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FINAL REPORT
March 2022

Evaluating Regional Traffic Signal Performance Measures Using Crowd-Sourced Data in 2021 Urban Mobility Report

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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle

Evaluating Regional Traffic Signal Performance Measures Using Crowd-Sourced Data in 2021 Urban Mobility Report

5. Report Date

05.31.2022

6. Performing Organization Code

7. Author(s)

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8. Performing Organization Report No.

9. Performing Organization Name and Address

Texas A&M Transportation Institute
3135 TAMU
College Station, TX 77843

10. Work Unit No. (TRAIS)

11. Contract or Grant No.

69A3551947136, TTI# 79075-00-B

12. Sponsoring Organization Name and Address

U.S. Department of Transportation
University Transportation Centers
1200 New Jersey Avenue, SE
Washington, DC 20590
United States

National Institute for Congestion Reduction
4202 E. Fowler Avenue
Tampa, FL 33620-5375 United States

13. Type of Report and Period Covered

Final Report (10.01.2021 to 05.31.2022)

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Traffic signal performance measures have historically been more difficult to quantify than other mobility measures, but new datasets obtained from crowdsourced data have improved the ability of users to quantify traffic signal performance measures at statewide, urban area, and corridor levels. Calculation of these metrics at the statewide and urban area levels is useful for tracking performance and trends, and at the corridor level the metrics can be used for both performance tracking and traffic signal operations from a planning perspective. One week of October 2020 data for approximately 210,000 traffic signals in the United States was used for this study. This dataset is useful for evaluation of signal operations using traditional metrics such as average delay and level of service, in addition to newer metrics such as arrivals on green and traffic signal efficiency index. This dataset provides actionable information for local traffic engineers at the corridor level by providing granular information on operations of individual traffic signals.

Community goals vary between urban areas, as some urban areas promote non-motorized transportation more than other communities, while some utilize traffic calming techniques to achieve other goals over optimizing signal systems to maximize vehicular throughput. These are important considerations when comparing urban areas to each other.

17. Key Words

Probe data, signal analytics, arterial street performance evaluation, congestion, delay

18. Distribution Statement

Unrestricted

19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. of Pages	22. Price
Unclassified.	Unclassified.	35	

Table of Contents

List of Exhibits

List of Tables

List of Figures

Executive Summary

Traffic signal performance measures have historically been more difficult to quantify than other mobility measures, but new datasets obtained from crowdsourced data have improved the ability of users to quantify traffic signal performance measures at statewide, urban area, and corridor levels without the installation and maintenance costs of detection and enhanced signal system equipment beyond what is needed to operate the intersection. Calculation of these metrics at the statewide and urban area levels is useful for tracking performance and trends, and at the corridor level the metrics can be used for both performance tracking and traffic signal operations from a planning perspective. One week of October 2020 data for approximately 210,000 traffic signals in the United States was used for this study, and below are some key takeaways from this evaluation:

- This dataset is useful for evaluation of signal operations using traditional metrics such as average delay and level of service, in addition to newer metrics such as arrivals on green and traffic signal efficiency index.
- Performance measures were validated by recognizing outliers at both the higher and lower ends of the traffic signal efficiency spectrum and considering events that occurred during the week that data was collected.
- This dataset provides actionable information from a planning perspective for local traffic engineers at the corridor level by providing granular information on operations of individual traffic signals.
- This dataset includes useful information at the urban area level for comparison to peer urban areas and to track performance over time.
- 2020 was a unique year, and some of the unique circumstances get reflected in signal efficiency metrics as well. The chart below shows urban areas' overall signal performance in 2020. It is easy to see the effects of COVID (virtual classes resulting in great signal performance in small college towns) as well as local weather conditions, special events, etc., resulting in contextual values of signal operational metrics.
- A vehicle is 1.7 times more likely to arrive at an intersection on green than red, based on the national average value of traffic signal efficiency index.
- Aggregating data to the statewide level might not be the best suited use of signal data in its current form, but it still provides some context to operational metrics, which can be investigated further at a more granular level depending on use case and scope of application.
- Community goals vary between urban areas, as some urban areas promote non-motorized transportation more than other communities, while some utilize traffic calming techniques to achieve other goals over optimizing signal systems to maximize vehicular throughput. These are important considerations when comparing urban areas to each other.

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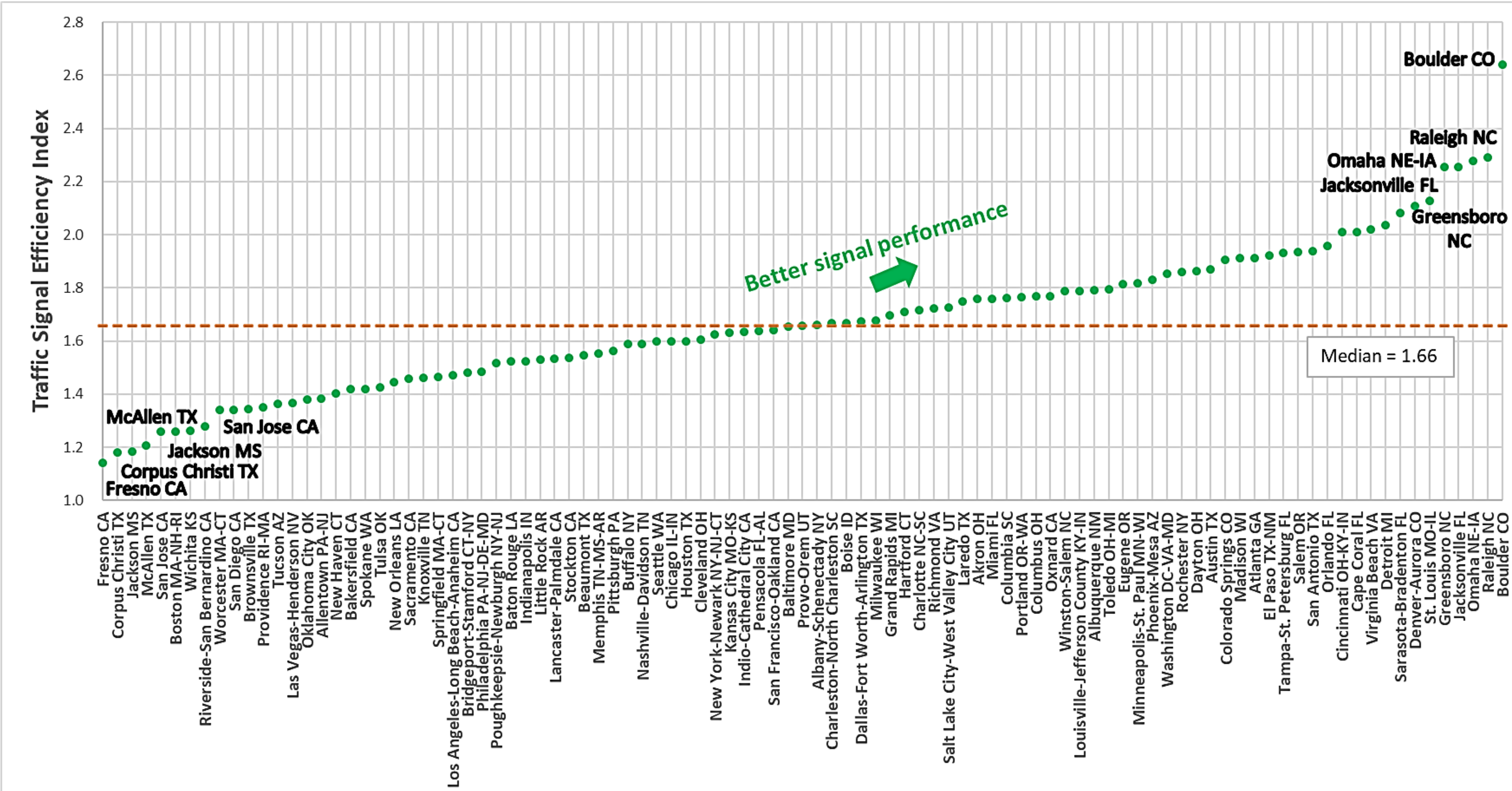

Traffic Signal Efficiency Index
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
Boulder CO
Raleigh NC
Omaha NE-IA
Jacksonville FL
Greensboro NC
Better signal performance
Median = 1.66
McAllen TX
San Jose CA
Jackson MS
Corpus Christi TX
Fresno CA
Fresno CA
Corpus Christi TX
Jackson MS
McAllen TX
San Jose CA
Boston MA-NH-RI
Wichita KS
Riverside-San Bernardino CA
Worcester MA-CT
San Diego CA
Brownsville TX
Providence RI-MA
Tucson AZ
Las Vegas-Henderson NV
Oklahoma City OK
Allentown PA-NJ
New Haven CT
Bakersfield CA
Spokane WA
Tulsa OK
New Orleans LA
Sacramento CA
Knoxville TN
Springfield MA-CT
Los Angeles-Long Beach-Anaheim CA
Bridgeport-Stamford CT-NY
Philadelphia PA-NJ-DE-MD
Poughkeepsie-Newburgh NY-NJ
Baton Rouge LA
Indianapolis IN
Little Rock AR
Lancaster-Palmdale CA
Stockton CA
Beaumont TX
Memphis TN-MS-AR
Pittsburgh PA
Buffalo NY
Nashville-Davidson TN
Seattle WA
Chicago IL-IN
Houston TX
Cleveland OH
New York-Newark NY-NJ-CT
Kansas City MO-KS
Indio-Cathedral City CA
Pensacola FL-AL
San Francisco-Oakland CA
Baltimore MD
Provo-Orem UT
Albany-Schenectady NY
Charleston-North Charleston SC
Boise ID
Dallas-Fort Worth-Arlington TX
Milwaukee WI
Grand Rapids MI
Hartford CT
Charlotte NC-SC
Richmond VA
Salt Lake City-West Valley City UT
Laredo TX
Akron OH
Miami FL
Columbia SC
Portland OR-WA
Columbus OH
Oxnard CA
Winston-Salem NC
Louisville-Jefferson County KY-IN
Albuquerque NM
Toledo OH-MI
Eugene OR
Minneapolis-St. Paul MN-WI
Phoenix-Mesa AZ
Washington DC-VA-MD
Rochester NY
Dayton OH
Austin TX
Colorado Springs CO
Madison WI
Atlanta GA
El Paso TX-NM
Tampa-St. Petersburg FL
Salem OR
San Antonio TX
Orlando FL
Cincinnati OH-KY-IN
Cape Coral FL
Virginia Beach VA
Detroit MI
Sarasota-Bradenton FL
Denver-Aurora CO
St. Louis MO-IL
Greensboro NC
Jacksonville FL
Omaha NE-IA
Raleigh NC
Boulder CO

Introduction

Arterial street delay accounts for approximately 60% (roughly 50% in large urban areas and about 75% in small urban areas) of delay in United States urban areas. A significant portion of delay on arterial streets occurs at traffic signals. Improving the efficiency of traffic signal operations is critical in both reducing delay and improving air quality. The Environmental Protection Agency (EPA) estimates that transportation accounts for approximately 29% of greenhouse gas (GHG) emissions in the United States. Between 1990 and 2019. GHG emissions in the transportation sector increased more in absolute terms than any other sector (*1*).

In addition, recognizing the connection between greenhouses gases and transportation system performance, the Federal Congestion Mitigation and Air Quality (CMAQ) program began in 1991 with a goal of reducing traffic congestion and improving air quality. A critical component in addressing these issues is to improve traffic signal performance measurement, which provides critical information to traffic management personnel when making necessary adjustments to improve traffic signal operations. Optimizing arterial signal systems can help better utilize existing roadway capacity which can be more cost-effective than adding new lane capacity and/or new interchanges to address congestion.

The *Urban Mobility Report* (UMR) has been providing information on urban congestion levels in the U.S. for more than three decades. The UMR uses private-sector crowdsourced travel speed data from INRIX combined with traditional public-agency roadway inventory data to measure mobility conditions. The current UMR statistics describe overall congestion levels, but do not categorize causes of congestion. With the advent of improvements in the third-party provider data streams, it is now possible to quantify at least some aspects of the mobility contribution provided by enhanced traffic signal systems.

Traffic Signal Performance Measures

Traffic signal performance measurement has historically been constrained with agencies relying on limited data collection and citizen complaints to gauge the performance of traffic signal systems. Recently, there has been an increased focus on a more proactive approach to measure traffic signal performance. Through the Every Day Counts (EDC) Initiative update, EDC-4, the Federal Highway Administration recognized the importance of Automated Traffic Signal Performance Measures (ATSPM). ATSPM is defined as a suite of performance measures, data collection and data analysis tools to support objectives and performance-based approaches to traffic signal operations, maintenance, management and design to improve the safety, mobility and efficiency of signalized intersections for all users (*2*).

Operations performance measurement, for example, traffic signals and pedestrian level of service, is much more challenging for agencies to quantify than more static items such as traffic signal maintenance, sidewalks/ramp condition, or pavement condition. Collection of data and measurement of traffic signal operations and performance is difficult due to required field equipment, software, staffing, and data processing requirements for continuous measurement of performance. Therefore, it is beneficial to explore other readily available options requiring minimal resources for measurement.

FHWA also recognized the importance of crowdsourced data for operations through Every Day Counts Initiative updates, EDC-5 and EDC-6. These initiatives identify crowdsourced data as a cost-effective data collection method which reduces the need for additional roadway sensors and equipment that require installation, costly maintenance and, due to speed of change in technology, are often not the most state-of-the-art when installed.

This evaluation used detailed crowdsourced intersection traffic data collected by INRIX to report on the performance of traffic signal systems. Urban areas were reviewed and ranked for signal operations by evaluating metrics obtained from crowdsourced data, including arrivals on green and split failures. These metrics enhanced the evaluations that can be performed using traditional metrics like arterial street delay. Urban areas were also categorized using factors including congestion levels, population and signal density to ensure that any comparisons include contextual elements which are key to decision-maker understanding and messaging strategies.

INRIX has continued to exponentially expand their probe vehicle coverage and data quality. The use of this data allows agencies to leverage existing probe data for the measurement of traffic signal performance and improve traffic signal operations. This approach reduces the burden on agency traffic engineering staff and infrastructure, while improving reporting on traffic signal performance to elected officials and the public.

The INRIX traffic signal analytics data was used to both summarize data provided for each urban area, and to calculate additional traffic signal performance measures. When choosing traffic signal performance measures, it is important to use multiple measures to gain a full understanding of traffic signal operations of an urban area. This section of the report provides an overview of the performance measures used in this study, and more details on these measures, including their calculation procedures are outlined in Appendix A (Methodology) accompanying this report.

Total Delay

Total delay is the sum of delay experienced by all vehicles at a signalized intersection. It is a good measure of the magnitude of delay at an individual signalized intersection because locations with more vehicles have more delay than intersections with fewer vehicles when operating at a similar level of service.

Average Delay Per Vehicle

Average delay per vehicle is a measure of operation of a traffic signal that is useful to understand the mean wait time for each vehicle at an intersection. Commonly, motorists wait longer at intersections with a higher delay per vehicle regardless of traffic volume at the intersection. This could be attributed to poor signal timing, preemption, or other factors that influence signal operation.

Vehicle Arrivals on Green

Percentage of vehicle arrivals on green is a measure of traffic signal progression, which is a calculation of the percentage of vehicles that proceed through the intersection without stopping.

Vehicle Arrivals on Red

Percentage of vehicle arrivals on red is also a measure of traffic signal progression and is the opposite of vehicle arrivals on green. Vehicles that stopped before proceeding through the intersection are included in this calculation.

Split Failures

Split failure count can be a measure of excessive delay, as it measures the number of vehicles that stopped at least twice before proceeding through the intersection – meaning that a vehicle was not able to get through the signal on one or more green indications. Although split failures can be an indication of poor signal timing, there are often other contributing factors, such as high traffic volumes relative to intersection capacity, emergency pre-emptions, and traffic incidents. One way to separate arrivals on red potentially due to poor signal timing from arrivals on red due to other factors is to subtract split failures from arrivals on red.

Traffic Signal Efficiency Index

This report introduces a new metric, traffic signal efficiency index (TSEI), that is easily understood as the multiplication factor by which a vehicle is more likely to arrive on green compared to red (X times more arrivals on green than red). It utilizes data available to calculate metrics similar to Platoon Ratio calculations in the Highway Capacity Manual. There are two traffic signal efficiency indices (raw and adjusted). The raw traffic signal efficiency index includes all vehicle arrivals, while the adjusted traffic signal efficiency index does excludes split failures in the arrivals on red. The adjusted index is used to measure signal timing efficiency under free flow conditions because split failures can be caused by factors other than signal timing (e.g., capacity constraints, pedestrian activity, emergency pre-emptions, traffic incidents, etc.).

Both raw and adjusted traffic signal efficiency indices are calculated to determine traffic signal efficiency for both normal and free flow conditions. With traffic volumes reduced in 2020 due to COVID, during the week of data collection, there were fewer split failures due to capacity limitations than would be expected in a normal traffic week. It is anticipated that if these measures are re-evaluated with traffic data in the future, there would be a larger difference between TSEI and adjusted TSEI, which would provide some insight on efficiency of signal timing isolated from other factors that cause intersection inefficiencies.

Applications of INRIX Traffic Signal Analytics Data

Applications of INRIX Signal Analytics data are wide ranging from an areawide, corridor, and individual intersection perspective. Data can be archived so that year over year comparisons can be made for each of these spatial levels. Also, Cities can dive deep into performance at intersections and corridors to report on changes (e.g., year over year, before and after projects, etc.). Before and after studies can be used to fulfill requirements for federal projects. This data can be used to assist with the prioritization process for Metropolitan Planning Organizations (MPOs) and other regional authorities are tasked with prioritizing signal timing projects as well as other types of projects for a region. While detection equipment is necessary to operate traffic signals, this data source provides an opportunity to effectively manage resources and significantly reduce internal data collection and processing.

This report discusses results for the urban area and state levels of analysis. Detailed analysis at the corridor and individual signalized intersection level is discussed in Appendix B (Signal and Corridor Level Analyses) accompanying this report.

Urban Area Traffic Signal Performance

The UMR tracks mobility performance measures in 494 urban areas, of which 101 are intensively studied. Evaluation of urban areas in this analysis focused on these 101 urban areas. All signalized intersections in the INRIX database were geo-located and assigned to urban areas. The same metrics as discussed in previous sections were calculated for all signalized intersections in respective urban areas. Like in the case of analyzing individual intersections and a sample corridor, this analysis uses only weekday all-day data.

Exhibit 1 provides data for four of the calculated metrics for the 97 urban areas (grouped by population size and sorted by TSEI rank within individual groups) among the 101 for which vehicle mobility data at signalized intersections are currently available from INRIX. A higher numerical TSEI rank (where 2 is greater than 1) is associated with a higher TSEI score and represents better signal operations. Table 1 at the end of this report provides data for all calculated metrics for the 97 urban areas (in increasing order of population). Additionally, graphical representation of the traffic signal efficiency index is shown in Exhibit 2 below, and the same for other metrics such as percent arrivals on green and weighted level of service for all intersections in these urban areas is provided in Figures 1 and 2 at the end of this report. Key takeaways from this analysis are as follows:

- The complete data for all 494 urban areas included a few urban areas with a very small number of signals in the sample data. Several such urban areas exhibited outlier behavior based on box plot diagrams, mostly in terms of high delay per vehicle and arrivals on red. After filtering out urban areas with fewer than 10 signals, the behavior was more consistent among the remaining areas. This filtering process removed 20 urban areas out of 463 for which INRIX signal data were available. This issue was not observed for the 101 urban areas, so no filtering was required.
- As shown on Exhibit 2 and Figures 1-2, several college towns appear at the better end of most metrics. A contributing factor might have been the period of observation (October 2020) when a majority of the colleges and universities were operating classes virtually, thus resulting in much lower congestion levels, reduced traffic demand and better signal operation.
- Special situations like hurricanes, snow or bad weather conditions, etc., might impact some of the urban areas which emerge at the lower end of most signal metrics. These factors can be local and specific to the time window of data observation, therefore, can be investigated further for a more conclusive identification of causal factors.

Exhibit 1. Summary Traffic Signal Performance Measures for 101 Urban Areas

Urban Area	Delay per veh (sec)	% AOG	% AOR	TSEI	Rank
Very Large Average (15 areas)				**1.65**	
Boston MA-NH-RI	20.5	55%	45%	**1.26**	**6**
San Diego CA	20.0	57%	43%	**1.34**	**10**
Los Angeles-Long Beach-Anaheim CA	19.4	59%	41%	**1.47**	**25**
Philadelphia PA-NJ-DE-MD	18.5	59%	41%	**1.48**	**27**
Seattle WA	18.1	61%	39%	**1.60**	**39**
Chicago IL-IN	18.3	61%	39%	**1.60**	**40**
Houston TX	19.5	61%	39%	**1.60**	**41**
New York-Newark NY-NJ-CT	21.5	61%	39%	**1.62**	**43**
San Francisco-Oakland CA	18.2	62%	38%	**1.64**	**47**
Dallas-Fort Worth-Arlington TX	18.0	62%	38%	**1.67**	**53**
Miami FL	21.1	64%	36%	**1.76**	**62**
Phoenix-Mesa AZ	17.1	65%	35%	**1.83**	**73**
Washington DC-VA-MD	18.4	65%	35%	**1.85**	**74**
Atlanta GA	19.2	65%	35%	**1.91**	**80**
Detroit MI	14.9	67%	33%	**2.04**	**89**
Large Average (31 areas)				**1.78**	
San Jose CA	20.9	56%	44%	**1.26**	**5**
Riverside-San Bernardino CA	20.1	56%	44%	**1.28**	**8**
Providence RI-MA	17.0	57%	43%	**1.35**	**12**
Las Vegas-Henderson NV	23.2	58%	42%	**1.37**	**14**
Oklahoma City OK	19.5	58%	42%	**1.38**	**15**
Sacramento CA	18.1	59%	41%	**1.46**	**22**
Indianapolis IN	17.1	60%	40%	**1.52**	**30**
Memphis TN-MS-AR	17.5	61%	39%	**1.55**	**35**
Pittsburgh PA	18.5	61%	39%	**1.56**	**36**
Nashville-Davidson TN	19.5	61%	39%	**1.59**	**38**
Cleveland OH	17.1	61%	39%	**1.61**	**42**
Kansas City MO-KS	15.6	62%	38%	**1.63**	**44**
Baltimore MD	19.1	62%	38%	**1.65**	**48**
Milwaukee WI	15.9	62%	38%	**1.68**	**54**
Charlotte NC-SC	17.6	63%	37%	**1.72**	**57**
Richmond VA	15.8	63%	37%	**1.72**	**58**
Salt Lake City-West Valley City UT	16.5	63%	37%	**1.73**	**59**
Portland OR-WA	16.0	64%	36%	**1.76**	**64**
Columbus OH	16.3	64%	36%	**1.77**	**65**
Louisville-Jefferson County KY-IN	17.8	64%	36%	**1.79**	**68**
Minneapolis-St. Paul MN-WI	15.0	64%	36%	**1.82**	**72**
Austin TX	18.1	65%	35%	**1.87**	**77**
Tampa-St. Petersburg FL	19.5	66%	34%	**1.93**	**82**
San Antonio TX	16.8	66%	34%	**1.94**	**84**
Orlando FL	19.2	66%	34%	**1.96**	**85**
Cincinnati OH-KY-IN	15.6	67%	33%	**2.01**	**86**
Virginia Beach VA	16.7	67%	33%	**2.02**	**88**
Denver-Aurora CO	15.4	68%	32%	**2.11**	**91**
St. Louis MO-IL	14.8	68%	32%	**2.13**	**92**
Jacksonville FL	16.2	69%	31%	**2.25**	**94**
Raleigh NC	13.4	69%	31%	**2.29**	**96**

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Exhibit 1. Traffic Signal Performance Measures for 101 Urban Areas, continued

Urban Area	Delay per veh (sec)	% AOG	% AOR	TSEI	Rank
Medium Average (31 areas)				**1.68**	
Fresno CA	20.6	53%	47%	**1.14**	**1**
McAllen TX	17.7	54%	46%	**1.21**	**4**
Wichita KS	17.1	56%	44%	**1.26**	**7**
Worcester MA-CT	17.5	57%	43%	**1.34**	**9**
Tucson AZ	19.5	58%	42%	**1.36**	**13**
Allentown PA-NJ	17.3	58%	42%	**1.38**	**16**
New Haven CT	17.8	58%	42%	**1.40**	**17**
Bakersfield CA	17.1	58%	42%	**1.42**	**18**
Tulsa OK	18.7	59%	41%	**1.42**	**20**
New Orleans LA	20.4	59%	41%	**1.45**	**21**
Knoxville TN	18.7	59%	41%	**1.46**	**23**
Springfield MA-CT	16.4	59%	41%	**1.47**	**24**
Bridgeport-Stamford CT-NY	17.7	59%	41%	**1.48**	**26**
Baton Rouge LA	20.3	60%	40%	**1.52**	**29**
Buffalo NY	16.5	61%	39%	**1.59**	**37**
Provo-Orem UT	17.0	62%	38%	**1.66**	**49**
Albany-Schenectady NY	16.2	62%	38%	**1.66**	**50**
Charleston-North Charleston SC	19.3	62%	38%	**1.67**	**51**
Grand Rapids MI	15.8	63%	37%	**1.70**	**55**
Hartford CT	15.6	63%	37%	**1.71**	**56**
Akron OH	15.2	64%	36%	**1.76**	**61**
Columbia SC	17.5	64%	36%	**1.76**	**63**
Albuquerque NM	15.5	64%	36%	**1.79**	**69**
Toledo OH-MI	14.7	64%	36%	**1.79**	**70**
Rochester NY	14.2	65%	35%	**1.86**	**75**
Dayton OH	14.6	65%	35%	**1.86**	**76**
Colorado Springs CO	15.8	65%	35%	**1.90**	**78**
El Paso TX-NM	15.2	66%	34%	**1.92**	**81**
Cape Coral FL	16.8	67%	33%	**2.01**	**87**
Sarasota-Bradenton FL	18.0	67%	33%	**2.08**	**90**
Omaha NE-IA	12.1	69%	31%	**2.28**	**95**
Small Average (20 areas)				**1.70**	
Corpus Christi TX	21.4	54%	46%	**1.18**	**2**
Jackson MS	21.9	54%	46%	**1.18**	**3**
Brownsville TX	19.7	57%	43%	**1.34**	**11**
Spokane WA	17.3	58%	42%	**1.42**	**19**
Poughkeepsie-Newburgh NY-NJ	17.3	60%	40%	**1.52**	**28**
Little Rock AR	17.1	60%	40%	**1.53**	**31**
Lancaster-Palmdale CA	16.6	60%	40%	**1.53**	**32**
Stockton CA	16.4	60%	40%	**1.54**	**33**
Beaumont TX	17.2	61%	39%	**1.55**	**34**
Indio-Cathedral City CA	16.0	62%	38%	**1.63**	**45**
Pensacola FL-AL	20.5	62%	38%	**1.64**	**46**
Boise ID	18.4	62%	38%	**1.67**	**52**
Laredo TX	17.1	63%	37%	**1.75**	**60**
Oxnard CA	15.0	64%	36%	**1.77**	**66**
Winston-Salem NC	14.5	64%	36%	**1.79**	**67**
Eugene OR	14.2	64%	36%	**1.81**	**71**
Madison WI	13.1	65%	35%	**1.91**	**79**
Salem OR	14.4	66%	34%	**1.94**	**83**
Greensboro NC	12.9	69%	31%	**2.25**	**93**
Boulder CO	12.2	72%	28%	**2.64**	**97**
101 Area Average				**1.69**	
Remaining Areas Average				**1.73**	
All 463 Area Average				**1.70**	

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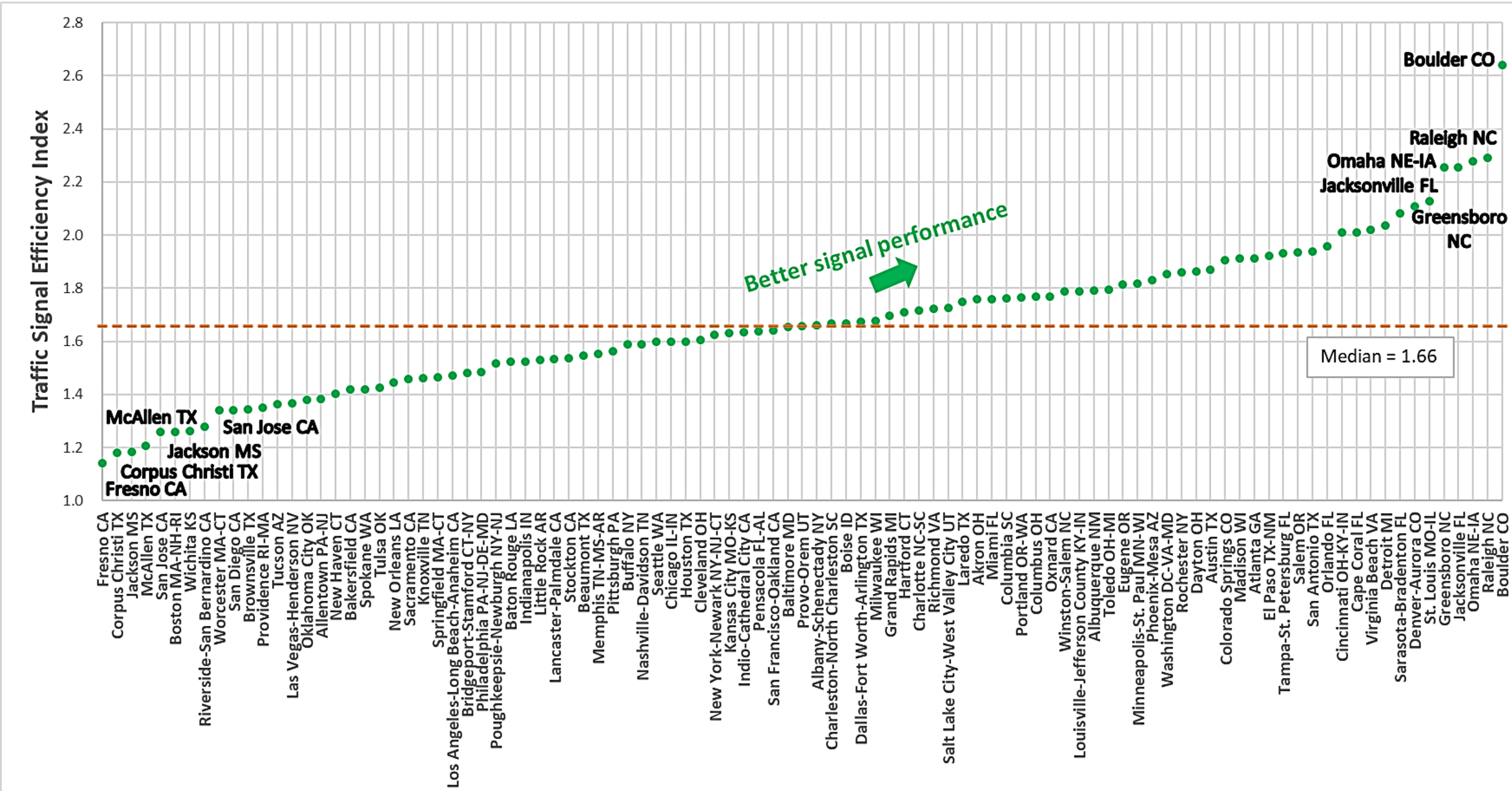
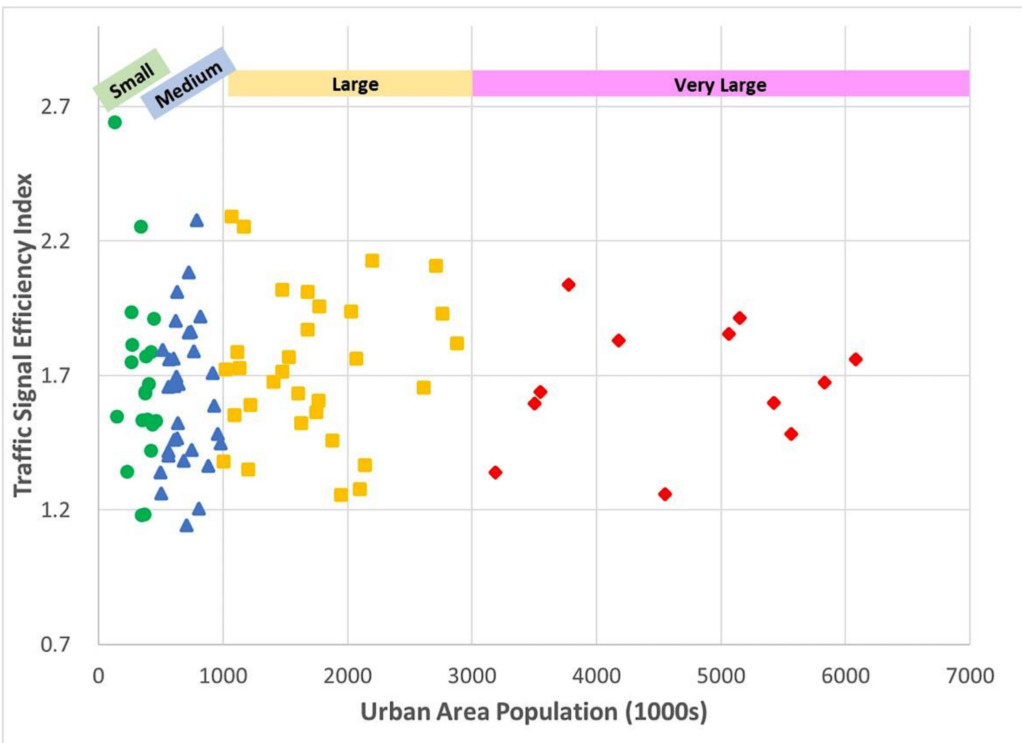
Exhibit 2. Traffic Signal Efficiency Index (TSEI) for Urban Areas



It can be expected that the size of the urban area also has an influence on how efficiently signals operate because of the relative scale of demand they need to serve. All calculated signal metrics were charted to examine any effect of the size of the urban area (using population as a proxy for size of urban area). Exhibit 3 shows the effect of population size on the traffic signal efficiency index, and Figures 3 and 4 do the same for the two other metrics – average delay per vehicle and weighted LOS.

It is observed that the size of the urban area (represented by population here) does at best show a mild influence on some of the signal measures. In particular, the range of variation in values gets moderated to some extent with increasing size of the urban area. The range of values is wider for small- and mid-sized urban areas, while the range gets tighter for larger areas. Moreover, the weighted level of service typically tends to increase (get worse) for larger areas compared to smaller urban areas, accompanied by a reduction in the spread (range) of values.

Exhibit 3. Variation of Traffic Signal Efficiency Index with Size of Urban Area

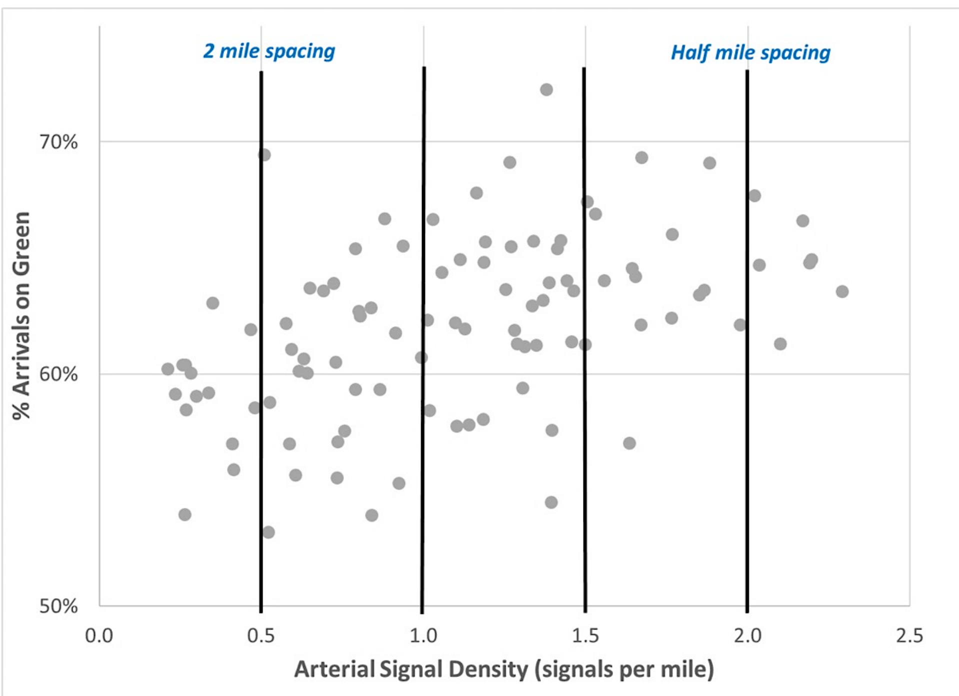


On similar lines as size (population) of urban area, signal density and magnitude of arterial delay in an urban area were used as classification factors to examine their impacts on the values of signal metrics. Signal density was calculated as the total number of signals divided by the total arterial center miles in an urban area (Equation A-16 in Appendix A). Arterial delay for an urban area was calculated per UMR methodology.

Exhibit 4 shows the effect of signal density on percent arrivals on green. Figures 5 and 6 show the effects of signal density on two other metrics – average delay per vehicle and weighted LOS. To extend the line of thought, similar charts were replicated to examine the effects of magnitude of arterial delay on these signal metrics. The following patterns emerge out of these graphical representations:

- Average delay per vehicle does not change appreciably with either increasing signal density or total arterial delay for an urban area. This observation can be attributed to the fact that urban areas with higher signal density and arterial delay are usually the larger, more resource rich areas where signals operate as a network rather than as isolated intersections. Therefore, the effect of higher demand (level of traffic) is offset to some extent by typically better utilization of more resources (funds, signal timing personnel, plan, routine, etc.). A comparison between different corridors with different signal densities in the same urban area might give us a more granular perspective and may result in a different inference, but the data at the urban area level exhibits the pattern discussed earlier.
- The observation on effect of signal density can be different depending on whether the analysis is performed at the corridor level or the urban area level. In the latter case, other confounding factors such as resources (funds, personnel), maintenance routine, equipment, etc., may impact results.
- Interestingly, percent arrivals on green improves with higher signal density in an urban area. This follows from the previous observation that an urban area with higher signal density tends to coordinate their operation and devotes more resources to keeping those signals well timed and coordinated, so as to allow a better progression of vehicles arriving at an intersection.
- The observation is the same in the case of arterial delay where percent arrivals on green is higher for urban areas with higher arterial delay. Consequently, the traffic signal efficiency index improves as signal density or arterial delay increases.
- Similar to average delay per vehicle, traffic signal weighted level of service does not show a definitive pattern with increasing signal density. It can be attributed to the same logic as for average delay – better, more intentional operations and use of resources by areas with higher signal density.

Exhibit 4. Variation of Percent Arrivals on Green with Signal Density of Urban Area



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Statewide Traffic Signal Performance

Traffic signal performance measures were also evaluated at the statewide level including the District of Columbia. Although this might not be the best suited use of signal data in its current form, it still provides some context to operational metrics at an aggregate level, which can be investigated further at a more granular level depending on use case and scope of application.

Exhibit 5 provides values of four of the calculated metrics at a statewide level for all 50 states and the District of Columbia, and data for all metrics are provided in Table 2. Researchers also examined if using just weekday daytime data (5 AM to 9 PM) shows significantly different results for the signal metrics compared to all-day traffic data. Table 3 provides those results for comparison. It was found that using only daytime data did not have a significant impact on the values of the calculated metrics. The only percent changes above 5% magnitude are in the split failure percentages, and those seem to be caused by the low base effect, as seen in the highlighted cells in the "Percent Change" section of Table 3.

Exhibit 6 shows the variation of traffic signal efficiency index for all states. Figures 7 and 8 show the variation of two other metrics – percent arrivals on red excluding split failures and weighted LOS – for all states. Some local/regional factors might be impacting the observations and thus the results for the states. The period of observation is short (1 week) and during October, when traffic in some of the northeastern states might be impacted by snow, fall foliage, or other regional conditions. Additionally, state and local priorities may dictate the acceptable levels of signal operational metrics. For example, prioritizing bike, pedestrian or other non-motorized traffic over vehicular traffic may be a desired outcome in a particular jurisdiction or location, and an associated moderate degradation in signal metrics may be entirely acceptable, if not desirable. Similarly, the tradeoff between land access and vehicular through movements is a local level priority decision which can have an effect on signal performance.

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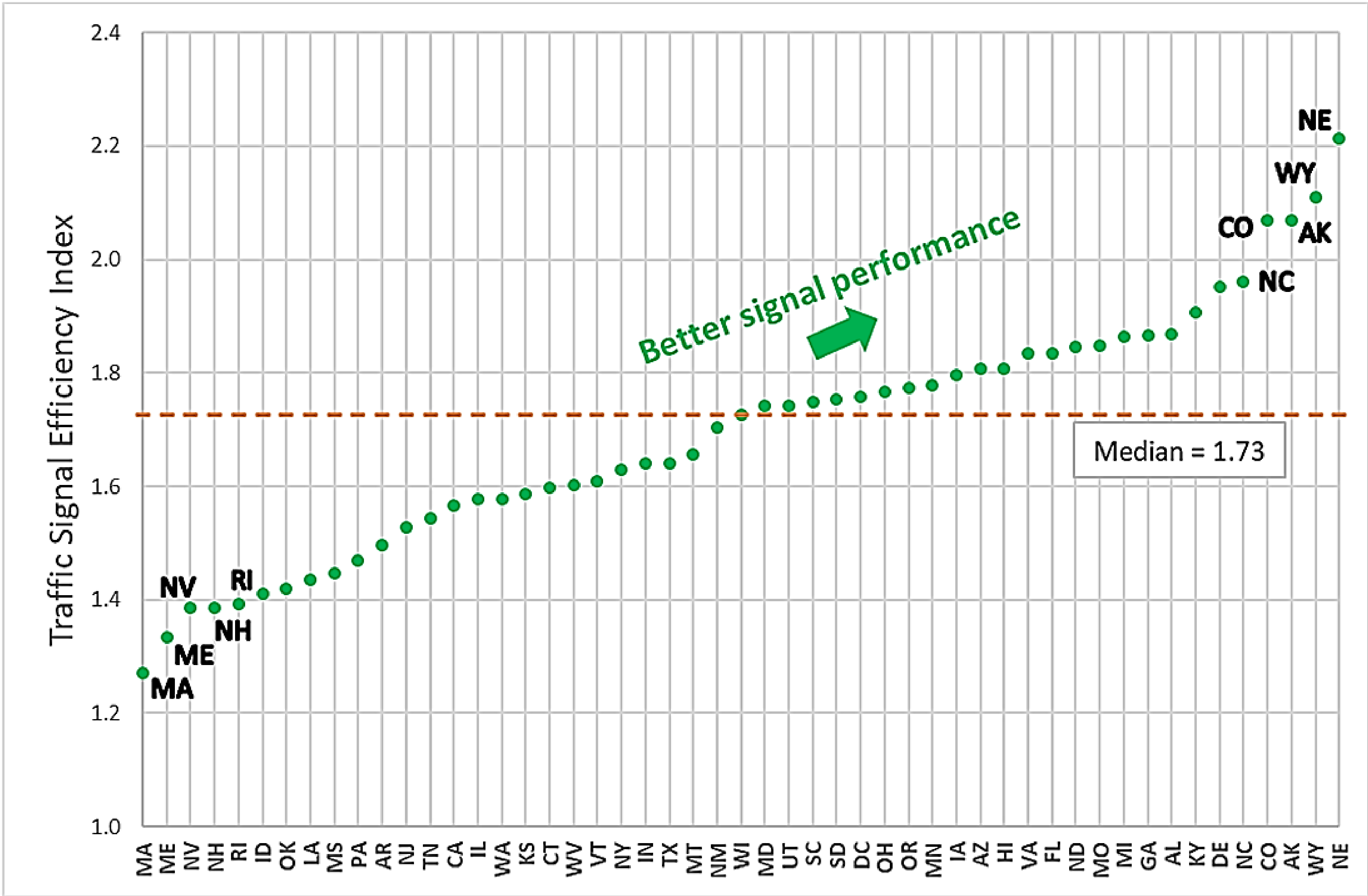
Exhibit 5. Summary Traffic Signal Performance Measures for 50 States and the District of Columbia

State	Avg Delay per Veh (sec)	% Arrivals on Green	% Arrivals on Red	TSEI (Adjusted)
AK	14.2	67%	33%	2.07
AL	17.0	65%	35%	1.87
AR	16.2	60%	40%	1.50
AZ	16.6	64%	36%	1.81
CA	17.6	61%	39%	1.57
CO	14.9	67%	33%	2.07
CT	15.8	61%	39%	1.60
DC	20.8	63%	37%	1.76
DE	16.6	66%	34%	1.95
FL	18.5	65%	35%	1.83
GA	17.7	65%	35%	1.87
HI	16.9	64%	36%	1.81
IA	13.4	64%	36%	1.80
ID	18.4	58%	42%	1.41
IL	17.6	61%	39%	1.58
IN	15.2	62%	38%	1.64
KS	15.1	61%	39%	1.59
KY	16.1	65%	35%	1.91
LA	19.5	59%	41%	1.44
MA	19.6	56%	44%	1.27
MD	17.9	63%	37%	1.74
ME	17.8	57%	43%	1.33
MI	15.1	65%	35%	1.86
MN	14.7	64%	36%	1.78
MO	15.0	65%	35%	1.85
MS	18.4	59%	41%	1.45

State	Avg Delay per Veh (sec)	% Arrivals on Green	% Arrivals on Red	TSEI (Adjusted)
MT	15.9	62%	38%	1.66
NC	14.4	66%	34%	1.96
ND	13.7	65%	35%	1.85
NE	12.2	69%	31%	2.21
NH	17.6	58%	42%	1.39
NJ	17.7	60%	40%	1.53
NM	15.3	63%	37%	1.70
NV	21.3	58%	42%	1.38
NY	20.4	61%	39%	1.63
OH	15.4	64%	36%	1.77
OK	18.1	58%	42%	1.42
OR	15.1	64%	36%	1.77
PA	17.6	59%	41%	1.47
RI	16.6	58%	42%	1.39
SC	16.1	63%	37%	1.75
SD	14.0	63%	37%	1.75
TN	18.4	60%	40%	1.54
TX	17.7	62%	38%	1.64
UT	15.8	63%	37%	1.74
VA	16.2	65%	35%	1.83
VT	16.2	61%	39%	1.61
WA	17.0	61%	39%	1.58
WI	14.3	63%	37%	1.73
WV	15.6	61%	39%	1.60
WY	11.7	68%	32%	2.11

Exhibit 6. Traffic Signal Efficiency Index by State



Discussion and Conclusions

The purpose of this evaluation was to determine if crowdsourced data could be used to quantify traffic signal performance measures at statewide, urban area, and corridor levels, since traffic signal performance measures have historically required more equipment and resources than other mobility performance measures. INRIX provided one week of data for approximately 210,000 traffic signals in the United States for October 2020, which was used for this evaluation. Below are some key takeaways from this effort:

- This dataset is useful for evaluation of signal operations using traditional metrics such as average delay and level of service, as well as newer metrics such as arrivals on green and traffic signal efficiency index.
- Performance measures were validated by outliers at both at the higher and lower ends of the traffic signal efficiency spectrum by events occurring during the week that data was collected:
    - Less delay due to virtual classes in university-centric communities
    - More delay in areas in Louisiana affected by a hurricane
    - Possibly more delay in New England region due to fall foliage visitors in more urbanized areas
- This dataset provides actionable information from a planning perspective for local traffic engineers at the corridor level by providing granular information on operations of individual traffic signals.
- This dataset provides useful information at the urban area level for comparison to peer urban areas and to track performance over time.
- The range of traffic signal efficiency was broader in smaller urban areas than larger urban areas.
- Traffic signals in urban areas with higher traffic signal density generally performed at a higher efficiency than urban areas with less traffic signal density. This is likely due to how signals are operated and resources dedicated to traffic signal timing and routine maintenance in areas with more signals and more traffic. A comparison between different corridors with different signal densities in the same urban area might give us a more granular perspective and may result in a different inference.
- Aggregating data to the statewide level might not be the best suited use of signal data in its current state, but it still provides some context to operational metrics, which can be investigated further at a more granular level depending on use case and scope of application.
- Community goals vary between urban areas, as some urban areas promote non-motorized transportation more than other communities. This is an important consideration when comparing urban areas to each other.

Additional considerations for future evaluations are identified below:

- Since some urban areas can have several dozen agencies operating traffic signals, this data also has potential to be evaluated at the city/county level, so that signals are grouped by operating agency. Because the Urban Mobility Report evaluates urban areas, this level of analysis was not included in this effort.
- Network topology (grid system vs less uniform roadway network) can have a significant impact on efficiency of traffic signals, but was not quantifiable for this effort.
- The ability to track performance measures over time is useful for identifying trends, so future evaluation at regular time intervals would be beneficial.
- Evaluation by time-of-day was performed at the corridor level in this study, but future effort can consider extending the scope of such analysis, particularly because it provides additional insights not seen in all-day patterns.

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Table 1. Traffic Signal Performance Measures for 101 Urban Areas

Urban Area	No. of Signals	Avg Delay per Veh (sec)	% Arrivals on Green	% Arrivals on Red	% Split Failure	% Arrivals on Red (not split failure)	TSEI (Raw)	TSEI (Adjusted)	Traffic Signal Weighted LOS
Boulder CO	97	12.2	72%	28%	0.4%	27%	2.61	2.64	1.69
Beaumont TX	121	17.2	61%	39%	0.4%	39%	1.53	1.55	2.10
Brownsville TX	200	19.7	57%	43%	0.5%	42%	1.33	1.34	2.29
Laredo TX	255	17.1	63%	37%	0.3%	36%	1.73	1.75	2.08
Salem OR	224	14.4	66%	34%	0.3%	34%	1.92	1.94	1.87
Eugene OR	264	14.2	64%	36%	0.4%	35%	1.79	1.81	1.86
Greensboro NC	362	12.9	69%	31%	0.2%	31%	2.24	2.25	1.75
Corpus Christi TX	147	21.4	54%	46%	0.4%	46%	1.17	1.18	2.44
Lancaster-Palmdale CA	93	16.6	60%	40%	0.3%	39%	1.52	1.53	2.04
Jackson MS	165	21.9	54%	46%	0.5%	46%	1.17	1.18	2.46
Indio-Cathedral City CA	108	16.0	62%	38%	0.2%	38%	1.63	1.63	2.02
Pensacola FL-AL	294	20.5	62%	38%	0.3%	38%	1.63	1.64	2.33
Oxnard CA	118	15.0	64%	36%	0.3%	36%	1.75	1.77	1.91
Stockton CA	41	16.4	60%	40%	0.3%	39%	1.52	1.54	2.03
Boise ID	323	18.4	62%	38%	0.3%	37%	1.65	1.67	2.17
Spokane WA	404	17.3	58%	42%	0.4%	41%	1.41	1.42	2.11
Winston-Salem NC	147	14.5	64%	36%	0.3%	36%	1.77	1.79	1.88
Poughkeepsie-Newburgh NY-NJ	272	17.3	60%	40%	0.4%	40%	1.50	1.52	2.10
Madison WI	407	13.1	65%	35%	0.2%	34%	1.90	1.91	1.77
Little Rock AR	116	17.1	60%	40%	0.5%	39%	1.51	1.53	2.10
Worcester MA-CT	237	17.5	57%	43%	0.5%	43%	1.33	1.34	2.11
Wichita KS	137	17.1	56%	44%	0.3%	44%	1.25	1.26	2.11
Toledo OH-MI	614	14.7	64%	36%	0.3%	36%	1.78	1.79	1.91
Bakersfield CA	97	17.1	58%	42%	0.3%	41%	1.41	1.42	2.10
New Haven CT	501	17.8	58%	42%	0.5%	41%	1.38	1.40	2.12
Provo-Orem UT	244	17.0	62%	38%	0.3%	38%	1.65	1.66	2.08
Akron OH	616	15.2	64%	36%	0.3%	36%	1.74	1.76	1.94
Columbia SC	262	17.5	64%	36%	0.4%	36%	1.74	1.76	2.12
Albany-Schenectady NY	788	16.2	62%	38%	0.5%	37%	1.64	1.66	2.00
Knoxville TN	173	18.7	59%	41%	0.5%	40%	1.44	1.46	2.22
Colorado Springs CO	555	15.8	65%	35%	0.3%	34%	1.89	1.90	1.99
Grand Rapids MI	485	15.8	63%	37%	0.3%	37%	1.68	1.70	2.01
Cape Coral FL	297	16.8	67%	33%	0.2%	33%	2.00	2.01	2.06
Springfield MA-CT	247	16.4	59%	41%	0.4%	40%	1.45	1.47	2.04
Baton Rouge LA	153	20.3	60%	40%	0.5%	39%	1.50	1.52	2.32
Charleston-North Charleston SC	168	19.3	62%	38%	0.5%	37%	1.64	1.67	2.27
Allentown PA-NJ	451	17.3	58%	42%	0.5%	42%	1.37	1.38	2.12
Fresno CA	157	20.6	53%	47%	0.3%	47%	1.14	1.14	2.37
Rochester NY	661	14.2	65%	35%	0.3%	35%	1.84	1.86	1.87
Sarasota-Bradenton FL	397	18.0	67%	33%	0.2%	32%	2.07	2.08	2.15
Dayton OH	554	14.6	65%	35%	0.2%	35%	1.85	1.86	1.90
Tulsa OK	409	18.7	59%	41%	0.4%	41%	1.41	1.42	2.22
Albuquerque NM	687	15.5	64%	36%	0.2%	36%	1.78	1.79	1.97
Omaha NE-IA	816	12.1	69%	31%	0.2%	30%	2.26	2.28	1.69
McAllen TX	635	17.7	54%	46%	0.4%	45%	1.20	1.21	2.15
El Paso TX-NM	430	15.2	66%	34%	0.4%	34%	1.90	1.92	1.93
Tucson AZ	362	19.5	58%	42%	0.2%	42%	1.36	1.36	2.27

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Table 1. Traffic Signal Performance Measures for 101 Urban Areas, continued

Urban Area	No. of Signals	Avg Delay per Veh (sec)	% Arrivals on Green	% Arrivals on Red	% Split Failure	% Arrivals on Red (not split failure)	TSEI (Raw)	TSEI (Adjusted)	Traffic Signal Weighted LOS
Hartford CT	580	15.6	63%	37%	0.4%	37%	1.69	1.71	1.96
Buffalo NY	1122	16.5	61%	39%	0.3%	39%	1.58	1.59	2.05
Bridgeport-Stamford CT-NY	460	17.7	59%	41%	0.6%	40%	1.46	1.48	2.14
New Orleans LA	281	20.4	59%	41%	0.6%	41%	1.43	1.45	2.37
Oklahoma City OK	909	19.5	58%	42%	0.3%	42%	1.37	1.38	2.27
Richmond VA	264	15.8	63%	37%	0.3%	37%	1.71	1.72	1.99
Raleigh NC	330	13.4	69%	31%	0.3%	30%	2.27	2.29	1.79
Memphis TN-MS-AR	582	17.5	61%	39%	0.3%	39%	1.54	1.55	2.13
Louisville-Jefferson County KY-IN	863	17.8	64%	36%	0.3%	36%	1.77	1.79	2.12
Salt Lake City-West Valley City UT	631	16.5	63%	37%	0.3%	37%	1.72	1.73	2.05
Jacksonville FL	791	16.2	69%	31%	0.3%	31%	2.24	2.25	2.01
Providence RI-MA	683	17.0	57%	43%	0.7%	42%	1.33	1.35	2.08
Nashville-Davidson TN	517	19.5	61%	39%	0.5%	38%	1.57	1.59	2.26
Milwaukee WI	1195	15.9	62%	38%	0.3%	37%	1.67	1.68	2.00
Charlotte NC-SC	877	17.6	63%	37%	0.4%	37%	1.70	1.72	2.11
Virginia Beach VA	658	16.7	67%	33%	0.3%	33%	2.00	2.02	2.04
Columbus OH	1073	16.3	64%	36%	0.3%	36%	1.75	1.77	2.03
Kansas City MO-KS	1543	15.6	62%	38%	0.2%	38%	1.62	1.63	1.99
Indianapolis IN	708	17.1	60%	40%	0.4%	39%	1.51	1.52	2.11
Austin TX	1344	18.1	65%	35%	0.3%	35%	1.85	1.87	2.15
Cincinnati OH-KY-IN	2012	15.6	67%	33%	0.3%	33%	1.99	2.01	1.98
Pittsburgh PA	1449	18.5	61%	39%	0.5%	39%	1.55	1.56	2.18
Cleveland OH	1535	17.1	61%	39%	0.4%	38%	1.59	1.61	2.09
Orlando FL	1088	19.2	66%	34%	0.3%	34%	1.94	1.96	2.22
Sacramento CA	187	18.1	59%	41%	0.4%	41%	1.45	1.46	2.16
San Jose CA	506	20.9	56%	44%	0.3%	44%	1.25	1.26	2.36
San Antonio TX	1289	16.8	66%	34%	0.4%	34%	1.91	1.94	2.04
Portland OR-WA	1783	16.0	64%	36%	0.3%	36%	1.75	1.76	1.99
Riverside-San Bernardino CA	377	20.1	56%	44%	0.4%	44%	1.27	1.28	2.31
Las Vegas-Henderson NV	983	23.2	58%	42%	0.3%	42%	1.36	1.37	2.54
St. Louis MO-IL	1582	14.8	68%	32%	0.3%	32%	2.11	2.13	1.91
Baltimore MD	2096	19.1	62%	38%	0.3%	38%	1.64	1.65	2.23
Denver-Aurora CO	2347	15.4	68%	32%	0.2%	32%	2.09	2.11	1.95
Tampa-St. Petersburg FL	1488	19.5	66%	34%	0.2%	34%	1.92	1.93	2.25
Minneapolis-St. Paul MN-WI	2094	15.0	64%	36%	0.2%	35%	1.81	1.82	1.92
San Diego CA	630	20.0	57%	43%	0.5%	43%	1.33	1.34	2.31
Seattle WA	2623	18.1	61%	39%	0.4%	38%	1.58	1.60	2.14
San Francisco-Oakland CA	1179	18.2	62%	38%	0.6%	38%	1.61	1.64	2.15
Detroit MI	4026	14.9	67%	33%	0.3%	33%	2.02	2.04	1.93
Phoenix-Mesa AZ	3237	17.1	65%	35%	0.2%	35%	1.82	1.83	2.09
Boston MA-NH-RI	3081	20.5	55%	45%	0.8%	44%	1.24	1.26	2.32
Washington DC-VA-MD	3736	18.4	65%	35%	0.4%	35%	1.83	1.85	2.13
Atlanta GA	2333	19.2	65%	35%	0.4%	34%	1.89	1.91	2.22
Houston TX	3451	19.5	61%	39%	0.4%	38%	1.58	1.60	2.27
Philadelphia PA-NJ-DE-MD	4189	18.5	59%	41%	0.6%	40%	1.46	1.48	2.20
Dallas-Fort Worth-Arlington TX	4853	18.0	62%	38%	0.3%	37%	1.66	1.67	2.17
Miami FL	3823	21.1	64%	36%	0.3%	36%	1.74	1.76	2.37
Chicago IL-IN	6456	18.3	61%	39%	0.4%	38%	1.58	1.60	2.18
Los Angeles-Long Beach-Anaheim CA	4535	19.4	59%	41%	0.4%	40%	1.46	1.47	2.26
New York-Newark NY-NJ-CT	15789	21.5	61%	39%	0.9%	38%	1.58	1.62	2.37

Table 2. Traffic Signal Performance Measures for 50 States and the District of Columbia

State	No. of Signals	Total Delay (hr)		Avg Delay per Veh (sec)	% Arrivals on Green	% Arrivals on Red	% Split Failure	% Arrivals on Red (not split failure)	TSEI (Raw)	TSEI (Adjusted)	Traffic Signal Weighted LOS
		Weekly	Annual								
AK	328	137,082	7,128,258	14.2	67%	33%	0.2%	33%	2.06	2.07	1.86
AL	2,199	889,840	46,271,689	17.0	65%	35%	0.3%	35%	1.85	1.87	2.07
AR	664	263,106	13,681,502	16.2	60%	40%	0.4%	40%	1.48	1.50	1.82
AZ	4,818	2,832,969	147,314,364	16.6	64%	36%	0.2%	36%	1.80	1.81	2.05
CA	27,527	14,363,403	746,896,971	17.6	61%	39%	0.4%	39%	1.55	1.57	2.12
CO	4,455	2,097,564	109,073,346	14.9	67%	33%	0.2%	33%	2.05	2.07	1.91
CT	2,440	786,933	40,920,526	15.8	61%	39%	0.5%	38%	1.58	1.60	1.98
DC	1,113	585,613	30,451,866	20.8	63%	37%	0.9%	36%	1.72	1.76	2.20
DE	889	347,086	18,048,457	16.6	66%	34%	0.3%	34%	1.94	1.95	2.05
FL	15,327	9,257,942	481,412,963	18.5	65%	35%	0.3%	35%	1.82	1.83	2.18
GA	4,670	2,006,126	104,318,559	17.7	65%	35%	0.4%	35%	1.85	1.87	2.12
HI	603	330,655	17,194,037	16.9	64%	36%	0.4%	35%	1.79	1.81	2.04
IA	1,752	437,667	22,758,659	13.4	64%	36%	0.3%	36%	1.78	1.80	1.79
ID	798	410,604	21,351,387	18.4	58%	42%	0.4%	41%	1.40	1.41	2.18
IL	9,402	4,393,650	228,469,776	17.6	61%	39%	0.4%	39%	1.56	1.58	2.14
IN	3,799	1,332,375	69,283,490	15.2	62%	38%	0.3%	38%	1.63	1.64	1.95
KS	1,696	556,794	28,953,298	15.1	61%	39%	0.2%	39%	1.58	1.59	1.94
KY	2,503	936,925	48,720,115	16.1	65%	35%	0.3%	34%	1.89	1.91	2.00
LA	892	362,937	18,872,704	19.5	59%	41%	0.6%	41%	1.42	1.44	2.28
MA	4,034	1,811,562	94,201,228	19.6	56%	44%	0.7%	44%	1.25	1.27	2.26
MD	4,772	2,465,239	128,192,416	17.9	63%	37%	0.3%	36%	1.73	1.74	2.14
ME	331	141,740	7,370,481	17.8	57%	43%	0.5%	43%	1.32	1.33	2.15
MI	7,091	3,108,932	161,664,483	15.1	65%	35%	0.3%	35%	1.85	1.86	1.95
MN	3,302	1,067,604	55,515,432	14.7	64%	36%	0.3%	36%	1.76	1.78	1.90
MO	4,016	1,320,140	68,647,288	15.0	65%	35%	0.3%	35%	1.83	1.85	1.92
MS	815	339,269	17,642,013	18.4	59%	41%	0.4%	41%	1.43	1.45	2.19
MT	446	181,285	9,426,842	15.9	62%	38%	0.4%	37%	1.64	1.66	1.99
NC	5,603	2,055,589	106,890,602	14.4	66%	34%	0.3%	34%	1.94	1.96	1.86
ND	290	98,315	5,112,355	13.7	65%	35%	0.4%	35%	1.83	1.85	1.83
NE	1,563	431,914	22,459,513	12.2	69%	31%	0.3%	31%	2.19	2.21	1.69
NH	763	305,941	15,908,948	17.6	58%	42%	0.4%	42%	1.37	1.39	2.13
NJ	7,771	2,814,912	146,375,448	17.7	60%	40%	0.5%	39%	1.51	1.53	2.14
NM	1,331	137,082	7,128,258	15.3	63%	37%	0.2%	37%	1.69	1.70	1.96
NV	1,713	1,299,274	67,562,251	21.3	58%	42%	0.3%	42%	1.37	1.38	2.41
NY	18,560	7,625,853	396,544,380	20.4	61%	39%	0.9%	38%	1.59	1.63	2.29
OH	9,251	2,909,804	151,309,789	15.4	64%	36%	0.3%	36%	1.75	1.77	1.96
OK	2,277	857,962	44,614,026	18.1	58%	42%	0.4%	41%	1.41	1.42	2.17
OR	3,071	1,077,211	56,014,997	15.1	64%	36%	0.4%	36%	1.76	1.77	1.93
PA	8,837	2,982,927	155,112,210	17.6	59%	41%	0.6%	40%	1.45	1.47	2.13
RI	640	236,092	12,276,780	16.6	58%	42%	0.7%	41%	1.37	1.39	2.04
SC	2,263	1,077,157	56,012,161	16.1	63%	37%	0.4%	36%	1.73	1.75	2.01
SD	569	147,158	7,652,204	14.0	63%	37%	0.3%	36%	1.74	1.75	1.85
TN	1,946	1,015,287	52,794,949	18.4	60%	40%	0.5%	39%	1.52	1.54	2.17
TX	18,024	7,247,095	376,848,938	17.7	62%	38%	0.4%	38%	1.63	1.64	2.14
UT	1,572	688,338	35,793,590	15.8	63%	37%	0.3%	36%	1.73	1.74	1.99
VA	4,489	1,921,471	99,916,488	16.2	65%	35%	0.3%	35%	1.82	1.83	2.01
VT	252	86,550	4,500,595	16.2	61%	39%	0.6%	38%	1.58	1.61	2.01
WA	5,101	2,173,791	113,037,117	17.0	61%	39%	0.4%	39%	1.56	1.58	2.06
WI	3,350	943,434	49,058,560	14.3	63%	37%	0.3%	37%	1.71	1.73	1.87
WV	542	190,266	9,893,809	15.6	61%	39%	0.4%	38%	1.59	1.60	1.97
WY	355	88,368	4,595,120	11.7	68%	32%	0.4%	32%	2.09	2.11	1.64

Table 3. Comparison of Values for Selected States Using Daytime vs All-day Data

Weekday Daytime Only (5 AM - 9 PM)

State	No. of Signals	Avg Delay per Veh (sec)	% Arrivals on Green	% Arrivals on Red	% Split Failure	% Arrivals on Red (not split failure)	TSEI (Raw)	TSEI (Adjusted)	Traffic Signal Weighted LOS
CA	27,527	18.09	59.6%	40.4%	0.4%	40.0%	1.47	1.49	2.16
DC	1,113	21.29	62.2%	37.8%	0.938%	36.9%	1.64	1.69	2.28
FL	15,327	19.03	63.4%	36.6%	0.3%	36.3%	1.73	1.75	2.22
GA	4,670	18.15	63.8%	36.2%	0.4%	35.8%	1.76	1.78	2.15
KY	2,503	16.50	64.2%	35.8%	0.300%	35.4%	1.80	1.81	2.03
MA	4,034	20.04	54.5%	45.5%	0.8%	44.7%	1.20	1.22	2.29
MN	3,302	14.95	63.0%	37.0%	0.300%	36.7%	1.70	1.72	1.92
NC	5,603	14.73	65.1%	34.9%	0.300%	34.5%	1.87	1.89	1.88
NE	1,563	12.36	67.7%	32.3%	0.300%	32.0%	2.10	2.12	1.71
OH	9,251	15.76	62.5%	37.5%	0.400%	37.2%	1.67	1.68	1.99
OR	3,071	15.49	62.7%	37.3%	0.400%	36.9%	1.68	1.70	1.95
WA	5,101	17.45	59.9%	40.1%	0.400%	39.7%	1.50	1.51	2.10

Weekday All-day

State	No. of Signals	Avg Delay per Veh (sec)	% Arrivals on Green	% Arrivals on Red	% Split Failure	% Arrivals on Red (not split failure)	TSEI (Raw)	TSEI (Adjusted)	Traffic Signal Weighted LOS
CA	27,527	17.59	60.8%	39.2%	0.4%	38.8%	1.55	1.57	2.12
DC	1,113	20.79	63.2%	36.8%	0.870%	35.9%	1.72	1.76	2.20
FL	15,327	18.55	64.5%	35.5%	0.3%	35.2%	1.82	1.83	2.18
GA	4,670	17.70	64.9%	35.1%	0.4%	34.8%	1.85	1.87	2.12
KY	2,503	16.09	65.4%	34.6%	0.324%	34.3%	1.89	1.91	2.00
MA	4,034	19.57	55.5%	44.5%	0.7%	43.7%	1.25	1.27	2.26
MN	3,302	14.68	63.8%	36.2%	0.276%	35.9%	1.76	1.78	1.90
NC	5,603	14.43	66.0%	34.0%	0.321%	33.7%	1.94	1.96	1.86
NE	1,563	12.16	68.7%	31.3%	0.262%	31.1%	2.19	2.21	1.69
OH	9,251	15.42	63.6%	36.4%	0.341%	36.0%	1.75	1.77	1.96
OR	3,071	15.11	63.7%	36.3%	0.352%	35.9%	1.76	1.77	1.93
WA	5,101	16.97	61.0%	39.0%	0.377%	38.6%	1.56	1.58	2.06

Percent Change

State	No. of Signals	Avg Delay per Veh	% Arrivals on Green	% Arrivals on Red	% Split Failure	% Arrivals on Red (not split	TSEI (Raw)	TSEI (Adjusted)	Traffic Signal Weighted LOS
CA	27,527	3%	-2%	3%	5%	3%	-5%	-5%	2%
DC	1,113	2%	-2%	3%	8%	3%	-4%	-4%	3%
FL	15,327	3%	-2%	3%	4%	3%	-5%	-5%	1%
GA	4,670	3%	-2%	3%	4%	3%	-5%	-5%	1%
KY	2,503	3%	-2%	3%	-7%	3%	-5%	-5%	1%
MA	4,034	2%	-2%	2%	5%	2%	-4%	-4%	2%
MN	3,302	2%	-1%	2%	9%	2%	-4%	-4%	1%
NC	5,603	2%	-1%	3%	-6%	2%	-4%	-4%	1%
NE	1,563	2%	-1%	3%	15%	3%	-4%	-4%	1%
OH	9,251	2%	-2%	3%	17%	3%	-5%	-5%	1%
OR	3,071	3%	-2%	3%	14%	3%	-4%	-4%	1%
WA	5,101	3%	-2%	3%	6%	3%	-4%	-4%	2%

Figure 1. Percent Arrivals on Green for Urban Areas

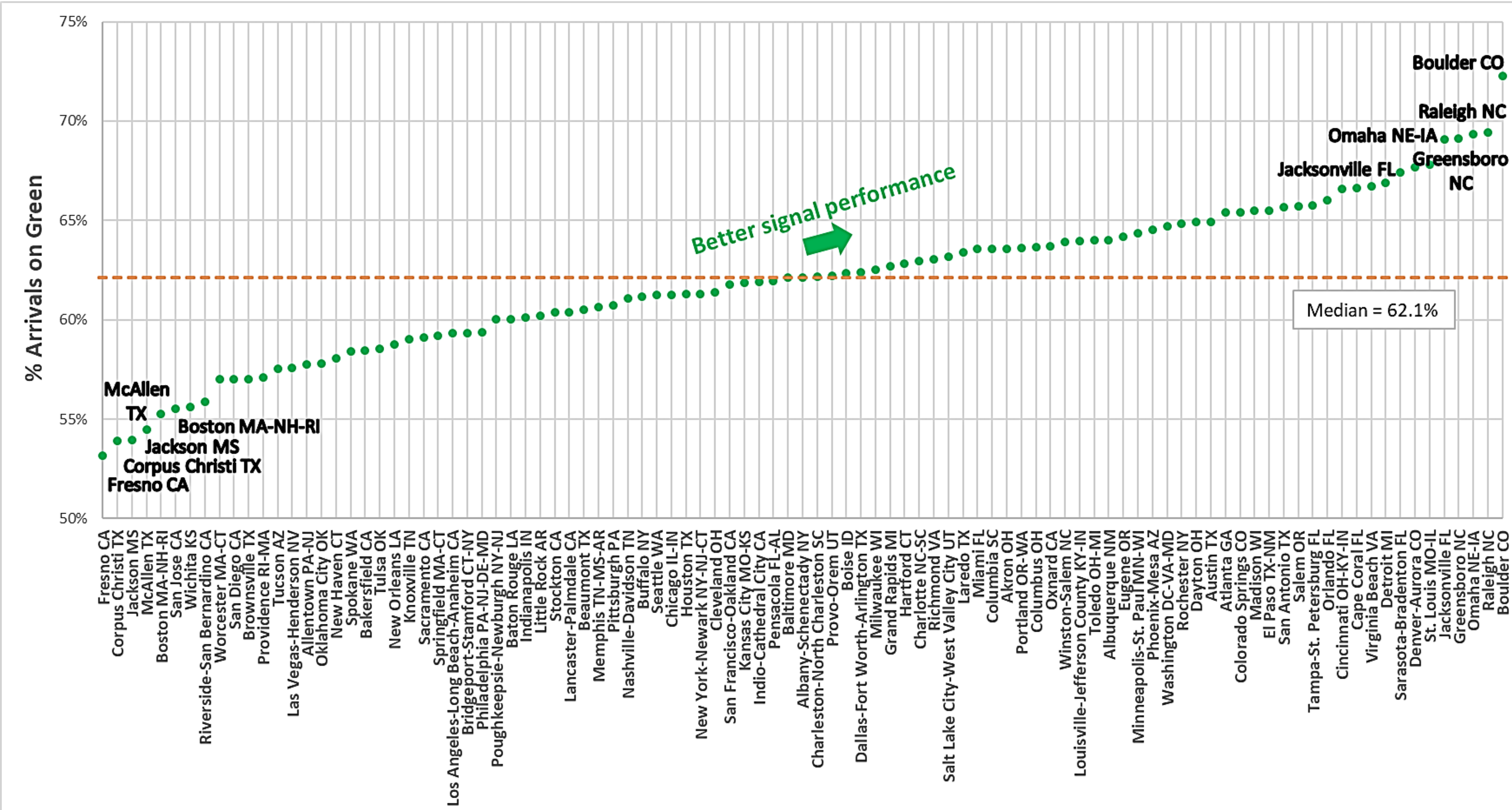


Figure 2. Weighted Level of Service for Urban Areas

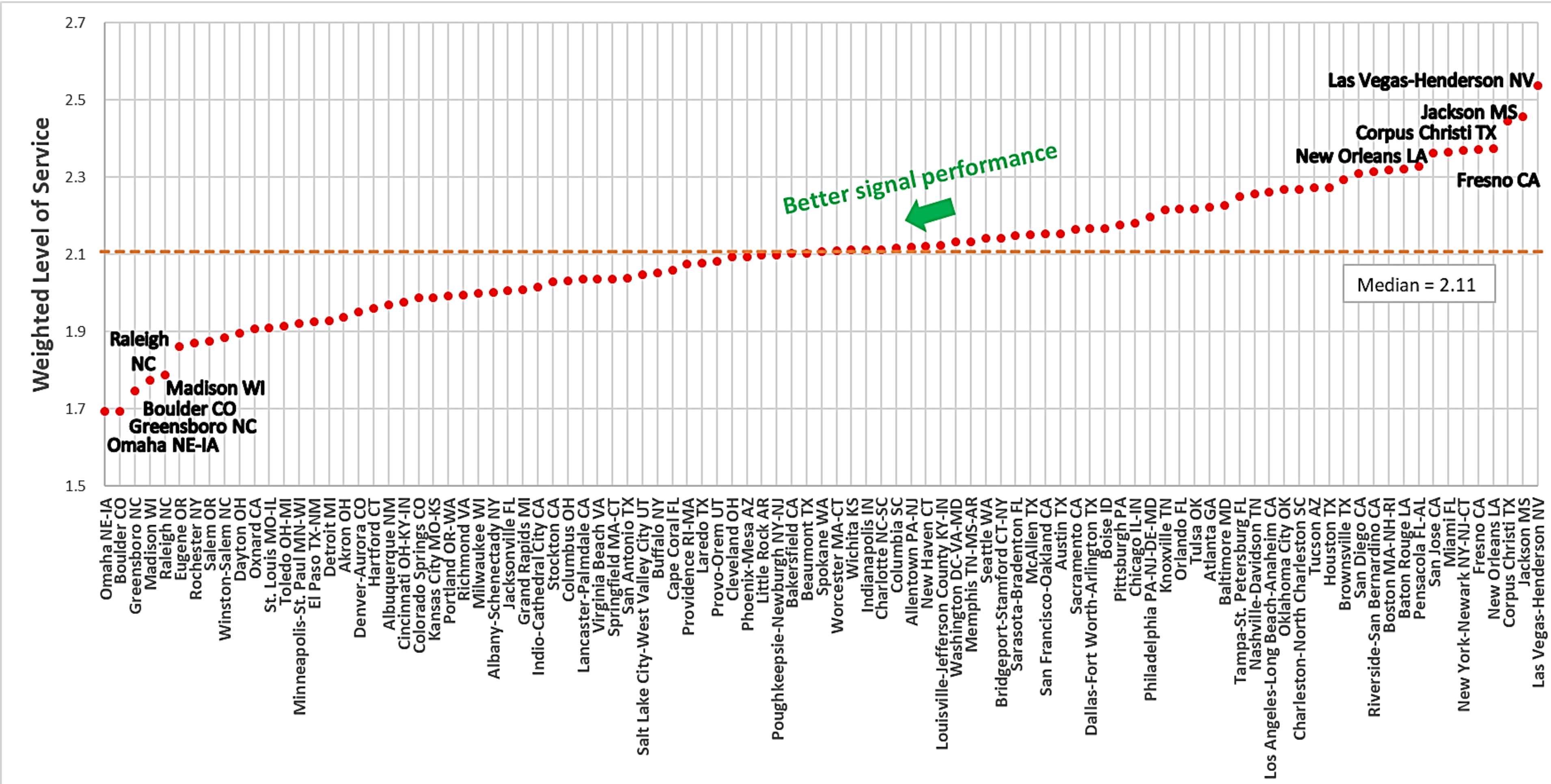
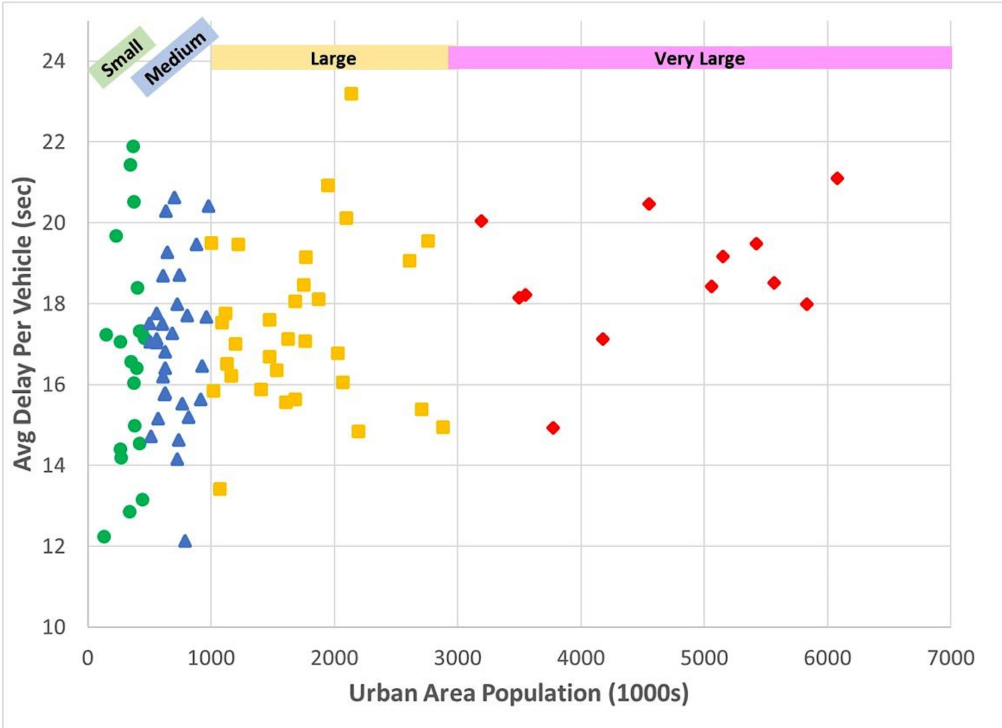
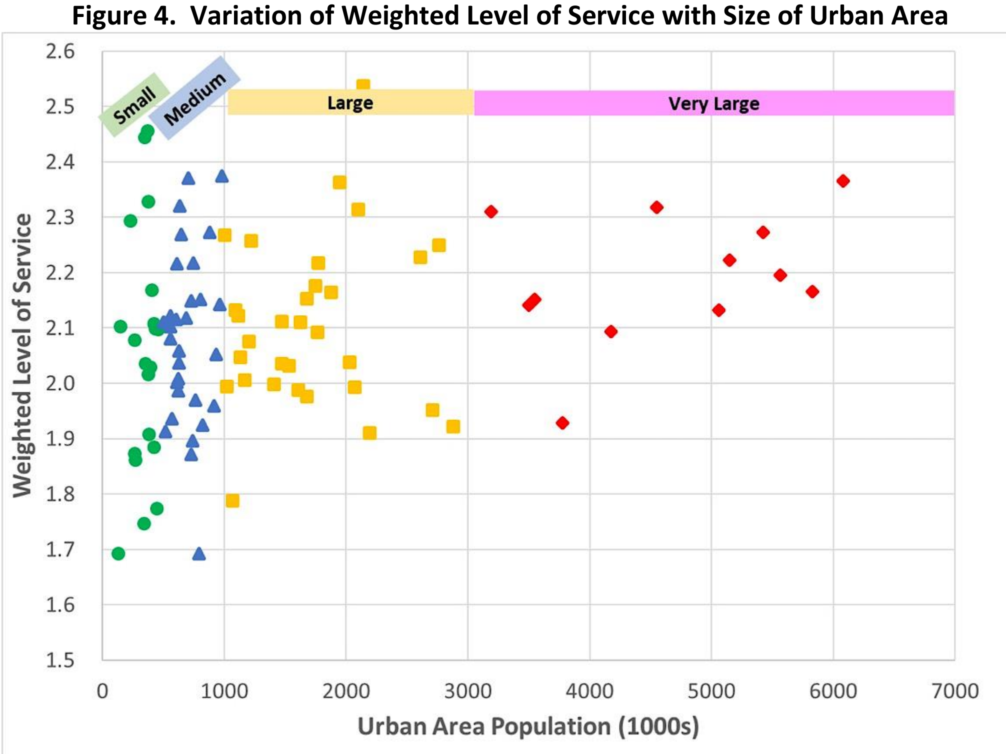


Figure 3. Variation of Average Delay per Vehicle with Size of Urban Area



Very Large Urban Areas–over 3 million population
Large Urban Areas–over 1 million and less than 3 million population
Medium Urban Areas– over 500,000 and less than 1 million population
Small Urban Areas– less than 500,000 population

Figure 4. Variation of Weighted Level of Service with Size of Urban Area



Very Large Urban Areas–over 3 million population
Large Urban Areas–over 1 million and less than 3 million population
Medium Urban Areas– over 500,000 and less than 1 million population
Small Urban Areas– less than 500,000 population

Figure 5. Variation of Average Delay per Vehicle with Signal Density of Urban Area

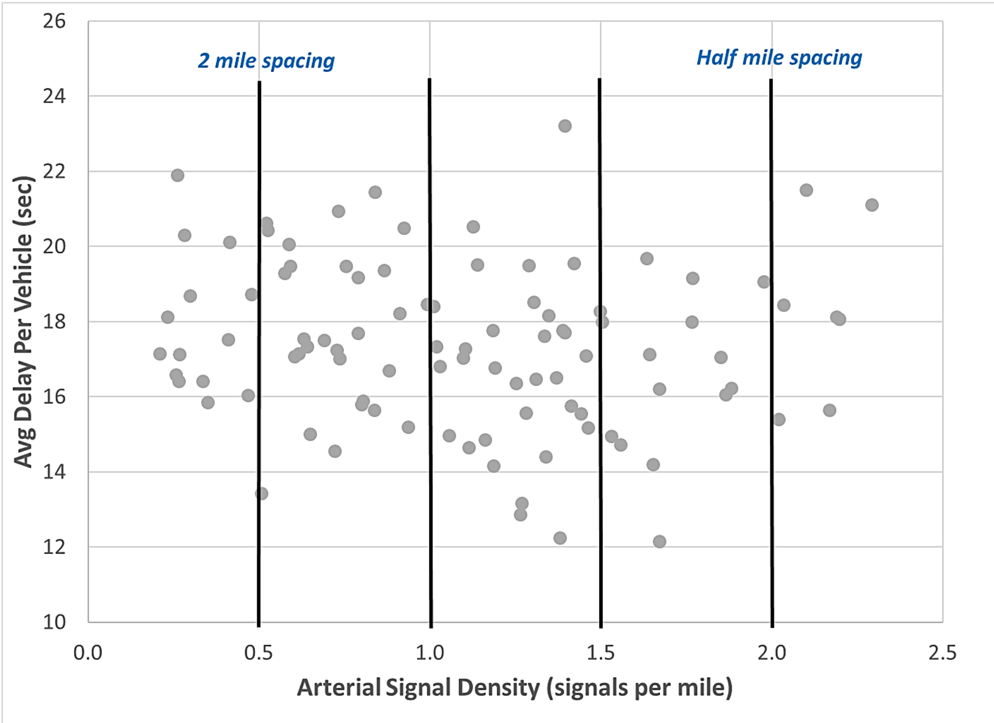


Figure 6. Variation of Traffic Signal Weighted LOS with Signal Density of Urban Area

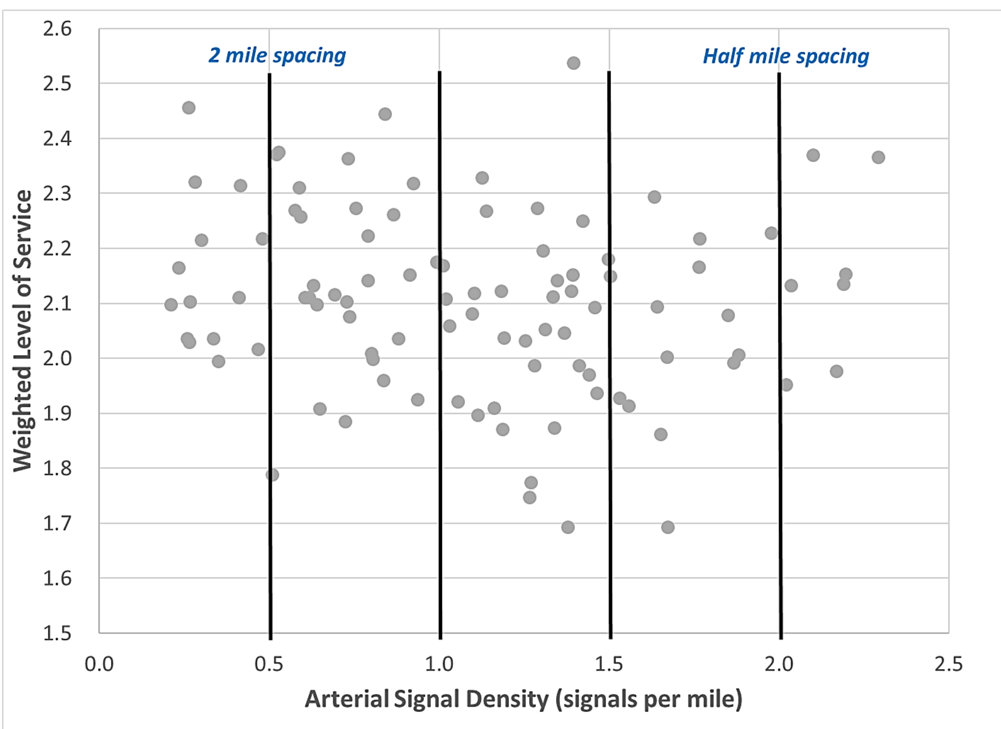


Figure 7. Percent Arrivals on Red by State

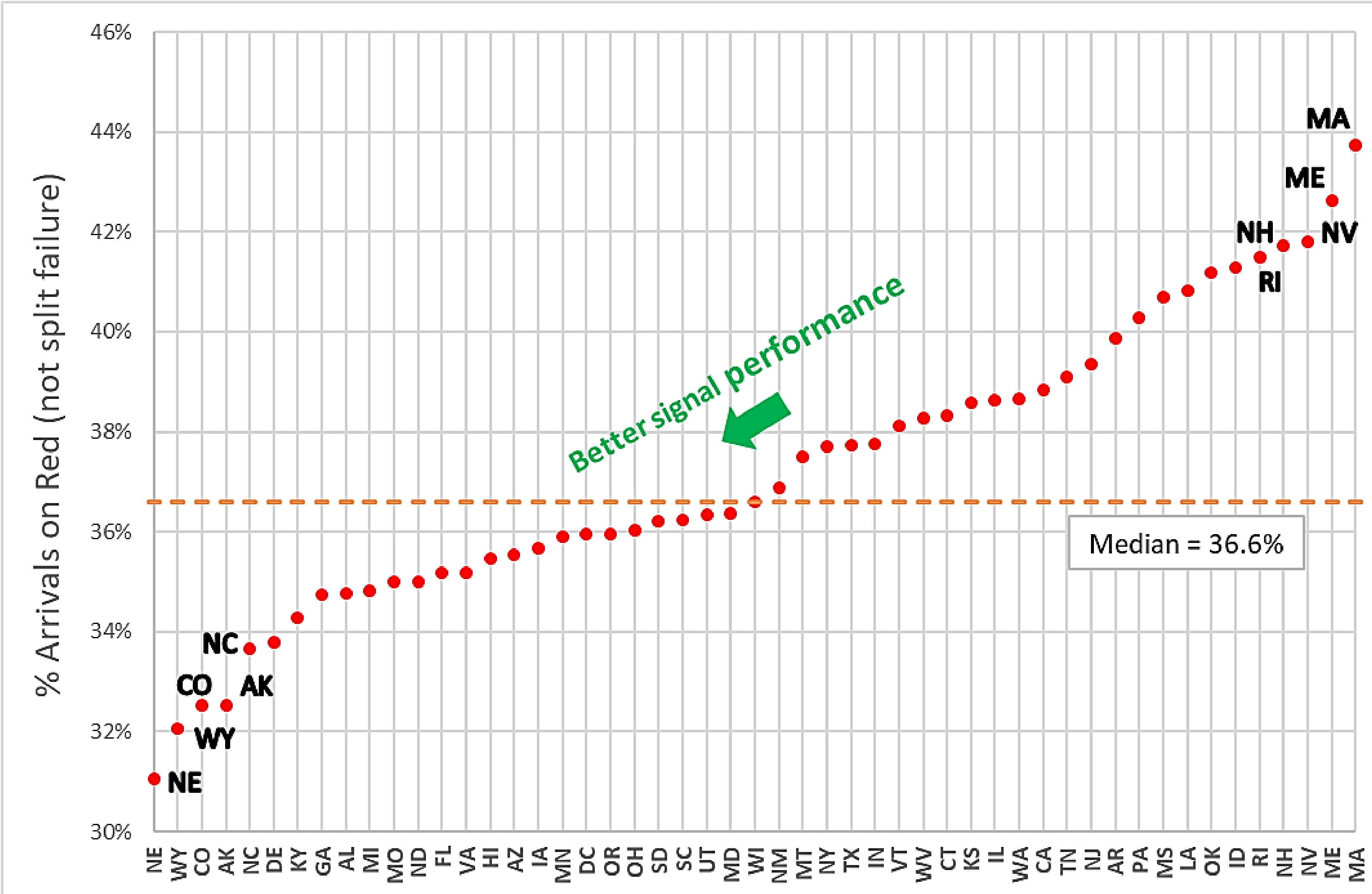


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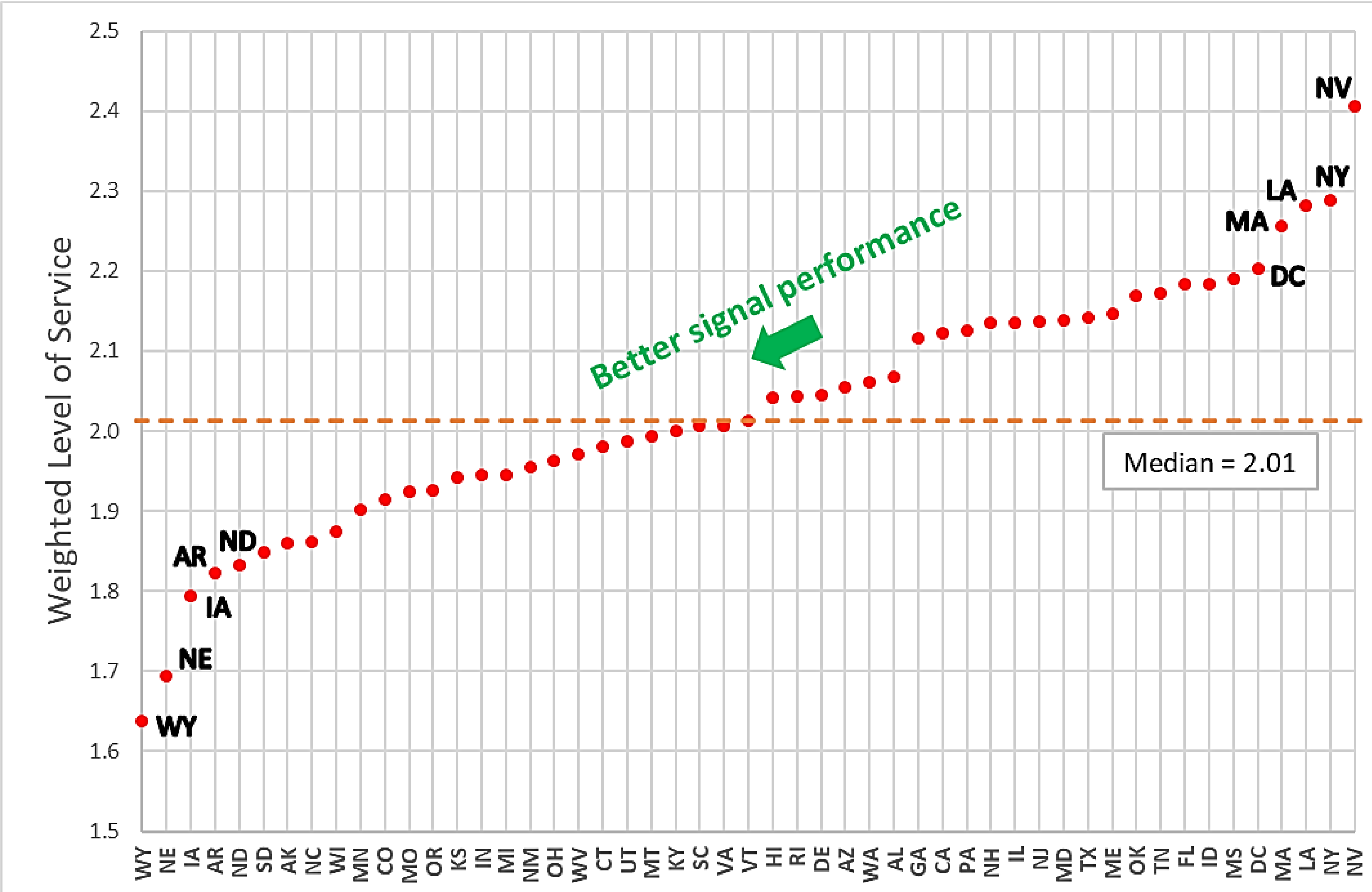
Figure 8. Traffic Signal Weighted Level of Service by State



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FINAL REPORT
March 2022

Evaluating Regional Traffic Signal Performance Measures Using Crowd-Sourced Data in 2021 Urban Mobility Report

Appendix A: Methodology

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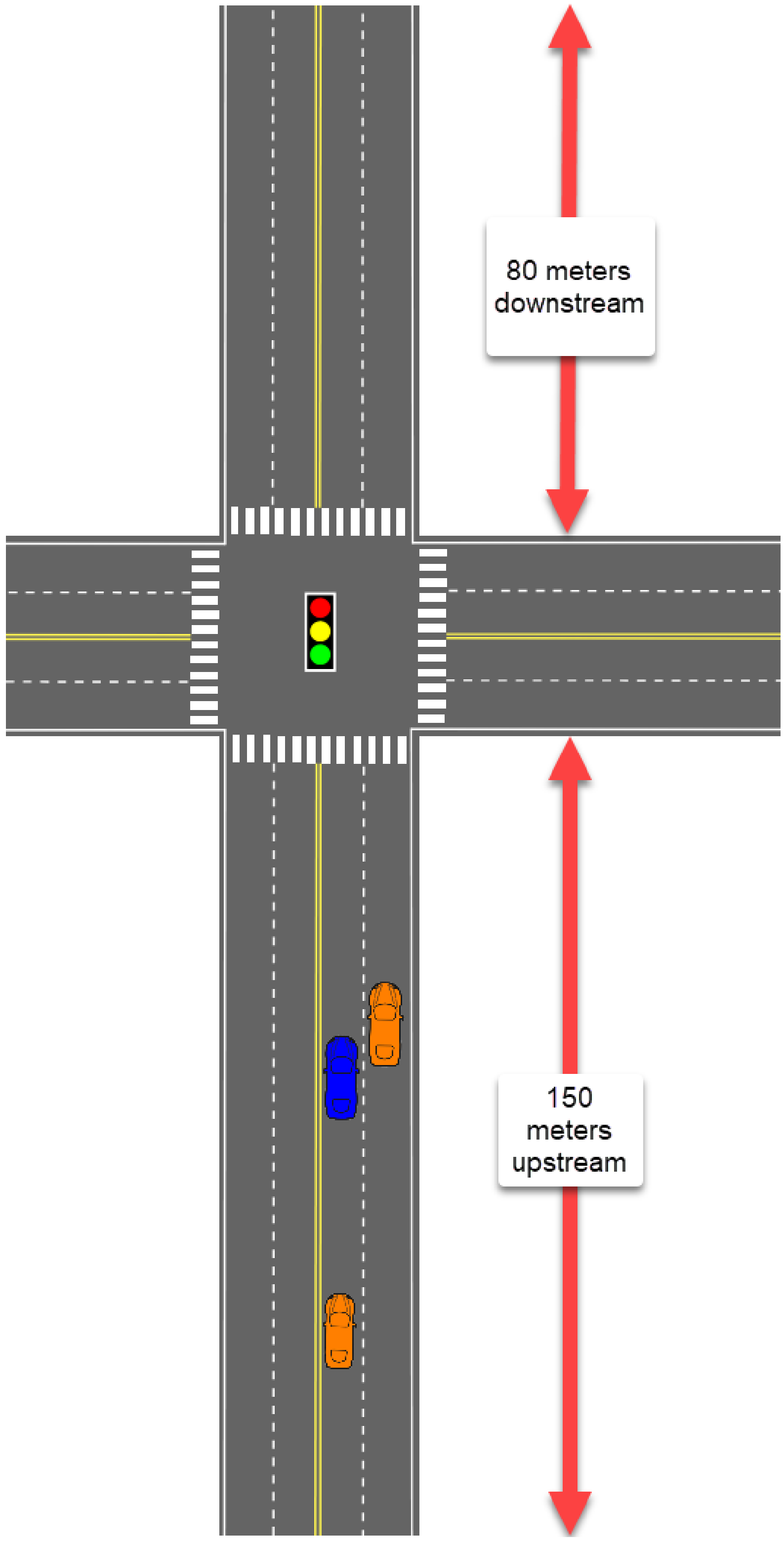
INRIX Traffic Signal Performance Data

INRIX developed a method to obtain traffic signal analytics data without needing to install field detection equipment. To obtain this data, INRIX collects anonymous vehicle waypoint "breadcrumbs" at 3 to 5 second intervals from probe vehicles. Individual vehicle waypoints are used to calculate travel times through intersections. Within the Traffic Signal Analytics application, INRIX uses the following assumptions when estimating vehicle attributes such as turning movements, vehicle stops, approach speed, and traffic signal split failures.

1. Shown in Exhibit A-1, the intersection influence area is 150 meters upstream and 80 meters downstream of the intersection. All data are aggregated together at the node (signal) for all intersecting roadways.
2. The 5^{th} percentile travel time is used to define the limit of unimpeded travel time, so vehicles traveling slower than the 5^{th} percentile travel time are considered to be delayed.
3. Vehicles that slow below 6 MPH for 3 seconds or more are considered stopped vehicles. This metric aligns with Advanced Traffic Signal Performance Measures (ATSPMs) in a detector-based system.

Exhibit A-1. INRIX Signal Analytics Intersection Influence Area



This data is aggregated by intersection and summarized over time periods (*1*).

For this analysis, one week of traffic signal data in October 2020 was obtained for approximately 210,000 signals across the United States. The sample rate for this dataset was approximately 2% to 8%, and the data was aggregated into 15-minute time periods over the seven days. The following information was included for each intersection:

- X and Y coordinates of each intersection
- Delay per vehicle – Seconds of delay per vehicle for each 15-minute time period
- Count (not scaled) – Actual count of each vehicle sampled
- Count (scaled) – Estimated count of total vehicles based on vehicles sampled and sample rate for that intersection. Each intersection's count of actual vehicle crossings over each rolling hour in 15-minute increments is scaled up using INRIX volume profiles. Then, all scaled values are added together for a national total (*2*).
- Percent arrival on green – Percentage of vehicles sampled that did not slow down below 6 MPH for at least 3 seconds
- Split failures – Count of vehicles that slowed below 6 MPH for at least 3 seconds multiple times before clearing intersection.
- Level of service for each 15-minute time period.

TTI utilized the X and Y coordinate information to assign the intersections to urban areas from the Urban Mobility Report, so that traffic signal performance measure data could be summarized for each urban area.

Data Considerations

While this dataset is excellent for a high-level comparison of traffic signal performance between urban areas, there are some limitations that must be considered when evaluating performances measures produced from this specific dataset. This data includes approximately 80% of traffic signals in the US covering one week in 2020 with a sample rate between 2% and 8%. There is a robust amount of information included in the dataset, but there are gaps in duration of data collection, intersection coverage and sample penetration that must be contemplated when assessing the data. Moreover, as alluded to earlier in the discussion, the data may be biased towards the major road performance because of lack of adequate data on lower volume routes/private driveways. Example events and/or activities that could affect traffic signal performance for all or a portion of an urban area include:

- major construction;
- special events;
- incidents;
- seasonal activities such as fall foliage viewing;
- weather events including hurricanes;
- community goals;
- major changes in travel patterns such as during the COVID-19 pandemic;
- traffic signal spacing and network.

For example, major construction projects, special events, or major incidents that took place during the week could affect traffic signal performance for a portion of an urban area. Only weekday data was used in the analysis in order to minimize the possibility of construction events or special events impacting the performance measure calculations.

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In addition, areas with Fall seasonal events (e.g., New England Fall foliage, major sporting events, etc.) have significantly different traffic patterns over a short period of time than the rest of the year. Further, severe weather events such as hurricanes can have significant effects on traffic. By aggregating data for the entire urban area, impacts of some major events in a small portion of the urban area are absorbed and may not be noticeable in calculations for the entire area.

Another element for consideration is that community goals regarding non-motorized transportation vary depending on the needs of the community. An urban area with a major college campus or heavy bicycle and pedestrian traffic amongst the general population might have lower traffic signal performance measures than communities that are car-centric. Since this is a measure of traffic signal performance, lower signal performance could be a result mode priority rather than poor signal timing efforts. One item of note regarding college towns and the October 2020 dataset is that most college classes were still virtual in Fall 2020 as a result of the COVID-19 pandemic. As a result, vehicle and pedestrian activity during the study week was much lower than typical traffic during school semester, so traffic signal performance around college campuses was generally much higher than during an otherwise normal Fall traffic.

Two final key considerations that affect the ability to coordinate traffic signals are signal spacing and network topology. Traffic signal spacing is discussed in more detail in the main report, but the closer the traffic signals are spaced, the more challenging it is for traffic engineers to coordinate traffic signals, particularly in multiple directions. Arrivals on green are generally lower and delay is typically higher on corridors which have closely spaced traffic signals. However, the observation on effect of signal density can be different depending on whether the analysis is performed at the corridor level or the urban area level. In the latter case, other confounding factors such as resources (funds, personnel), maintenance routine, equipment, etc., may impact results. Network topology (grid network vs non-uniform roadway network) is also a key consideration, but was not quantifiable for this evaluation.

Traffic Signal Performance Measures

The INRIX traffic signal analytics data was used to both summarize data provided for each urban area, and to calculate additional traffic signal performance measures. When choosing traffic signal performance measures, it is important to use multiple measures to gain a full understanding of traffic signal operations of an urban area. This section of the report outlines the calculation methodology of performance measures. Each of the equations outlined below represents the calculation for one 15-minute time period that was used to aggregate for the week and for the urban area.

Total Delay

Total delay is a good measure of the magnitude of delay at an individual signalized intersection because locations with more vehicles have more delay than intersections with fewer vehicles when operating at a similar level of service. Equations A-1 and A-2 illustrate the total weekly and annual delay calculation for each 15-minute time period that is summed for all time periods for all intersections in the urban area.

$$\text{Total Delay (Weekly)} = \sum(\text{Scaled Count X Delay Per Vehicle}) \qquad \text{(Eq. A 1)}$$

$$\text{Total Delay (Annual)} = \text{Total Delay (Weekly) X 52} \qquad \text{(Eq. A 2)}$$

Average Delay Per Vehicle

Average delay per vehicle is a measure of operation of a traffic signal that is useful to understand the mean wait time for each vehicle at an intersection. Commonly, motorists wait longer at intersections with a higher delay per vehicle regardless of traffic volume at the intersection. This could be attributed to poor signal timing, preemption, or other factors that influence signal operation. In order to calculate delay per vehicle, first the total number of vehicles must be estimated. The calculation for total scaled count is shown in Equation A-3, which sums the scaled count across all time periods and intersections. Calculation of delay per vehicle is shown in Equation A-4.

$$\text{Total Scaled Count} = \sum \text{Scaled Count} \qquad \text{(Eq. A 3)}$$

$$\text{Average Delay Per Vehicle} = \frac{\text{Total Delay (Weekly)}}{\sum \text{Scaled Count}} \qquad \text{(Eq. A 4)}$$

Vehicle Arrivals on Green

Percentage of vehicle arrivals on green is a measure of traffic signal progression, which is a calculation of the percentage of vehicles that proceed through the intersection without stopping. Below are equations used to calculate total arrivals on green (Eq. A-5) and percent arrivals on green (Eq. A-6).

$$\text{Total Arrivals on Green} = \sum(\text{Percent Arrivals on Green} \times \text{Scaled Count}) \qquad \text{(Eq. A 5)}$$

$$\text{Percent Arrivals on Green} = \frac{\text{Total Arrivals on Green}}{\text{Total Scaled Count}} \qquad \text{(Eq. A 6)}$$

Vehicle Arrivals on Red

Percentage of vehicle arrivals on red is also a measure of traffic signal progression and is the opposite of vehicle arrivals on green. Vehicles that stopped before proceeding through the intersection are included in this calculation. Calculations for total arrivals on red and percent arrivals on red are shown in equations A-7 and A-8.

$$\text{Total Arrivals on Red} = \text{Total Scaled Count} - \text{Total Arrivals on Green} \qquad \text{(Eq. A 7)}$$

$$\text{Percent Arrivals on Red} = \frac{\text{Total Arrivals on Red}}{\text{Total Scaled Count}} \qquad \text{(Eq. A 8)}$$

Split Failures

Split failure count can be a measure of excessive delay, as it measures the number of vehicles that stopped at least twice before proceeding through the intersection – meaning that a vehicle was not able to get through the signal on one or more green indications. Although split failures can be an indication of poor signal timing, there are often other contributing factors, such as high traffic volumes relative to intersection capacity, emergency pre-emptions, and traffic incidents. The calculation of total split failures and percentage of split failures are depicted in equations A-9 and A-10. One way to separate arrivals on red potentially due to poor signal timing from arrivals on red due to other factors is to subtract split failures from arrivals on red, as shown in Equation A-11. Lastly, the calculation of percentage of vehicles arriving on red that were not split failures is shown in Equation A-12.

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$$\text{Split Failure Count} = \sum\left(\frac{\text{Scaled Count}}{\text{Count (Not Scaled)}} \times \text{Split Failures}\right) \qquad \text{(Eq. A 9)}$$

$$\text{Percent Split Failures} = \frac{\text{Split Failure Count}}{\text{Total Scaled Count}} \qquad \text{(Eq. A 10)}$$

$$\text{Arrivals on Red (Not Split Failure)} = \text{Total Arrivals on Red} - \text{Split Failure Count} \qquad \text{(Eq. A 11)}$$

$$\text{\% Arrivals on Red (Not Split Failure)} = \frac{\text{Total Arrivals on Red} - \text{Split Failure Count}}{\text{Total Scaled Count}} \qquad \text{(Eq. A 12)}$$

Traffic Signal Efficiency Index

The traffic signal efficiency index (TSEI) is another performance measure for traffic signal progression that measures the likelihood a driver is to arrive on green versus red. There are two traffic signal efficiency indices (raw and adjusted). The raw traffic signal efficiency index includes all vehicle arrivals, while the adjusted traffic signal efficiency index does excludes split failures in the arrivals on red. The adjusted index is used to measure signal timing efficiency under free flow conditions because split failures can be caused by factors other than signal timing (e.g., capacity constraints, pedestrian activity, emergency pre-emptions, traffic incidents, etc.). Traffic signal efficiency indices calculations are shown in Equations A-13 and A-14.

$$\text{Traffic Signal Efficiency Index (Raw)} = \frac{\text{Percent Arrival on Green}}{\text{Percent Arrival on Red}} \qquad \text{(Eq. A 13)}$$

$$\text{Traffic Signal Efficiency Index (Adjusted)} = \frac{\text{Percent Arrival on Green}}{\text{Percent Arrival on Red (Not Split Failure)}} \qquad \text{(Eq. A 14)}$$

Both raw and adjusted traffic signal efficiency indices are calculated to determine traffic signal efficiency for both normal and free flow conditions. With traffic volumes reduced in 2020 due to COVID, during the week of data collection, there were fewer split failures due to capacity limitations than would be expected in a normal traffic week. It is anticipated that if these measures are re-evaluated with traffic data in the future, there would be a larger difference between TSEI and adjusted TSEI, which would provide some insight on efficiency of signal timing isolated from other factors that cause intersection inefficiencies.

This report introduces a new metric, TSEI, that is easily understood as the multiplication factor that a vehicle is more likely to arrive on green compared to red (X times more arrivals on green than red). It utilizes data available to calculate metrics similar to Platoon Ratio calculations in the Highway Capacity Manual. The HCM 6th Edition includes details on using Platoon Ratios as a measure to describe signal progression quality. A Platoon Ratio measure is meant to be applied to a specific signal movement group (e.g., major street through movements), however, both metrics are related to arrivals on green.

Orange County Transportation Authority is proactive in measurement of traffic signal performance and uses a combination of measures to develop an index to report the overall signal system. Included in this index is a ratio of arrivals on green to arrivals on red (*4*). Based on the example corridors shown on their website, a 1.8-2.0 ratio resulted in a Corridor Synchronization Performance Index (SCPI) Level Tier 3 which is Fair and the minimum level for which they do not recommend consideration for applying for signal synchronization funding.

Level of Service

The most common measure of delay at an intersection is level of service (LOS) derived from the Highway Capacity Manual. Signalized intersection LOS is defined in terms of average total delay of all movements through an intersection (*3*). Letter grades are applied to LOS delay ranges, from LOS A (10 seconds or less delay per vehicle) to LOS F (greater than 80 seconds per vehicle). LOS D (between 35 and 55 seconds per vehicle) or better is generally considered to be an acceptable level of service, so data was aggregated to determine the percentage of time that each intersection was operating at LOS D or better.

In addition, traffic signal weighted LOS was calculated for each urban area, and the calculation for weighted LOS is shown in Equation A-15 with the following number scores applied to each LOS:

- LOS A = 1
- LOS B = 2
- LOS C = 3
- LOS D = 4
- LOS E = 5
- LOS F = 6

$$\text{Traffic Signal Weighted LOS} = \frac{\sum(\text{Level of Service Number Score} \times \text{Scaled Count})}{\text{Total Scaled Count}} \qquad \text{(Eq. A 15)}$$

Weighted LOS is a metric that normalizes LOS for an urban area by considering the amount of traffic at each intersection. Regions with a weighted LOS score of less than or equal to 4 have weighted LOS for the region of D or better, which is considered to be an acceptable level of service.

Traffic Signal Density

Traffic signal density was calculated by dividing the number of signalized intersections analyzed in the urban area by the centerline miles of arterial roads (principal and minor arterials from FHWA statistics dataset). This calculation is shown in Equation A-16.

$$\text{Traffic Signal Density} = \frac{\text{Number of Traffic Signals}}{\text{Miles of Arterial Roads}} \qquad \text{(Eq. A 16)}$$

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FINAL REPORT
March 2022

Evaluating Regional Traffic Signal Performance Measures Using Crowd-Sourced Data in 2021 Urban Mobility Report

Appendix B: Signal and Corridor Level Analyses

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Applications of INRIX Traffic Signal Analytics Data

Applications of INRIX Signal Analytics data are wide ranging from an areawide, corridor, and individual intersection perspective. Data can be archived so that year over year comparisons can be made for each of these spatial levels. Also, Cities can dive deep into performance at intersections and corridors to report on changes (e.g., year over year, before and after projects, etc.). Before and after studies can be used to fulfill requirements for federal projects. This data can be used to assist with the prioritization process for Metropolitan Planning Organizations (MPOs) and other regional authorities are tasked with prioritizing signal timing projects as well as other types of projects for a region. While detection equipment is necessary to operate traffic signals, this data source provides an opportunity to effectively manage resources and significantly reduce internal data collection and processing.

Corridor Level Traffic Signal Performance

This effort did not evaluate traffic signal performance measures at the corridor level for all urban areas, but an example corridor was assessed as a proof of concept for use of this data at a corridor level. The example seven-mile long corridor has an ADT of approximately 40,000 to 60,000 vehicles under normal traffic conditions, and includes a single point urban interchange at the west end, a diamond interchange at the east end in addition to 19 signalized intersections in between. The remaining 19 intersections are a mix of arterial, collector and driveways and are spaced between ¼ and one mile apart. The density of the signals gets higher starting at intersection 8 where nearly every intersection is ¼ mile apart, whereas on the east end signals are between 1 mile to ½ mile spacing. The traffic signals along the corridor with approximate spacing and intersecting roadway functional classification are shown in Exhibit B-1. There are a variety of land uses along the corridor that range from residential, to office, to commercial including intense commercial development and a regional mall on the west end served by signals 17-21. So, this example corridor helps in assessing the effects land use might have on signal timing.

Exhibit B-2 includes information about traffic signal spacing, land uses, and traffic signal performance measures (weekday data only) for each intersection along this corridor. Additionally, average delay per vehicle, percent arrivals on green, traffic signal efficiency index, and weighted level of service for each intersection along the corridor are presented in Exhibits B-3 through B-6. Key takeaways from this analysis are as follows:

- As expected, overall signal performance is much lower (arrivals on green less than 50%) at arterial-arterial intersections, especially where commercial development is most dense with grocery store and regional mall. The least delays are at the collector street intersections with residential and light commercial or mixed-use land uses.
- Traffic signal performance is extremely high (arrivals on green of 70% or higher) at arterial intersections with collector roads and driveways because the heavy flow of traffic along the arterial is able to be served with most of the green time for each cycle, and sometimes the entire cycle if there is no side street traffic.
- Traffic signal performance along this corridor appears to be independent of signal spacing, as the intersections that are spaced further apart (intersections 3 through 8) had comparable performance measures when compared with more closely spaced similar intersections (intersections 9 through 22).
- The split failures – the proportion of vehicles not getting through the intersection on the first green light – are low for all the intersections. Worth revisiting here is that this is one week of data in October 2020 when many schools were still providing virtual options, and a lot of people were still working from

home so there was less traffic demand and shorter lines at the signals. One other thing to point out though is that INRIX is not considering vehicles outside the intersection influence area discussed earlier, so some very long queues – more than 150 m upstream – are not accounted for in the split failure count and this value may be artificially low or underestimated. There is however an INRIX corridor tool that takes this into consideration when conducting a corridor analysis, so the information is available.

- This dataset is useful for understanding traffic signal performance for intersections along a corridor to alert traffic engineers of potential areas that need closer evaluation.
- While this dataset cannot replace the need for detection equipment to serve as the "eyes" of the traffic signal controller, it can serve as a tool for traffic engineers to easily aggregate data and calculate easy to understand performance measures.
- One challenge for traffic engineers developing signal timing plans is when corridors cross jurisdictional boundaries. This dataset can provide the ability to measure performances for a corridor in multiple jurisdictions, regardless of equipment used by each agency along the corridor.

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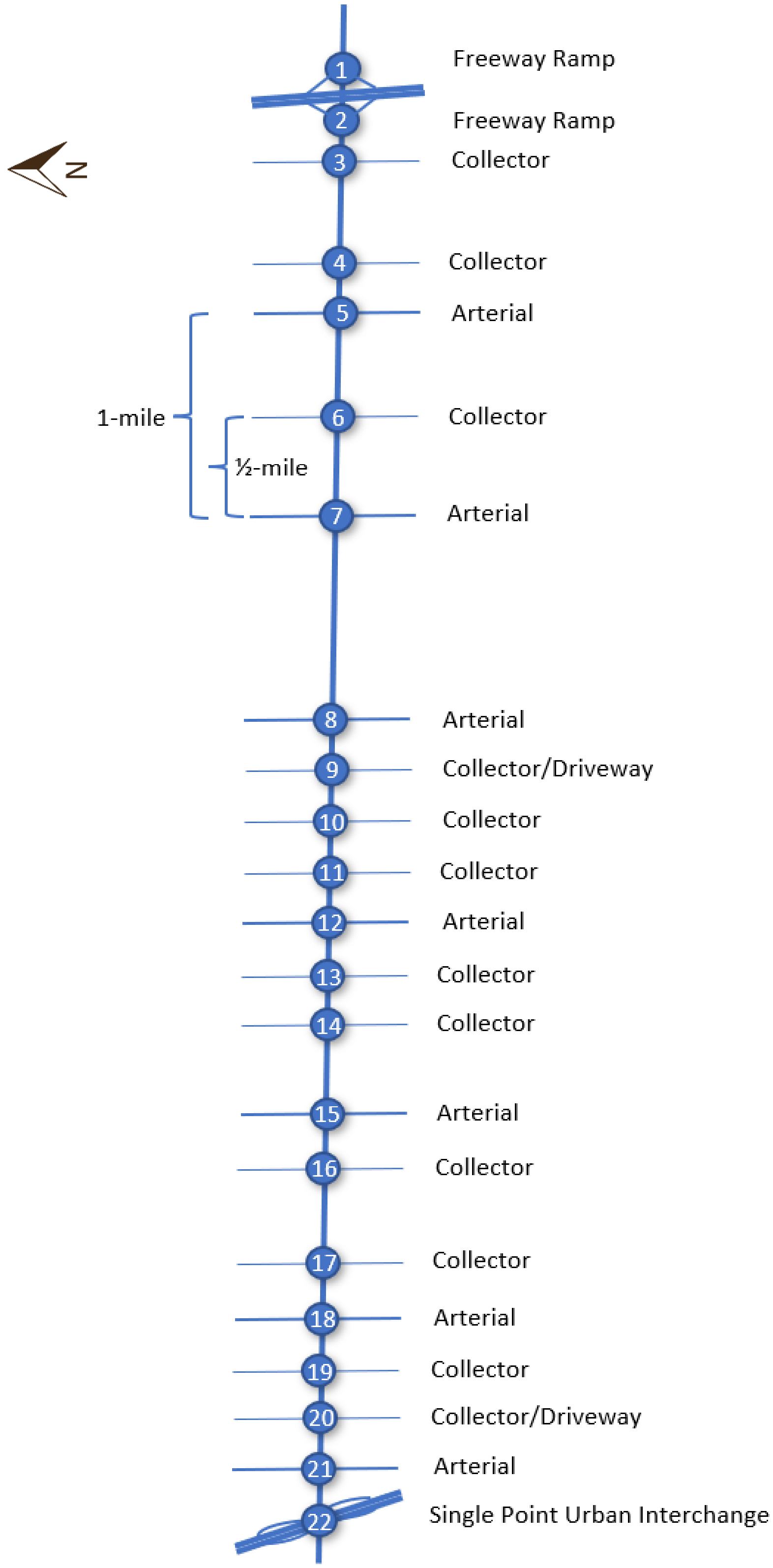
Exhibit B-1. Sample Corridor Intersection Information



The data for percent arrivals on green tend to follow the same pattern as the delay data, with the exception of intersection #20 down towards the bottom of Exhibit B-2. This could be because the cross streets at this intersection are a combination of a collector street and a driveway and the results are aggerated over all the weekdays.

The two traffic signal efficiency index numbers – a measure of the relative likelihood of arriving on a green versus red signal indication – are also about the same with the low split failure rates. Based on this data, drivers arriving at intersection #13 are over 9 times more likely to arrive on green versus red. At intersection #18, the traffic signal efficiency index is 0.69, so drivers are in fact more likely to arrive on red than green – nearly 1.5 times more likely.

Finally, for the weighted LOS data shown in Exhibit B-2, the lower the number the better the level of service provided. LOS is another measure to help tell the story on how a signal is operating, but because the letters cover a range of delay values, performance measures like the TSEI provide more detailed insight for both traffic engineers and the public on how the signal is operating.

Exhibit B-2. Sample Corridor Traffic Signal Performance Measures

Intersection #	Distance to Prior Signal (Miles)	Side Street Classification	Avg Delay per Veh (sec)	% Arrivals on Green	% Arrivals on Red	% Split Failure	% Arrivals on Red (not split failure)	TSEI (Raw)	TSEI (Adjusted)	Traffic Signal Weighted LOS	Land Uses
1	0	Freeway Ramp	19.75	54.0%	46.0%	0.2%	45.9%	1.17	1.18	2.44	Dense Commercial
2	0.2	Freeway Ramp	18.53	57.6%	42.4%	0.1%	42.3%	1.36	1.36	2.32	Dense Commercial
3	0.25	Collector	18.29	57.0%	43.0%	0.3%	42.7%	1.33	1.33	2.28	Residential/Commercial (Grocery Store)
4	0.5	Collector	7.77	82.2%	17.8%	0.0%	17.8%	4.61	4.61	1.26	Residential/Small Commercial
5	0.25	Arterial	26.60	43.1%	56.9%	0.2%	56.7%	0.76	0.76	2.94	Residential/Small Commercial
6	0.5	Collector	7.68	80.9%	19.1%	0.0%	19.1%	4.22	4.22	1.28	Residential
7	0.5	Arterial	26.41	44.0%	56.0%	0.5%	55.5%	0.79	0.79	2.90	Mixed Use
8	1	Arterial	26.80	44.7%	55.3%	0.3%	55.0%	0.81	0.81	2.96	Medium Commercial
9	0.25	Collector/Driveway	5.50	87.9%	12.1%	0.0%	12.1%	7.25	7.27	1.09	Mixed Use
10	0.25	Collector	8.95	76.2%	23.8%	0.2%	23.6%	3.20	3.22	1.40	Mixed Use
11	0.25	Collector	11.36	74.7%	25.3%	0.0%	25.3%	2.95	2.96	1.65	Mixed Use
12	0.25	Arterial	33.55	37.9%	62.1%	0.5%	61.6%	0.61	0.61	3.35	Dense Commercial
13	0.25	Collector	5.05	90.1%	9.9%	0.1%	9.8%	9.14	9.21	1.04	Medium Commercial
14	0.25	Collector	12.49	70.9%	29.1%	0.0%	29.0%	2.44	2.44	1.76	Medium Commerical/Multi-Family
15	0.5	Arterial	35.01	35.4%	64.6%	1.2%	63.4%	0.55	0.56	3.48	Medium Commercial (Grocrery Store)
16	0.25	Collector	9.19	76.1%	23.9%	0.1%	23.8%	3.19	3.20	1.45	Medium Commercial/Multi-Family
17	0.5	Collector	9.29	80.0%	20.0%	0.1%	19.9%	4.00	4.03	1.46	Dense Commercial
18	0.25	Arterial	35.70	40.5%	59.5%	0.5%	59.1%	0.68	0.69	3.50	Dense Commerical/Regional Mall
19	0.25	Collector	31.07	39.8%	60.2%	0.4%	59.8%	0.66	0.66	3.19	Dense Commerical/Regional Mall
20	0.25	Collector/Driveway	22.59	62.7%	37.3%	0.7%	36.6%	1.68	1.72	2.61	Dense Commerical/Regional Mall
21	0.25	Arterial	39.45	39.0%	61.0%	1.3%	59.7%	0.64	0.65	3.69	Dense Commercial
22	0.25	Single Point Urban Interchange	28.80	54.8%	45.2%	0.0%	45.2%	1.21	1.21	3.07	Dense Commercial

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Exhibit B-3. Average Delay Per Vehicle by Intersection

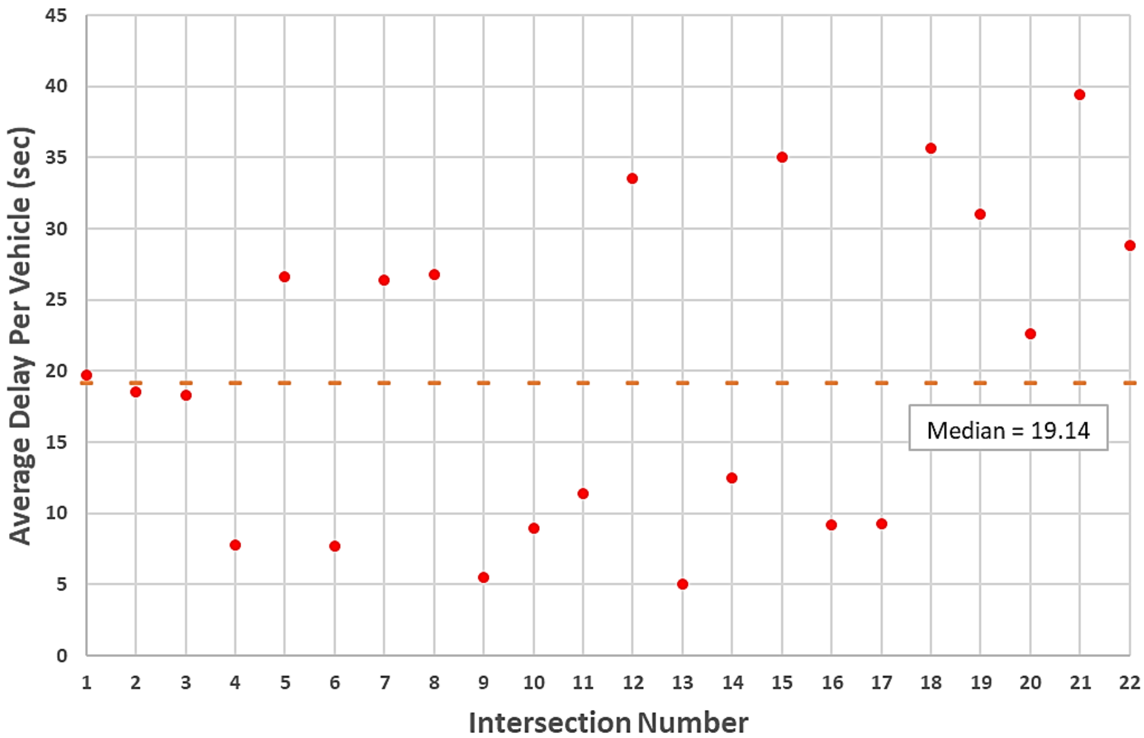


Exhibit B-4. Percent Arrivals on Green by Intersection

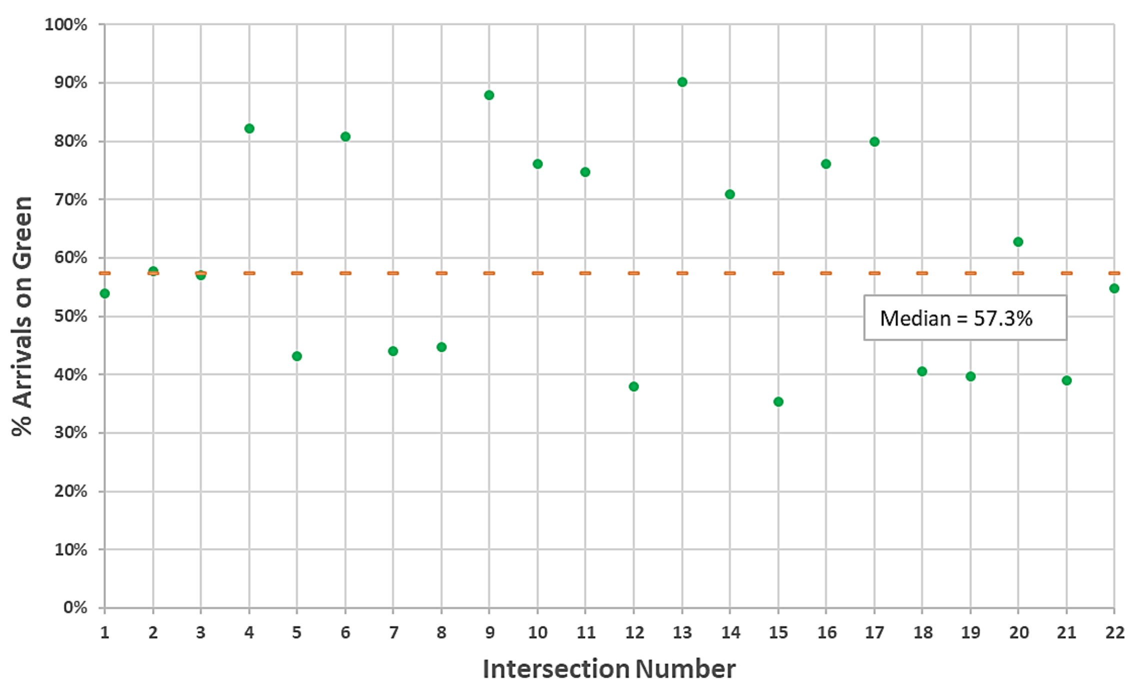


Exhibit B-5. Traffic Signal Efficiency Index by Intersection

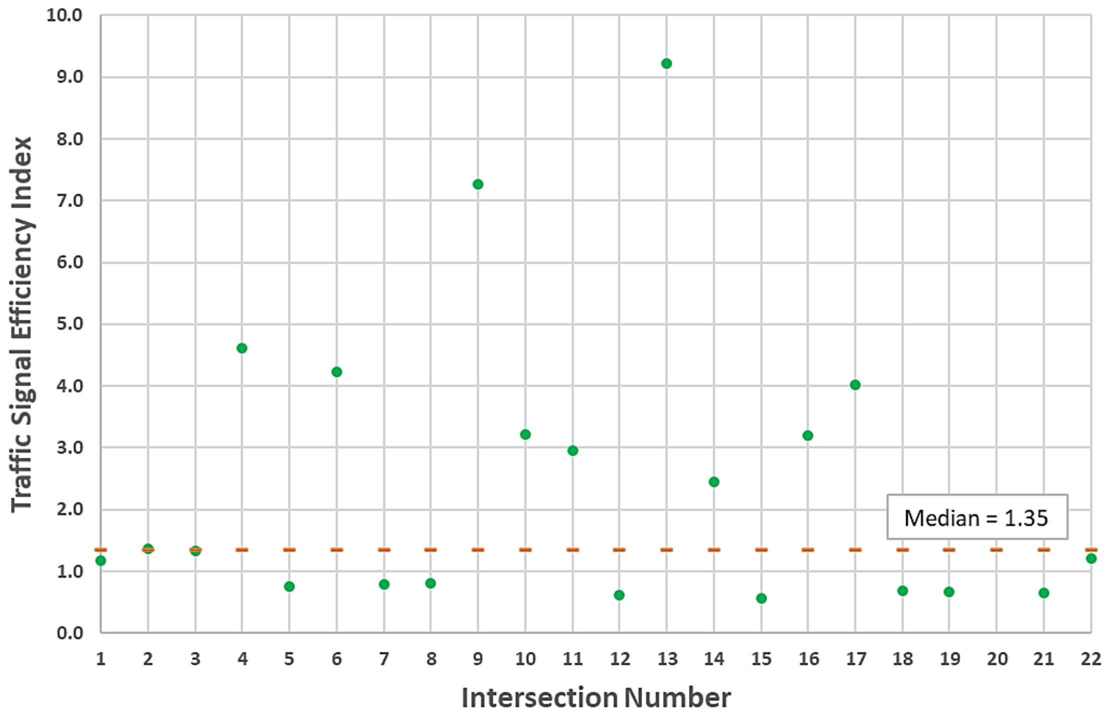
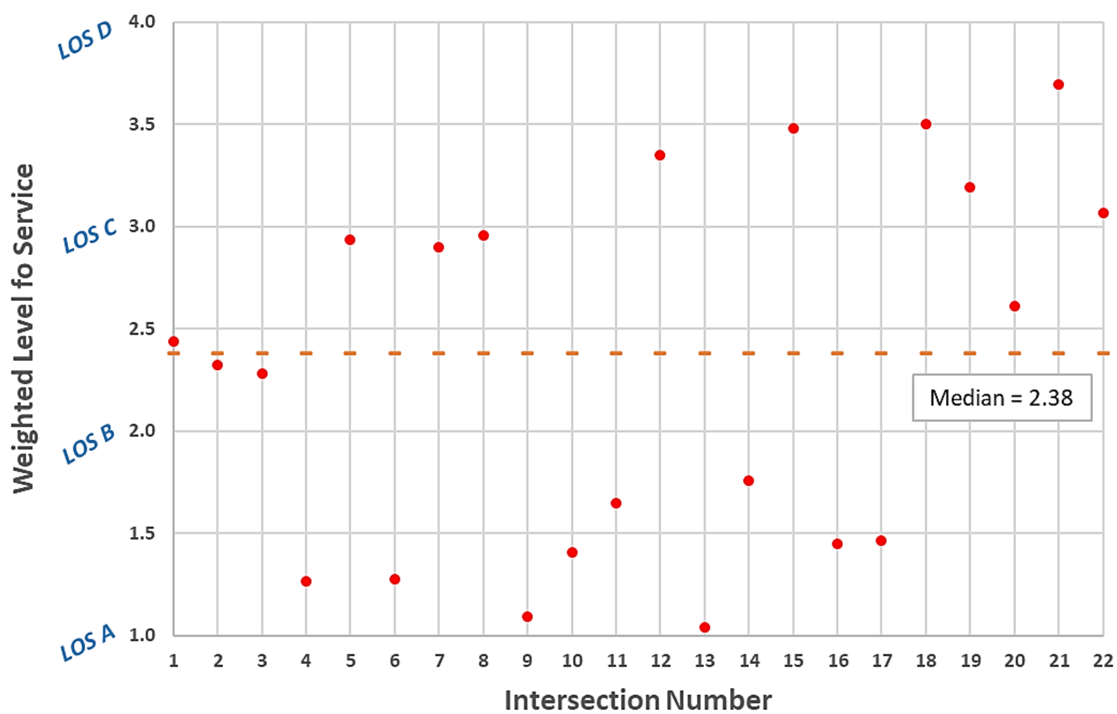


Exhibit B-6. Weighted Level of Service by Intersection



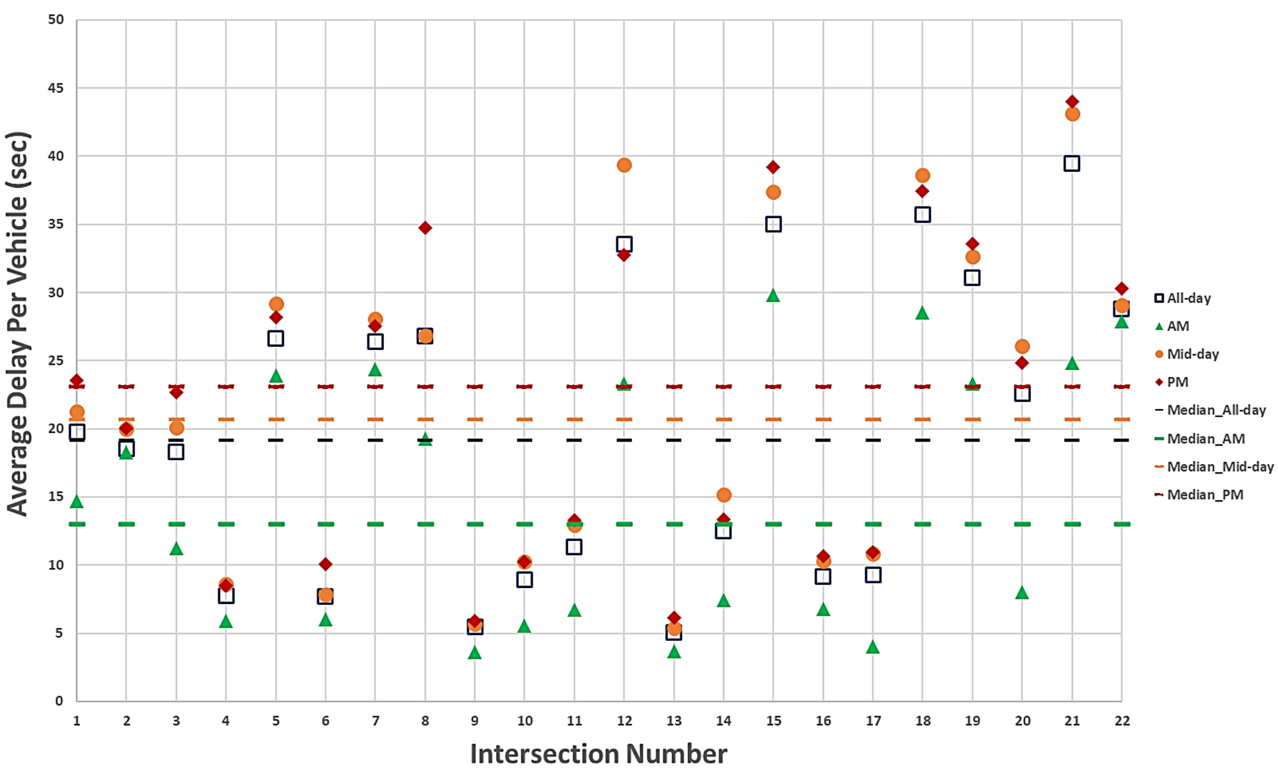
Recognizing that traffic patterns and signal operations change throughout the day, researchers delved a little further into what that meant for the performance measures. Exhibit B-7 shows an example for average delay.

The straight dashed lines in the middle of the charts indicate median values for different times of day. The black line in the center is the median delay for the overall corridor for the whole day. Unsurprisingly with 2020 COVID traffic data, the median AM delay is lower and shown in the green. The mid-day delay shown by the orange line is slightly above the all-day median delay and the PM peak corridor delay is at the top in red.

This analysis also provides opportunities to look at how individual intersections perform. The color scheme stays the same, but different shapes help delineate the different time periods. It can be seen that the delay levels are more spread out throughout the day on the west end of the corridor where there is intense commercial development. The delay tends to be more constant throughout the day as we travel eastward where there are more residential areas.

Interestingly, there are a handful of locations where the mid-day delay is larger than the PM peak delay. These could be locations where people are venturing out to run their errands mid-day or lunch time.

Exhibit B-7. Avg Delay Per Vehicle by Time of Day by Intersection



As discussed earlier, the density of the signals started to pick up after intersection 8. In Exhibit B-8 we can see that the arrivals on green does not seem to be impacted by the more closely spaced intersections until the regional mall area. There is good progression between intersections #9 and #17, with the exception of two (#12 and #15), which are both arterial street intersections. In these cases, the cross street may be a higher priority corridor and these are programmed stop locations. It may also be that the lower percent arrivals on green is actually for vehicles on the cross streets since the performance measure data is collected for all approaches to the intersection.

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Exhibit B-8. Percent Arrivals on Green by Time of Day by Intersection

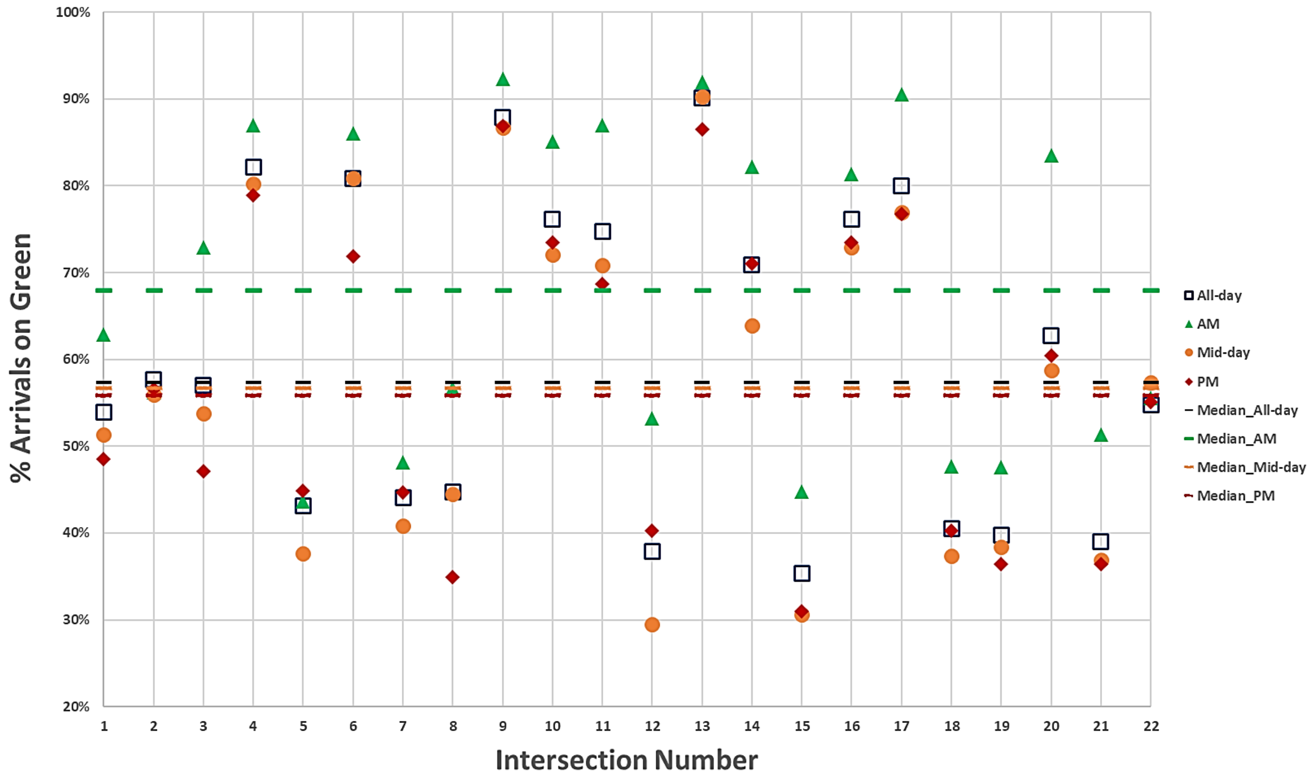


Exhibit B-9 shows the traffic signal efficiency index for each intersection. As a refresh to the earlier discussion on this index, an efficiency index value of 2.0 means that a vehicle is twice as likely to arrive at an intersection on green versus red, and therefore, this index is a measure of signal coordination.

About half of the intersections have an efficiency index above 2.0 for at least one part of the day – showing good coordination. There are a couple of outperforming signals with TSEI values near 12.0 for the AM peak and above 6.0 for the whole day. The majority of the intersections with lower traffic signal efficiency indices are at the freeway interchanges or arterial streets where there are larger competing traffic flows and signal engineers may be trying to balance coordination or there may be more active transportation users. Interestingly, the indices at these locations do not change much throughout the day.

Exhibit B-10 shows the weighted level of service for the corridor as a whole and individual intersections for the different times of day. Because signal LOS is a function of delay, it looks similar to the delay chart (Exhibit B-7). There can be minor changes from the delay graph based on the influence of higher or lower traffic demands because this metric is weighted by traffic volumes.

Exhibit B-9. Traffic Signal Efficiency Index by Time of Day by Intersection

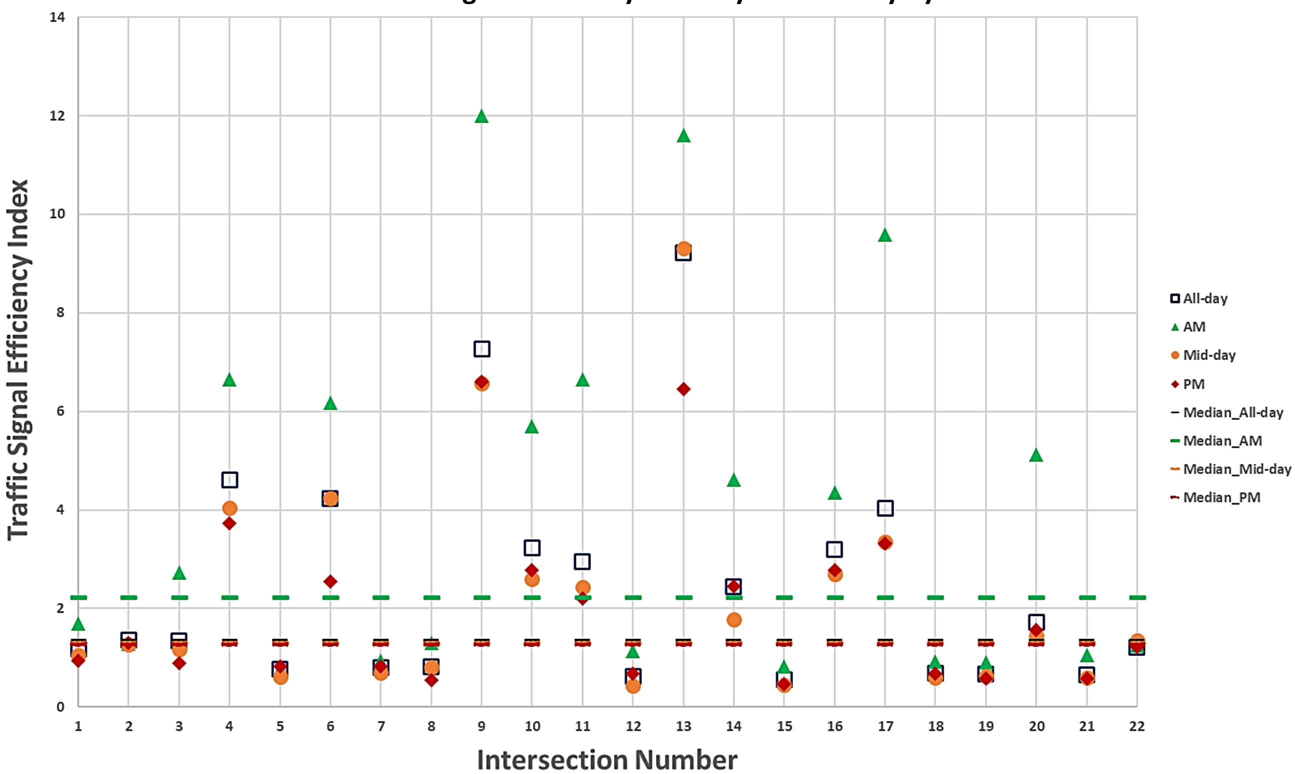
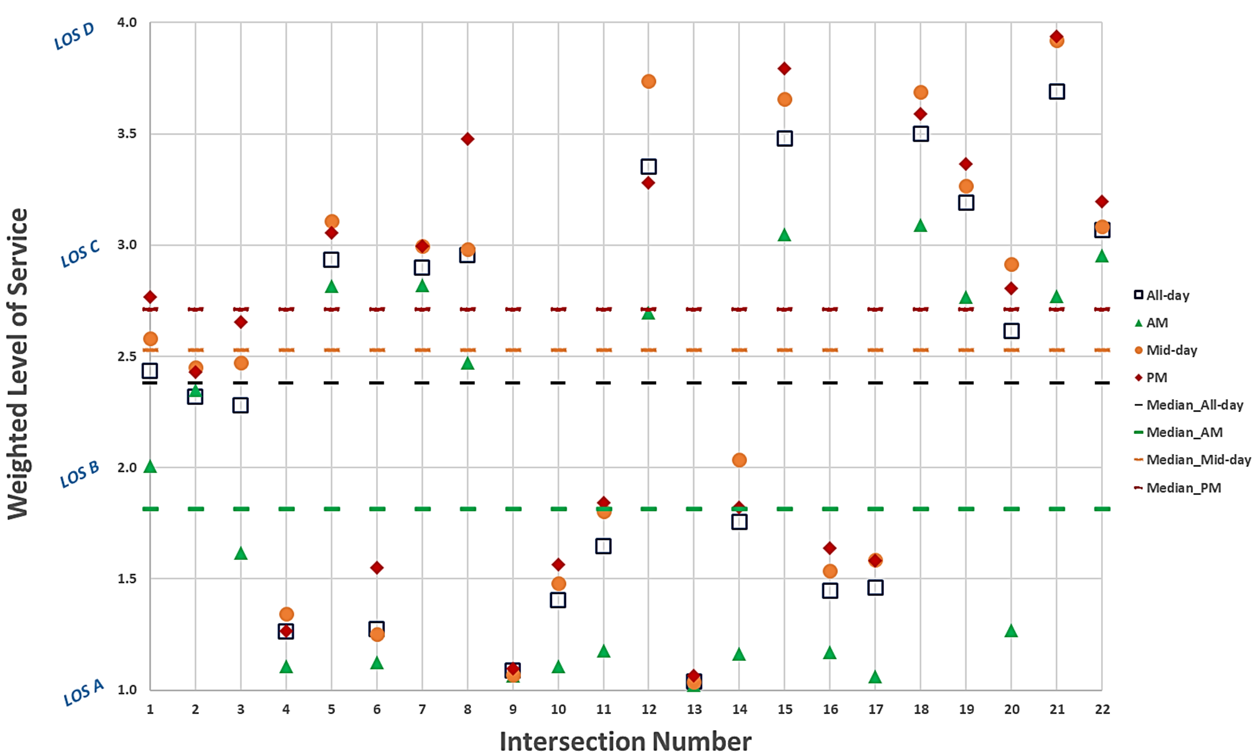


Exhibit B-10. Weighted Level of Service by Time of Day by Intersection



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