corridor has been retimed. This allows for the computation of a travel time reduction metric, which is the principle measure of effectiveness for the retiming of the corridor. However, given that each corridor is usually driven only three to five times while conducting the probe vehicle runs, there are many factors that could disrupt the accuracy of then metric, particularly seasonal fluctuations and random variation.

Review of Potential Data Sources

CTR considered a number of different data sources for use in Task 2017-08, all of which were in use by the CoA or otherwise easily available. However, a key factor for this project was the coverage of a given data type over the study area. Three of the main data sources considered were various sensors deployed and maintained by the CoA, which are Bluetooth sensors, GRIDSMART detection cameras, and Wavetronix radar sensors. Both GRIDSMART and Wavetronix have only been deployed in limited numbers, with both exhibiting coverage on 18 percent of the CoA corridors. Bluetooth sensors have been used more extensively by the CoA, with 53 percent of corridors containing at least two sensors. This level of data coverage still proved too low for effectively assessing the performance of corridors across the whole city. Figure 1 shows that there were very few corridors containing more than three Bluetooth sensors. Although these data sources may be explored further for future use by the CoA, they were not suitable for the immediate needs of this project.

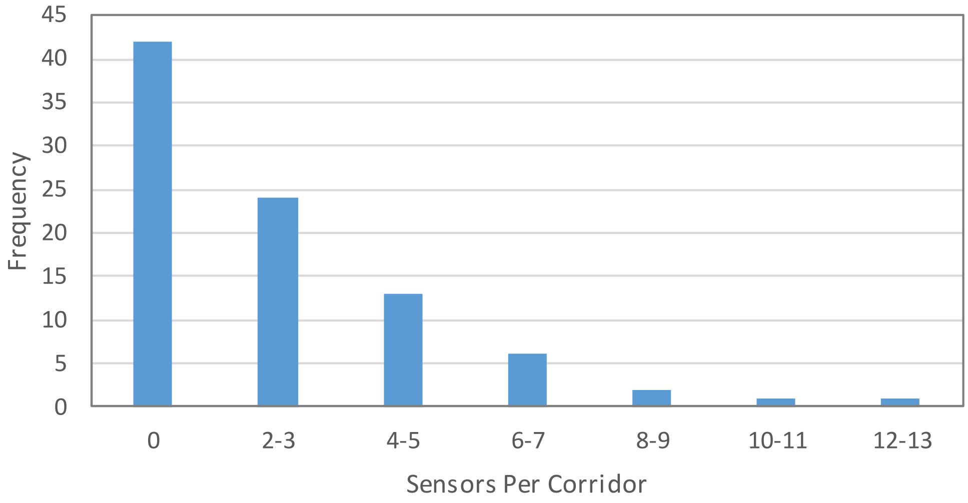


Figure 1: Number of Bluetooth Sensors per Corridor

The fourth data source consisted of crowd-sourced probe vehicle speed measurements. This dataset, for which the CoA was not required to install or maintain sensors to collect, was purchased by the CoA from third-party vendor INRIX. Initially, the INRIX data covered 80 percent of the corridors identified by CoA, but the CoA was able to request that INRIX add additional corridors to the coverage. At the time of this report, 87 percent of the CoA corridors (79 out of 90) were covered by INRIX data. Figure 2 depicts the data coverage for the INRIX dataset. Due to this superior data coverage, the INRIX data was chosen by CTR for use in building a ranking methodology.

INRIX divides each road into short pieces, generally ranging from 0.1 to 0.5 miles long, called "XD segments." They crowd-source speed data through their app's user base, supplementing with other sensors where available, and then present the average speed on each XD segment at a given time, with one-minute average speed as the finest data granularity. Since the data logs the length of each unique XD segment, a travel time can be calculated based on the reported speed.

There are some inherent advantages and drawbacks to the INRIX data. Given that it is acquired from a third party, there is a lower level of customizability inherent in the data acquisition process. However, since INRIX handles the data collection and cleaning processes, this saves considerable resources. Additionally, this data only captures vehicle speeds (and travel times), and is not able to obtain traffic volumes, which are a key component of corridor performance. However, at the end of the day, the exceptional data coverage of the INRIX data put it head-and-shoulders above the other options for the purpose of this project.

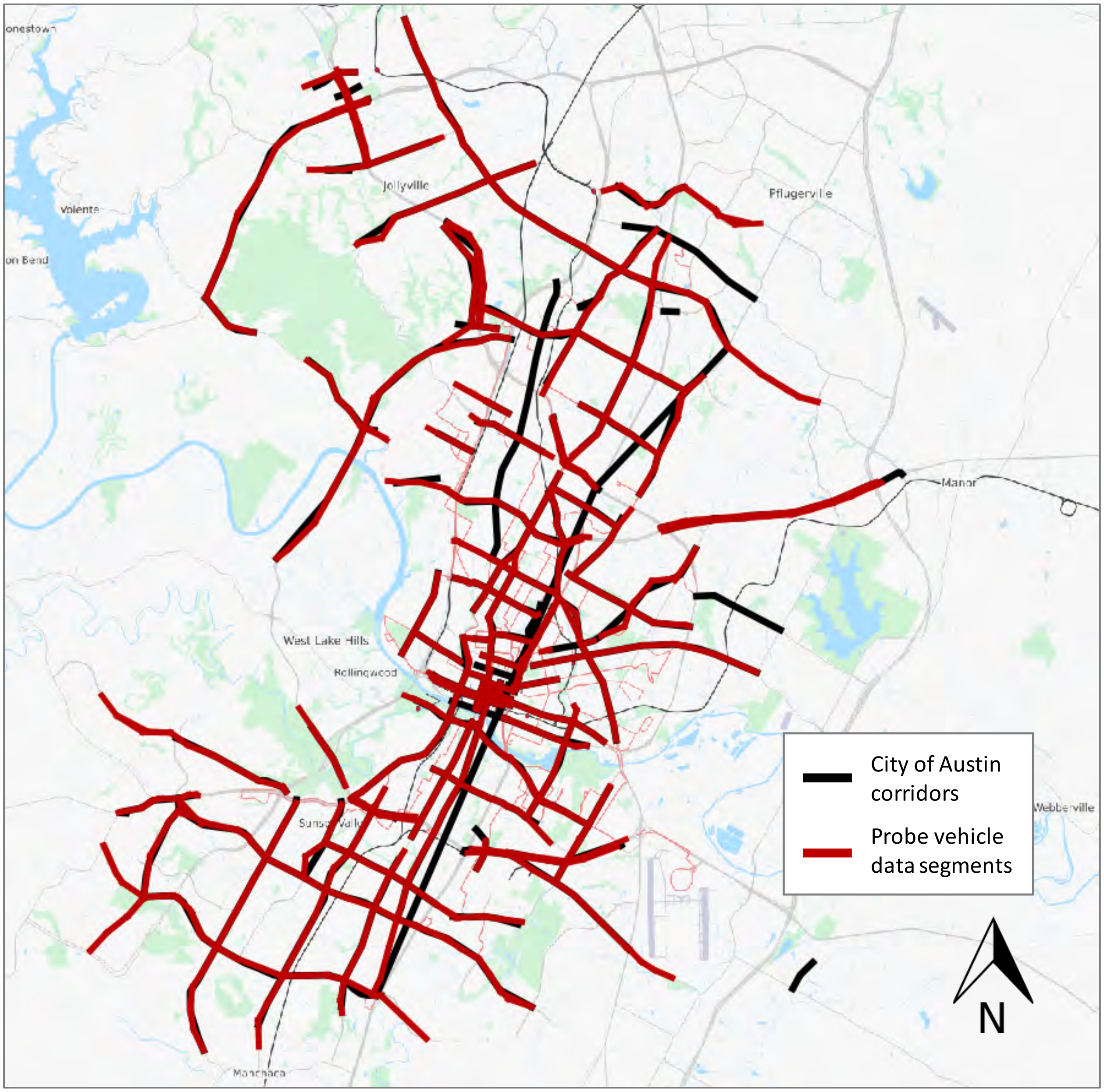


Figure 2: Map of INRIX Probe Vehicle Data Coverage for the City of Austin

Review of Literature for Signal Retiming Prioritization

The literature review for this project explored both the relevant academic literature pertaining to signal retiming, as well as the signal retiming operations conducted by other agencies across the country. This practical, agency-specific information was more difficult to uncover, so CTR worked with the CoA to develop and distribute a survey regarding retiming practices to augment the literature review.

Signal Retiming Practices

In terms of signal retiming frequency, the City of Austin is in line with the majority of US agencies that retime their signals on a three- to five-year cycle. Austin currently operates on a three-year signal retiming rotation. Many agencies show a strong inclination to retime major arterials more frequently than low-traffic corridors (Gordon, 2010). Some agencies try to combine signal improvement projects with roadway improvement projects where practical.

The "three-year rule" is generally considered the industry standard and rule of thumb. It dictates that signals should be retimed every three years to maintain an adequate standard of operation. However, there is little research to back it up. In fact, so many factors affect traffic signals that it is not productive to rely on a universal rule for retiming frequency. For instance, arterials benefit from frequent retiming, but downtown urban networks generally do not (Humphreys et al., 2018). Thus, certain traffic signal corridors may require retiming every one or two years, while others may only need adjustment every five years. The fairly strict schedule-based system used by the CoA and many other agencies cannot easily anticipate or adjust for these various factors. Additionally, cost-per-intersection factors affect how frequently an agency can retime their signals.

In a given year, the CoA's schedule may be adjusted due to unexpected changes in performance, resource availability, or other reasons, but the three-year schedule serves as a foundational plan for retiming. Surveys have been conducted to explore the factors that most often affect signal retiming and the triggers that may cause an agency to disrupt its retiming schedule (Dazhi et al., 2012). Primary triggers for retiming include requests from the public, significant changes in land use, changes in traffic volume or congestion patterns, and crash history, among others. The City of Austin takes many of these triggers into account, particularly citizen feedback, but the main motivation to retime is usually the three-year rule.

Performance Measures and Prioritization

Surveys also touched on methods for monitoring signal performance, indicating that the most common was citizen feedback, followed by anecdotal or video observation, probe vehicle travel time runs, and level-of-service analysis. The City of Austin predominately uses probe vehicle travel time runs to assess the effectiveness of retiming. The CoA conducts such runs in a consistent manner, at carefully chosen times before and after retiming a corridor. The collected data is used to compute a percent travel time reduction metric, the principal measure of effectiveness for the retiming of the corridor. However, this percent travel time reduction is not used to prioritize corridors for retiming operations.

Use of probe vehicle traffic data has been on the rise in the last ten years, and has been increasingly employed by researchers and practicing engineers alike to explore traffic patterns, congestion, and mobility in a variety of applications. Many US states have recently produced reports that leverage this sort of data to assess statewide mobility by examining congestion on major freeways, including Indiana (Day et al., 2016), Maryland (Mahapatra et al., 2016), California (California DOT, 2013), Alabama (Hainen et al., 2015), and Washington (Washington State DOT, 2017). The body of research that has been conducted in this area has focused on small subsets of freeways and major arterials, as opposed to a cross-section of all road types in a given region. A smaller portion of this work has explored ranking higher-volume roads based on their performance, including ranking arterial corridors (Day et al., 2015) and freeway bottlenecks (Gong et al., 2018).

Given that the wide majority of transportation agencies conducts signal retiming operations with little-to-no quantitative prioritization, this project has the potential to significantly improve the efficiency of transportation operations. Current literature does not contain decisive research in using crowd-sourced probe vehicle data to compare a wide variety of corridors. The methodology developed in this study has the potential to significantly increase the quality of service that agencies can deliver to their stakeholders.

Survey Distribution and Results

CTR and the CoA determined that, in addition to the findings from the academic literature sources, it would be valuable to be aware of how a broad range of agencies handle traffic signal retiming. Researchers used the Institute of Transportation Engineers online member forum, in which they posted a call for responses. This method was selected over a more prescriptive survey technique in hopes that it would more accurately communicate the intricacies of different agencies' processes. The survey, developed by both CoA and CTR staff, contained some guiding questions, but generally left the respondents with a fair amount of autonomy. The message follows:

> *The Center for Transportation Research at the University of Texas at Austin is currently working with the City of Austin to improve the process by which traffic signals and corridors are prioritized and chosen for retiming. We are hoping to collect information about how agencies from around the country handle this process, as a survey of the state of practice.*
>
> *Please take 5 minutes to send us replies to the questions below. When our summary report is complete, we can email it to anyone who is interested.*
>
> - *How many signals does your agency maintain, and of those how many are retimed each year?*
> - *Does your agency have any sort of guidelines or rules used to prioritize intersections or corridors to be retimed? If so, what are those?*
> - *Does your agency measure the effectiveness of retiming operations? What metrics are preferred? What data sources (e.g., travel time runs, INRIX or other probe data) are used?*
> - *Has your agency used or explored the use of Adaptive Signal Control? If so, how do you evaluate candidate corridors, and measure the effectiveness?*
>
> *Any information you can share regarding this process would be appreciated. Thank you for your time!*

Twelve responses were received; nine answered the survey questions in some form. Additionally, some respondents forwarded older reports detailing similar or relevant studies. Responses to the survey represented agencies ranging in size from small communities and counties to large metropolitan areas. Interestingly, most agencies that responded were located on the West Coast and in the Pacific Northwest. For a complete enumeration of the survey responses, see Appendix I. Table 1, shown on the following page, summarizes the responses, which provided an interesting cross-section of different methods. Overall, the results confirmed the findings in the literature, which stated that many agencies retime on a fixed schedule and primarily use probe vehicle travel time and citizen requests as measures of priority and effectiveness.

Table 1: Summary of Survey Responses

	Hennepin County, MN	Campbell, CA	Washington County, OR	Clark County, WA	Salt Lake City, UT	Federal Way, WA	Medford, OR	Toronto, Canada
Number of signals	460	44	300	100	1220	82	120	2350
Per year	80-100	Varies based on funding	50	Varies, no schedule	Varies based on funding, needs	Retime all at once, every 3-5 years	--	260
Prioritization criteria	Crash rates, volumes, traffic pattern changes, citizen requests	Traffic pattern changes, time since last retiming	Measure and observed congestion, citizen requests	Citizen requests	ASTPMs, volumes, progression quality	Citizen requests	Citizen requests	Major arterials, changes in traffic patterns and volumes
Measures of effectiveness	LOS, delay, stops, emissions, travel times	Travel time, delay	Travel time, queue spillback, cycle/split failures	Travel time	Travel time, split failures, platoon ratios	Travel time	Travel time, volume	Delay, stops, speed, fuel consumption, emissions, benefit/cost
Data sources	Probe vehicle	Probe vehicle	Bluetooth, controller data, CCTV	Currently comparing probe vehicle, Bluetooth, and INRIX	HERE (crowdsourced probe data)	Probe vehicle	Probe vehicle	Probe vehicle, Bluetooth, HERE
Adaptive Signal Control	No	No, but considering	Yes, 42 in operation and 27 in consideration	No, but considering	Yes	Currently implementing	Yes, one corridor	300 signals on SCOOT, 20 piloting new systems

Data Acquisition

Data was accessed through the INRIX Analytics web-based interface. While the interface contains valuable tools for visualizing certain aspects of the data, it was not adequate for the needs of this study. For this reason, data needed to be downloaded and examined independently by CTR. The INRIX interface allows the user to select groups of roadway segments and save them as corridors. CTR defined all seventy-nine corridors covered by the INRIX data according to the City of Austin's signal corridor definitions, made available through the Austin Transportation Data and Performance Hub. Some corridors (as defined by the CoA) included signals nearby or on adjacent roadways, as opposed to on the main thru-corridor. For the purpose of this analysis, each corridor was defined as the principle collection of signals along the same roadway.

Each direction for each corridor was defined and saved separately. The INRIX interface is generally good at filling in intermediate segments when the first and last segments have been selected. However, there were numerous instances where errors within the INRIX interface caused bugs in the selected segments. By double-checking the segments chosen by the interface (to make sure they were all in the same direction, on the right road, etc.) major data errors were avoided. This process was performed manually, though exploration of methods for automating parts of this process could be an area for future work.

Defining the corridors in the INRIX interface allowed for data to be downloaded and analyzed independently for those corridors. Data was downloaded at fifteen-minute granularity for each study corridor. Two years of data for the seventy-nine corridors was acquired from the provider's internet-based user interface and ingested into PostgreSQL, an open-source database management system, for ease of handling. The seventy-nine corridors were made up of 1,759 roadway segments, and all told there were 116,278,732 speed records.

This study utilized the portion of the data corresponding to weekdays in September 2016 and September 2017. This was done due to an error with the INRIX data downloader. CTR noted an anomaly in the INRIX data when plotting corridor travel times at 15-minute intervals for the full two-year period (2016-2017). An example of this can be seen in Figure 3, where travel times for the Lavaca corridor flat-line for a stretch of about 8 months between 2016 and 2017. This same pattern is seen with consistency across the 24 corridors analyzed. CTR speculated that this was due to INRIX populating the data during this period with historical averages or simply the free-flow speed. Given the striations in the data during this period, it appeared that different travel times were used for different times of day, and the pattern was different between weekdays and weekends.

The INRIX data includes a three-part data score which provides information on how the data was acquired. The three facets of the data score are Score 30, Score 20, and Score 10. Each of the scores represent what percentage of the data used to create a single data point is acquired using a particular method. Therefore, the sum of the three scores is always 100. Score 30 represents data acquired from real-time speed measurements of minute-level data. Score 20 represents data filled in from the historical speed data profile. Score 10 represents data filled in with the "reference speed," INRIX's proxy for free flow speed which is constant for the entire day (INRIX, 2017).

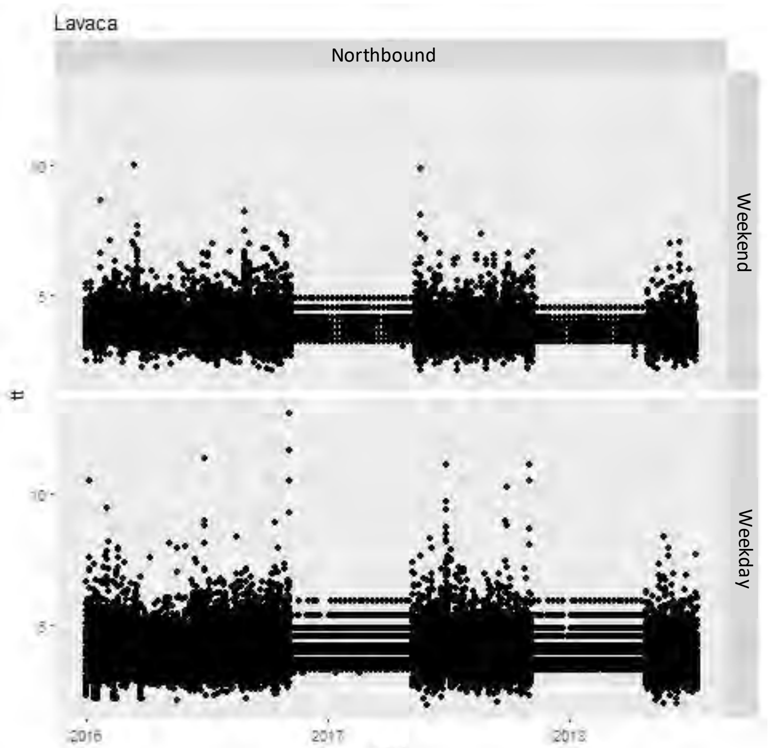


Figure 3: Fifteen-minute travel times for the Lavaca corridor

Given these definitions and corridor travel time plots such as the one shown in Figure 3, CTR suspected that the issue was stemming from this data source question. It would appear that, for periods of many months at a time, INRIX was not able to collect or present measured speed values. To explore this further, CTR analyzed trends in the three different data scores over the two years for which data had been downloaded for twenty corridors, and this is shown in Figures 4 and 5 on the following page.

Figure 4 tracks the percentage of data points during each month which corresponded to certain conditions. The green line tracks the percentage of data points for which Score 30 was equal to 100, meaning that the data point was calculated entirely using real measured data. Similarly, the yellow and red lines depict the percentage of data points for which Score 20 and Score 10 were equal to 100. Finally, the black line shows the percentage of data points where greater than 70 percent was calculated based on real measured data. This figure shows that around November of 2016, the percentage of completely measured data points drops off and the percentage of data points calculated exclusively with the historical average shoots up to nearly 100 percent. Around May of 2017 they each return to normal, and the pattern appears to repeat in November 2017. Additionally, the red line shows that INRIX is almost never exclusively using the free flow speed to compute the data.

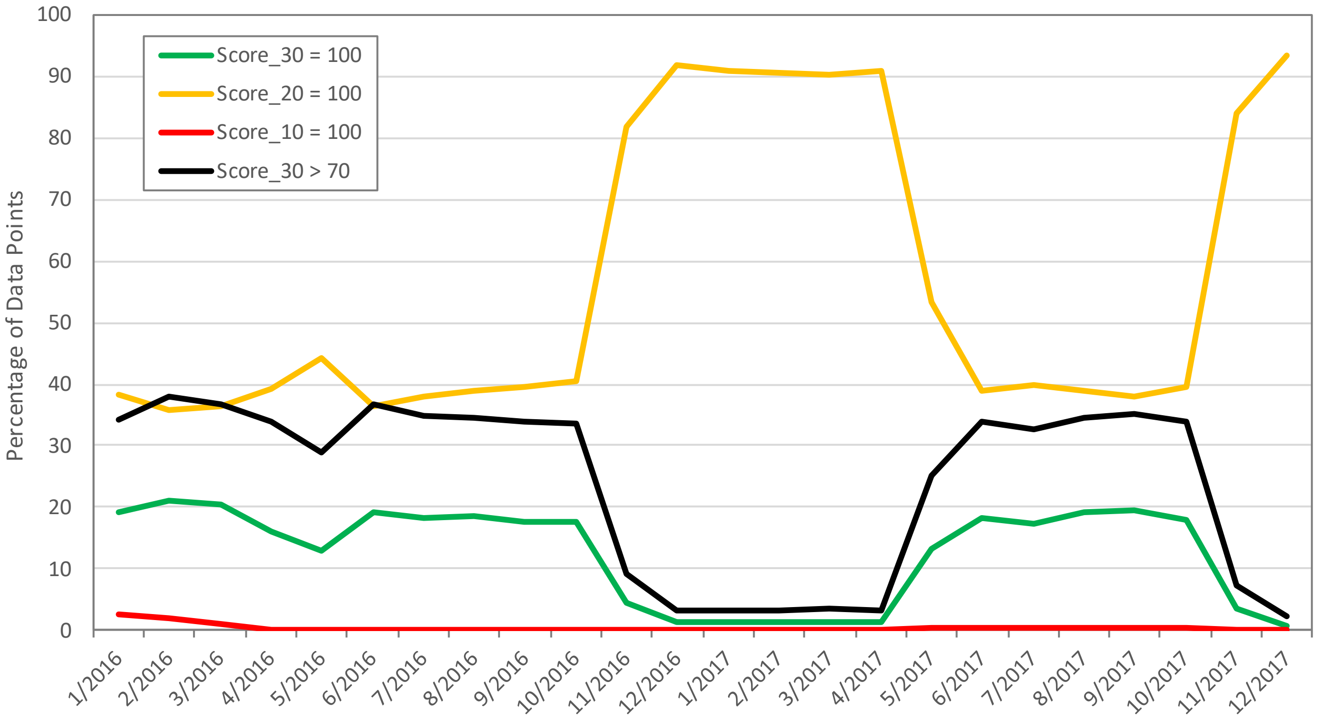


Figure 4: Percent of data points during each month for which the data score satisfied various conditions

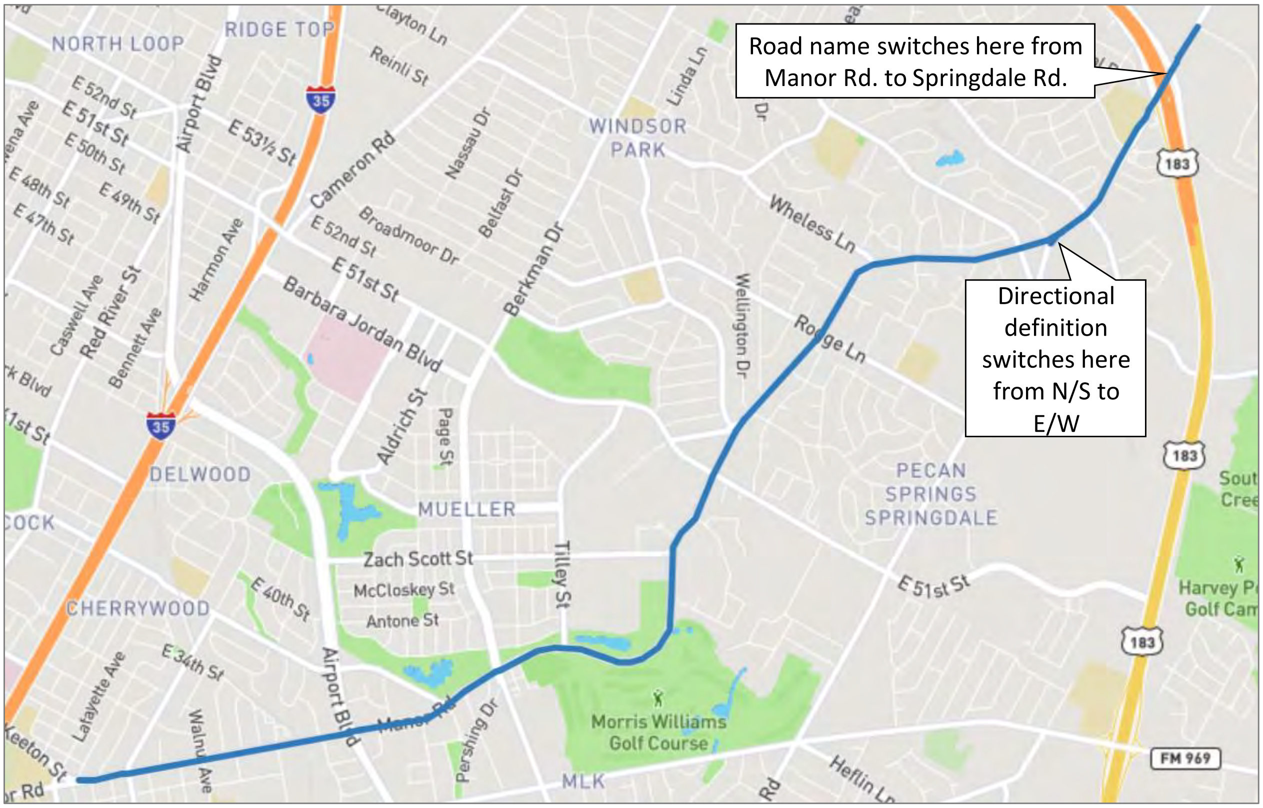
Figure 5 shows the average of each of the three score components for each day over the two-year period. Notice that it depicts a similar pattern to Figure 4, with the precipitous decrease in Score 30 and increase in Score 20 from November 2016 to May 2017.

After discovering the error, CTR presented a summary of this information, as well as a documented workflow for analyzing the anomaly, to the CoA and INRIX. INRIX explored the issue further and determined that it stemmed from an error within the data downloader tool that was overriding the correct data when large portions of data (such as two years' worth) were downloaded at once. INRIX worked to develop a solution which was implemented in mid-August. Limiting the data in the initial analysis to only the month of September had the benefit of effectively avoiding any issues that might arise due to seasonal variation. This is something which could be explored in future work.

Figure 5: Daily average for each data score

Once downloaded, the data for each corridor consisted of two .csv files. The first, the “data” file, contains the individual speed records for every segment on the corridor for every time stamp in the study period. The second file, the “metadata” file, is much smaller and contains information describing each segment on the corridor (segment ID, length, start and end latitude and longitude, road name, etc.). These two files are related by using the unique segment ID for each segment.

Before ingesting the data files into the Postgres database, two columns were added to the metadata file. The first, “CoA Corridor,” was filled with the corridor name defined by the City of Austin. This was done because in some cases the City of Austin corridor definitions spanned multiple roads. Having one consistent name associated with each corridor was essential for later analysis. The second column was called “CoA Direction” and it performed a similar function: creating a consistent directional definition for the corridor in question. This was necessary due to some corridors not being aligned perfectly straight, so that INRIX may have defined some of the segments on the corridor as north-south aligned, while others might be east-west. Figure 6 below depicts an example of both of these phenomena for further illustration.


Road name switches here from Manor Rd. to Springdale Rd.

Directional definition switches here from N/S to E/W

Figure 6: Manor Corridor in INRIX Wed Interface, Displaying Mid-Corridor Switches in Road Name and Directional Definition

The data was then ingested into two separate tables in a Postgres database (one for the data files and one for the metadata files). This process was automated using a Linux script. Having the data in a database made it easier to search, aggregate, and compare across the seventy-nine corridors in the study.

For a full step-by-step guide to the process of defining corridors within the INRIX Analytics web interface, using the INRIX data downloader tool, and ingesting the data into a database, see Appendix II.

Development of Metrics for Prioritization

A significant challenge in developing meaningful metrics arose in choosing how to aggregate the data both spatially and temporally in order to best communicate the need for retiming. The first step in developing these metrics was to inspect the data. This was done by producing a variety of plots, examples of which are shown below. The plots were produced by using R to access data in the Postgres database.

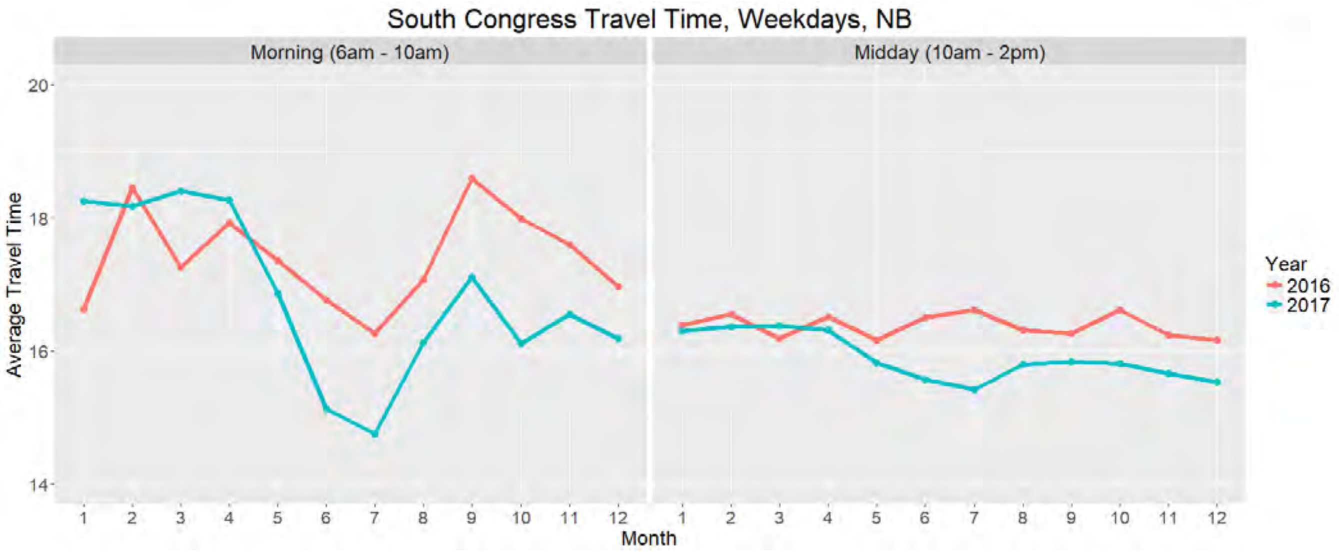


Figure 7: Travel time by month for pre-defined date ranges and time periods

The plot in Figure 7 depicts the travel time on the northbound South Congress corridor for specific time-of-day periods during each month of 2016 and 2017. Plots such as this one show variation throughout the year as well as between different times of day for the entirety of the corridor.

Similarly, the plot in Figure 8 shows the average hourly travel time for the corridor over the course of a weekday, differentiating between 2016 and 2017. This plot clearly shows the directional effects present on the corridor, with a clear peak in the northbound direction during the morning and in the southbound direction during the evening.

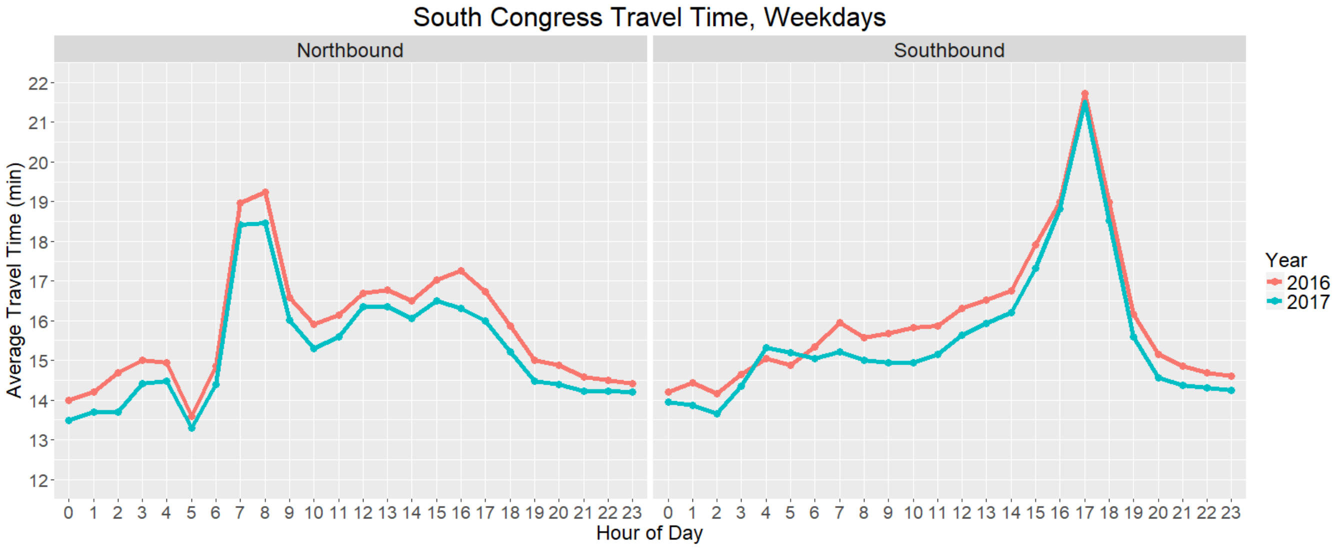


Figure 8: Travel time by time-of-day for pre-defined date ranges

The third type of plot that was developed to visualize the data is shown in Figure 9 below. It depicts the average speed on each segment of the corridor in question, where each bar in the plot is a segment on the corridor. The varying width of the bars represents the varying length of the segments. This allows for the distinction between, for example, a speed decrease of 3 mph on a 300-foot segment and a (more notable) speed increase of 2 mph on a half-mile segment. In this version of the plot, Date Range 1 corresponds to 2016, and Date Range 2 to 2017.

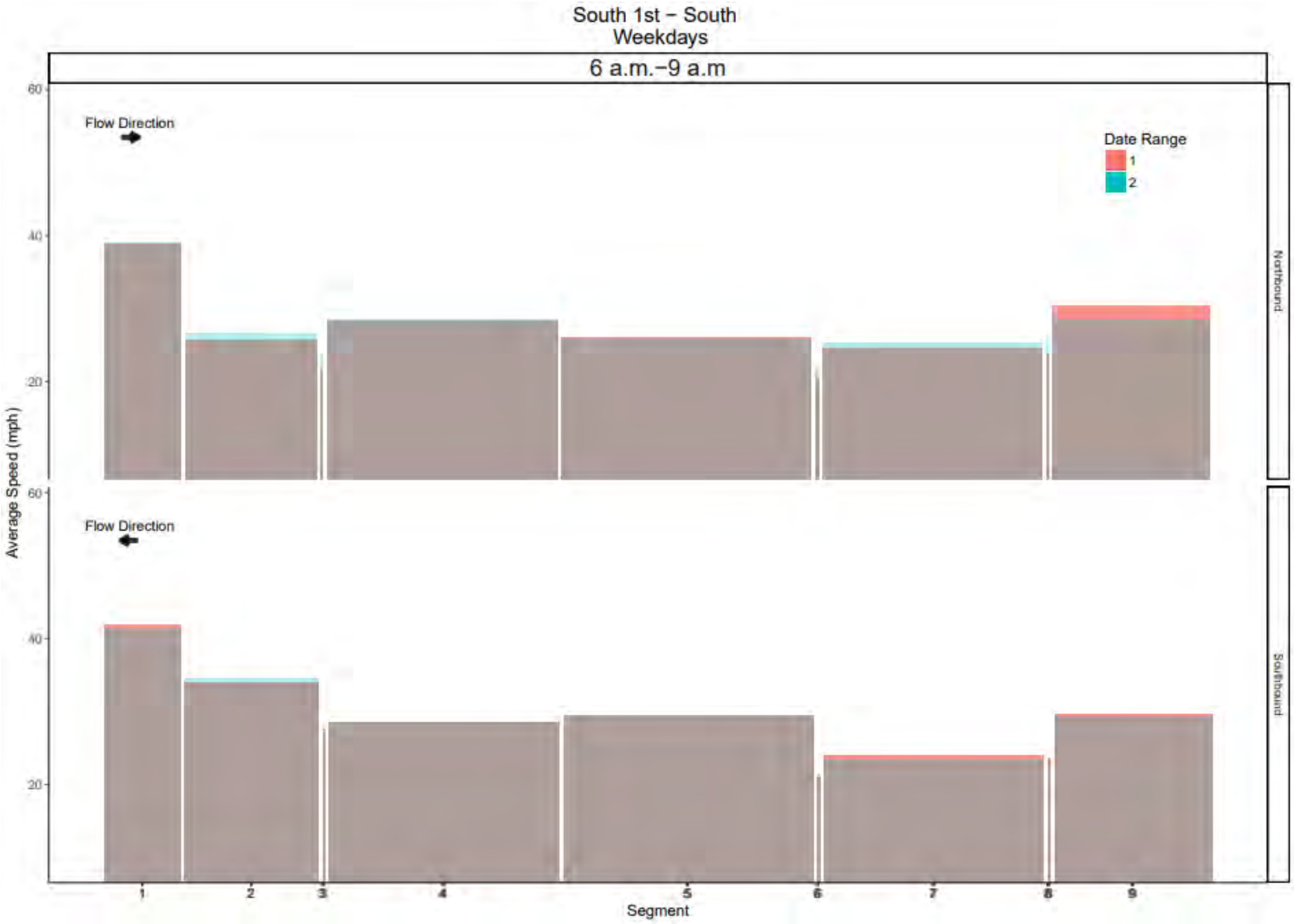


Figure 9: Segment speed plot for South 1st – South corridor

Through exploration of the data, it was determined that computing corridor-level metrics based on averaging values across all corresponding segments could lead to problematic sections being balanced out by other sections that were operating well. This was particularly an issue on the longer corridors, which were more likely to operate very differently at different points along the corridor. Therefore, the most effective way to communicate corridor performance given these concerns was to produce corridor-level metrics from segment-level analyses. In other words, it was desirable to avoid over-aggregating the data.

Similarly, given that most roads experience volume approaching or exceeding capacity for only a handful of hours in a day, averaging values across an entire day tended to "wash out" some of the trends.

However, leaving the data in fifteen-minute bins would make drawing clear conclusions across a lengthy study period difficult. For this reason, the fifteen-minute data was rolled into three time-of-day periods: morning peak (0700–0900), midday (1100–1300), and evening peak (1600–1800). It was particularly important to analyze both morning and evening peaks due to the directional nature of traffic throughout the day on many urban streets.

Given the desire to use the ranking methodology as a tool for regular use by practicing signal timing engineers, the chief goal was to develop ranking metrics that were easy to understand and that communicated the underlying need for corridor retiming clearly and accurately. This simplicity of the ranking metrics is important due to the sheer volume of data, and also because transportation engineers must be able to easily explain and defend retiming decisions to CoA officials, the public, and other stakeholders.

Developing appropriate metrics involved many iterations of calculations, through which a few challenges were noted. One problem was that travel time is not effective in comparing corridors of different lengths. Focusing on segment speed, as opposed to travel time, as the basis of the metrics allowed for comparison between corridors of differing lengths. Another issue was that absolute speed, particularly without any vehicle volume information, is not effective for comparing corridors with different functional classifications or speed limits. In order to compare roads with different speed limits or functional classifications, the methodology was built around calculating speed change on a corridor between two comparison periods. These comparison periods could represent weeks, months, or years that would be compared to assess whether corridor performance had improved or worsened between the comparison periods. In this study, the two comparison periods were September 2016 and September 2017. A third challenge was in capturing the under-performance of one section of a corridor when another section (or even most of the rest of the corridor) was performing well. To account for this, the metrics focus on the portions of the corridor that have experienced a decrease in speed between the two comparison periods.

The three metrics used in the final ranking process are: percent of the corridor (by length) that experienced a decrease in speed between comparison periods; percent of the corridor that experienced a decrease in speed of three miles per hour or greater between comparison periods; and, the maximum speed decrease for any one segment on the corridor. It is important to note that this methodology is designed to analyze changes in performance over time as the major indicator of the need to retime a corridor. Further extensions to this work could consider the ideal threshold for minimum desirable speed or maximum allowable speed decrease.

Each record in the data set is represented by $s_{i,t,d}$, where s is the segment speed for segment i during fifteen-minute interval t on day d. The average segment speed for a given time-of-day period T (morning peak, midday, or evening peak) on day d is therefore calculated by taking the average of the speed records for all of the fifteen-minute intervals in that time-of-day period (Equation 1). Since all of the time-of-day periods for this study were two hours long, the number of fifteen-minute intervals per time period, $|T|$, is 8.

$$a_{i,T,d} = \frac{\sum_{t \in T} s_{i,t,d}}{|T|} \tag{1}$$

The average segment speed for each of the comparison periods P for time-of-day period T is given by Equation 2, where $|P|$ is the number of days in comparison period P.

$$A_{i,T,P} = \frac{\sum_{d \epsilon P} a_{i,T,d}}{|P|} \tag{2}$$

Finally, the speed difference on segment i during time-of-day perid T between comparison periods P_1 and P_2 can be computed using Equation 3.

$$D_{i,T} = A_{i,T,P_2} - A_{i,T,P_1} \tag{3}$$

This segment speed difference then forms the basis for the metrics used to rank corridors j. The first of these is the length of the corridor, in miles, that has experienced a decrease in speed between the comparison periods, and is computed according to Equation 4.

$$l_{j,T,0} = \sum_{i \epsilon j} l_i \left[D_{i,T} < 0\right] \tag{4}$$

The condition $D_{i,T}$ less than zero represents a decrease in speed for time-of-day period T. This is then used to compute the percent of the corridor which has experienced a speed decrease, $K_{j,T,0}$, shown in Equation 5. In this equation, L_j represents the total length of corridor j.

$$K_{j,T,0} = \frac{l_{j,T,0}}{L_j} \tag{5}$$

It follows then that a similar metric could be computed for a certain threshold speed decrease, by calculating the mileage along the corridor that experienced a speed decrease greater than m miles per hour:

$$l_{j,T,m} = \sum_{i \epsilon j} l_i \left[D_{i,T} < -m\right] \tag{6}$$

$$K_{j,T,m} = \frac{l_{j,T,m}}{L_j} \tag{7}$$

The third and final metric used for ranking is the largest speed decrease among all segments on the corridor, given by Equation 8. It should be noted that this metric seeks to identify the largest negative speed change, which is why it is computed using a minimum. If every segment on a corridor actually experienced an increase in speed between comparison periods, then this metric would result in a positive number for that corridor.

$$M_{j,T} = \min_{\mathrm{i} \epsilon \mathrm{j}} D_{i,T} \tag{8}$$

Implementation and Results

The final prioritization of corridors combines the three metrics (percent of corridor experiencing speed decrease $K_{j,T,0}$, percent of corridor experiencing speed decrease greater than m miles per hour $K_{j,T,m}$, and maximum segment speed decrease $M_{j,T}$) for each of the three time-of-day periods, and ranking the result.

Figure 10 summarizes the ranking process. All corridors were ranked by each of the three metrics for each of the three time-of-day periods to determine each corridor's worst-performing direction. The practice of ranking corridors based on their worst-performing direction assumes that an agency would retime both directions of a corridor simultaneously. The final ranking for a corridor is then computed by taking the average of that corridor's place (accounting for ties) in each of the preliminary rankings.

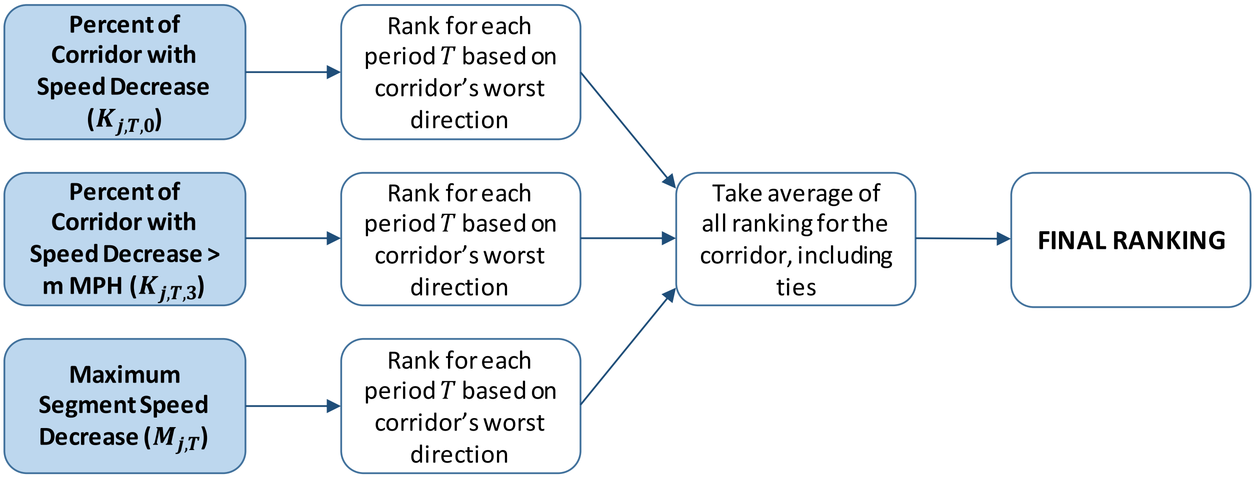


Figure 10: Ranking process

Table 2 presents an excerpt of the ranking and results of the different metrics. The top twenty-two corridors are shown because they account for 373 signals, and the City of Austin aims to retime approximately 375 signals per year. Note that the average ranking among the three metrics for the three time-of-day periods has the potential for ties among multiple corridors. For example, the tenth- and twelfth-ranked corridors show that two corridors tied for these rankings. The full version of Table 2, including all seventy-nine corridors, can be found in Appendix III.

Table 2: Excerpt of Corridor Ranking Results

		Percent of Corridor Experiencing Speed Decrease			Percent of corridor Experiencing Speed Decrease > 3 MPH			Maximum Speed Decrease				
Rank	**Corridor**	**AM**	**Midday**	**PM**	**AM**	**Midday**	**PM**	**AM**	**Midday**	**PM**	**Total Length (mi)**	**Number of Signals**
1	US 290 - East	95.93	85.36	96.85	21.30	22.48	25.62	-28.38	-27.31	-28.25	5.30	19
2	US 183 - Central	86.29	100.00	86.14	48.51	48.51	30.02	-19.61	-16.75	-5.17	2.79	10
3	US 183 - South	48.37	65.58	65.08	47.65	35.90	48.68	-11.35	-10.52	-11.23	3.08	15
4	51st	70.75	69.59	94.57	24.87	24.87	24.87	-3.82	-3.78	-5.79	3.26	12
5	Airport	63.07	74.65	80.88	14.66	16.87	21.64	-3.82	-5.59	-7.30	6.41	27
6	MLK - East	60.12	85.10	89.35	19.54	18.03	13.38	-3.55	-7.59	-6.04	5.42	15
7	Lamar - North	75.65	100.00	86.24	7.93	7.93	7.93	-3.69	-3.69	-5.45	5.88	15
8	Enfield	56.49	76.61	100.00	8.28	8.53	21.47	-3.21	-6.02	-4.09	1.30	9
9	Ben White - East	91.28	52.06	52.72	37.55	0.19	28.08	-5.43	-3.17	-9.35	3.61	14
10	Manor	79.88	57.12	67.69	3.55	3.55	3.55	-4.96	-6.03	-6.47	3.83	15
10	Pleasant Valley	80.22	80.22	99.05	0.00	1.67	42.95	-2.16	-3.33	-8.38	2.93	11
12	IH 35 SRVC RDS	46.65	33.61	67.96	16.66	13.12	55.77	-6.09	-5.23	-6.40	2.27	16
12	Southwest Parkway	46.57	48.05	71.24	21.57	9.33	21.57	-5.99	-3.34	-6.96	5.16	18
14	Parmer - West	44.31	52.13	74.05	11.13	5.26	14.86	-10.02	-4.44	-8.85	13.99	29
15	Loop 360 - North	26.26	54.34	49.05	3.60	19.46	31.89	-8.31	-8.12	-13.48	8.17	14
16	Brodie	100.00	78.71	70.96	0.17	0.00	8.28	-4.09	-2.65	-4.37	6.55	19
17	Slaughter	49.52	38.84	67.71	17.30	16.34	20.29	-5.20	-3.50	-5.37	9.75	31
18	7th - East	66.31	57.41	89.97	0.96	0.96	20.79	-3.28	-3.38	-3.90	2.38	12
19	Riverside	63.00	67.76	83.07	0.77	0.00	13.76	-3.35	-2.91	-5.37	3.79	24
20	Braker	59.18	89.63	63.70	0.36	2.25	0.00	-4.03	-7.14	-2.48	5.56	19
21	Lamar - Central	90.14	62.31	63.44	0.00	10.88	0.95	-2.51	-5.19	-3.35	3.78	15
22	Cameron - South	61.16	46.32	59.75	6.67	5.84	0.00	-3.98	-4.57	-2.72	2.10	14

There are a few results to note from the corridor ranking. Most significantly is the ranking of three major frontage road systems in the top three places (US 290 – East, US 183 – Central, and US 183 – South). Signalized frontage roads along limited-access facilities are a common feature in Austin, and throughout Texas. Examining the results for these frontage roads reveals that each corridor exhibited a relatively high percentage of speed decrease and high maximum speed decrease values. However, roadway construction projects were ongoing throughout the latter half of 2017 on all three corridors, which significantly affected their performance. It is therefore important to note that familiarity with the local roadway network, ongoing and planned construction, special events, and other factors impacting traffic flow should be considered outside of the ranking methodology presented.

One concern was that the ranking methodology might unnecessarily favor corridors based on length. This trend does appear, but there is significant unexplained variability, leading to a low R^2 value that is not statistically significant (Figure 11). Additionally, results show that the methodology slightly favored corridors with lower traffic signal density (Figure 12). This is unsurprising, as corridors with lower signal density are often more difficult to coordinate. However, although there is once again a linear pattern, the unexplained variability is significant and the R^2 for the linear relationship is not statistically significant.

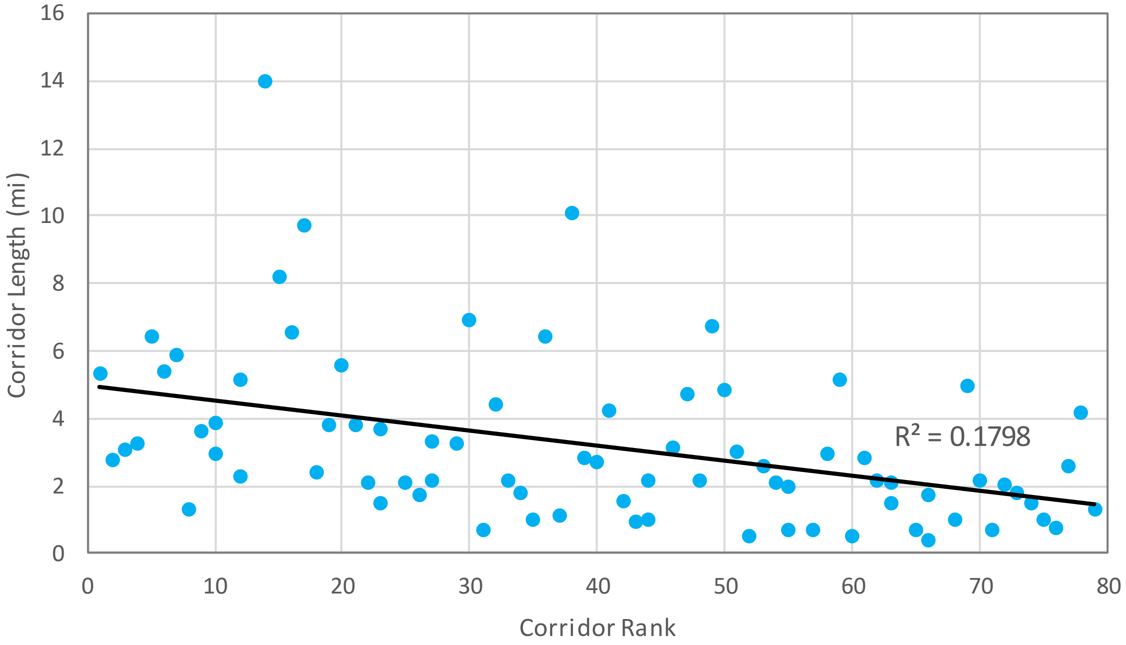


Figure 11: Corridor rank versus corridor length

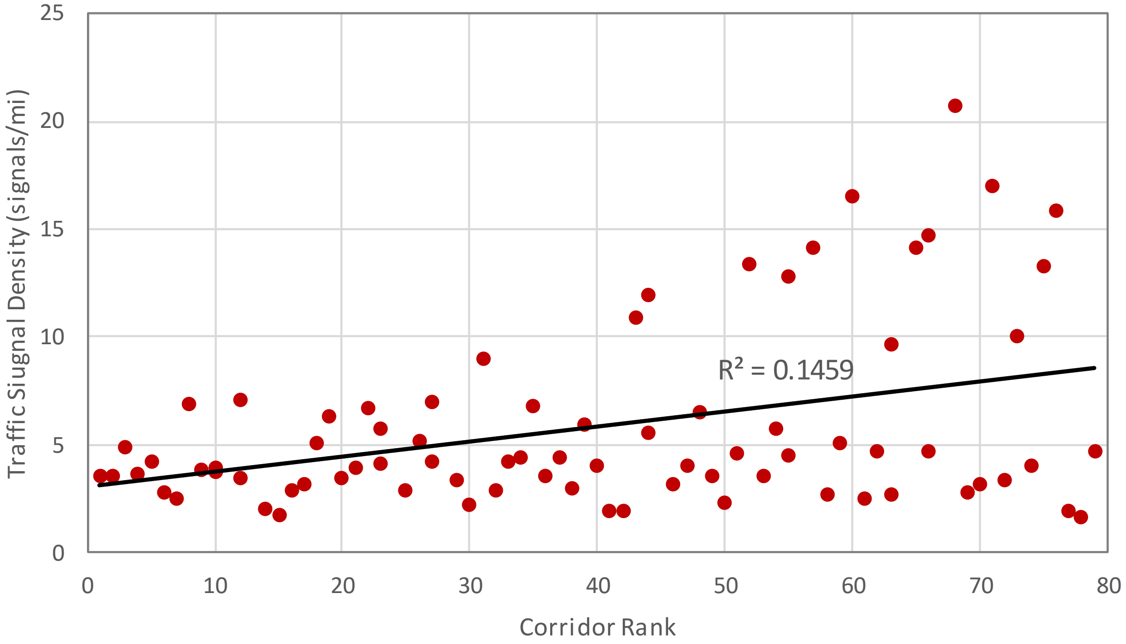
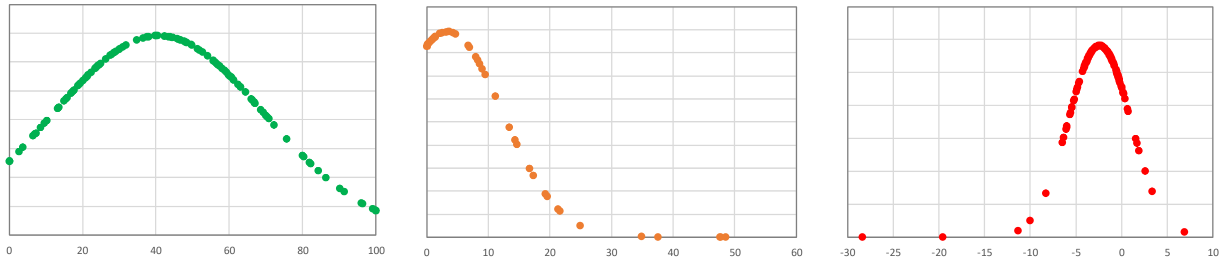


Figure 12: Corridor rank versus traffic signal density

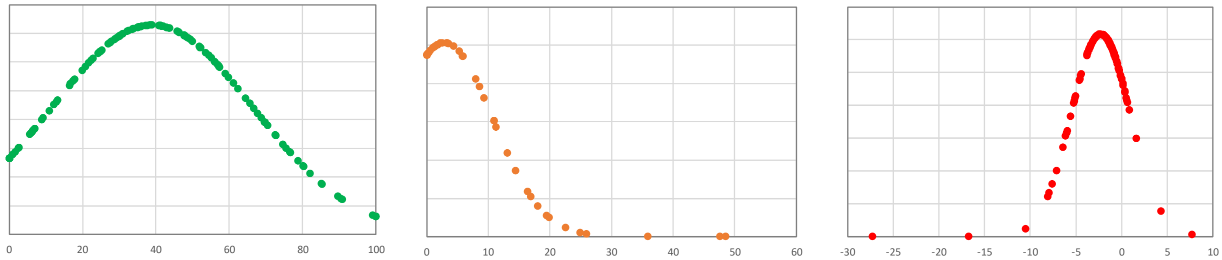
The distributions of the proposed ranking metrics provide additional insight into the meaning of the observed results and the operation of the ranking methodology (Figure 13). The metric for percent of the corridor experiencing a speed decrease shows a distribution that appears fairly normal (Figure 13a, b, and c). However, the distribution for the percent of the corridor that experienced a speed decrease greater than 3 mph is skewed significantly to the left. This is due to the introduction of the 3 mph threshold, which allows for the clear identification of problematic corridors (shown by the points farthest to the right in the distribution in Figure 13d, e, and f). Finally, the distribution for maximum segment speed decrease shows a narrow pattern with most corridors experiencing a maximum speed change between -5 and zero mph (Figure 13g, h, and i). However, few corridors t are far to the left on the distribution, indicating a large speed decrease. The differing distribution of the metrics allows the ranking methodology to evenly assess the corridors and to easily identify particularly problematic cases.



a) Percent of Corridor Experiencing Speed Decrease, AM Period ($K_{j,AM,0}$)

d) Percent of Corridor Experiencing Speed Decrease > 3 MPH, AM Period ($K_{j,AM,3}$)

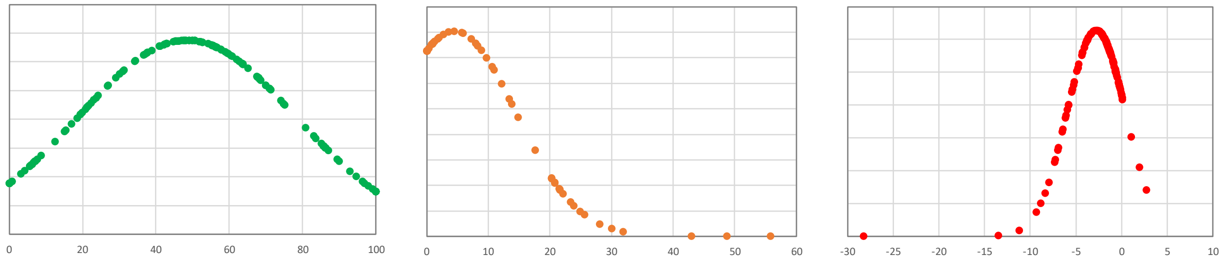
g) Maximum Segment Speed Decrease, AM Period ($M_{j,AM}$)



b) Percent of Corridor Experiencing Speed Decrease, Midday Period ($K_{j,Mid,0}$)

e) Percent of Corridor Experiencing Speed Decrease > 3 MPH, Midday Period ($K_{j,Mid,3}$)

h) Maximum Segment Speed Decrease, Midday Period ($M_{j,Mid}$)



c) Percent of Corridor Experiencing Speed Decrease, PM Period ($K_{j,PM,0}$)

f) Percent of Corridor Experiencing Speed Decrease > 3 MPH, PM Period ($K_{j,PM,3}$)

i) Maximum Segment Speed Decrease, PM Period ($M_{j,PM}$)

Figure 13: Distribution of metrics used for ranking

Review of Literature for Adaptive Signal Control

The final phase of Task 2017-08 involved conducting a review of literature to understand existing practices for adaptive signal control, including corresponding data, software, and infrastructure needs. The relationship between signal retiming operations and the implementation of adaptive signal control will be considered as a possible extension of this project.

Adaptive signal control (ASC), also known as adaptive traffic control, is a technique that uses hardware and software technologies to manage traffic demand by adjusting signal timings to optimize traffic flow. It does this by collecting current demand data, using this data to assess system performance, and then implementing modified signal timings based on the evaluation. When implemented effectively, ASC can significantly reduce delay and improve travel time and travel time reliability. The traditional method for handling variation in traffic demand across a day is to develop time-of-day plans for the signal timings during each segment of the day. This can be an effective strategy, particularly where demand is consistent day-to-day. However, ASC has a major benefit over time-of-day plans when demand varies from day-to-day. Similarly, ASC offers a significant advantage given its ability to react to traffic collisions, special events, construction, and other unexpected sources of variation. Studies have shown that ASC improves travel time, delay, and other metrics by 10 percent or more. This improvement can increase to over 50 percent in areas with particularly poor conditions (Curtis, 2016).

ASC systems have been in use abroad for thirty years, and in the US for about the last twenty years. However, they have only been installed on fewer than 1 percent of US traffic signals. Some of the barriers to widespread deployment of these technologies include the cost of the systems, their complexity, uncertainty about the benefits of ASC, and overhead costs associated with improving detection and communications. However, it is believed that ASC can be used very effectively on corridors or closed networks that experience variability in demand, or where demand regularly exceeds capacity.

Software Needs for Adaptive Signal Control

The substance of any ASC system is its software. There are a number of different software products designed to perform adaptive signal control, and each goes about it in a different way. The purpose of this literature review is not to detail every ASC software product, but instead to give an overview of some of the available options.

While all ASC software are essentially performing the same tasks, they do so using a wide variety of methods. A few of the areas in which different software products vary are the types of algorithms, the types of systems, and the system architectures (Fehon, 2004). Algorithms can be sequence-based, meaning they use a set cycle length (similar to coordinated systems) and have a pre-determined phase sequence. Alternately they can be non-sequence based, in which the cycle length and sequence of phases are both variable. The systems themselves can be stand-alone products with full management capabilities (SCOOT, SCATS), or a unit within a proprietary signal management system (Synchro Green, Centracs Adaptive), or external to the signal management system (ACS Lite, Kadence, InSync). Finally, the system architecture can either be centralized, distributed, or peer-to-peer. Centralized systems process all strategic and tactical decisions at a central location, whereas distributed systems conduct the strategic portion at a central location but leave the tactical decisions to the local signals. Peer-to-peer systems conduct all operations on an entirely local basis, with no central supervisor.

One important difference between some software systems is the frequency with which they update the signal timings based on changes in demand. Most ASC software will update the signal controllers in small increments every few seconds. However, some, such as ACS Lite and Kadence, only update the timings every 3–4 cycles. According to the developers, this slower transition schedule improves the reliability, safety, and accuracy of the updates.

The software operates by implementing different operational strategies for different situations. If the network is oversaturated, the ASC system will adjust to maximize throughput and manage queues, whereas when the network is undersaturated, the system will adjust to provide smooth flow for the vehicles present. If there are many turning movements present, the system will focus on the distribution of green time.

Some of the software products that have been piloted by the City of Austin are Kadence (developed by Kimley-Horn as an improvement on ACS Lite) and InSync (developed by Rhythm). Additionally, the CoA has explored the local adaptive features available through the D4 signal controller software as well as traffic responsive timing plan selection, a strategy that is somewhat similar to adaptive signal control.

Infrastructure Needs for Adaptive Signal Control

Detection is the crux of any adaptive signal control system. This is because detection the primary method by which the system collects real-time data about traffic demand, thus enabling the rest of the adaptive signal control process. Therefore, an emphasis is put on the available forms of detection and the detection needs of a particular ASC product. Most ASC systems require stop-bar detection for all phases that are adaptively controlled, and advance detection for phases that are run in coordination. The City of Austin generally does not maintain stop-bar inductive loop detection on through movements, but often includes advance detection on these movements. Fortunately, ASC systems generally can accommodate any form of detection (video, inductive loop, magnetometer, or radar). This is important, as the CoA has been exploring various alternatives to loop detection, including video and radar technology. Depending on the software product, different firmware might be required in the signal cabinet. However, the necessity of consistent, effective detection infrastructure is the most pressing need for implementing an ASC system.

Conditions for Implementing Adaptive Signal Control

Adaptive signal control is designed to handle difficult traffics situations, but it is not always the best solution. This, combined with the cost of implementing the technology, means that an agency should carefully select locations for implementing ASC in order to use their resources as efficiently as possible. The ideal situation for implementing ASC would be where traffic demand varies significantly on a corridor or across an area. Another situation in which ASC can be helpful is when demand is greater than capacity and the system is oversaturated.

In order to assess a given traffic signal system and explore whether or where ASC might be helpful, it is crucial to understand the current state of traffic demand. This means that a thorough, accurate source of traffic volume data is needed. This is something that the CoA is currently lacking, however investments in video detection technology will hopefully provide for easy data collection at a wide range of intersections.

Conclusions and Recommendations

Task 2017-08 explored a technique for utilizing probe vehicle speed data to rank the performance of traffic signal corridors for prioritizing signal retiming operations. A methodology for computing metrics and developing a corridor ranking system was presented, and an analysis was conducted on seventy-nine traffic signal corridors in the Austin, Texas, utilizing fifteen-minute average speed data acquired by the City of Austin from probe vehicle data vendor INRIX. The methodology is intended to supplement prioritization decisions in order to improve upon the current schedule-based signal retiming system. This report detailed the existing retiming processes used by the CoA, reviewed relevant literature, and described the process of acquiring data and developing the methodology.

Metrics were computed using data at the segment level for three time-of-day periods to address daily variation in traffic patterns and to avoid over-aggregating the data. The data used to compute the metrics was drawn from all weekdays in September 2016 and September 2017. The two months were compared to generate three metrics based on speed change: percent of the corridor that exhibited a decrease in speed between the comparison periods; percent of the corridor that exhibited a decrease in speed greater than three miles per hour between the comparison periods; and, the maximum decrease in speed for any segment on the corridor. These metrics were chosen for their ability to compare across corridors of differing length and functional classification.

Results showed that the ranking methodology did not significantly favor corridors based on length or traffic signal density, indicating that the metrics equitably assessed corridor performance regardless of such factors, which varied widely across the corridors utilized in the study.

There are numerous opportunities to extend this work. The probe vehicle data utilized in this study did not include any measure of traffic volume or vehicle throughput, both of which are key components of roadway performance. Simply reviewing travel speeds (or travel times) cannot fully depict how effectively a corridor is operating. For instance, the travel time on a cross-street might suffer if the signal is timed to favor a heavier vehicle volume on the mainline. In this case, even though vehicles on the side-street are accruing delay while waiting at a red light, this is outweighed by the higher volume passing through the intersection on the mainline. This study utilized probe vehicle data due to its superb coverage over a wide area. However, future work might explore different or supplementary data sources that account for traffic volumes in an attempt to more fully describe the operation of the signal corridors. Similarly, these and other metrics could be computed from different data sources, such as high-resolution detector data, to gain a different perspective on various aspects of signal and corridor performance. Another factor that could affect corridor performance is seasonal variation, which was not addressed here. Additionally, this study was limited to assessing signal performance from a corridor-based perspective. Organizing signals into length-wise corridors is effective for limited-access or isolated roads, or arterials that clearly take precedence over the surrounding local streets. However, this doesn’t translate cleanly to all signalized roadways within a city. There are often roads, such as in downtown grids, which operate more as elements in a network area than as separate corridors. Devising area-wide metrics could increase understanding of the performance of such signals.

Finally, the relationship between signal retiming and the implementation of Adaptive Signal Control could be explored further to identify ideal candidate corridors for ASC.

A data-driven, needs-based methodology for prioritizing traffic signal retiming, such as the one presented here, represents an improvement from the schedule-based system that the City of Austin currently uses to organize retiming operations. Implementing a process based on this corridor ranking methodology would increase the agency's ability to provide the best possible transportation services to the public by directing attention to signal corridors most in need of retiming. This then allows for the allocation of resources in the most efficient way possible.

References

Curtis, E. Adaptive Signal Control FAQs. Federal Highway Administration, 2016.

Day, C. M., D. M. Bullock, H. Li, S. M. Remias, A. M. Hainen, R. S. Freije, A. L. Stevens, J. R. Sturdevant, and T.M. Brennan. Performance Measures for Traffic Signal Systems: An Outcome-Oriented Approach. Purdue University, West Lafayette, Indiana, 2014.

Day, C.M., S. Remias, H. Li, M.M. Mekker, M.L. McNamara, E. Cox, and D.M. Bullock. Performance Ranking of Arterial Corridors Using Travel Time and Travel Time Reliability Metrics. *Transportation Research Record: Journal of the Transportation Research Board*, 2015.

Day, C.M., M.L. McNamara, H. Li, R.S. Sakhare, J. Desai, E.D. Cox, D.K. Horton, and D.M. Bullock. *2015 Indiana Mobility Report and Performance Measure Dashboards*. Purdue University, 2016.

Dazhi, S., L. Dodoo, A. Rubio, H.K. Penumala, M. Pratt, and S. Sunkari. Synthesis Study of Texas Signal Control Systems: Technical Report. Texas Department of Transportation, 2012.

Fehon, K. Adaptive Traffic Signals Overview. DKS Associates, 2004.

Gong, L. and W. Fan. Developing a Systematic Method for Identifying and Ranking Freeway Bottlenecks Using Vehicle Probe Data. *Journal of Transportation Engineering, Part A*, 2018.

Gordon, Robert L. Traffic Signal Retiming Practices in the United States. National Cooperative Highway Research Program, 2010.

Hainen, A.M. and M.R. Dunn. *Alabama Statewide Mobility Report 2014*. The University Transportation Center for Alabama, 2015.

Highway Capacity Manual, Vol. 5, Transportation Research Board, National Research Council, 2010.

Humphreys, Emily and Steven Click. Evaluating the Three-Year Rule for Retiming Coordinated Traffic Signals using Simulation with Real-World Traffic Data. Tennessee Department of Transportation. Transportation Research Board, 2018.

INRIX Analytics. Frequently Asked Questions. 2017.

Lu, Jian J. and Zhengyu Wang. Development of a Procedure for Prioritizing Intersections for Improvements Considering Safety and Operational Factors. Florida Department of Transportation, 2005.

Mahapatra, S., M. Wolniak, K.F. Sadabadi. *2016 Maryland State Highway Mobility Report.* Maryland Department of Transportation, 2016.

Mobility Performance Report 2012. California Department of Transportation, 2013.

Pulipati, S.B. Regional Prioritization of Corridors for Traffic Signal Retiming. The University of Texas at Arlington, 2006.

Schrank, D., T. Lomax, B. Eisele, J. Bak. The 2015 Urban Mobility Socrecard. Texas Transportation Institute, 2015.

The 2017 Corridor Capacity Report. Washington State Department of Transportation, 2017.

Witkowski, James M. Prioritizing Signalized Intersection Operational Deficiencies. Transportation Research Board, 1992.