APPENDIX A | METHODOLOGY

Appendix A summarizes the methodology for auto data, transit data, and peak duration analysis for the current 2022 monitoring cycle.

A.1 | Auto Methodology

This section discusses the methodology used for measuring level of service (LOS) in the current monitoring cycle. Overall, the data cleaning process was intended to ensure that LOS data was only analyzed for days and times that were representative of normal traffic conditions.

The monitoring period, which spans March to May of 2022, was first screened to identify and remove days that may have produced lighter than usual traffic conditions (such as public holidays) or heavier than usual traffic (such as special events). Similarly, field data collection days were planned to avoid local events and school holidays to ensure representative travel conditions.

The second step consisted of the actual data collection using either probe-vehicle based commercial speed data (e.g., INRIX data), freeway express lanes Electronic Toll System (ETS) data, or floating car survey data. Data was collected for 140 miles of freeways, 98 miles of high-occupancy vehicle (HOV) and high-occupancy toll (HOT/Express Lanes) lanes, and 413 miles of the arterial network.

In the final step, data was analyzed separately for INRIX speed data, ETS data, and floating car surveys to assign LOS based on Highway Capacity Manual (HCM) methodologies.

A.1.1 | Screening for Data Collection Periods

As a preliminary step in the analysis, it was necessary to identify all the days and time periods during which the CMP network could be monitored. Monitoring days for both LOS data sources (INRIX and floating car surveys) were reviewed and identified separately. This process was necessary to identify data generally representative of normal conditions on the CMP network for the current monitoring cycle.

All potential factors that may adversely impact traffic conditions were examined so monitoring results are an accurate reflection of the average driving conditions experienced by daily commuters. The following sections describe each of these screening steps in more detail.

A.1.1a | LOS Monitoring Times

LOS monitoring data was collected in spring 2022, when schools were in session.

Weekday data was collected on Tuesdays, Wednesdays and Thursdays between March 1 and May 31, 2022, for the morning and afternoon peak-periods. The morning peak-period was defined as 7:00 AM to 9:00 AM, and the afternoon peak-period was defined as 4:00 PM to 6:00 PM. These windows are consistent with typical time periods during which peak travel occurs (highest volumes and congestion).

Weekday data was collected on Tuesdays, Wednesdays and Thursdays between March 1 and May 31, 2022, for the morning and afternoon peak-periods. The morning peak-period was defned as 7:00 AM to 9:00 AM, and the afternoon peak-period was defned as 4:00 PM to 6:00 PM. These windows are consistent with typical time periods during which peak travel occurs (highest volumes and congestion). Please note that INRIX data was also collected for a 24/7 time period along select freeway corridors to inform supplemental analyses like the peak-duration analysis. However, for LOS monitoring purposes, these windows described here were used.

Please note that INRIX data was also collected for a 24/7 time period along select freeway corridors to inform supplemental analyses like the peak-duration analysis. However, for LOS monitoring purposes, these windows described here were used.

A.1.1b | Public Holidays

Roads are typically less congested on public holidays, and were therefore screened for removal from the monitoring period. Upon review, no public holidays occurred during the 2022 monitoring period.

A.1.1c | Special Events

Special events typically produce more congestion, although the effects are more localized and are often most noticeable on roadways near the event area. Traffic associated with special events such as Oakland A's home games were removed from the monitoring dataset in the vicinity of the affected roadway segments.

A.1.1d | Weather Events

The monitoring period was also screened for severe weather events such as heavy rainstorms or fog events, which could alter traffic patterns. No significant weather events were observed as impacting traffic conditions during the 2022 monitoring period.

A.1.1e | Construction and Maintenance

The project team reviewed various information sources to identify significant construction and maintenance projects that may have impacted typical traffic patterns during the monitoring period. These included the following:

- Alameda CTC projects webpage;
- Other government websites (including Caltrans District 4);
- Specific construction project websites;
- Facebook and Twitter feeds (such as the 511 SF Bay Twitter Feed[1]); and
- Caltrans Performance Measurement System (PeMS) lane closure database.

Construction and maintenance incidents were reviewed and if significant impacts were identified, then data for those identified dates were removed across all relevant CMP segments.

A.1.1f | Incidents

Incidents (collisions, broken down vehicles, etc.) negatively impact traffic conditions, and therefore data associated with those incidents was excluded. For floating car surveys, where the driver observed an incident, the floating car survey run was repeated to collect unaffected data. For commercial speed data, freeway incident data sets from the Performance Monitoring System (PeMS) were reviewed and the speed data records for the time period corresponding to an incident were removed across all relevant CMP segments.

A.1.2 | Data Collection

Speed data was collected from both probe vehicle-based commercial speed data (i.e. INRIX) and floating car survey data which was then used to calculate LOS .

A.1.2a | Commercial Speed Data

The 2022 Monitoring report primarily utilized INRIX XD data, which reflects aggregated auto speeds in five-minute increments collected from GPS-enabled devices and other sources, to analyze road performance.

[1]Twitter Feed for 511 SF Bay twitter.com/511SFBay
[2]INRIX. http://inrix.com

In 2013, MTC contracted with a third-party commercial data vendor, INRIX, to obtain region-wide commercial speed data, and has made the data available free of charge to congestion management agencies (CMAs) such as Alameda CTC and other local governments for planning and monitoring purposes. This LOS Monitoring effort used the commercial speed data from INRIX through MTC's contract.

INRIX "aggregates traffic data from GPS-enabled vehicles and mobile devices, traditional road sensors and hundreds of other sources."[2] Traffic data is reported by INRIX using discrete roadway links defined as INRIX XD segments. INRIX and MTC changed their approach to roadway segmentation in 2019 to use XD segments, which offer greater granularity and are better able to adapt quickly to changes in road networks than Traffic Message Channels (TMC) segments. Alameda CTC began using INRIX data in the 2014 cycle, meaning that the 2022 cycle reflected the second time that INRIX XD data was fully used.

It is also worth noting the following differences between TMC and XD data in general:

- XD links are contiguous along corridors whereas the TMC segments had occasional gaps between segments and occasional segment overlaps.
- On arterial roadways (non-freeway segments) the XD links beginning and ending points are aligned with roadway intersections whereas the TMC segments many times ended mid block.
- The TMC segments were relatively long in rural or non-urbanized areas. The XD links are all generally less than a mile or so in length.

INRIX reports travel speeds on pre-determined XD segments. For the 2022 monitoring cycle, the five-minute raw INRIX XD data was used, given that the latter is deemed of high quality without data gaps and aggregating five-minute data onto CMP segments will run more efficiently and accurately than at a more granular one-minute level. The average vehicular speed reported for each five-minute period on each XD link culminates in millions of lines of data for a three-month countywide dataset.

A.1.2b | Floating Car Survey Data

Where commercial speed data lacked either spatial or temporal coverage, floating car surveys were used. The floating car surveys were completed using GPS technology to determine the travel time between the start and end of each CMP segment, and thereby usable for further calculation of segment speeds. For each of these CMP segments on the arterials (Tier 1) and HOV/express lanes, the study completed six (6) floating car surveys during both the morning peak period (7AM-9AM) and afternoon peak period (4PM-6PM).

Floating car runs were completed using the industry accepted approach of attempting to represent the average vehicle. Drivers aimed to pass as many vehicles as passed them. Surveys were only undertaken on Tuesdays, Wednesdays, and/or Thursdays. For a particular segment, the surveys were scheduled so they spanned a range of days and times. The aim of this is to ensure that a range of representative traffic conditions are surveyed.

Drivers were instructed to comply with all road rules. This includes the speed limit, traffic signal displays and not stopping within intersections. In this respect, it is noted that there may be some minor differences between the results from these professional floating car surveys and normal driving behavior; however, these differences are unavoidable.

Several freeway ramps, which were not covered by commercial data, were also measured using floating car survey. If a CMP segment that used floating car surveys experienced congestion (LOS F) in the afternoon peak and the segment was subject to CMP conformity, then two additional runs were generally completed.

A.1.2c | Electronic Toll System (ETS) Data

Finally, along the Interstate 580 Express Lane system in the Tri-Valley, via an intra-agency request, Alameda CTC was provided with 15-minute data for all days in the spring 2022 monitoring period. The data included the average speed and 15-minute volume count by lane along 17 westbound gantry locations and 15 eastbound gantry locations. The relevant ETS data was associated with lane number 1 in the dataset.

A.1.3 | Data Analysis

The methodology for deriving LOS from raw commercial speed and floating car survey data includes two key steps. The first step consists of converting the raw speed data into average peak-period speeds on every CMP segment. In the second step, average speeds are converted to estimate LOS using a specific method depending on the type and classification of roadway. This process is specific to the identification of deficient segments for the legislative process, but was also applied for off-peak and weekend analysis by applying different filters to the raw data.

A.1.3a | Calculate Average Peak-Period Speed

The steps for converting raw speed data to average peak-period speeds vary based on the data source.

Commercial Speed Data

Once collected from the INRIX database, commercial speed data points were conflated to the appropriate CMP segment through a spatial mapping process. As previously discussed, data outside the monitoring period and data with poor data quality (such as locations with low available sample sizes) were eliminated. To calculate average speed for all data points, the data was averaged on each CMP segment for each peak-period using the harmonic mean.

Step 1. Mapping INRIX XD links onto CMP Segments

Commercial speed data collected by INRIX was reported for lengths of roadway called INRIX XD links. For the purposes of the 2022 Multimodal Monitoring Report, it was required that the average speed be reported against an Alameda CTC CMP segment. CMP segments are typically longer sections of roadway, averaging approximately 1.2 miles in length (range: 0.2 to 5.0 miles). Therefore, INRIX XD links needed to be aligned against or mapped onto the CMP segments.

It should be noted that for some CMP segments, the ends of the CMP did not align with the ends of the INRIX XD segments. Figure A-1 shows a schematic example to explain this concept. It shows one CMP segment that is made up of three INRIX XD segments. However, the end of the last INRIX XD segment does not align with the end of the CMP segment. In these instances, only the overlapping portion of the XD length was used to calculate the average speed.

Step 2. Filter Raw Data

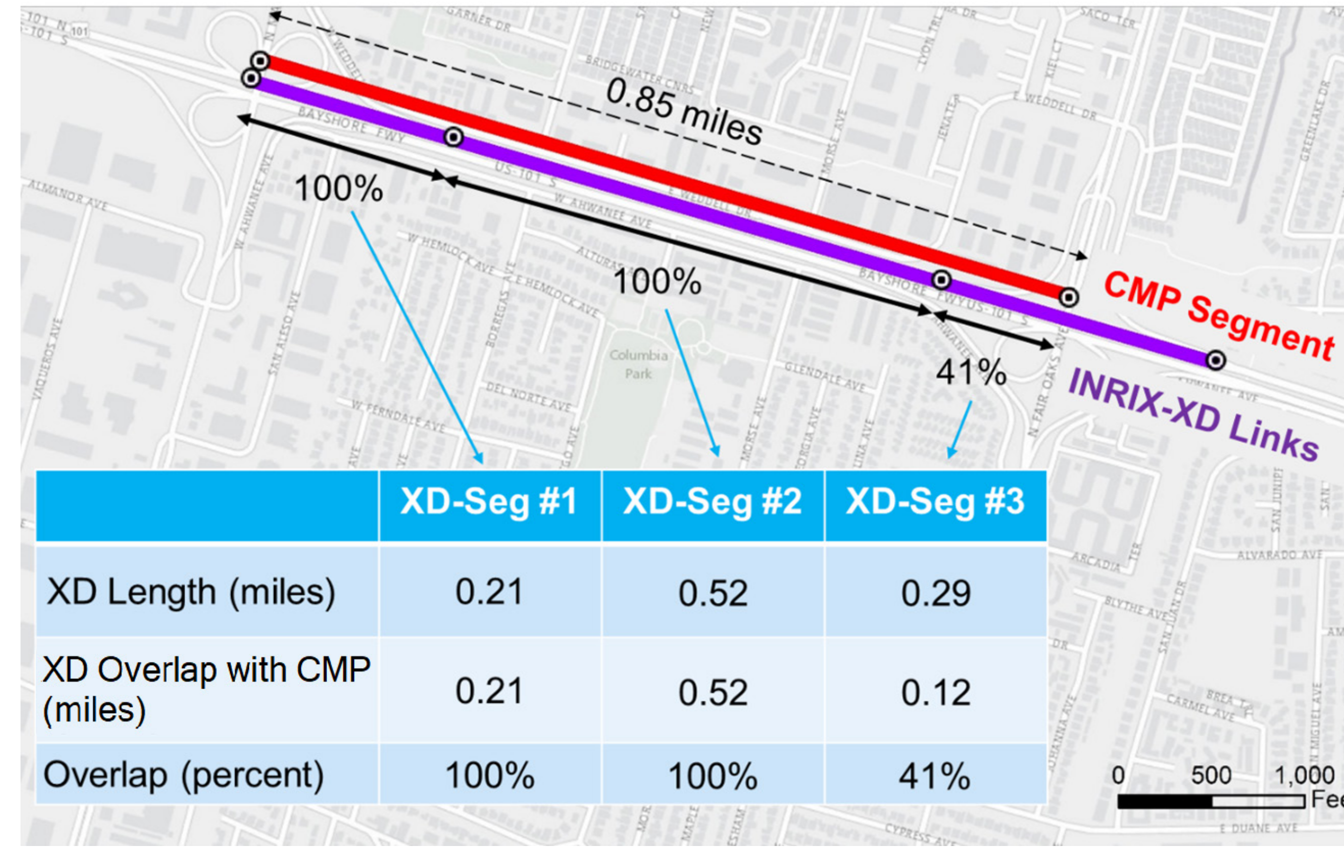
The raw INRIX data was filtered to remove:

- Times outside the morning and afternoon peak periods;
- Days other than Tuesdays to Thursdays;
- Data points impacted by special events (e.g., incidents, construction, major events); and data points with lower data quality scores:
  - INRIX includes a data quality score that accompanies every INRIX data point. The score value is defined as:
    - Score of 30: Data are exclusively generated from real-time sources.
    - Score of 20: A mix of historical and real-time sources are used.
    - Score of 10: Data are exclusively generated from historical data.

Only raw speeds that were directly measured were used for computing LOS in the CMP network. As such, data points with scores of 10 and 20 were removed, and only data with scores of 30 (equivalent to 100% observed) were kept, as illustrated in **Figure A-2.**

The quantity of remaining data points was tracked so the sample size of score 30 was known. The sample sizes are presented in conjunction with all associated commercial speed data results.

Figure A 1: End points of CMP and INRIX XD do not align



	XD-Seg #1	XD-Seg #2	XD-Seg #3
XD Length (miles)	0.21	0.52	0.29
XD Overlap with CMP (miles)	0.21	0.52	0.12
Overlap (percent)	100%	100%	41%

Step 3. Spatial and Temporal Data Aggregation - Average Speed Computations

This step covers the methodology of aggregating the data, both spatially and temporally.

Spatial Aggregation

Using the mapping created in Step 1 and the filtered INRIX data from Step 2, the INRIX XD data was spatially aggregated to corresponding CMP segments. In cases where multiple INRIX XD segments span a single CMP segment, the travel time was summed for all INRIX XD segments.

$$CMP\ Travel\ Time = XD_1 + XD_2 + \cdots + XD_n$$

Temporal Aggregation

Temporal aggregation involved the translation of the CMP travel time metric for each five-minute increment into one average speed value corresponding to each CMP segment for the entire monitoring period. The following formula was used for this:

$$Average\ CMP\ Speed = \frac{\sum CMP\ Length}{\sum CMP\ Travel\ time}$$

Sample size information was retained to assess the confidence level in the computed statistics.

Sample Size

The sample size is the number of data points that contributed to the final calculation of average speed. The sample size varied on each INRIX XD segment through removal of data points during the monitoring period and special event filtering process discussed below.

Floating Car Survey Data

Once floating car survey data was collected using GPS units, it was processed to extract the average speed and travel time on subsegments of each CMP segment. The subsegment average speeds and travel times were then input into a spreadsheet that calculated aggregated average speed for each CMP segment using the segment's travel time and length.

Figure A-2: Example of Filtering Process

Time Period	XD1	XD2	XD3	XD4	Length
1	20	30	30	30	¾
2	20	30	30	30	¾
3	30	30	30	30	1
4	30	30	30	30	1
5	30	30	30	30	1
6	20	30	20	30	½
7	30	30	20	30	¾

A.1.3b | Assign LOS

The next step in the analysis process was to assign LOS based on the average speeds calculated for each CMP segment. As adopted in the 2013 CMP, LOS is estimated for the entire CMP network based on HCM 1985 with the exception of Tier 2 arterial segments, which were also reported using HCM 2000 for comparison purposes. This study uses the LOS speed standards as shown in **Tables A-1, A-2** and **A-3.**

Table A 1: Freeway LOS (Source: HCM 1985)

Level of Service	Speed (mph)	Density (pc/mi/ln[1])	Volume-to-Capacity (V/C[2]) Ratio	Maximum Service Flow (pcphpl[3])
A	≥ 60	≤ 12	0.35	700
B	≥ 55	≤ 20	0.58	1,000
C	≥ 49	≤ 30	0.75	1,500
D	≥ 41	≤ 42	0.90	1,800
E	≥ 30	≤ 67	1.00	2,000
F	< 30	> 67	- [4]	-

LOS F Sub-Designations for Freeways:[5]
F30—Average Travel Speed < 30 mph
F20—Average Travel Speed < 20 mph
F10—Average Travel Speed < 10 mph

Source: Adapted from Table 4-1, Special Report 209, HCM 1985
[1] Density measured in passenger cars per mile per lane
[2] V/C is the ratio between roadway demand (vehicle volumes) and roadway supply (carrying capacity). Volume refers to the number of vehicles using a roadway during a period of time, while capacity is defined as the ability to support that volume based on its design and number of lanes.
[3] Maximum service flow under ideal conditions, expressed as passenger cars per hour per lane
[4] Highly variable, unstable flow; V/C Ratio is not applicable
[5] Approved by Alameda CTC in June 2004 to show degrees of LOS F on congested roadways.

Table A 2: Arterial LOS (Source: HCM 2000)

Urban Street Class	I	II	III	IV
Range of free-flow speed (mph)	45-55	35-45	30-35	25-35
Typical free-flow speed (mph)	50	40	35	30
Level of Service		**Average Travel Speed (mph)**		
A	> 42	> 35	> 30	> 25
B	> 34-42	> 28-35	> 24-30	> 19-25
C	> 27-34	> 22-28	> 18-24	> 13-19
D	> 21-27	> 17-22	> 14-18	> 9-13
E	> 16-21	> 13-17	> 10-14	> 7-9
F	≤ 16	≤ 13	≤ 10	≤ 7

Source: Exhibit 15-2, HCM 2000 (U.S. Customary Units)

Table A 3: Arterial LOS (Source: HCM 1985)

Arterial Class	I	II	III
Range of free-flow speed (mph)	35-45	30-35	25-35
Typical free-flow speed (mph)	40	33	27
Level of Service		**Average Travel Speed (mph)**	
A	≥ 35	≥ 30	≥ 25
B	≥ 28	≥ 24	≥ 19
C	≥ 22	≥ 18	≥ 13
D	≥ 17	≥ 14	≥ 9
E	≥ 13	≥ 10	≥ 7
F	< 13	< 10	< 7

Source: Table 12-1, Special Report 209, HCM 1985

Assigning LOS - Freeways

Based on the average speed of the freeway in the morning and afternoon peak-periods and using the HCM standards as shown in Table A-1, LOS was estimated for each CMP segment in each time period.

Based on the suggested guidelines from the HCM:

- LOS A occurs when vehicles are traveling at a free-flow speed for the given roadway conditions.
- LOS F occurs when speeds have dropped below 50 percent of the free-flow speeds.
- Levels of Service B to E are calculated at even intervals between free-flow speeds and LOS F speeds.

Assigning LOS - Ramps and Special Segments

To determine LOS for ramps, the free-flow speed was obtained from special studies conducted in 1992, during off-peak low-volume conditions. There is one ramp segment that is classified as a weaving segment and is therefore not assigned an LOS consistent with previous monitoring cycles. The performance of this segment can be judged on its average speed.

Assigning LOS - Arterials

Both HCM 1985 and 2000 methods first require classification of the arterial according to its free-flow speed and other road characteristics. The road classification based on HCM 1985 could be Class I, II or III and based on HCM 2000 it could be Class I, II, III or IV.

Using the classification of the street and the average travel speed, and based on relevant HCM standards as shown in Tables A-2 and A-3, LOS for the arterial segment is determined for both HCM methodologies. For the number of LOS F segments being tallied and compared to previous years, LOS F segments were identified using the HCM 2000 methodology for Tier 2 Arterials. The HCM 1985 methodology was also kept for use to maintain consistency with previous reporting cycles.

Assigning LOS - Rural Roadways

Several Tier 1 and Tier 2 CMP routes (mostly located in the east county) are rural roadways and require a special analysis procedure. Traffic and speed characteristics are fairly uniform on these roadways. Variations in speed are a function of roadway curvature and the presence of slower trucks in the traffic stream. One such Tier 1 roadway is SR-84 between the southern city limit of Livermore and Mission Boulevard in Fremont. Rural roadways identified in the Tier 2 network include a portion of Vasco Road in Livermore and a part of Crow Canyon Road, both connecting to the county line.

To be consistent with the methodology used in previous monitoring cycles and in order to capture the variations of less pronounced traffic patterns, the HCM 1985 guidelines were used to assess LOS on Tier 1 and Tier 2 rural roads during the 2022 Monitoring Cycle. LOS A occurs when vehicles are traveling near the free-flow speed for the given roadway conditions. LOS F occurs when speeds have dropped below 50 percent of the free-flow speeds. Levels of Service B to E are calculated at even intervals between free-flow speeds and LOS F speeds.

A.2 | Peak Duration Analysis Methodology

This section discusses the methodology used for the peak duration analysis conducted for the current 2022 monitoring cycle. The objective of the analysis was to determine how the peak periods along various freeway corridors throughout Alameda County may have shifted as a result of the COVID-19 pandemic. In particular, this analysis was conducted to determine if peak periods had shifted to be earlier or later in the day, and if these peak periods had changed in the length of time (i.e. duration) for each of these peak periods. The peak duration data used for this analysis represents the same March-May observation period as with the LOS monitoring.

A.2.1 | Peak Duration Monitoring Dates and Corridor Locations

As with the level of service methodology, spring 2022 INRIX data was filtered and screened in an identical manner, to only display and analyze days that were expected to result in normal commuter traffic conditions. This filtered data was collected and downloaded at the 15-minute granularity level for the typical 24-hour weekday period. Additionally, spring 2018 data from INRIX was re-collected as a historical pre-COVID-19 pandemic baseline for comparison. The 2018 data was also filtered in the same manner as was done in 2022. While this analysis was conducted for all directions during all time periods of the typical weekday, the peak direction for travel was generally selected and applied for this data analysis, as the off-peak direction would not experience a drop in speeds significant enough to cause non-free-flow conditions.

As the purpose of the analysis was to compare freeway segment performance across connected corridors throughout Alameda County, the data analysis was applied to and conducted on combined freeway corridors that represent typical peak travel patterns throughout the county, instead of individual CMP segments. The following freeway corridors, bridges, and arterial areas were selected by peak direction to conduct the peak duration analysis:

- Freeways
  - I-80 (from I-580/Bay Bridge (MacArthur Maze) to Contra Costa County)
  - I-238 (from I-880 to I-580)
  - I-580 (from Contra Costa County to MacArthur Maze)
  - I-580 (from MacArthur Maze to SR-238)
  - I-580 (from SR-238 to San Joaquin County)
  - I-680 (from Contra Costa County to Santa Clara County)
  - I-880 (from MacArthur Maze to I-980)
  - I-880 (from I-980 to Santa Clara County)
  - I-980 (from I-880 to I-580/SR-24)
  - SR-13 (from SR-24 to I-580)
  - SR-24 (from I-580 to Contra Costa County)
- Bridges
  - I-80 (Bay Bridge)
  - SR-84 (San Mateo-Hayward Bridge)
  - SR-92 (Dumbarton Bridge)

- Arterials
  - » 14th Street/International Boulevard (from Lake Merritt to SR-238)
  - » Ashby Avenue (from I-80 to Claremont Avenue)
  - » San Pablo Avenue (from Downtown Oakland to Contra Costa County Line)
  - » Mission Boulevard (from I-680 to SR-92)

A.2.2 | Calculate 15-Minute and Free Flow Speeds

The processed 15-minute data from INRIX was then used to calculate speeds along the selected CMP segments of interest for both 2018 (to represent pre-pandemic conditions) and 2022. For each of the 96 15-minute increments per day, the mean speed, 25th percentile speed, and 75th percentile speed was calculated.

For purposes of the peak duration analysis, the free flow speed for each of the CMP segments was set at the mean speed collected at the 2 AM time period. This time period was selected as it would not be expected to experience high travel demand or congestion along the freeway network in Alameda County. Furthermore, conditions that would cause unusual speeds during that time such as nighttime construction would have been removed as part of the INRIX filtering and data cleaning process.

A.2.3 | Definition of Peak Period and Peak Period Speed Threshold

Following the calculation of the various speeds of interest, a sensitivity analysis was conducted to selected a threshold speed that would define the beginning and ending of a peak period. The analysis was conducted to best identify a speed that would clearly show when freeway congestion would result in a drop in speeds and to avoid false positive times of day that could have occurred due to data noise. Based on the sensitivity analysis, a 15% drop in speeds, or 85% of each CMP segment corridor's 2022 free flow speed at 2 AM was set and used to define the threshold in which a peak period would begin. Mean speeds during 15-minute time periods above this 85% threshold were considered to not be part of a peak period, and values below the 85% threshold were considered to be part of a peak period.

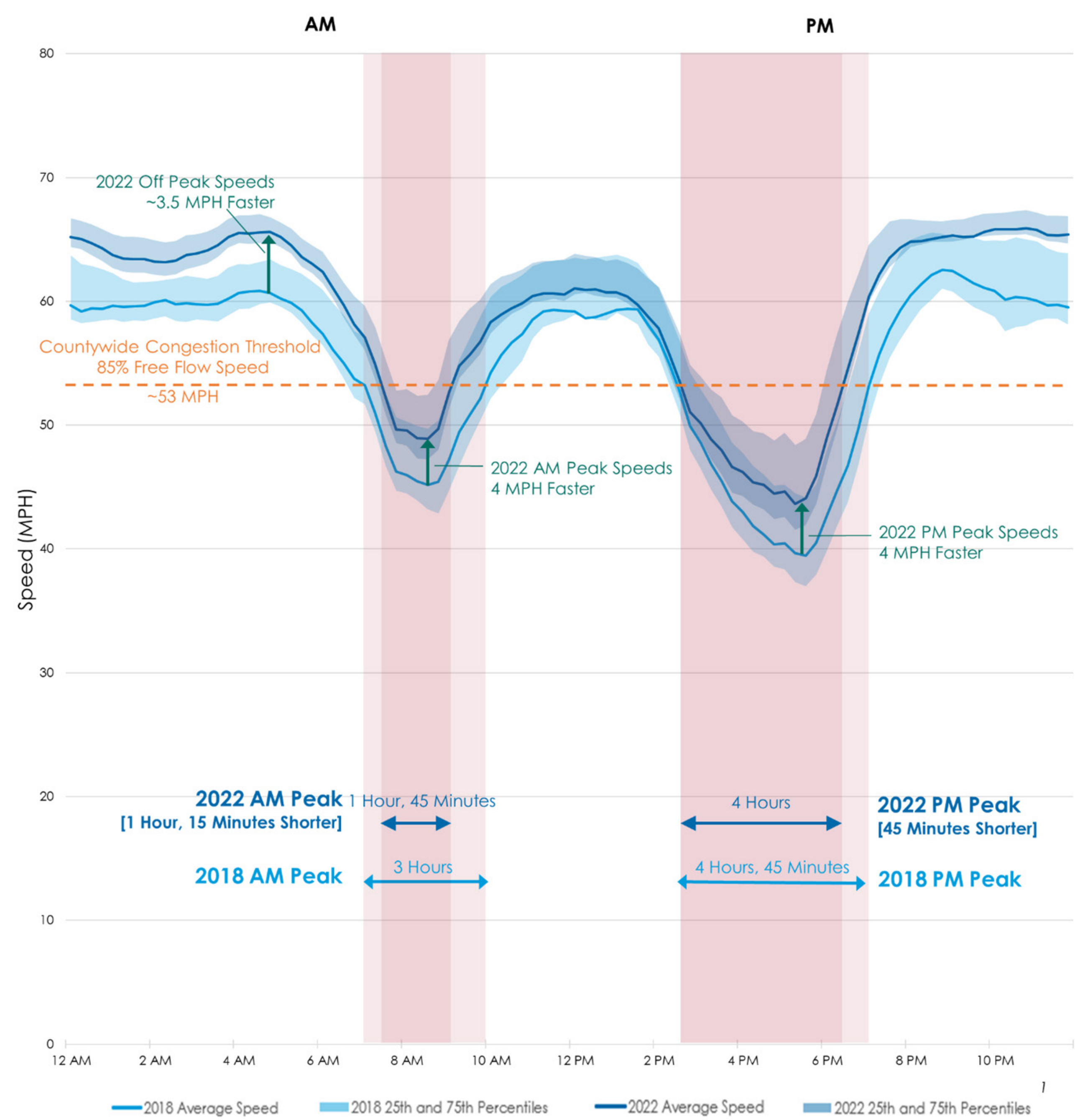
A.2.4 | Development of Metrics

Following this threshold definition, a spreadsheet analysis using Microsoft Excel was prepared, with various statistics developed to better compare how speed trends changed between 2018 and 2022 during the 24-hour period and more specifically how peak period measures changed. For purposes of the analysis, the following statistics were used to conduct the peak duration analysis:

- Start Time: The 15-minute period when the mean speed dropped below the 85% free-flow speed threshold, starting a peak period
- End Time: The 15-minute period when the mean speed rose above the 85% free-flow speed threshold, ending a peak period
- Duration: The time between the start time and end time when the mean speed of the corridor remained below the 85% free-flow speed threshold
- Time of Slowest Speed: The 15-minute time period during each peak period when the slowest average speed was observed
- Slowest Speed: The observed speed during the 15-minute time period defined as the time of slowest speed
- Free-Flow Speed: The speed at 2 AM along the selected corridor
- Peak Period Threshold Speed: 85% of the calculated free-flow speed

Using these metrics, spreadsheet tables and charts comparing the 24-hour weekday speeds between the 2018 and 2022 monitoring cycles were developed and used for this monitoring report. The Excel chart below shows the countywide weighted average speeds across the 2018 and 2022 monitoring periods, demonstrating how the graphics and tables were used to provide a visual and analytical method of comparing how speeds along freeways changed following the COVID-19 pandemic.

Example Illustration of Peak Period Analysis Metrics: Countywide Freeway Average



A.3 | Transit Methodology

To better measure progress towards the agency's multimodal goals, Alameda CTC began to measure transit performance data along with the legislatively required auto performance data in 2018. This methodology allows the agency to compare transit and auto speed and performance on the same roads at the same time for a true apples-to-apples comparison of performance. Transit monitoring was paused for the 2020 monitoring cycle due to the COVID-19 pandemic, but resumed for the 2022 cycle.

A.3.1 | Transit Data

Transit speed monitoring was performed using data provided by AC Transit and LAVTA. Each agency provided a primary data source for measuring speeds: AC Transit provided data from Automatic Vehicle Location (AVL) units on their busses and LAVTA provided manually collected Running Time data.

AC Transit has onboard GPS devices in buses that keep track of geospatial movement throughout the network. These GPS devices monitor and archive the bus location (longitude and latitude) and a date-time stamp of when the Longitude/Latitude data were recorded. The AVL data shows snapshots of bus locations along the routes. They are called snapshots because each data record identifies one bus location at one specific point in time, like a series of photos or snapshots, rather than being a continuous recording. The time interval between data recordings is not necessarily constant, and can differ from one bus to another and may be different for the same bus from day to day. Analysis of the snapshot data showed that the time interval between the AC Transit recordings varies from a few seconds to several minutes. Since 2018, AC Transit has updated onboard AVL units, and consequently the quality of the transit data has improved. The date range for the requested AVL data was Monday through Friday between March 1 to May 31, 2022. The data covered a full 24-hour period for each weekday.

AVL data were not available for LAVTA's buses along the CMP routes, as LAVTA currently does not have AVL units on their buses. LAVTA provided what is commonly called "Running Time" data, which is aggregated travel time between major bus stops. The LAVTA data was averaged over 15-minute periods for each route per direction. Like AC Transit data, the date range for the requested LAVTA Running Time data was Monday through Friday between March 1 and May 31, 2022. with data covering a full 24-hour period for each weekday.

Additional information, such as published bus route maps and bus schedules, was used during the analysis to clean, filter, and interpret the location data, and to perform reality checks as well as quality control on the data and resulting transit speeds. The following list documents the datasets used for monitoring transit speeds on CMP segments:

- AC Transit Data: AVL, AC Transit bus route maps and schedules, and bus route GIS shapefiles.
- LAVTA Data: Running times and LAVTA bus route maps/schedules.

A.3.2 | Transit Data Analysis

Both AC Transit and LAVTA data were screened to include only Tuesdays, Wednesdays and Thursdays between March 1 and May 31, 2022, excluding holidays. Data was extracted for three analysis time periods: (1) Morning peak-period: 7:00 – 9:00 AM; (2) Afternoon peak-period: 4:00 –6:00 PM; and (3) Off-peak-period: 10:00 AM – 12 PM. Data was further screened to include transit trunk routes only, as defined by Alameda CTC as specific transit routes of interest along CMP network segments within various jurisdictions in Alameda County.

The data was cleaned up by removing inaccurate data points. There are many factors that could affect the quality of GPS readings. For example, trees, buildings, and clouds could block satellite's line of sight in some portion of the road and result in poor GPS reading. No matter what the cause of the suspect GPS reading, a data point was considered inaccurate whenever one or two of the following criteria had not been met.

- The recorded points must be inside the roadway boundary. A point outside the roadway boundary means GPS triangulation reading has a significant error and must be removed. For example, a data point that falls on top of a building would be considered inaccurate and removed.
- The GPS heading must be along the general direction of movement. Consecutive points must show forward movement. In other words, it is expected that the bus distance from the very first bus stop (for a specific route) increases by time. If a location point indicates that this distance has decreased, it means the bus moved backward which is not possible in normal service conditions and therefore it is an erroneous GPS reading that must be removed.

Using the AC Transit and LAVTA data, weekday average peak-period and off-peak transit speeds were then calculated for the monitored CMP arterial roadways. In the process of developing the methodology for transit performance monitoring, three measures were identified and used:

- Average bus speed during peak-periods
- Average bus speed to average auto speed ratio
- Peak-to-off-peak bus speed ratio

Given that the format of transit data differed by operator, separate data analysis procedures were developed to derive comparable metrics or performance measures from both AC Transit and LAVTA data.

A.3.2a | Average Transit Speed for Peak-Periods

After cleaning the AVL data based on geospatial criteria and monitoring periods, the data points (snapshots) were mapped on the corresponding bus routes. Next, speeds were estimated for the CMP segments by inserting new data points at the CMP segment end-points, and then interpolating or extrapolating the date/time stamp at the CMP end-points. For each bus run, it was assumed that buses would operate in a safe manner within the roadway speed limits. To produce the final results, the results for all of the monitored routes were consolidated and aggregated using the weighted average method with the weights set equal to sample sizes.

A similar approach was taken to calculate speeds for LAVTA bus routes using the Running Time database. However, given that the Running Time database only contains highly aggregated records for each period, only one speed could be calculated without knowledge of speed variations within peak-periods.

A.3.2b | Average Bus Speed to Average Auto Speed Ratio

The ratio of average bus speed to average auto speed, or the transit-to-auto speed ratio, compares speeds at the same time, on the same CMP segment, with typical values between 0.5 and 1. Higher values indicate where transit is more competitive. If the ratio is closer to 1, then the transit speed is nearing auto speeds. The Transit Capacity and Quality of Service Manual[3] identified transit-to-auto-travel-time ratio as a primary factor affecting passenger's decision to use transit on a regular basis. The manual acknowledged that transit travel time might be longer than personal vehicle trips, but the time on transit can be used for more productive activities without the hassles of driving during peak-period congestion. If transit-to-auto-travel-time is 1.5 or below, which translates to a transit-to-auto speed ratio of 0.65 or above, transit is considered as a viable choice by users.

A.3.2c | Peak-to-Off-Peak Bus Speed Ratio

Another measure of transit network performance is the peak-to-off-peak-period bus speed ratio. This compares service on the same route at different times of day and measures the difference in service during peak-period congestion and uncongested mid-day service between 10 AM and 12 PM. A peak-to-off-peak speed ratio closer to one indicates the peak-period speeds are unimpaired by congestion.

[3]Transit Capacity and Quality of Service Manual, Third Edition, Transportation Research Board, Washington, D.C., 2013.