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Multiple ICM Management: Task ID 3706 (65A0764), Final Report

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Multiple ICM Management

Task ID 3706 (65A0764)

Final Report

August 11, 2022

Partners for Advanced Transportation Technology works with researchers, practitioners, and industry to implement transportation research and innovation, including products and services that improve the efficiency, safety, and security of the transportation system.

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1. INTRODUCTION

In order to improve corridor network operations, the vision of integrated corridor management (ICM) is to identify corridor managers who serve as experts for individual corridors, and to enable these managers to oversee corridor operations, to coordinate with partner agencies, and to improve collaborative, multi-agency planning. While it makes sense to manage freeways, arterials, and transit in a coordinated way within a corridor, it is less clear how multiple corridors interact with each other, and how incidents and response plans along one corridor impacts a nearby corridor or multiple corridors.

This project formulates recommendations and strategies for large scale traffic management and enabling multiple corridor management efforts and/or ICMs to work together. In addition, it identifies situations where conditions on one corridor influences management decisions on another corridor. To accomplish this, both probe data and traditional sensor data are analyzed to answer questions about aggregate traffic patterns on a multi-corridor scale.

This research effort begins with a focus on the parallel corridors of I-210 and I-10 in the northern section of Los Angeles County. The rationale for this choice arises from the quality of data available on these two corridors as well as their relative proximity and levels of recurrent congestion. The scope of the analysis includes several other freeway groupings across California, including freeways in the Orange County triangle.

The analysis approach in this effort is broadly applicable for determining regional traffic patterns. Insights are to be gained in regions where not every corridor is included in an ICM or where some are and some are not. In addition, this approach identifies traffic patterns that suggest natural strategies for incident response plans that involve multiple freeways.

It is crucial for future systems to have a basic level of data, data exchange, and situational awareness. Actionable information is the lifeblood of effective traffic management. Command and control systems/elements may be rather simple or sophisticated. Either way, the critical enabler is having wide-area, and regional access to trustworthy data and information.

The deployment of a response plan from an ICM decision support system is intended to mitigate incident-related traffic congestion and improve safety through the reduction of secondary incidents. The extension of decision support to cover multiple corridors is the next step in the evolution of ICM and will yield safety benefits commensurate with the interoperability of these systems. Early identification of compatibility challenges for multiple corridors is a necessary condition to avoid wasteful deployments and to hasten the realization of the true potential of future ICM projects. Reducing unintended consequences and costs of future ICM projects is a key motivation.

All travelers are highly inconvenienced when they are impacted by incident-related traffic congestion. Success of future ICM and corridor management projects depends on understanding how travelers respond to unexpected congestion, how multiple corridors interact with each other, and how incidents and response plans deployed along one corridor may impact other nearby corridors. Ultimately, having multiple ICMs and/or corridor management efforts that together support performance improvement objectives will assist the public by allowing travelers to make informed decisions about route choice, thus reducing the inconveniences to transportation system users that may result from unexpected situations.

Improved traffic management decisions will further translate to improved environmental outcomes, and improved livability.

1.1. PURPOSE

This document integrates prior technical memoranda delivered over the course of the project into a final report that describes the findings in their entirety. Its purpose is to present the methodology in the analysis, the facts of the case studies, the general patterns identified in the data, and the recommendations for future efforts.

This work is important because it helps to provide insight for the formulation of response plans and the structuring of decision-making processes for operations. This document describes high-level features across the various case studies and comments on geometric and situational characteristics that determine how an incident may influence a large geographical region and route choices among multiple freeways. In addition, it explores consequences of different possibilities for ICM organizational structures.

1.2. GEOGRAPHICAL SCOPE

The following freeway groupings were investigated as a part of this analysis:

- I-210, I-10, and SR-60 in the Los Angeles area
- I-5 and I-805 near San Diego
- I-5 and SR-99 near Sacramento
- I-5 and SR-99 between SR-4 and SR-120 in Stockton
- I-5, SR-91, SR-57, and SR-55 in the Orange County Triangle
- I-880 and I-680 at the southern end of Fremont and Milpitas

This selection of freeway groupings offers a range of topologies, congestion patterns, and differing options for alternate paths.

1.3. DOCUMENT ORGANIZATION

The remainder of this document is organized as follows:

- **Section 2** describes the methodologies used in the collection and analysis of data
- **Section 3** presents each of the incident case studies
- **Section 4** synthesizes the patterns identified in the case studies into a set of factors that influence routing decisions.
- **Section 5** explores the considerations for large scale traffic management across multiple jurisdictions including metrics, boundaries, and technologies
- **Section 6** describes structures for organizing ICMs and explores practical challenges of data-driven decision making in the context of multiple ICMs
- **Section 7** closes with recommendations for the future

2. METHODOLOGY

There are two main stages in the data collection and analysis methods employed in this effort. In the first stage, PeMS and INRIX data are used to study an initial selection of freeway incidents. In the second stage, Streetlight data is used for a broader analysis.

2.1. STAGE ONE

This section describes the geographical scope and range of data gathered on freeways and arterials to support the first stage of the study. Figure 2-1 illustrates the freeway segments that were considered. These include:

- I-210, from SR-134 in Pasadena to SR-57 in San Dimas
- I-10, from the I-710 interchange to the I-605 interchange
- SR-60, from the I-710 interchange to the I-605 interchange

These three freeway segments were considered because they run parallel to each other. Analysis of incidents occurring on the I-210 looked at whether diversions occurred to the I-10. For incidents occurring on I-10, the analyses looked at whether the I-210 or SR-60 were used as alternate paths.

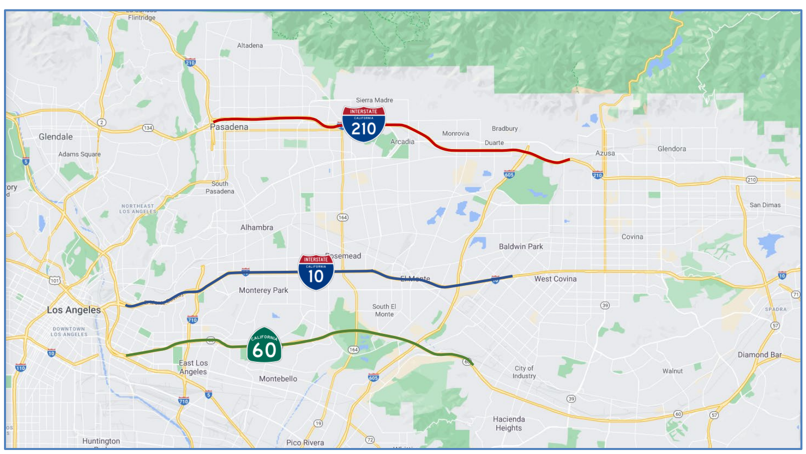

Figure 2-1 – Freeway Sections Considered

2.1.1. LOCAL ARTERIALS CONSIDERED FOR I-210 INCIDENTS

For the I-210 freeway, the arterial segments shown in Figure 2-2 were also considered to evaluate the impacts of freeway incidents on local traffic conditions. These segments include:

- Orange Grove Blvd / Rosemead Blvd
- Maple Street
- Corson Street
- Walnut Street
- Colorado Blvd, from SR-134 to Rosemead Blvd
- Foothill Blvd
- Huntington Blvd / Colorado Blvd (section between Rosemead Blvd and Mt. Olive)

No arterials related to the I-10 and SR-60 freeways were analyzed.

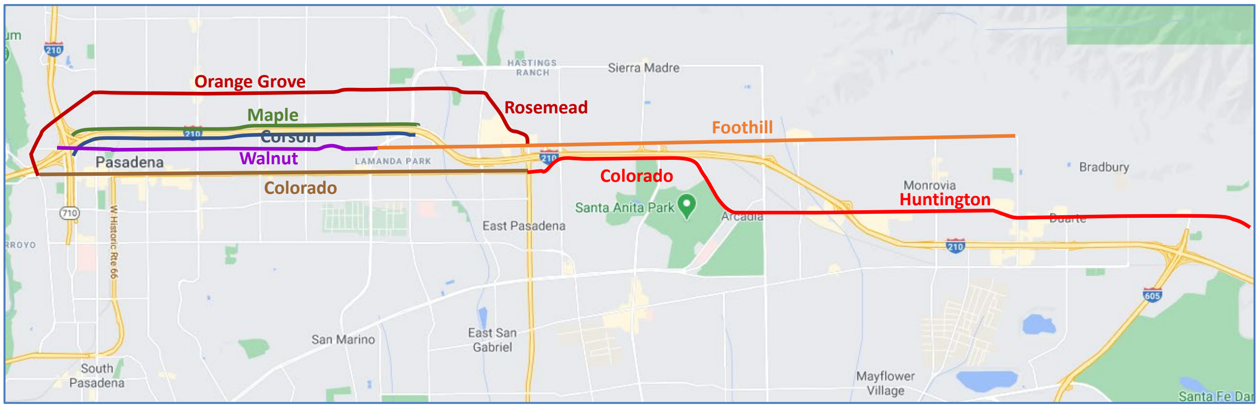

Figure 2-2 – Arterial Segments Considered for I-210 Analyses

2.1.2. INCIDENT DATA

Lists of incidents to review along the I-210 and I-10 freeways were obtained from Caltrans. These lists included all the incidents that had been logged from January to December 2019 into the Caltrans Advanced Traffic Management System (ATMS) by staff working at the Los Angeles County Traffic Management Center (TMC). They provided information on 151 incidents, distributed as follows across the freeway sections of interest:

- I-210 East: 23 incidents
- I-210 West: 30 incidents
- I-10 East: 46 incidents
- I-10 West: 52 incidents

For each incident, the following information was provided:

- Event type (incident or emergency closure)
- Time of occurrence
- Duration
- Location milepost
- Nearest cross-street
- Roadway affected (mainline, off-ramp, on-ramp)
- Travel lanes blocked

To focus the attention on events most likely to affect traffic conditions on nearby local arterials and other surrounding freeways, only incidents having the following features were considered:

- Duration equal or greater than 30 minutes
- Two or more lanes blocked

This reduced to 47 the number of incidents to consider for more detailed analysis as follows:

- I-210 East: 10 incidents

- I-210 West: 8 incidents
- I-10 East: 11 incidents
- I-10 West: 25 incidents

Ultimately, nine incidents were selected as case studies in the Pasadena area environs. This choice was determined by the quality of available data, the traffic impacts observed, and evidence of rerouting.

2.1.3. TRAVEL TIME DATA

Travel time data and congestion profiles were retrieved from the INRIX website. The website allows users to query observed speeds and travel times from various freeway and arterial segments. The website also produces a congestion profile highlighting the percentage of time that speeds on a given segments are observed to be below 65% of the speed limit. In particular, it is possible to put side by side profiles for two specific days, or, for two specific periods. An example is shown in Figure 2-3. This figure compares the congestion profile along I-210 E for November 26, 2019 to the average weekday profile for the month of November.

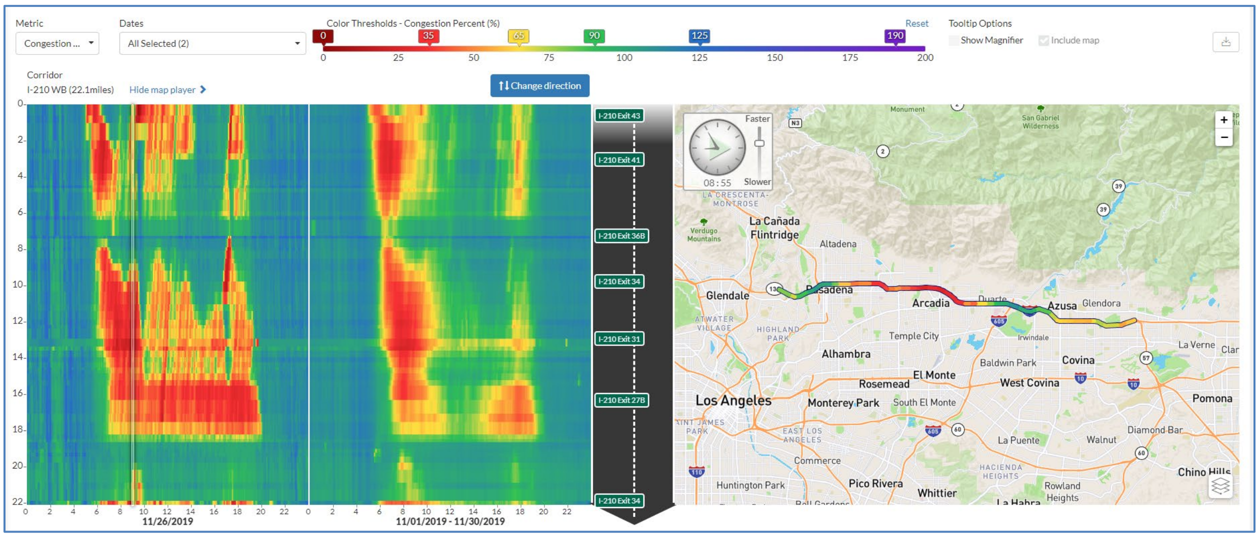

Figure 2-3 – INRIX Congestion Profile Example

2.2. STAGE TWO

This section describes the methodology used during the second stage of the project to scan for incidents, to assess evidence for rerouting, and to use the StreetLight Analytics platform for investigation of the selected incidents.

2.2.1. FREEWAY GROUPINGS CONSIDERED

In addition to the original set of freeway sections on I-210, I-10, and SR-60, the following freeway groupings were considered for further analysis:

- I-5 and I-805 near San Diego
- I-5 and SR-99 near Sacramento
- I-5 and SR-99 between SR-4 and SR-120 in Stockton
- I-5, SR-91, SR-57, and SR-55 in the Orange County Triangle
- I-880 and I-680 at the southern end of Fremont and Milpitas

These additional freeway segments were considered because they offer a range of topologies, congestion patterns, and differing options for alternate paths.

2.2.2. PROCESS FOR IDENTIFYING INCIDENTS OF INTEREST

For the portion of the I-210 corridor between the SR-134 and I-605 freeways, as well as the I-10 corridor between I-5 and I-605, incidents to investigate were identified from an event summary log that had been provided by Caltrans District 7. This log indicated the location, type, duration and affected lanes for all significant incidents known to have occurred on both freeways. Typically, only incidents occurring during the day, lasting more than 30 minutes, and affecting more than one traffic lane were considered for analysis.

For the other corridors considered, the project team was not able to retrieve similar incident logs. In this case, the identification of potential incidents of interest went through a survey of observed weekly travel times. For each corridor, average congestion patterns were retrieved from INRIX for each week of 2019. These congestion patterns reflect the observed travel times on successive freeway segments that were collected by INRIX over the analysis period.

An example from the analysis of traffic conditions on SR-57 in the Orange Triangle is shown in Figure 2-4. The figure shows the average congestion level that has been observed on both the northbound and southbound sections of SR-57 between the I-5 and SR-91 freeways for the nine weeks contained within the months of July and August 2019. A relative repetitiveness of traffic patterns can be observed in both travel direction, except for the week of August 11. For this week, a significant increase is observed in the duration and extent of congested conditions in the northbound direction, as indicated by the yellow arrow. An unusual congestion pattern can also be observed in the opposite direction.

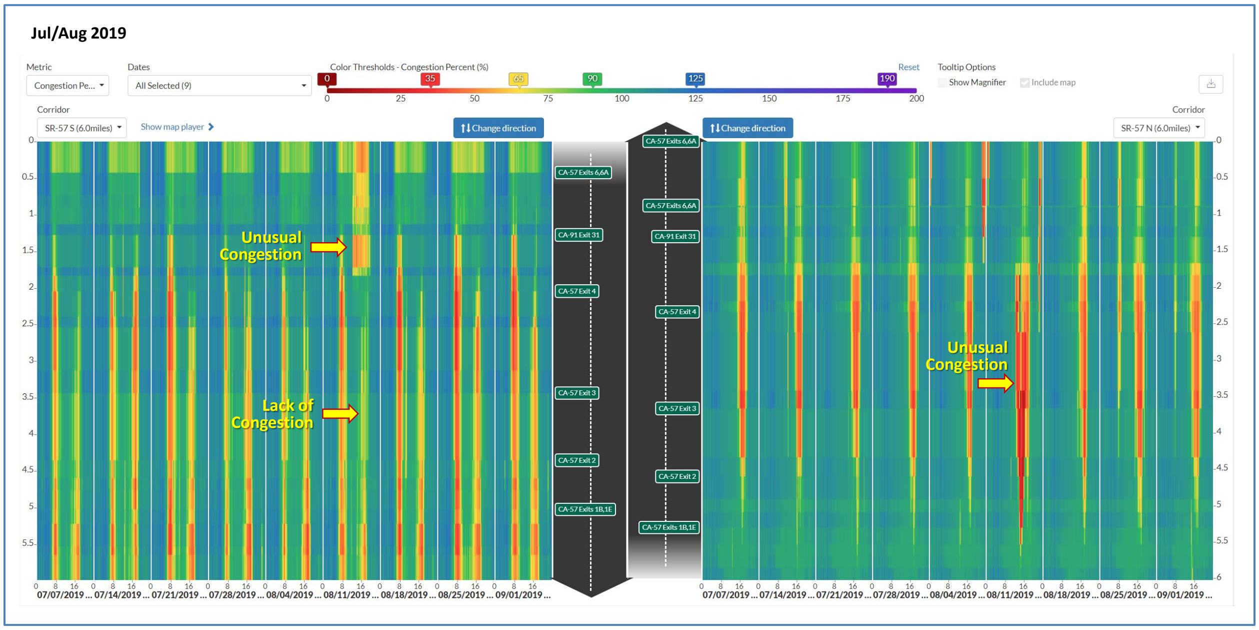

Figure 2-4 – Observed weekly average congestion on SR-57, July-August 2019

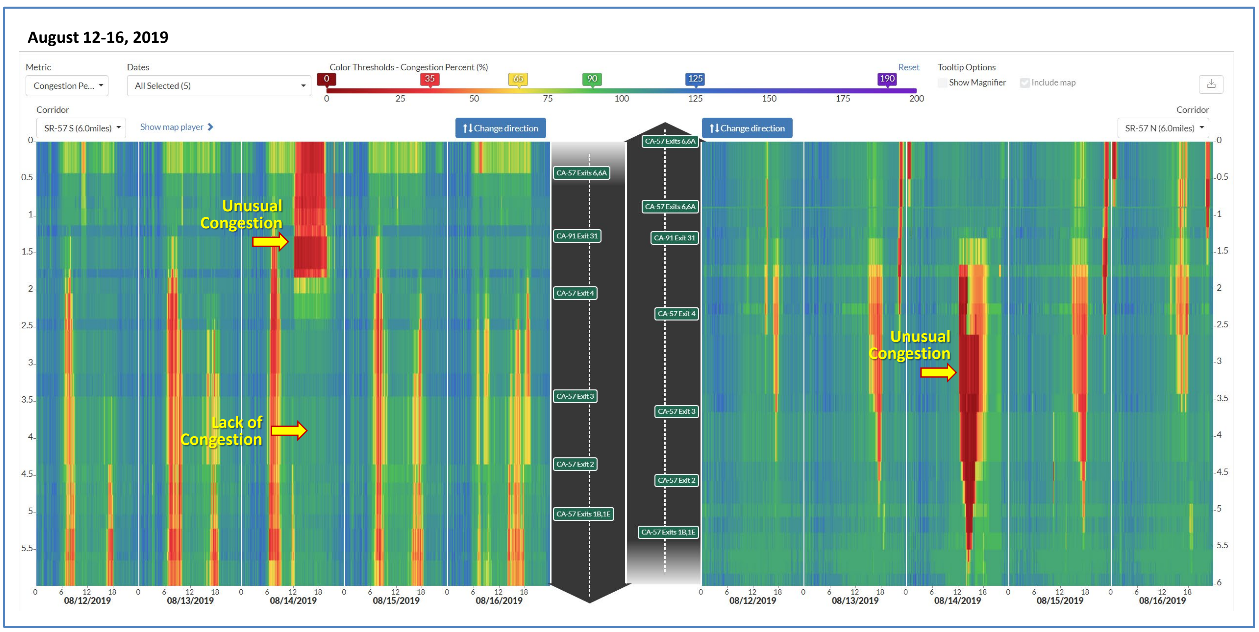

Figure 2-5 – Observed daily congestion scan for SR-57, week of August 11, 2019

For each week during which an unusual congestion pattern was observed, a more detailed analysis was then conducted by pulling from INRIX the congestion scan for each day of the week of interest. Figure 2-5 shows the follow-up to the example of Figure 2-4. It shows the observed northbound and southbound congestion patterns on SR-57 for each weekday during the week of August 11. This allowed to see if a particular day showed a significant deviation from the previous or following days. In this case, the daily scans indicate the existence of a major event that affected both directions of the freeway on Wednesday, August 14, 2019.

For each case in which a day of particular interest was identified, a final check was made by analyzing the flow and speed patterns recorded in PeMS for the freeway under investigation, as well as the CHP Incident log for that specific day. Figure 2-6 is a continuation of the example described above. It shows the flows and speeds that were recorded at two PeMS stations along SR-57 on August 14. The top diagram confirmed that a full freeway blockage occurred on SR-57 N just south of the SR-91 interchange between 2 PM and 10 PM. The bottom diagram further confirmed that a partial blockage occurred on SR-57 S over the same period. In this case, an analysis of the CHP Incident log indicated that a freeway closure was ordered to handle the cleanup of an oil spill caused by a heavy truck crash in the HOV lane.

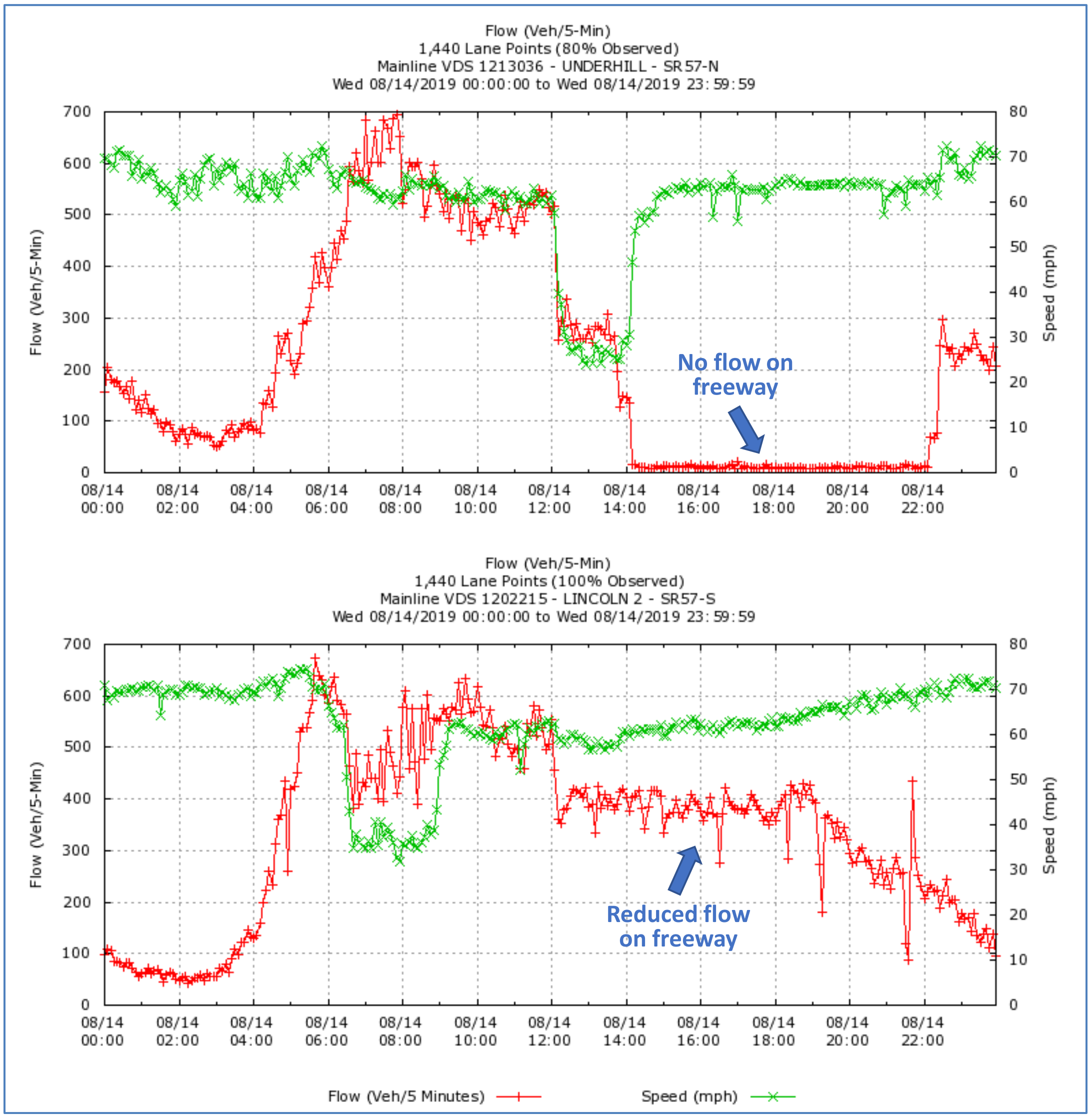

Figure 2-6 – Observed Flows and Speeds on SR-57 for August 14, 2019

The above process was repeated for each of the specific freeways associated with the corridors listed at the beginning of this section. The process allowed to identify major incidents that had the potential to trigger changes in traffic patterns, but not necessarily all incidents. This is because of the use of averages. The above process only allowed to identify incidents that caused notable changes in the average traffic patterns. Some moderate incidents that could have had some local effects may thus have been missed. This was deemed the best approach to identify incidents in the absence of other records.

Another approach could have consisted in analyzing the CHP Incident logs. This approach, however, is rather difficult to implement, as the incident logs recorded in PeMS do not always appropriately describe what has been happening. The recorded durations also do not always correspond to the actual duration of an incident, but rather to the duration that messages have been recorded. In particular, an end-of-event message is not recorded for many incidents, making it difficult to determine the duration of the incident.

2.2.3. ANALYSIS SUMMARY

Based on the process described in the previous section, days with incidents of interests were identified for the following corridors:

- I-5, SR-91, SR-57, and SR-55 in the Orange County Triangle

No incidents of interest were identified for the following corridors:

- I-5 and I-805 near San Diego
- I-5 and SR-99 near Sacramento
- I-5 and SR-99 between SR-4 and SR-120 in Stockton
- I-880 and I-680 in the southern end of Fremont and Milpitas

For the I-5/I-805 and I-680/I-800 corridors, this lack of identification is the result of the inability to distinguish a specific week with a significantly different congestion pattern than other weeks across all of 2019. The impacts of any incidents that may have occurred on these freeways was likely masked by the typical congestion patterns normally experienced from day-to-day on these freeways.

For the remaining three corridors, days of potential interest were identified by the analysis. However, a cross analysis of traffic conditions on other freeways revealed a lack of influence. For instance, while a significant congestion event was observed on SR-99 North south of Elk Grove near Sacramento on the same day that an unusual event was observed on I-5 North on the outskirts of Sacramento, an analysis of travel times along the major roads linking both freeways did not suggest any traffic rerouting. Through a review of CHP Incident logs, it was determined that the two congestion events had separate causes. In this case, the 5-mile separation between the two freeways may also have had a significant negative impact on the attractiveness of using the other freeway as a detour.

While the I-5/SR-99 corridor near Stockton offered a more compact, and thus attractive, couplet, the analysis also failed to identify incidents sending significant traffic to the other freeway. In this case, the I-5 and SR-99 freeways are only 3-4 miles apart and unusual congestion days were observed along SR-120 linking the two freeways. However, these congestion events appeared to be caused by normal fluctuations in traffic demand and treated as normal traffic conditions by motorists. While it is possible that some traffic that intended to use SR-120 may have diverted 12 miles to the north to using SR-4, the number of vehicles that may have done so were too low to affect the weekly INRIX averages. If traffic on SR-120 is not destined to go that far north, a strong disincentive then exists to in using SR-4 as a detour in the absence of exceptional congestion. Another likely explanation of the lack of impacts may be linked to traffic demand patterns. A detour to the north would only be considered for individuals traveling north past the connection offered by the other freeway. The same can be said for switching between I-5 and SR-99. If most of the traffic is not heading in the same direction as the detour, the expected impacts are then much lower.

2.2.4. STREETLIGHT ANALYTICS

During this project, limited access to StreetLight Analytics was made available. This access made it possible to incorporate trip-based data into the rerouting analysis. StreetLight was used to investigate incidents in the Orange County triangle. In addition, it was used to revisit the analyses of incidents during stage one of this project.

The analysis contained here should not be construed as an evaluation of StreetLight Analytics, or as an endorsement of products and services furnished by StreetLight. In this study the data from StreetLight were accepted as given and used to further elucidate rerouting patterns that were consistent with those observed using PeMS and INRIX data.

The provenance of StreetLight data is not transparent. It is possible that an analysis based on StreetLight may over-represent drivers who are digitally connected, and who use navigational apps for dynamic routing. In this research, the goal was to study dynamic routing caused by large traffic incidents, and therefore the choice of StreetLight data was well suited to the task. The key takeaway from the StreetLight data is not so much the absolute value of the flow of vehicles along certain routes, but rather the geographical extent of the observed rerouting behavior.

2.2.5. STREETLIGHT METHODOLOGY

Several functions in the StreetLight Analytics platform were used for this effort. The two most useful for investigation of re-routing patterns were:

- Zone Analysis
- Top Routes Between Zones

The Zone Analysis function allows the selection of up to twenty geographical regions as either origins or destinations and to display the top routes between these zones. In this study, the zones were selections of zip codes. Lists of zip codes were chosen to discover a distribution of likely paths between origins and destinations during different days, and times of day.

The Top Routes Between Zones function is like the Zone Analysis function except that specific roadway sections can be selected as entrance or exit gates. Using the function, it is possible to discover a distribution of likely paths between entrance or exit gates during different days, and times of day.

3. CASE STUDIES

This section presents the case studies that were investigated as part of this project using StreetLight, INRIX and PeMS data. It worth noting upfront a few general observations that can be inferred from what follows:

- Vehicles appear more likely to divert to another freeway if the alternate route allows them to keep moving in the same general direction as their travel destination. Examples of attractive alternatives include using SR-91 and SR-57 to go around incidents on I-5; using SR-55 instead of SR-57; or using I-10 instead of SR-60 to travel between Los Angeles and the Pomona/Ontario/San Bernadino areas.
- Detouring through alternate freeways is only attractive if some noticeable time savings can be obtained. Opting to use a 20-minute detour through alternate freeways to avoid a 10-minute delay at a given location is usually not seen as attractive. However, taking the same 20-minute detour to avoid a 30-minute delay associated with an incident occurring at the same place and time would likely be viewed more favorably and generate more rerouting.
- The attractiveness of alternate freeways is heavily linked to the distance between them. This strongly relates to the travel times and directionality issues discussed in the two preceding points. Freeways that are only 2-3 miles apart provide much stronger incentives than freeways 5-6 miles apart.
- Absence of unusual congestion at a freeway-to-freeway interchange may be a key disincentive to seek an alternate route. Many drivers will try to stay on a given route unless they notice something unusual.
- Very little detouring activity is observed for short incidents (typically less than 30 minutes) or incidents blocking only one or two lanes.
- Rerouting through another freeway appears to be more attractive for long-distance trips than short trips.

3.1. CASE STUDY HIGHLIGHTS

This section highlights a few key findings from each of the freeways in the study. Detailed analysis is provided in the following descriptions of each incident.

- **Orange County Triangle**
  - SR-57 N, Wednesday, August 14, 2019
    - SR-55 supports SR-57 as an alternate route
    - Significant dispersion of paths were observed at the junction between SR-22, I-5 and SR-57
    - StreetLight data revealed additional arterial paths on the west side of SR-57 that were not initially expected.
    - The geospatial influence of the incident was 4-5 miles
  - I-5 N, Thursday, January 24, 2019

        - StreetLight data confirmed PeMS observations that vehicles are using local arterials to reach SR-91 W from I-5 N,
        - StreetLight data helped to find evidence of vehicles re-entering I-5 downstream of the incident
        - The geospatial influence of the incident was 2-3 miles
    - SR-91 E, Friday, November 1, 2019
        - The StreetLight data did not indicate that traffic used I-5 S as a detour. This is likely because using I-5 S as an alternate route may be seen as a long detour and a detour that appears to take traffic too far away from the intended travel direction (mainly eastbound or north-eastbound away from I-5)

- **SR-60**
    - SR-60 E, Wednesday, May 22, 2019
        - Only local arterial detouring activities are observed, as the congestion normally existing on other nearby freeways make detouring less attractive
        - The large-scale event of the weather event at the source of the congestion may have reduced the willingness of drivers to seek alternate routes

- **I-10**
    - I-10 W, Thursday, January 17, 2019
        - StreetLight data largely reinforced previous findings from PeMS and INRIX
        - Some local paths and dispersion were observed
        - The geospatial influence of this incident was small
    - I-10 E, Thursday, June 6, 2019
        - This incident had a large geospatial influence of about 4-6 miles
        - Drivers bound for I-10E appear to stay on I-10 E
        - Drivers bound for I-605 N / I-210 E reroute via local streets
        - Drivers bound for I-605 S / SR-60 reroute via local streets
        - More detailed investigation may inform potential response plan strategies for an I-10 ICM project

- **I-210**
    - I-210 W, Friday, July 26, 2019
        - StreetLight data showed dispersion of routes along I-605, Live Oak, Duarte, and Foothill
        - StreetLight data consistent with INRIX data on the same day showing increased travel times on Foothill and Colorado
    - I-210 W, Thursday, Nov 14, 2019
        - Streetlight data only shows noticeable detouring activity along local arterials
        - The back of congestion generated by the incident does not reach the I-605 interchange, the closest upstream major interchange; as a result, motorists have already committed to using I-210 by the time they reach the congestion
        - Detouring to I-10 may take more time than the roughly 10-minute delay generated by the incident

3.2. SR-57 N -- WEDNESDAY, AUGUST 14, 2019

A full freeway closure on SR-57 N near California PM 15.4 (Absolute PM 4.7) occurred on Wednesday, August 14, 2019. An incident began around noon and by about 2:00pm, traffic was diverted off SR-57. The left-hand side of Figure 3-1 displays a time-space diagram of SR-57 comparing traffic congestion on August 14, the incident day, with the weekday monthly average for August. A yellow rectangle denotes the duration of the full closure. The right-hand side of Figure 3-1 displays a map of the environs showing the location of the closure with a blue arrow.

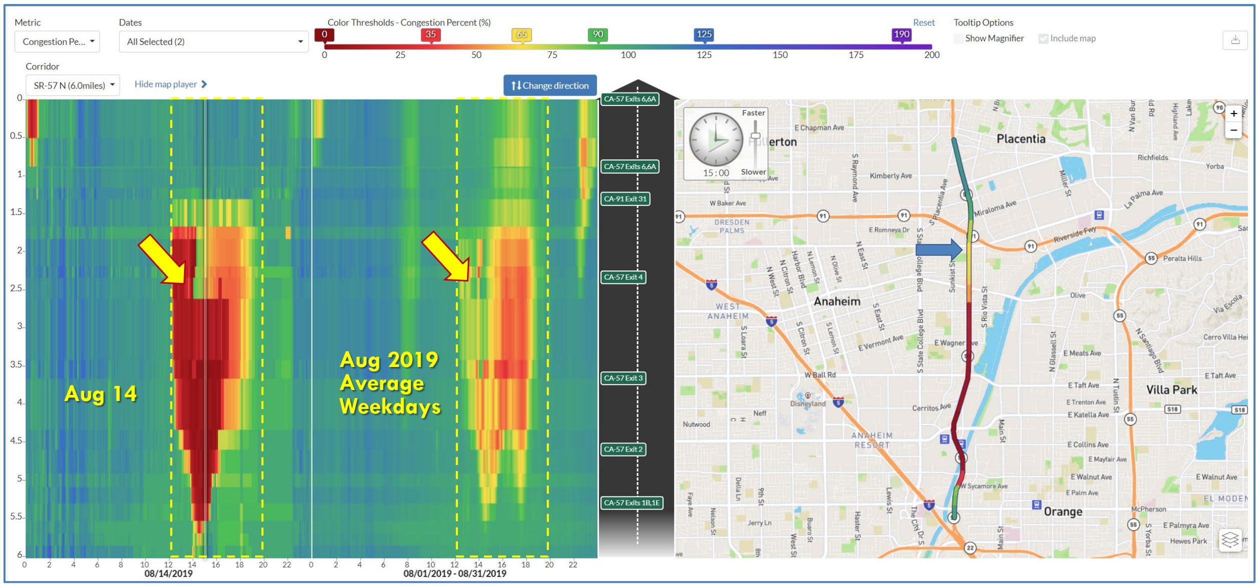

Figure 3-1 – Traffic conditions on SR-57 N for the August 14, 2019 incident

Analysis of StreetLight data show that the geospatial influence of this incident was about four to five miles in extent. In addition, SR-55 and SR-57 appear to be closely coupled as SR-55 supports SR-57 as an alternate route. A significant dispersion of paths was observed at the junction of SR-22, I-5, and SR-57. StreetLight data also revealed additional arterial paths on the west side of SR-57.

Figure 3-2 displays a StreetLight top routes analysis for a typical day from Tustin Ranch along I-5 to Cal State along SR-57 on Tuesday, August 13, 2019. The top routes reflect observed data collected by StreetLight about vehicle traces between the specified origins and destinations. Notice that there is only one predominant route along SR-57 for this O-D pair on this day. The height of the 3-D wall along the links of the route is proportional to the estimated flow of vehicles along the route.

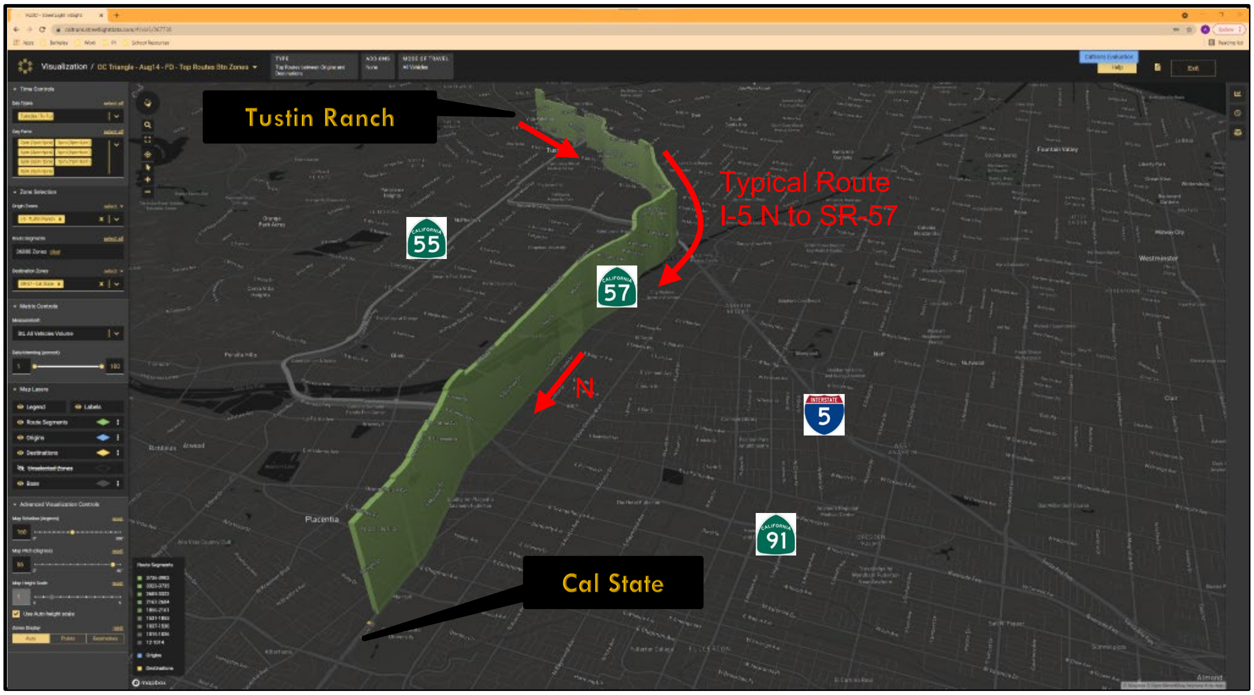

Figure 3-2 – Predominant route along SR-57 on Tuesday, August 13, 2019

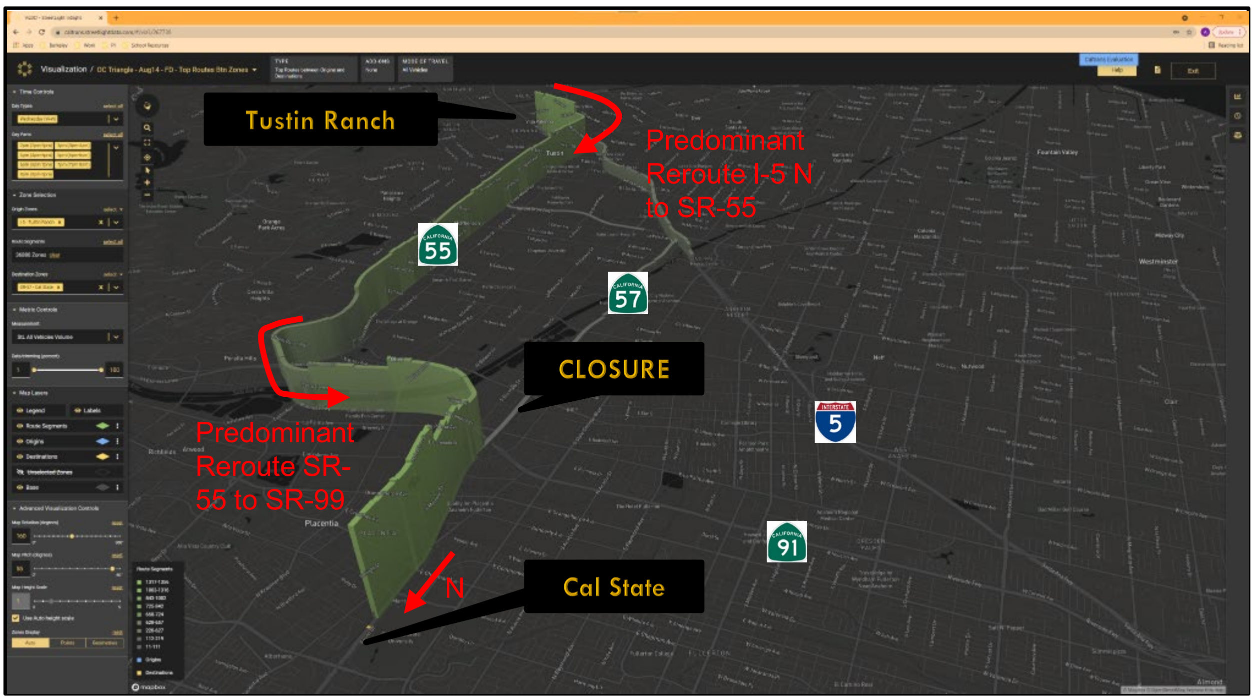

Figure 3-3 – Predominant route along SR-55 on Wednesday, August 14, 2019

Figure 3-3 displays a StreetLight top routes analysis for the incident day from Tustin Ranch along I-5 to Cal State along SR-57 on Wednesday, August 14, 2019. Notice that the predominant route for this O-D pair is along SR-55 for this day. The height of the 3-D wall along the links of the route is proportional to the estimated flow of vehicles along the route. A fewer number of vehicles, according to StreetLight, continue along I-5 and then disperse near the junction of I-5 and SR-57.

StreetLight has a privacy policy such that links displayed in the top routes analysis will not be revealed unless the number of representative trips through that link is above some threshold. The purpose of the policy is to prevent the identification of a specific traveler within the data. As a result, not all routes are shown in full detail.

Figure 3-4 displays a StreetLight top routes analysis for the incident day from a gate defined on SR-22 to Cal State along SR-57 on Wednesday, August 14, 2019. Although SR-55 appears to be the main detour, there is a large dispersion of paths. 3-D walls are visible for this O-D pair along SR-55, SR-91, and off-ramps of SR-57. Red arrows denote inferred paths at points where the 3-D wall suddenly increases or decreases in height. Blue arrows show onramps along SR-91 where the 3-D wall increases in height, revealing locations where paths of a sufficient number of vehicles continuing to Cal State overlapped.

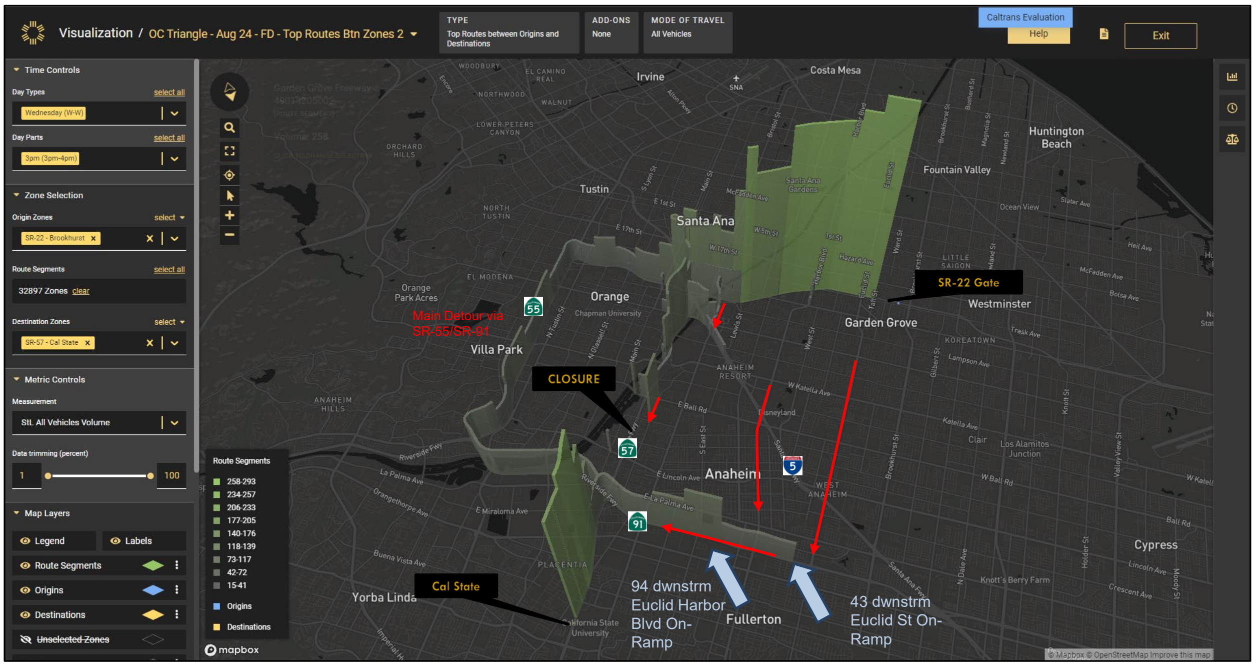

Figure 3-4 – Top routes from SR-22 gate to SR-57 near Cal State

Like Figure 3-4, Figure 3-5 also displays a StreetLight top routes analysis for the incident day from a gate defined on SR-22 to Cal State along SR-57 on Wednesday, August 14, 2019. However, Figure 3-5 is rotated to show the view from the south. In this view, the paths of vehicles exiting SR-22 at Garden Grove, and The City are clearly visible. In addition, paths are also visible on local streets. This visualization suggests that the geographical extent of the incident on SR-57 extends to SR-22, I-5, SR-55, and local streets in between.

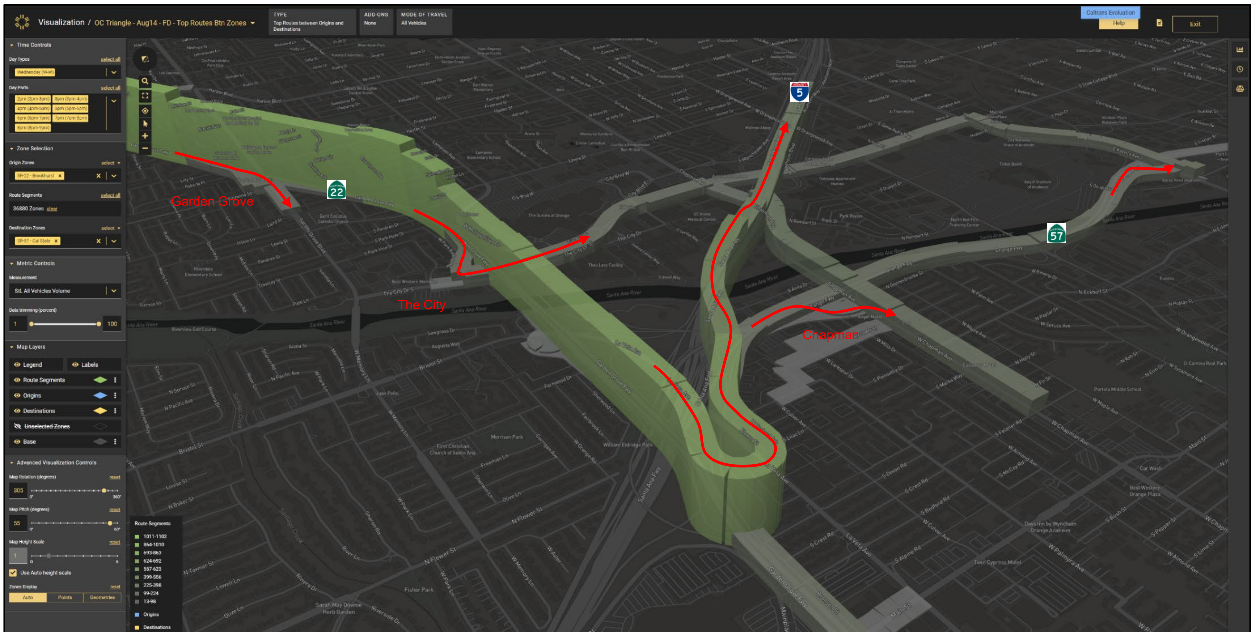

Figure 3-5 – Route dispersion near SR-22 and SR-57 interchange

3.3. I-5 N -- THURSDAY, JANUARY 24, 2019

An incident on I-5 N just south of the SR-91 interchange occurred on Thursday, January 24, 2019. The left-hand side of Figure 3-6 displays a time-space diagram of I-5 N comparing traffic congestion on January 24, the incident day, with the weekday monthly average for January. A yellow rectangle denotes the duration of the full closure. The right-hand side displays a map of the environs showing the location of the incident with a blue arrow. Black arrows show inferred rerouting based on flow counts collected from PeMS and travel time data from INRIX.

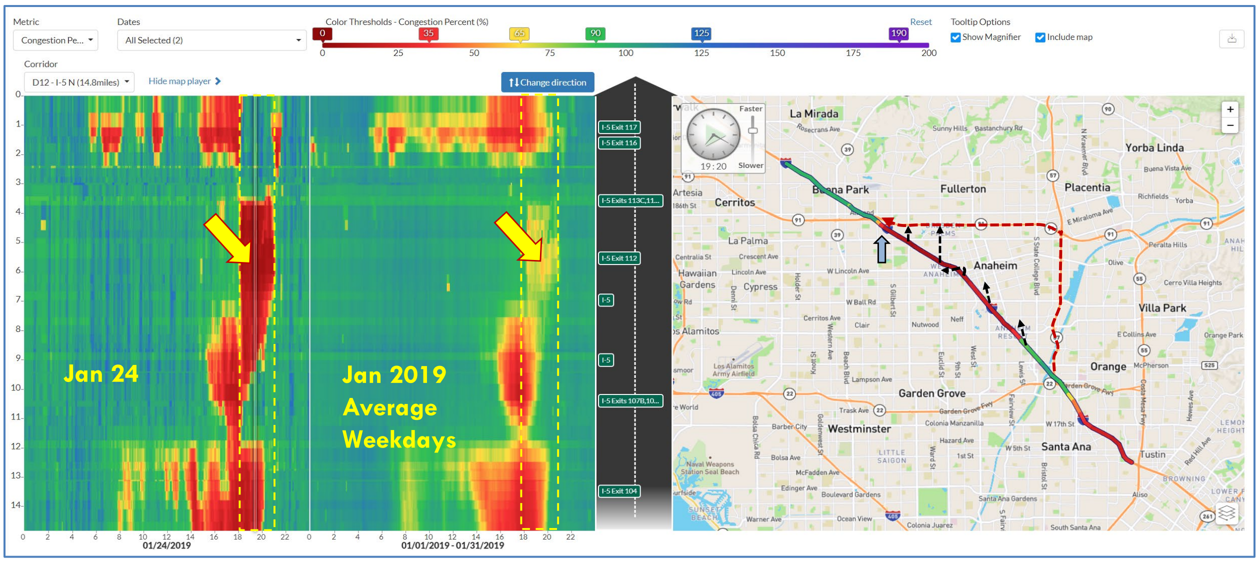

Figure 3-6 – Traffic conditions on I-5 N for the January 24, 2019, incident

Evidence of the use of the SR-57 and SR-91 freeways as a detour is shown Figure 3-7. The figure compares the observed flow on the freeway-to-freeway connectors on the day of the incident (Thursday) to the flows that were observed on the previous day (Wednesday). The shaded area in each graph marks the incident period. As can be observed, a clear increase in traffic can be noted on all three connectors during the incident period, particularly on the SR-91 W to I-5 N connector.

Figure 3-8 and Figure 3-9 further provide evidence of traffic exiting the I-5 N freeway and using local arterials to go around the incident. Figure 3-8 illustrates the flows that were observed on January 24 on off-ramps along I-5 N upstream of the incident location while Figure 3-9 illustrates the flows on the two on-ramps along SR-91 W closest to the I-5 interchange. As in Figure 3-7, the shaded area in each diagram marks the incident period. As with the freeway connector diagrams, a significant surge in off-ramp and on-ramp traffic can be observed during the incident, clearly indicating the use of local arterials as detours.

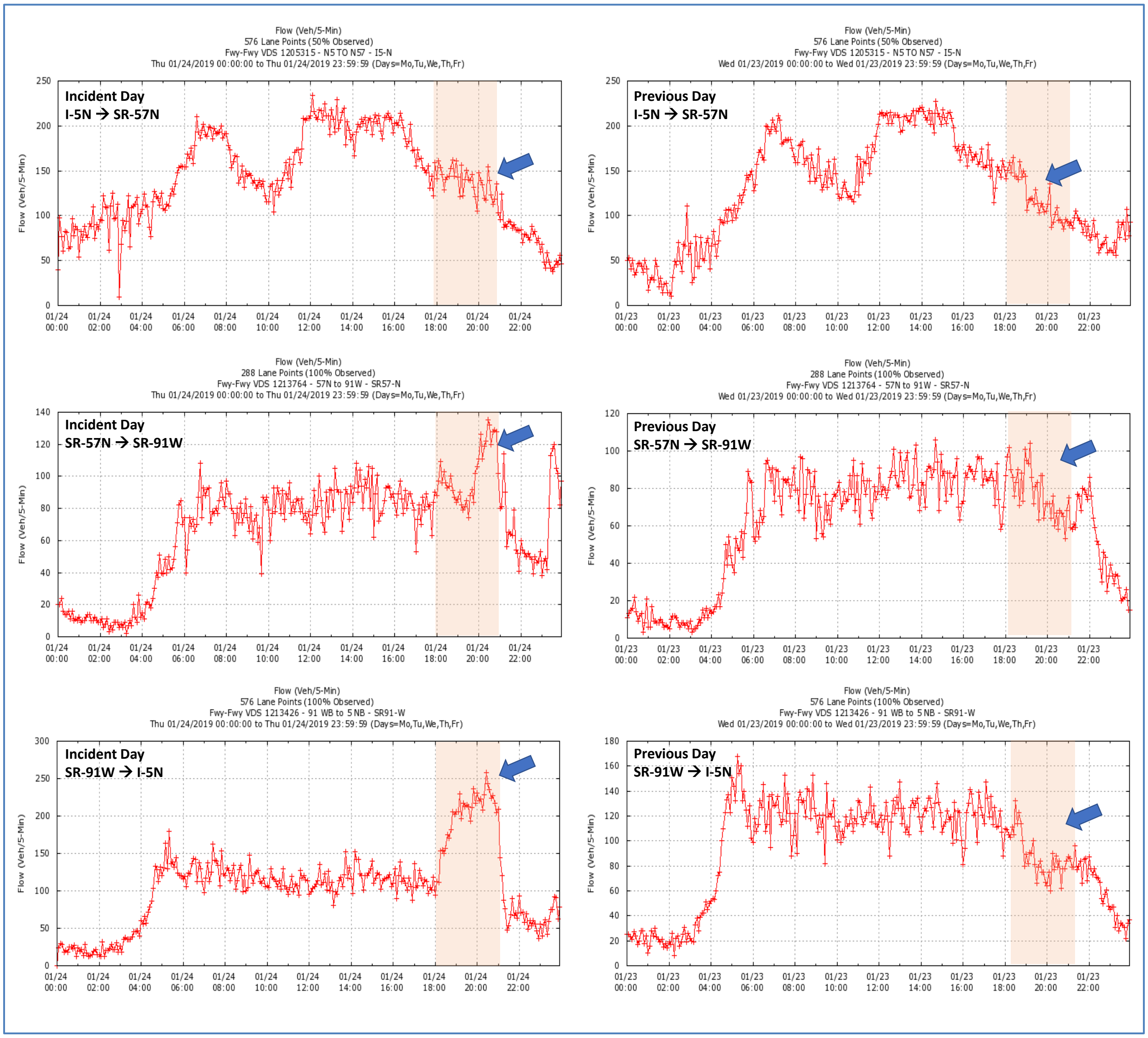

Figure 3-7 – Flows on connectors between I-5 N, SR-57 N and SR-91 W on January 23-24, 2019

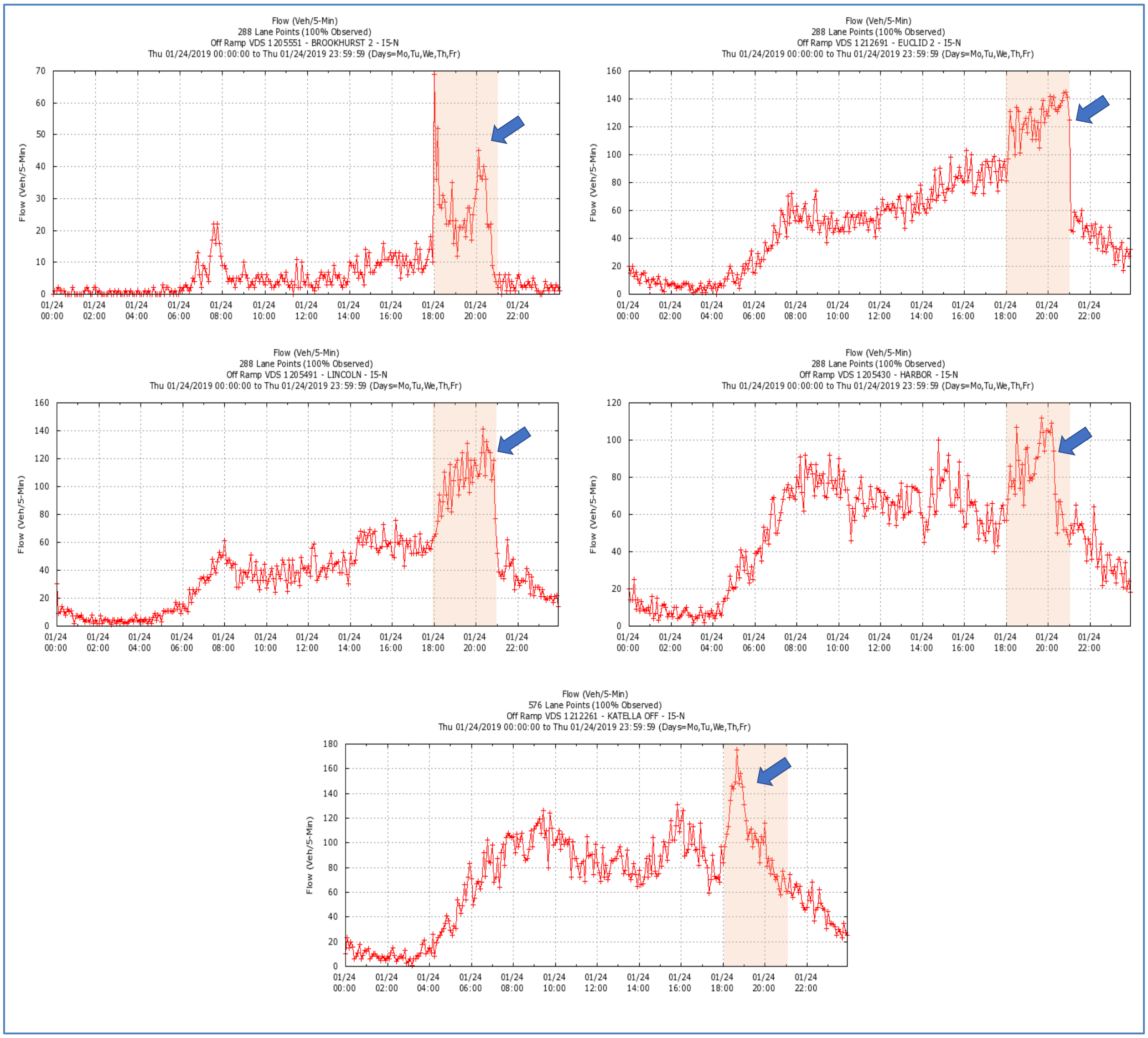

Figure 3-8 – Flows on I-5 N off-ramps on January 24, 2019

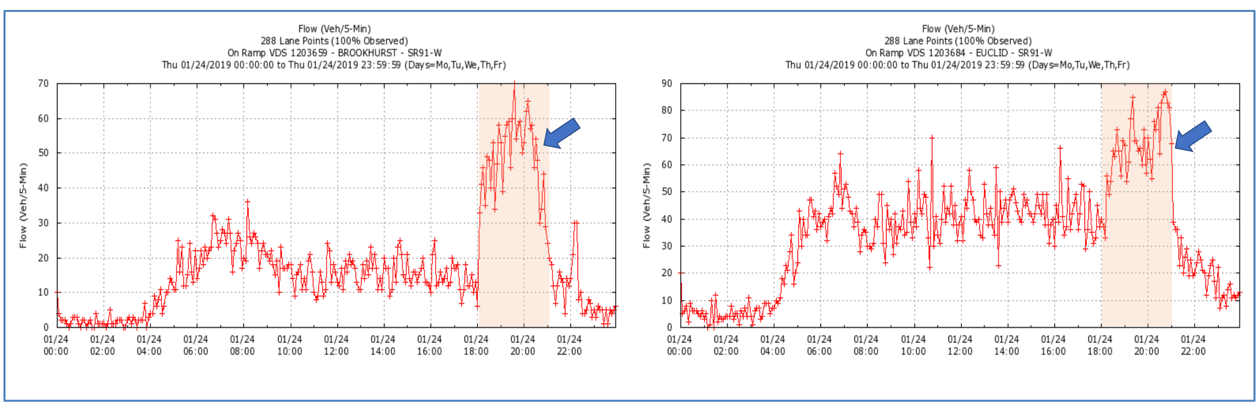

Figure 3-9 – Flows on SR-91 W on-ramps on January 24, 2019

Figure 3-10 further displays a StreetLight top routes analysis for the incident day along I-5 from several miles upstream of the incident to a location downstream of the incident on Thursday, January 24, 2019. Once again, the height of the 3-D wall along the links of the route is proportional to the estimated flow of vehicles along the route. Red arrows denote locations where the height of the wall decreases along I-5 and increases along SR-91. The conclusion from this evidence is that vehicles rerouted around the incident at those locations. The bulk of the geospatial influence of this incident appears to be within about two to three miles.

Figure 3-10 – Top routes between zones upstream and downstream of the I-5 N incident

Figure 3-11 and Figure 3-12 display a StreetLight top routes analysis for the incident day along I-5 from several miles upstream of the incident to a location downstream of the incident on Thursday, January 24, 2019. However, Figure 3-11 shows the view from the east and Figure 3-12 shows an orthogonal view. Red arrows in both figures show inferred routes of vehicles along local streets to reenter I-5 downstream of the incident.

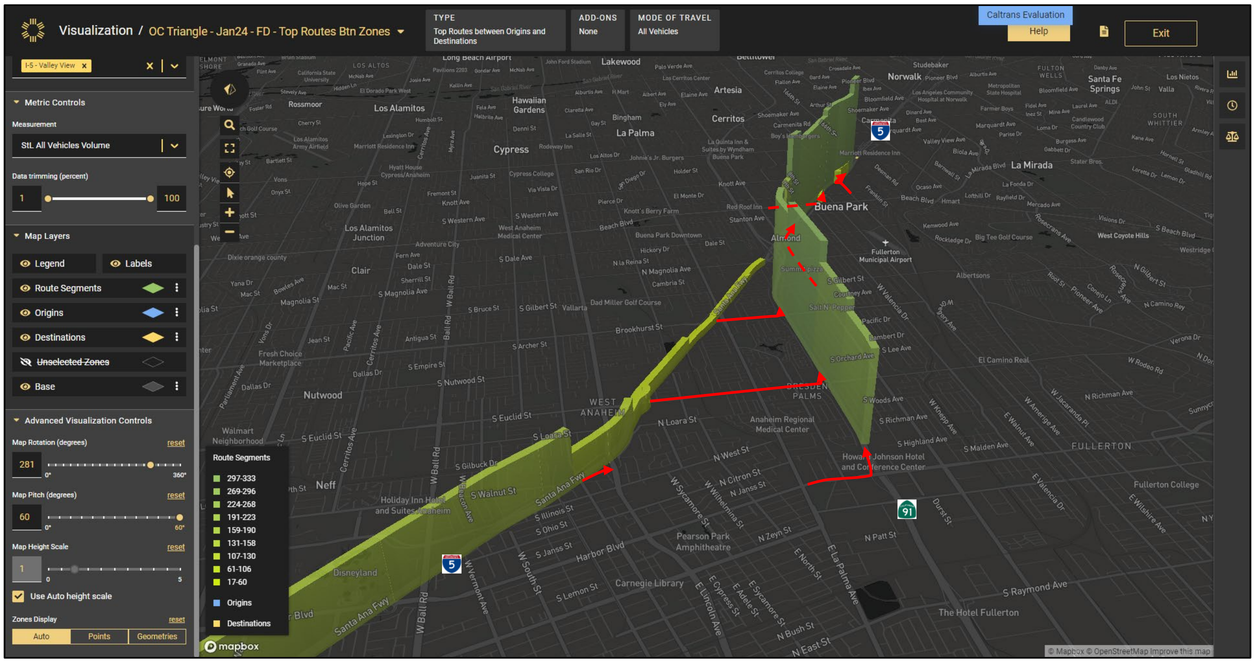

Figure 3-11 – View of routes using SR-91 around the I-5 N incident

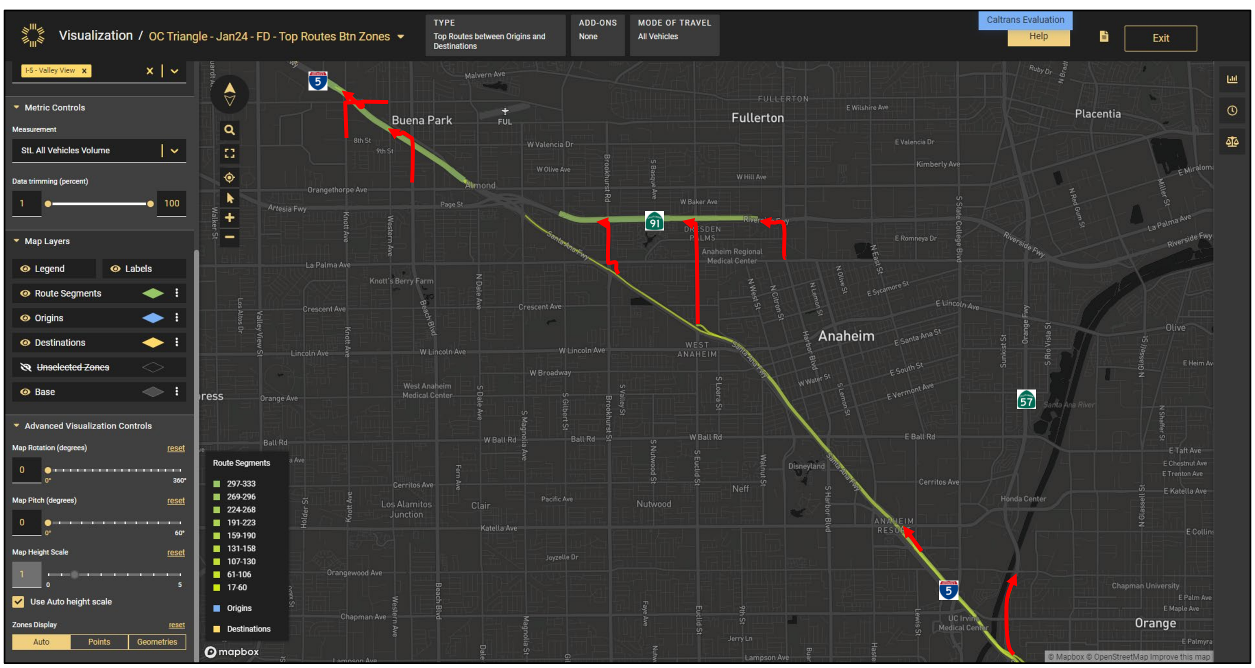

Figure 3-12 – Inferred routing around the I-5 N incident

3.4. SR-91 E -- FRIDAY, NOVEMBER 1, 2019

This section examines an incident that occurred on SR-91 E on Friday, November 1st, 2019. This incident involves a truck that overturned on the freeway around 3 AM near the SR-57 interchange, and blocked the three middle lanes of the freeway, leaving only the HOV lane open. Lanes started to reopen around 7 AM, four hours after the start of the incident, with all lanes being reopened by 8:20 AM. Due to the large number of lanes closed, this incident was therefore a good candidate for analysis.

Figure 3-13 illustrates the extent of the congestion observed on SR-91 E on the day of the incident. The left-hand side of the figure compares congestion scans that were retrieved from INRIX for the day of the incident, November 1st, to the average weekday traffic conditions that were observed between mid-October and mid-November. The impact of the incident is clearly visible, as pointed out the by yellow arrows. The right-hand side of the figure further illustrates the extent of the freeway queue on a map. As can be observed, the resulting congestion extended from the SR-57 interchange to the I-5 interchange.

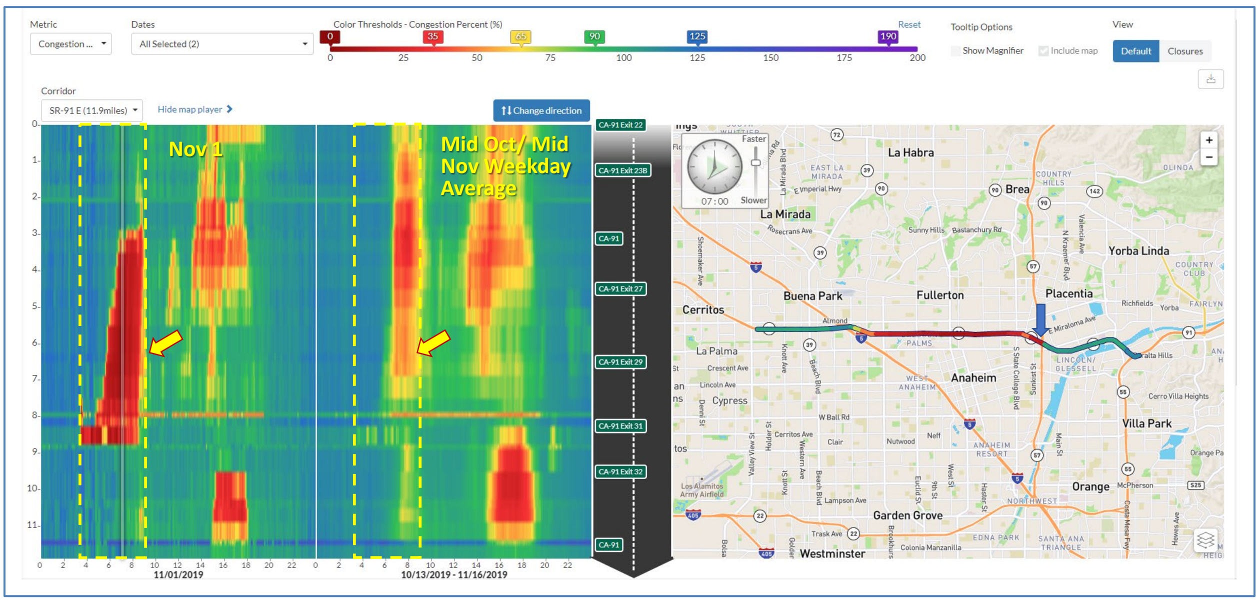

Figure 3-13 – Traffic conditions on SR-91 E during the November 1st, 2019, incident

Figure 3-14 illustrates the eastbound traffic patterns around SR-91 that were recorded on the day of the incident. By comparing these patterns those from other days on the same week, it could be determined that a certain number of vehicles were getting off the freeway near the SR-57 interchange, just upstream of the incident, to go around it. The figure depicts in red a few of the arterial detours that appeared to have been used. Figure 3-15 presents further evidence of traffic exiting the SR-91 freeway within the congested area. As indicated by the red arrows, significantly higher off-ramp volumes were observed in the StreetLight data as compared to volumes on typical days. Unfortunately, the StreetLight data did not provide much information about which arterials were taken.

While the analysis has presented clear evidence of traffic rerouting off the SR-91 freeway using local arterials, the available data does not suggest that a significant number of vehicles detoured all the way around the triangle using I-5 S and either the SR-57 N or SR-55 N freeways. The INRIX data showed that the incident day and typical days all had relatively similar travel conditions on these freeways. While some vehicles are observed using these freeways on November 1st, this behavior is also observed on other days.

While the StreetLight flow indices for these three freeways appear slightly higher on November 1st than on other days, they are only marginally so, and within the apparent day-to-day variance.

Figure 3-14 – Top route analysis from I-5 S and SR-91 E (north view)

Figure 3-15 – Top route analysis from I-5 S and SR-91 E (south view)

The above observation may be explained by the relation between the location of the incident and the intended direction of travel of vehicles using the SR-91 E freeway in the morning. The StreetLight data suggests that most vehicles on SR-91 E in the morning are traveling eastbound away from I-5, with some vehicles aiming to use SR-57 N. In this context, attempting to detour around the incident using I-5 S represents a significant increase in travel distance that may be beyond what drivers are willing to accept in the Los Angeles area context. In this case, drivers may simply view attempting to use local arterials as being more efficient than attempting a long freeway detour that appears to take them away from their intended destination.

3.5. SR-60 E -- WEDNESDAY, MAY 22, 2019

This section examines an incident that occurred on SR-60 E on Wednesday, May 22, 2019 near Pipeline Avenue in Chino. This incident is a flooding event on the freeway that started around 2:30 PM and lasted until 7:00 PM following a weather event that brought heavy rain and hail to the area.

Figure 3-16 illustrates the extent of the congestion observed on SR-60 E on the day of the incident. The impact of the incident is clearly visible on the left-hand side of the figure, which compares congestion scans that were retrieved from INRIX on May 22 to the average weekday traffic conditions from May 2019. The map on the right further illustrates the extent of the congestion along the freeway. This resulted in a congested queue extending about 16 miles.

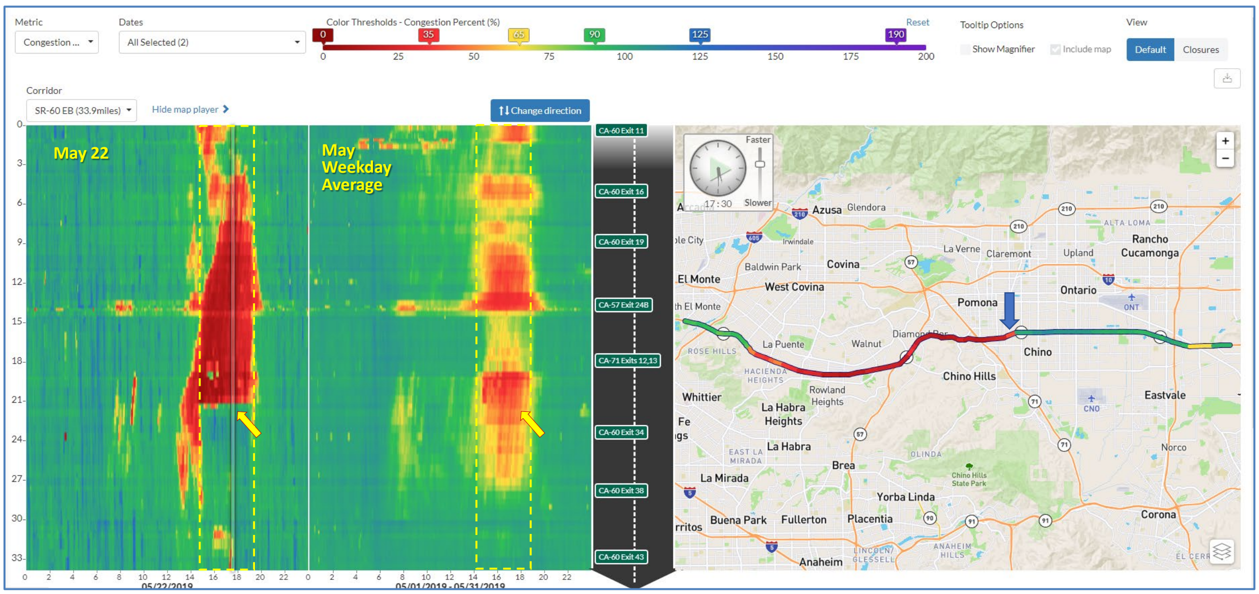

Figure 3-16 – Traffic conditions on SR-60 E during the May 22nd, 2019, incident

Figure 3-17 further compares the traffic conditions on I-10 E and I-210 E during the middle of the event. As can be observed, all three freeways were generally congested at that time. In the case of the I-10 and I-210 freeways, the observed condition is relatively typical of what exists at this time of the day. Based on this assessment, regular commuters may have had in this case a strong disincentive to try to use other freeways.

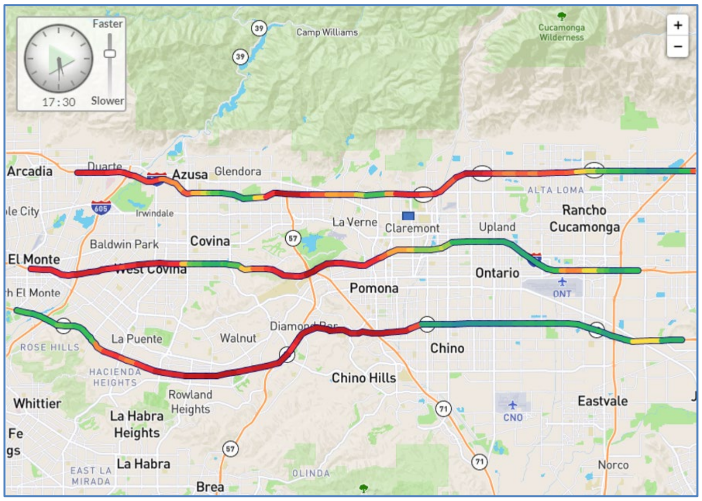

Figure 3-17 – Traffic conditions on SR-60 E, I-10 E and I-210 E during the May 22nd, 2019, incident

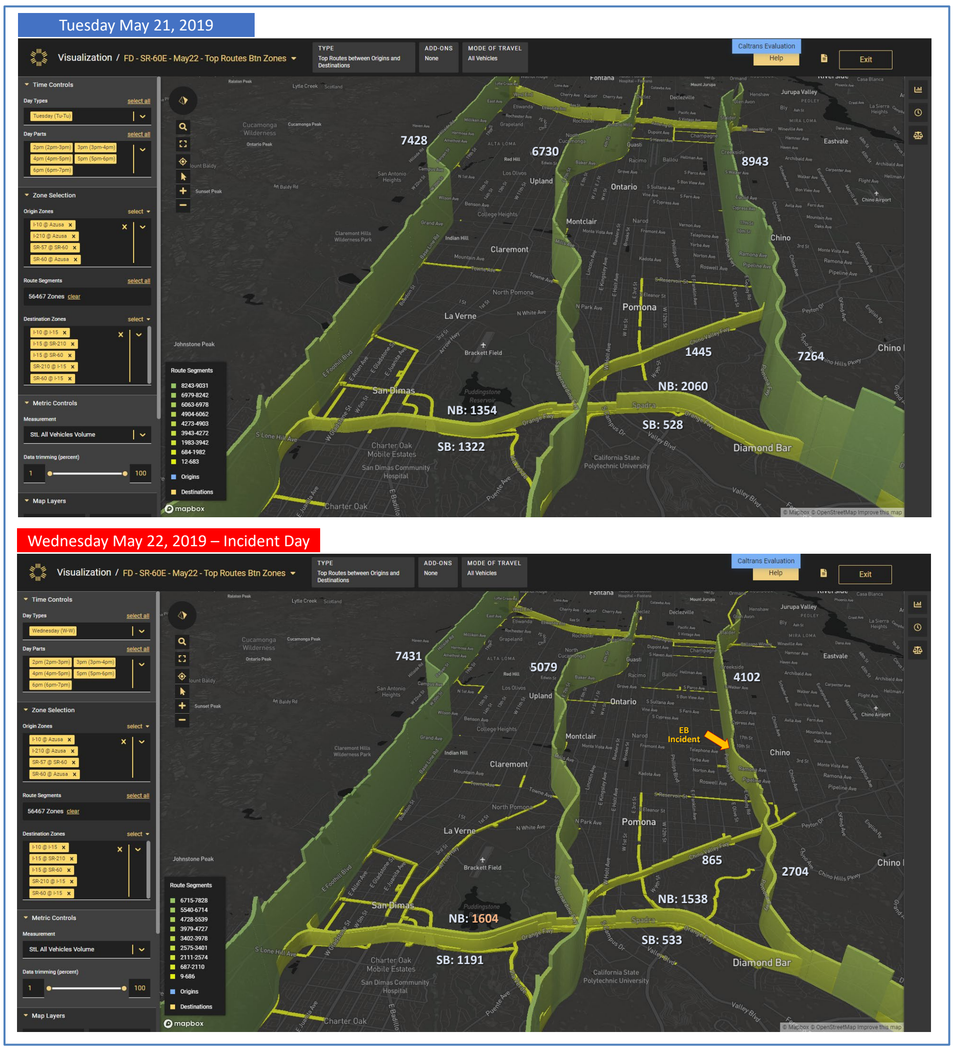

Figure 3-18 – Top Route Between Zones Analysis for May 21 and May 22, 2019

The above statement is supported by the routing patterns captured on this day by StreetLight. Figure 3-18 compares the patterns captured on May 21 and May 22. The May 21 patterns are typical of what can be observed on other days. While reduced flows are seen on SR-60 E during the incident, reduced flow can also be observed on I-10E. This is likely due to the weather event affecting traffic conditions on both freeways. Almost no change is observed on I-210 E.

While there does not appear to be much freeway-to-freeway travel shifts, the StreetLight data further suggests that some traffic used local arterials to try to avoid congestion on SR-60 E. Figure 3-19 illustrates a few of the local detours that can be inferred. They mainly involved traffic on SR-57 S and SB-71 S attempting to use local arterials to travel eastward along SR-60.

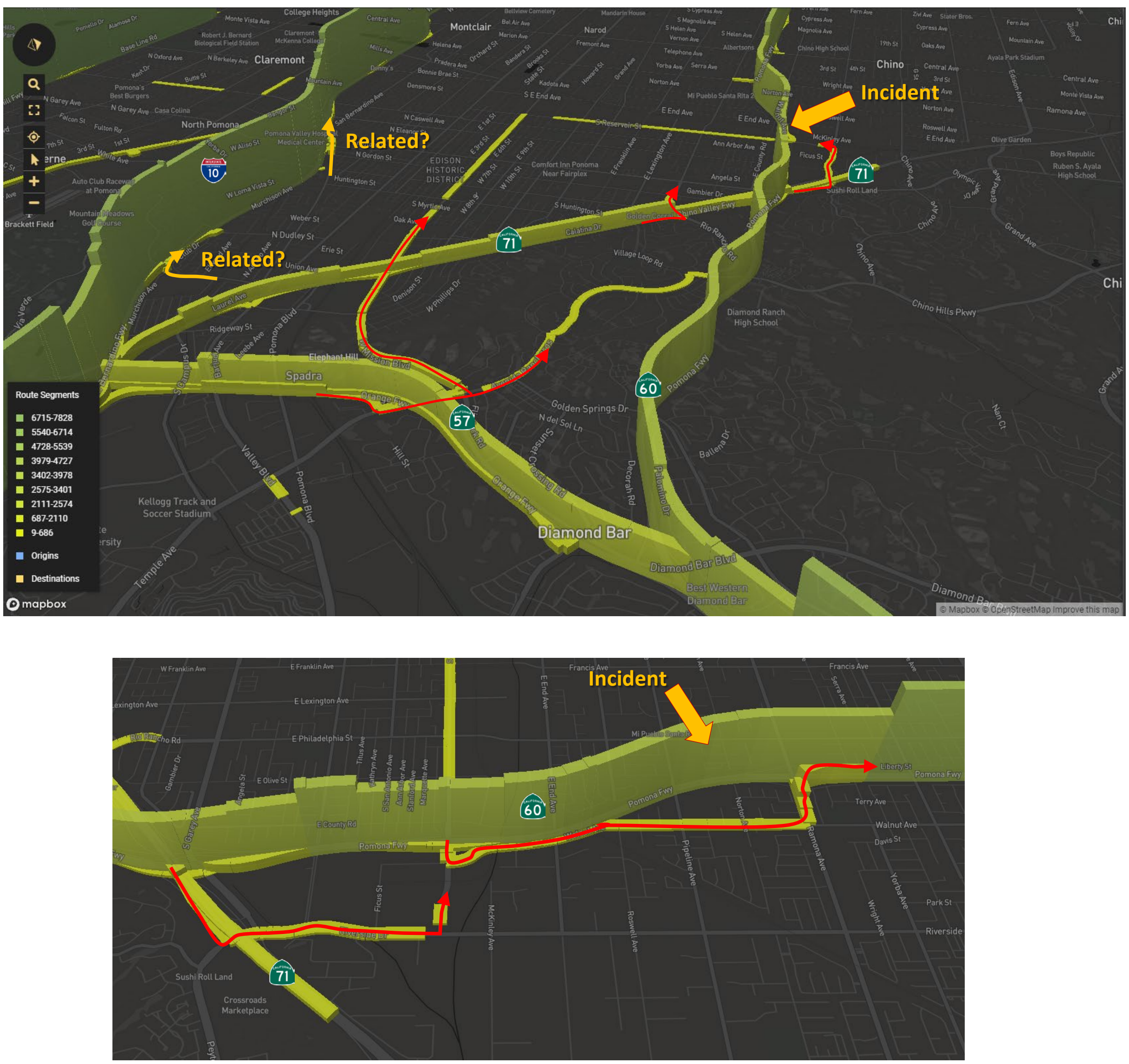

Figure 3-19 – Inferred arterial detours used on May 22, 2019

3.6. I-10 W -- THURSDAY, JANUARY 17, 2019

An incident blocking the HOV and one mainline traffic lane occurred at milepost 24.83 near the New Avenue interchange in Rosemead, from a reported time of 6:40 AM to 8:20 PM (1.75-hour incident).

As can be observed in Figure 3-20, this incident caused noticeable congestion along I-10W, with unusual congestion compared to the January 2019 weekday average conditions extending up to the I-605 interchange. As shown in Figure 3-21, this unusual congestion appears to have pushed some vehicles to use I-210 W instead, causing higher congestion than usual along this freeway. While a review of traffic volumes along I-210 W, shown in Figure 3-22, indicates much lower volumes were recorded on January 17 than other weekdays in January, a review of travel speeds, shown in Figure 3-23, indicate that these lower volumes were the results of significantly slower than average speeds, and thus, the presence of significant congestion on the freeway. However, it cannot be conclusively determined in this case that this additional congestion was the result of traffic diverting from the I-10 W. As shown in Figure 3-24 and Figure 3-25, lower than average traffic flows were also recorded both on the I-605 N to I-210 W connector and on the I-210 W approach to the interchange. This suggests that motorists may not have used the I-605 N nor SR-57 N to divert to I-210 W. An interesting observation from Figure 3-23 is that the longest travel times were recorded during the I-10 W incident period, and that travel times started to decrease after the incident was cleared. This may point to some traffic potentially using I-210 W as an alternate route, but it may also simply reflect the fact that the incident terminates at the same time that peak-hour traffic starts to wane in the morning.

Figure 3-26 also indicates higher congestion than usual along SR-60W, suggesting that some traffic also used this freeway as an alternate route. This observation is confirmed in Figure 3-27 by the higher traffic flows observed along SR-60 during the incident, and in Figure 3-28 by the increasing travel times during the incident period and decreasing travel times following the incident clearance.

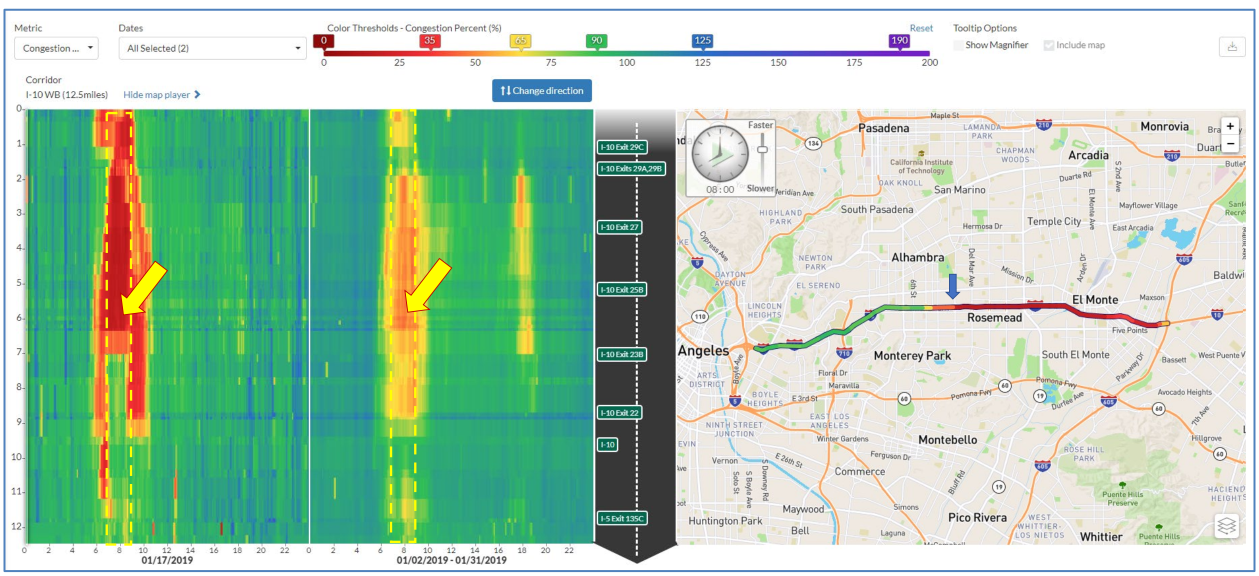

Figure 3-20 – Traffic Conditions on I-10 W for the I-10 W January 17 Incident

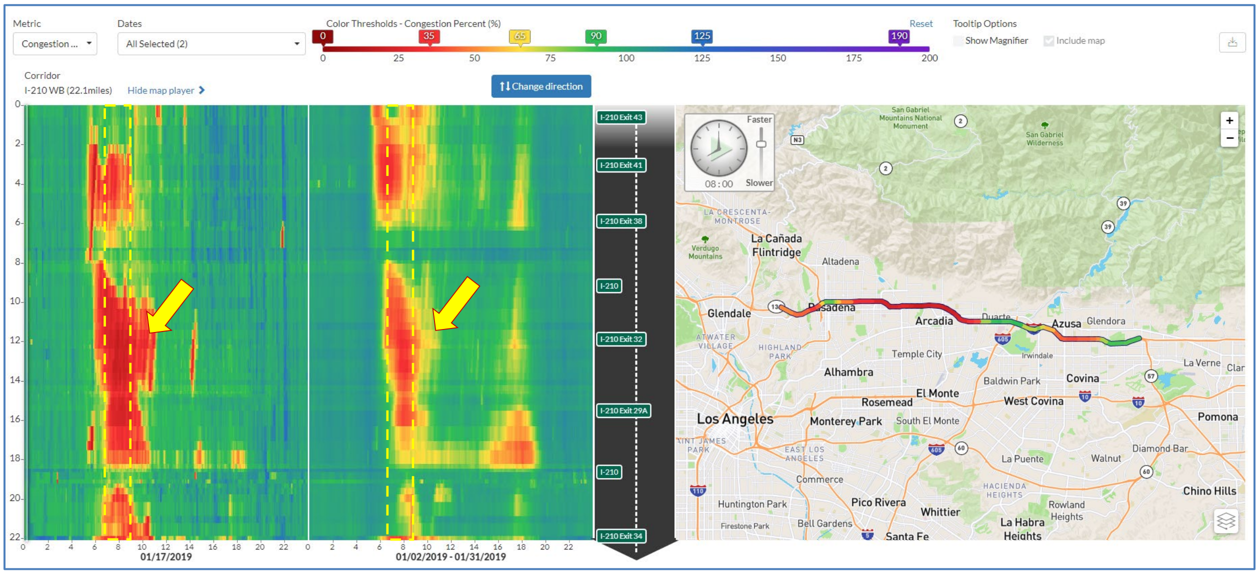

Figure 3-21 – Traffic Conditions on I-210 W for the I-10 W January 17 Incident

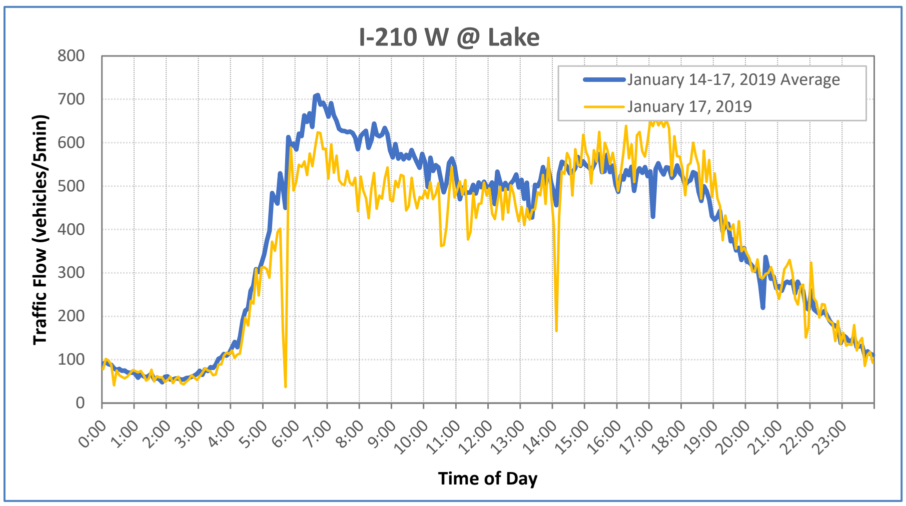

Figure 3-22 – Traffic Flow on I-210 W in Pasadena on January 17, 2019

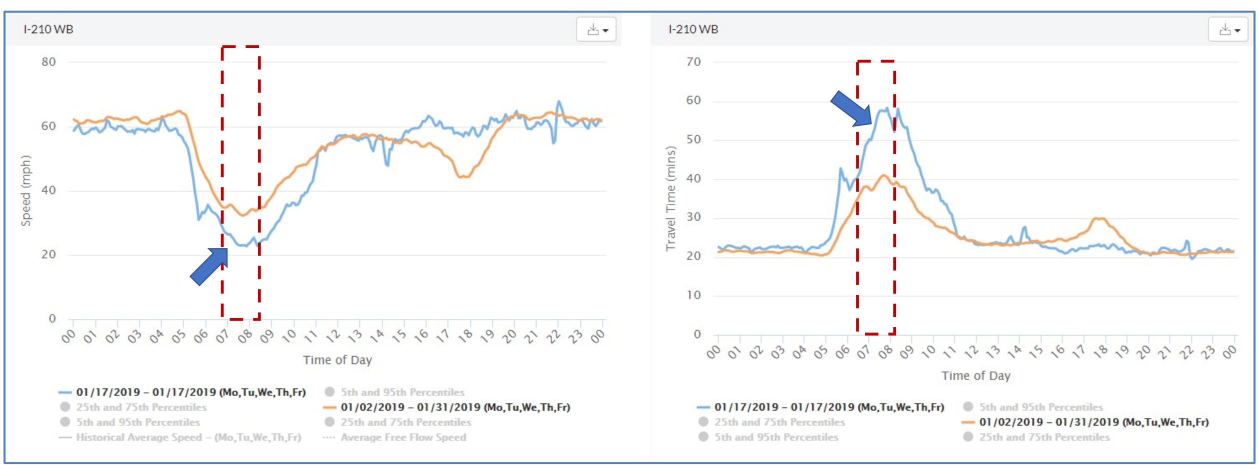

Figure 3-23 – Speeds and Travel Times along I-210 W on January 17, 2019

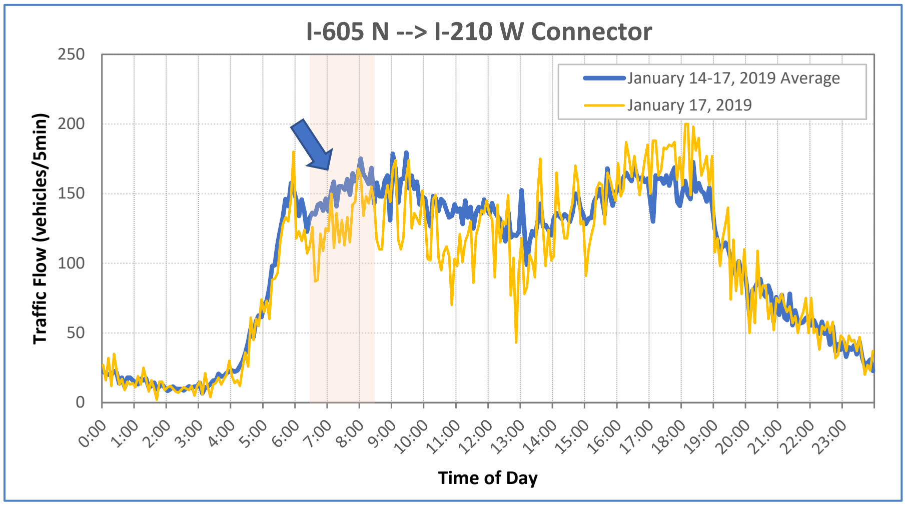

Figure 3-24 – Traffic Flow on the I-605 N to I-210 W Connector on January 17, 2019

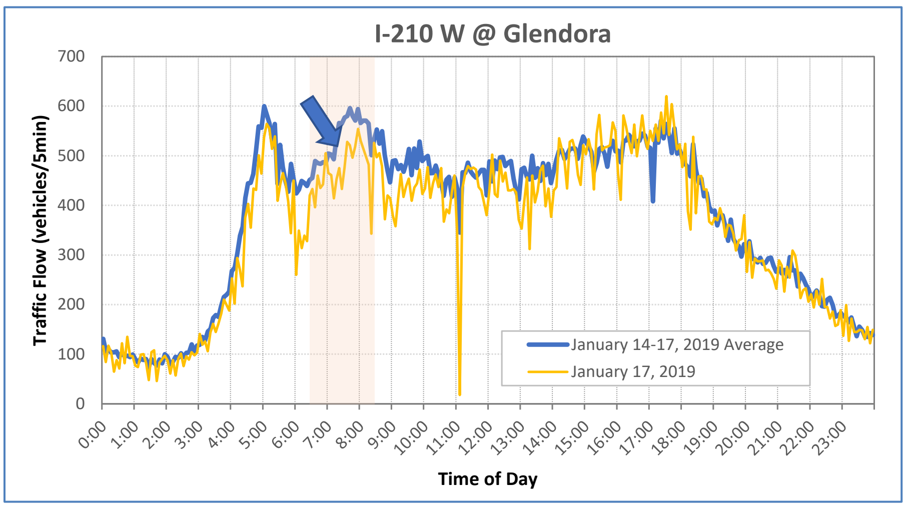

Figure 3-25 – Traffic Flow on I-210 W approaching the I-605 Interchange on January 17, 2019

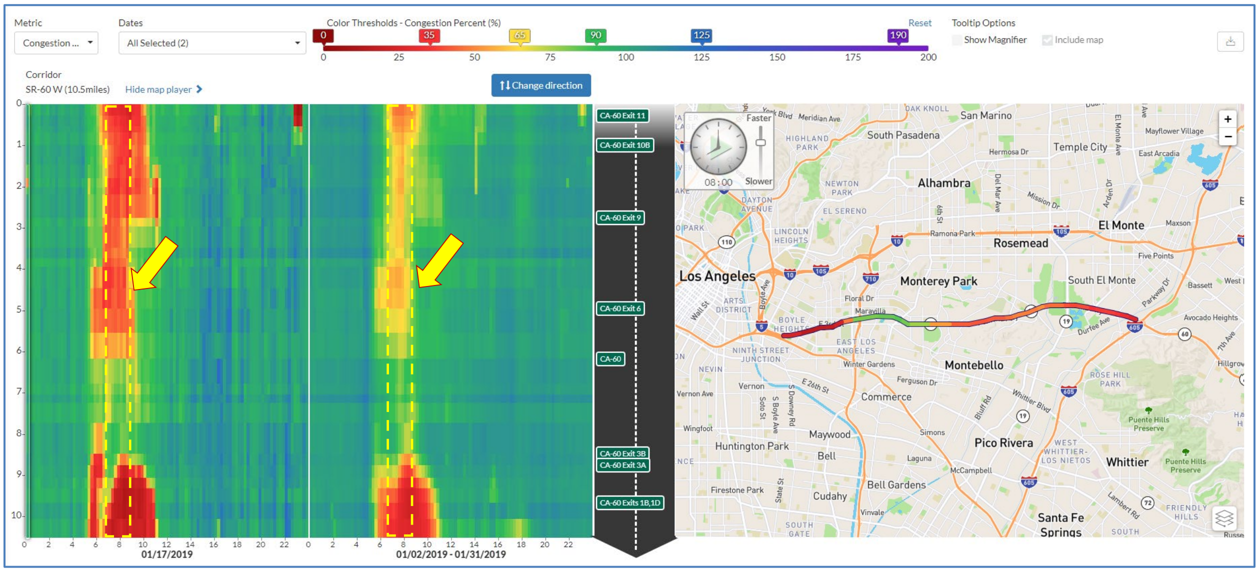

Figure 3-26 – Traffic Conditions on SR-60 W for the I-10 W January 17 Incident

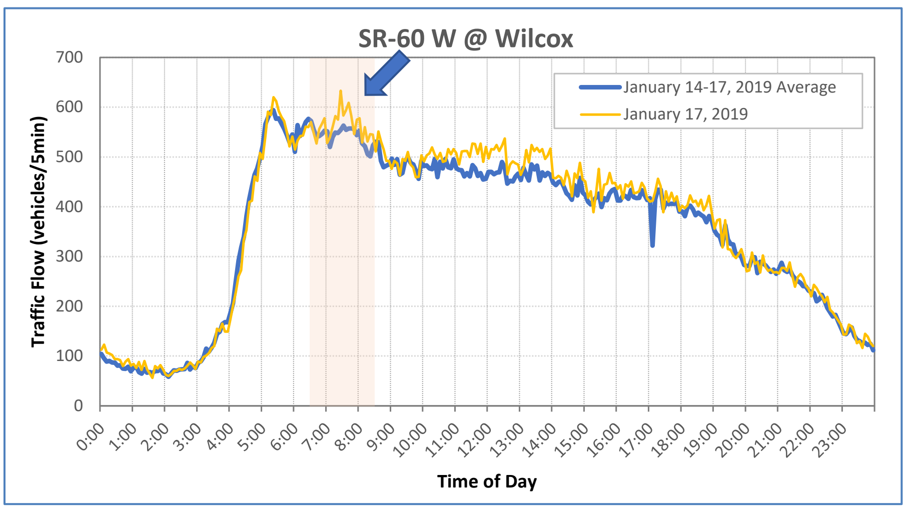

Figure 3-27 – Traffic Flow on SR-60 W on January 17, 2019

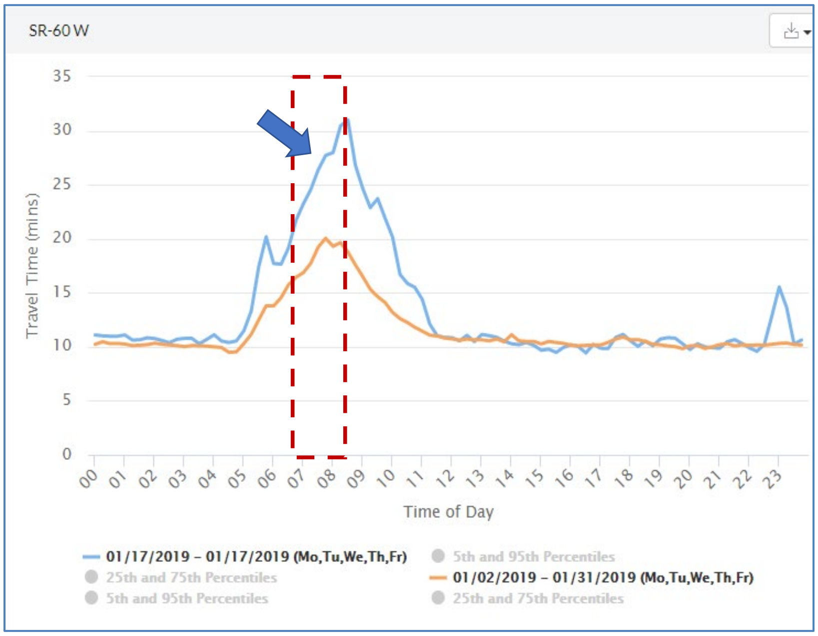

Figure 3-28 –Travel Times along SR-60 W on January 17, 2019

Figure 3-29 displays a zone analysis on a typical day from the Pomona area to downtown LA on Tuesday, January 15, 2019. According to the heights of the 3-D walls along the most-used links, I-10 appears to support the bulk of these trips between the specified O-D regions. However, some drivers appear to use I-210, SR-60, and I-605 as well as a few major arterials to make these trips.

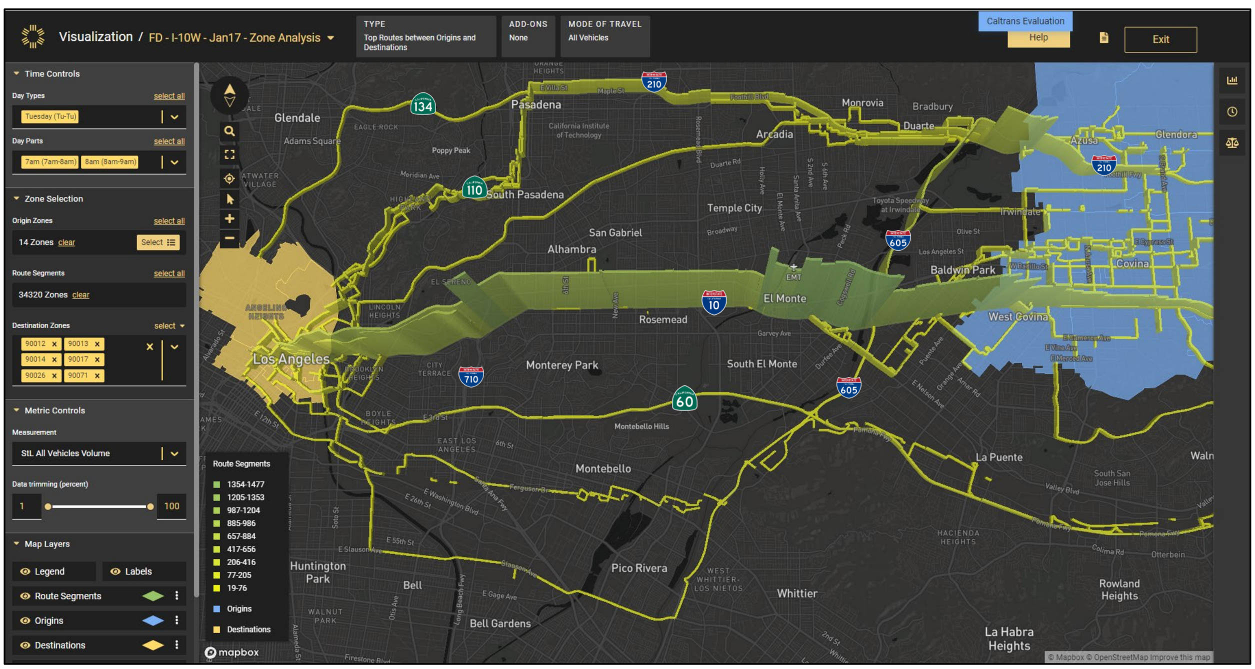

Figure 3-29 – Zone Analysis from Pomona area to downtown LA on Tuesday, January 15, 2019

Figure 3-30 further displays a zone analysis on the incident day from the Pomona area to downtown LA on Thursday, January 17, 2019. Once again, I-10 appears to support the bulk of these trips between the specified O-D regions. There are a few routes that appear parallel to I-10 on arterial roads just upstream of the incident. However, it is difficult to see a significant difference between Figure 3-29 and Figure 3-30.

These visualizations support the initial findings from the PeMS and INRIX data that the geospatial influence from this incident was small.

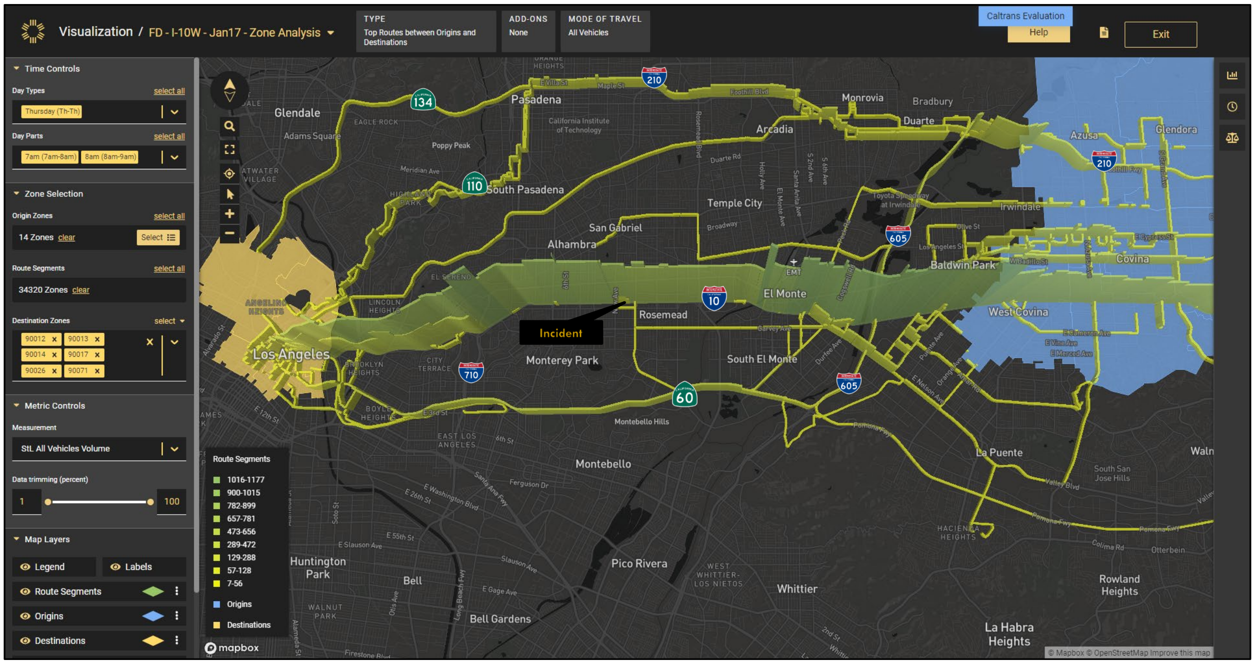

Figure 3-30 – Zone Analysis from Pomona area to downtown LA on Thursday, January 17, 2019

3.7. I-10 E -- THURSDAY, JUNE 6, 2019

An incident blocking all traffic lanes on I-10 E occurred at milepost 25.39 near the San Gabriel Blvd interchange, from a reported time of 4:11 PM to 8:47 PM (4.5-hour incident).

As shown in Figure 3-31, which compares traffic conditions on I-10 E on June 6 to the weekday average conditions in June 2019, this incident significantly impacted traffic conditions the freeway. When looking at the congestion map for I-210 E, shown in Figure 3-32, this incident did not appear to have caused significant traffic diversion towards I-210 E as the congestion pattern for June 6 appears similar to the weekday average for June 2019. While unusual congestion is observed upstream of the Baldwin interchange between 10:30 AM and 2:00 PM, this is likely the result of another incident that has not been entered into the ATMS. Despite the average congestion pattern, some evidence of traffic diversion to the I-210 E does exist. When analyzing traffic volumes along I-210 E, shown in Figure 3-33, a noticeable surge in traffic along I-210 E can be observed near the end of the incident period. The impact of this surge is also visible on travel times along the freeway, as shown in Figure 3-34. The travel time data also indicate an increase in travel time near the beginning of the incident period. This may also be related to the I-10 incident.

An analysis of traffic conditions on SR-60 E, the freeway to the south of I-10 E further reveals that SR-60 may be used as a primary diversion route. As shown in Figure 3-35, there is a noticeable increase in the duration of the congestion period along this freeway within the incident period. Figure 3-36, which compares eastbound flows near the Paramount Blvd interchange, further shows an increase in traffic volume along the freeway during the incident period, while Figure 3-37 indicates significant increases in travel times. These observations confirm that SR-60 E was used as the primary diversion route for the I-10 E incident.

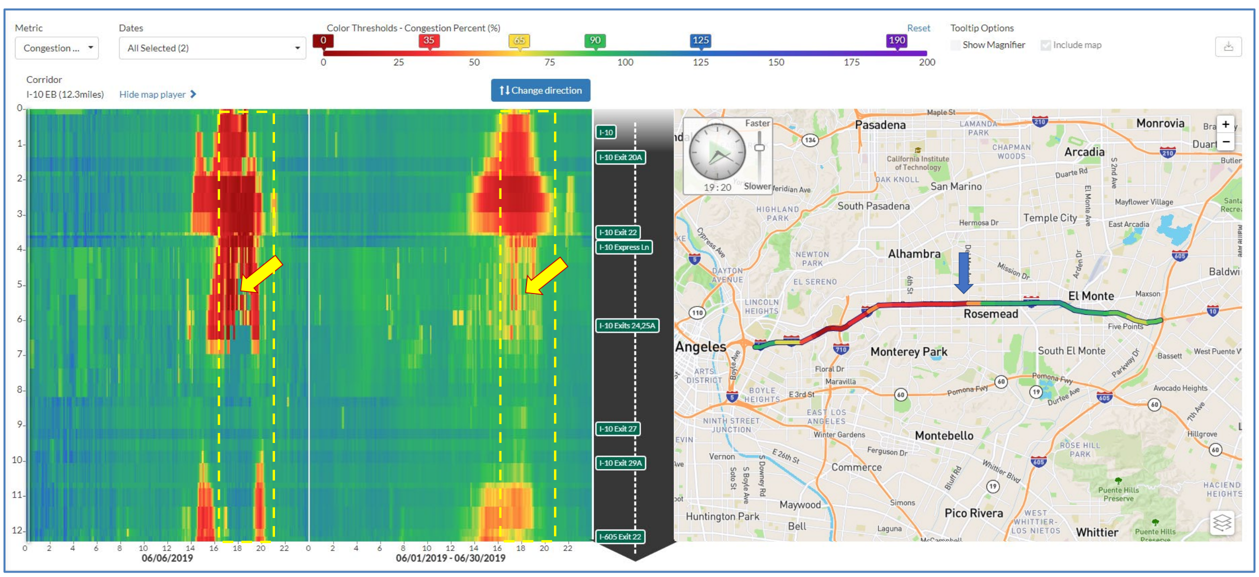

Figure 3-31 – Traffic Conditions on I-10 E for the I-10 E June 6 Incident

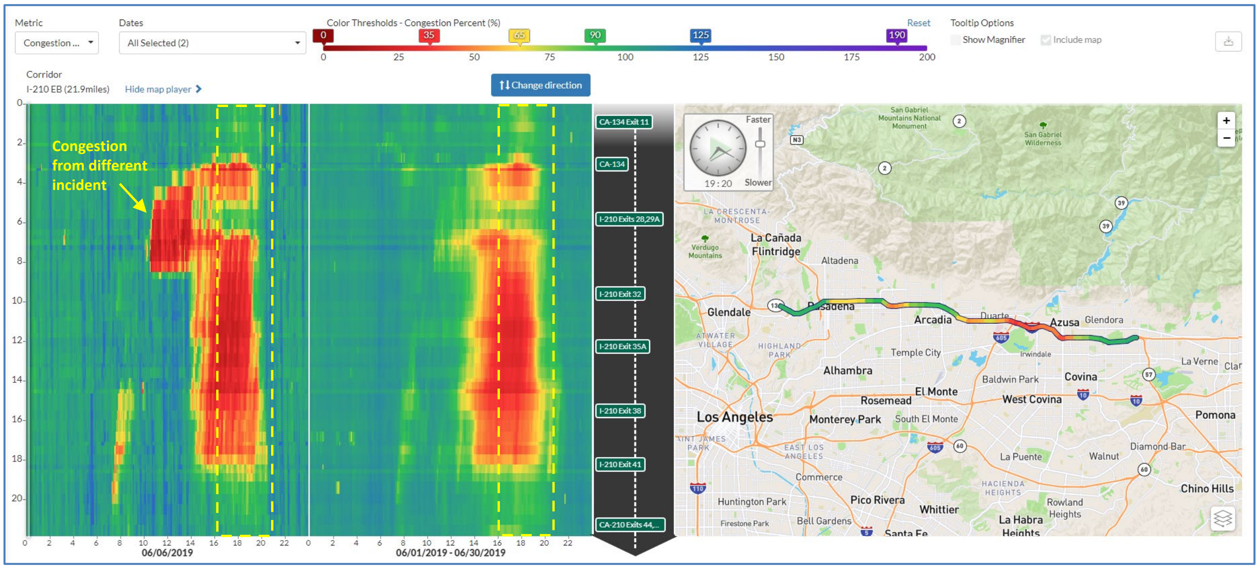

Figure 3-32 – Traffic Conditions on I-210 E for the I-10 E June 6 Incident

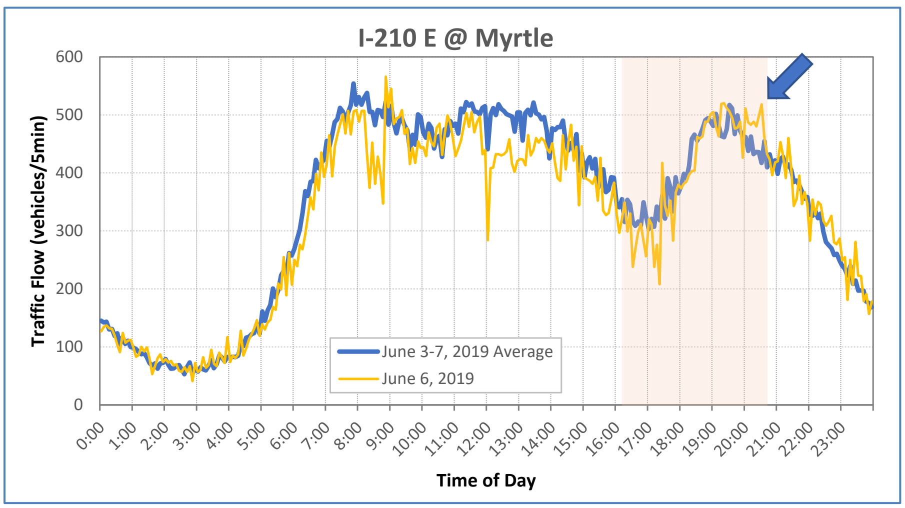

Figure 3-33 – Traffic Flow on I-210 E Upstream of the I-605 Interchange on June 6, 2019

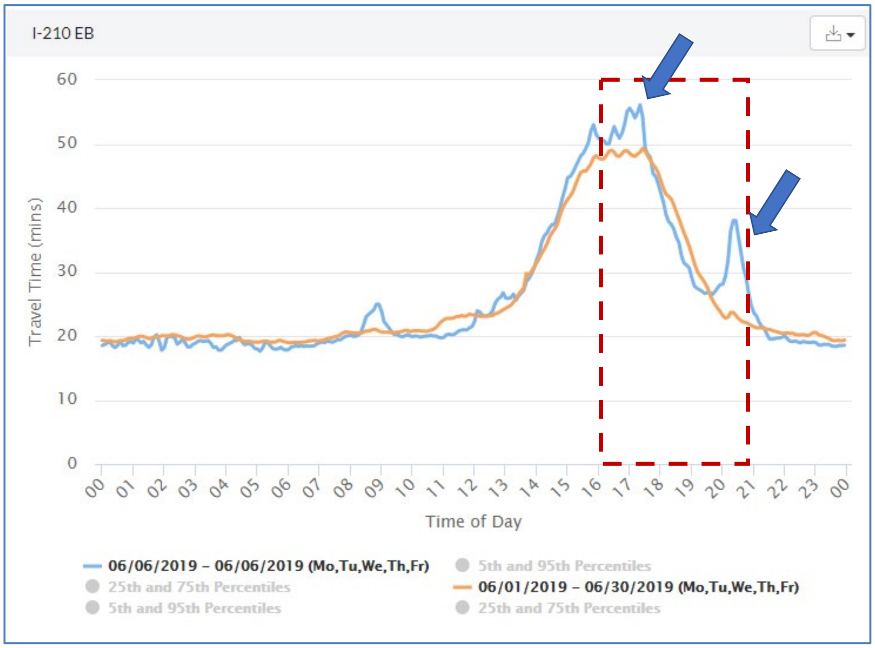

Figure 3-34 – Travel Times along I-210 E on June 6, 2019

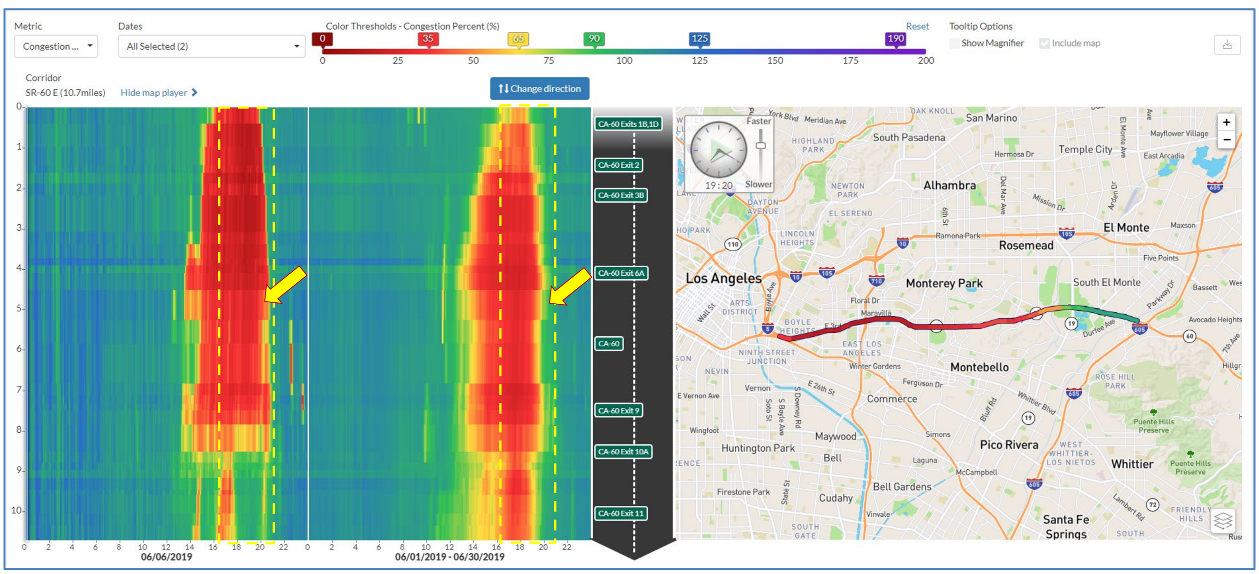

Figure 3-35 – Traffic Conditions on SR-60 E for the I-10 E June 6 Incident

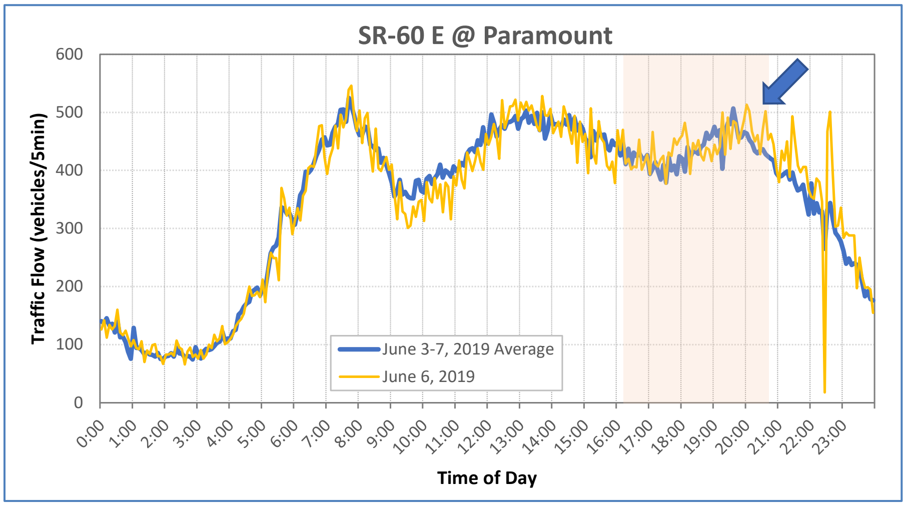

Figure 3-36 – Traffic Flow on SR-60 E on June 6, 2019

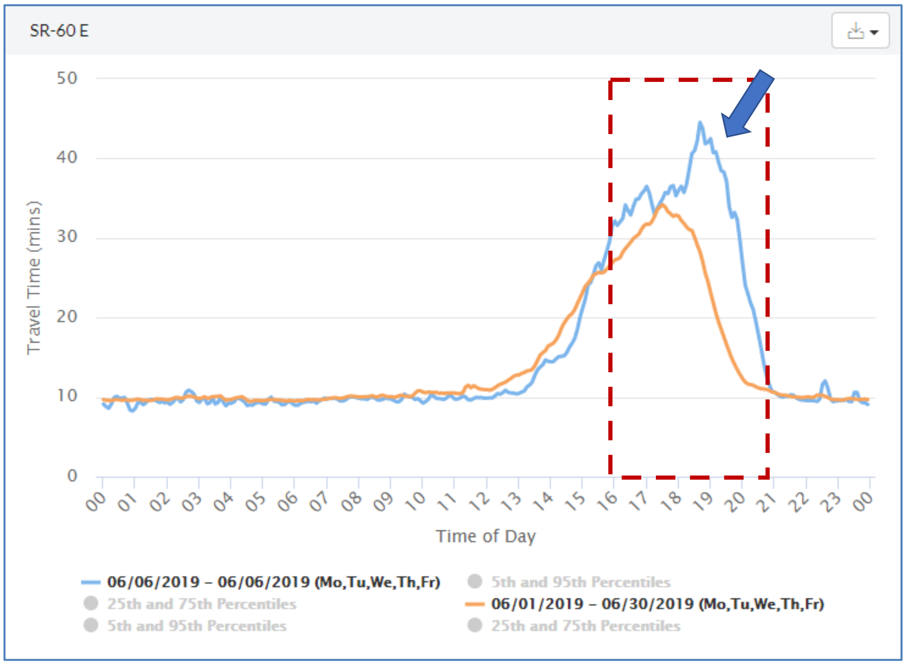

Figure 3-37 – Travel Times along SR-60 E on June 6, 2019

According to StreetLight data, this incident has a large geospatial influence extending four to six miles. More detailed investigation may inform potential response plan strategies appropriate for an I-10 ICM project.

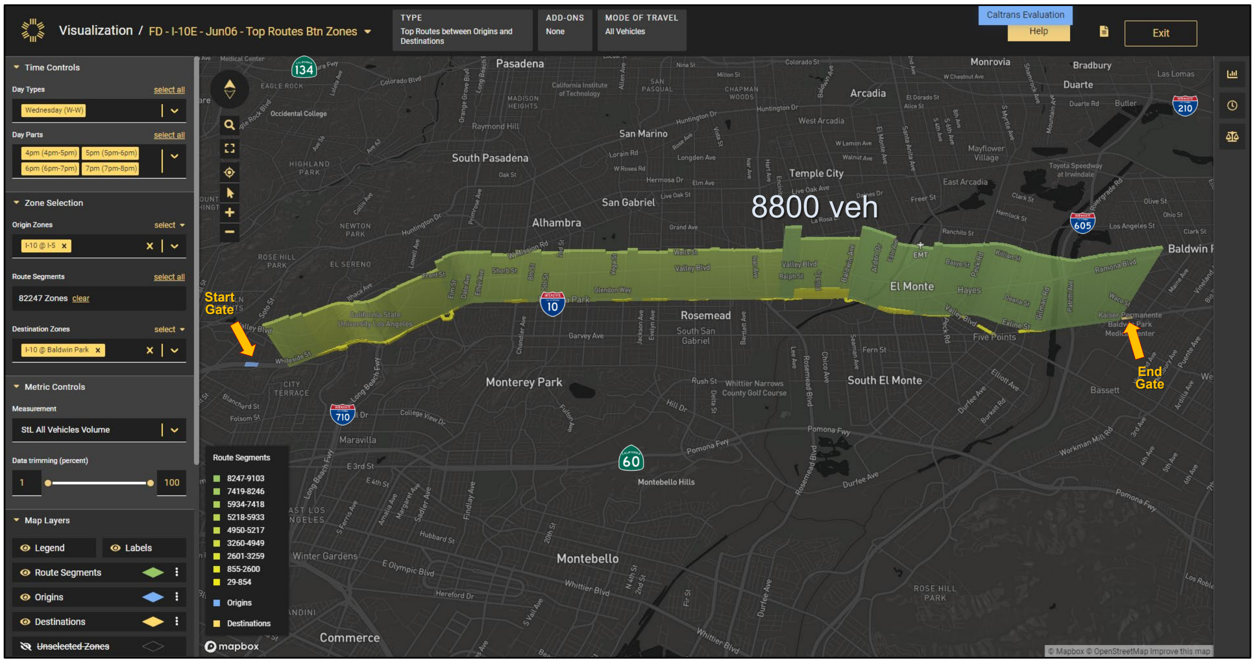

Figure 3-38 – Top routes between zones from I-10 E to I-10 E on Wednesday, June 5, 2019

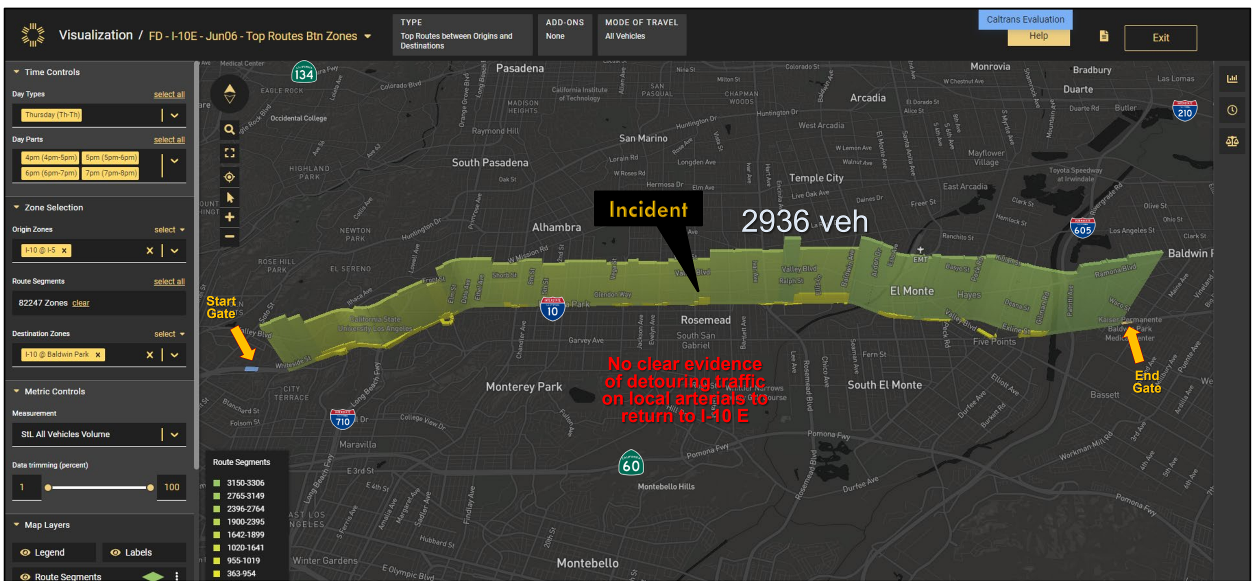

Figure 3-39 – Top routes between zones from I-10 E to I-10 E on Thursday, June 6, 2019

Figure 3-38 further displays a StreetLight top routes analysis for a typical day along I-10 E from the start gate upstream of I-710 to the end gate downstream of I-605 on Wednesday, June 5, 2019. The gates are denoted with yellow arrows. Figure 3-39 displays the same analysis for the incident day on Thursday, June 6, 2019. The two figures are very similar. The main difference is that the height of the 3-D wall along the links of I-10 show lower flow due to the incident. However, the conclusion is that drivers who continue along I-10 E beyond the junction with I-605 tend to stay on I-10 E. There was limited evidence of diversion for this O-D pair.

Figure 3-40 displays a StreetLight top routes analysis for a typical day along I-10 E from the start gate upstream of I-710 to I-210 E or I-605 N on Wednesday, June 5, 2019. Figure 3-41 displays the same analysis for the incident day on Thursday, June 6, 2019. The two figures are very different.

Figure 3-41 shows significant rerouting for this O-D pair. Many vehicles are observed using arterial streets to continue their trips using I-210 or Huntington drive. The conclusion is that for this situation many drivers who are headed toward I-210 or I-605 N decide to reroute.

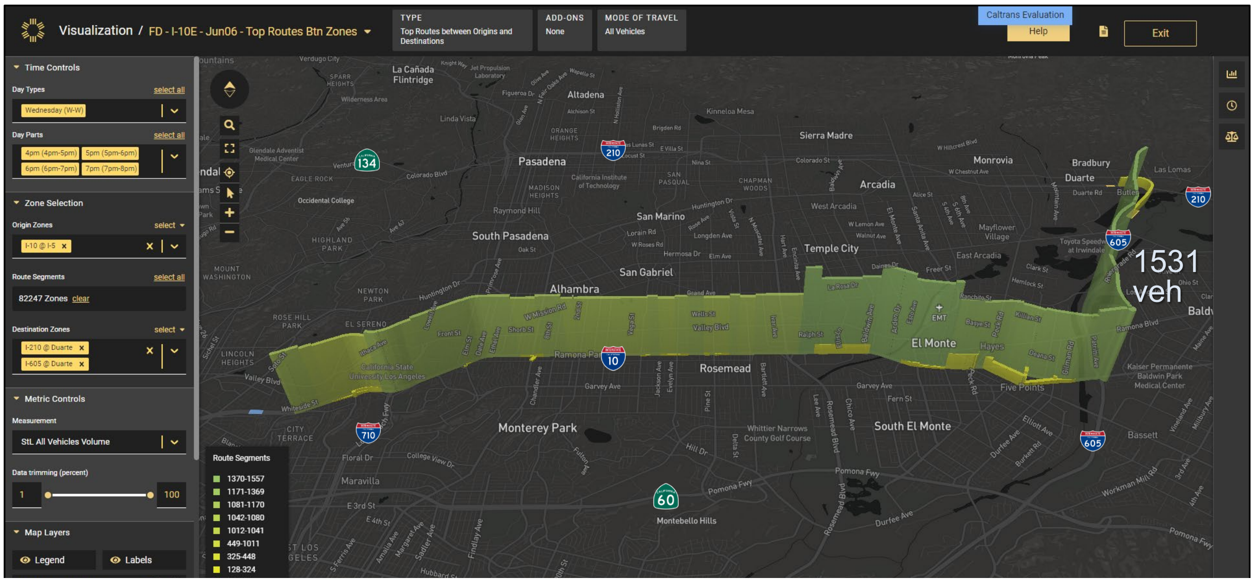

Figure 3-40 – Top routes between zones from I-10 E to I-210 E / I-605 N on Wednesday, June 5, 2019

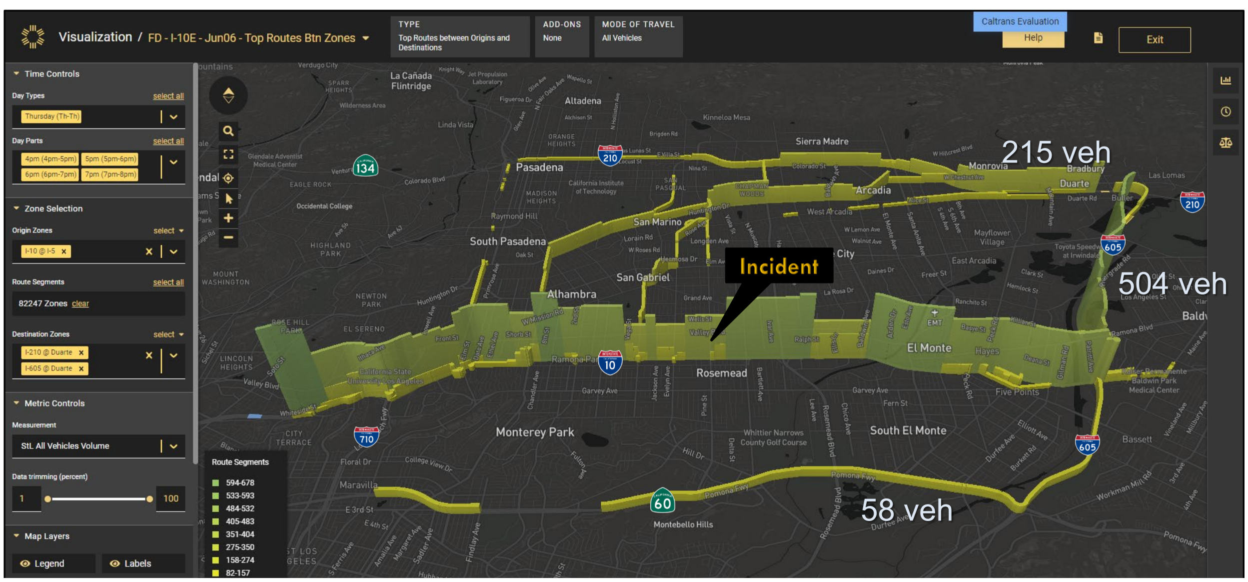

Figure 3-41 – Top routes between zones from I-10 E to I-210 E / I-605 N on Thursday, June 6, 2019

Figure 3-42 displays a StreetLight top routes analysis for a typical day along I-10 E from the start gate upstream of I-710 to SR-60 E or I-605 S on Wednesday, June 5, 2019. Figure 3-43 displays the same analysis for the incident day on Thursday, June 6, 2019. Once again, the two figures are very different.

Figure 3-43, finally, shows significant rerouting for this O-D pair. Many vehicles are observed using I-710 or arterial streets to continue their trips using SR-60 E. The conclusion is that for this situation many drivers who are headed toward SR-60 E or I-605 S decide to reroute.

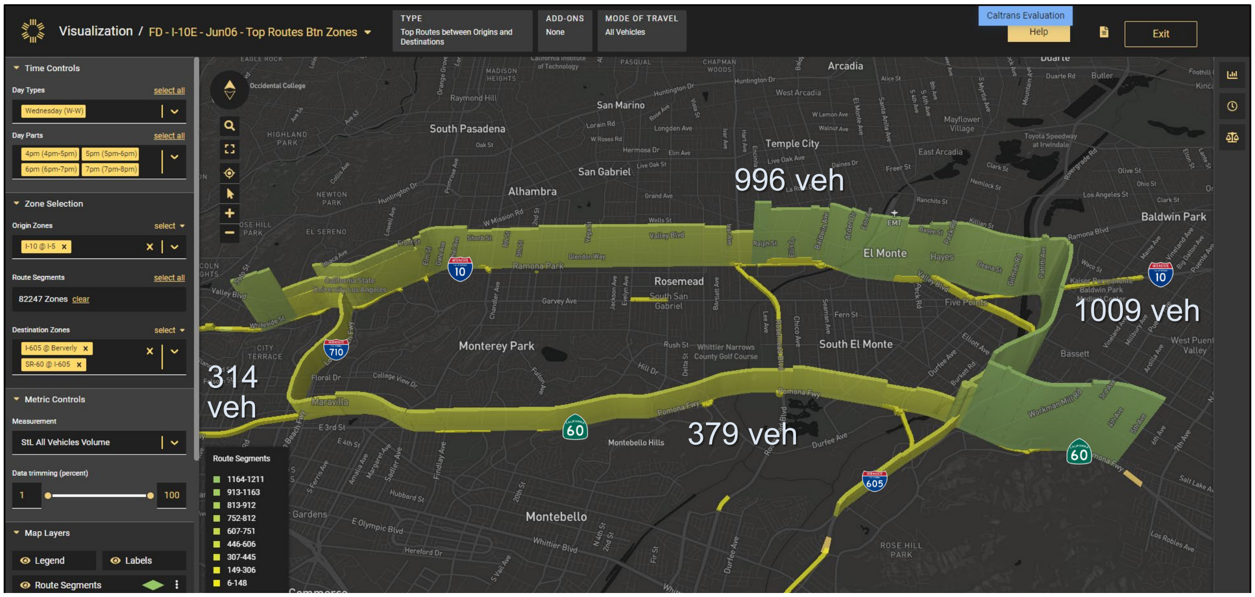

Figure 3-42 – Top routes between zones from I-10 E to SR-60 E / I-605 S on Wednesday, June 5, 2019

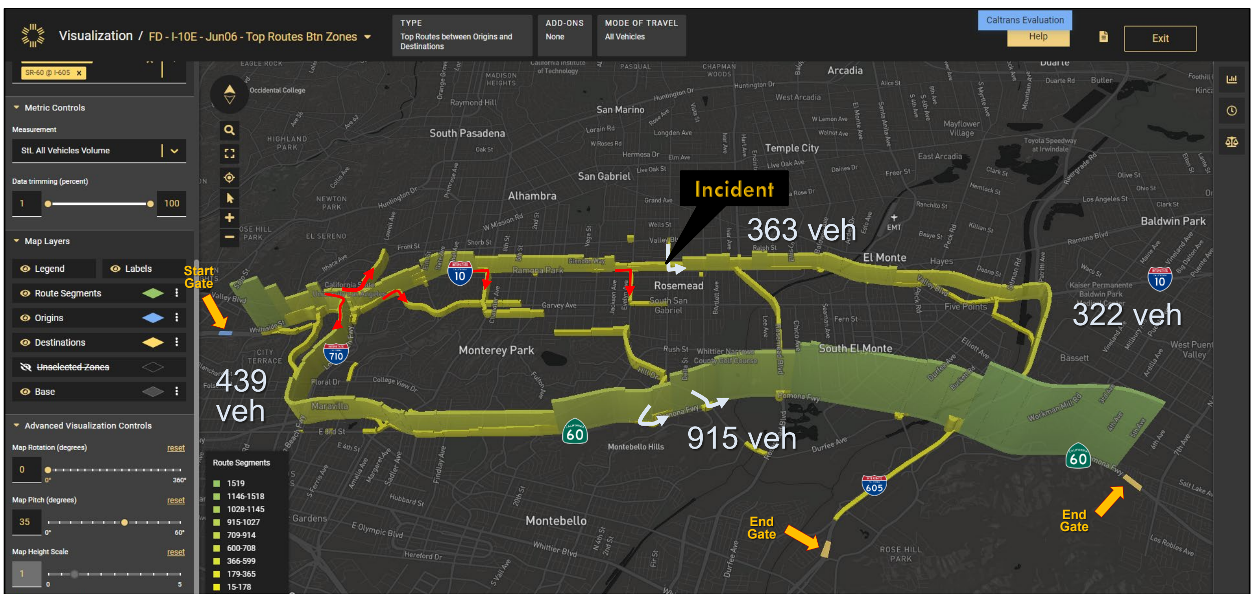

Figure 3-43 – Top routes between zones from I-10 E to SR-60 E / I-605 S on Thursday, June 6, 2019

3.8. I-210 W – FRIDAY, JULY 12, 2019

An incident blocking the HOV lane and one of the four mainline lanes occurred at milepost 32.09 near Santa Anita Ave., from a reported time of 10:26 AM to 2:26 PM (3-hour duration).

The impact of this incident on traffic can clearly be viewed in Figure 3-44. This figure compares the congestion map extracted from INRIX for the day of the incident to the map illustrating the average weekday conditions for July 2019. As shown in Figure 3-45, this incident also likely produced additional congestion on I-10W, in El Monte downstream of the I-605 interchange, likely from westbound traffic diverting from I-210 W. As further shown in Figure 3-46 this incident may also be the cause of additional congestion on arterials parallel to the I-210. The diagram on the right shows slightly higher than average westbound travel times along Huntington Blvd and Colorado Blvd on July 12 between 10:30 AM and 1:30 PM (blue line) compared to typical July conditions (orange line). However, there is no conclusive evidence in this case that increased congestion occurs along Foothill Blvd, which runs parallel north of the freeway.

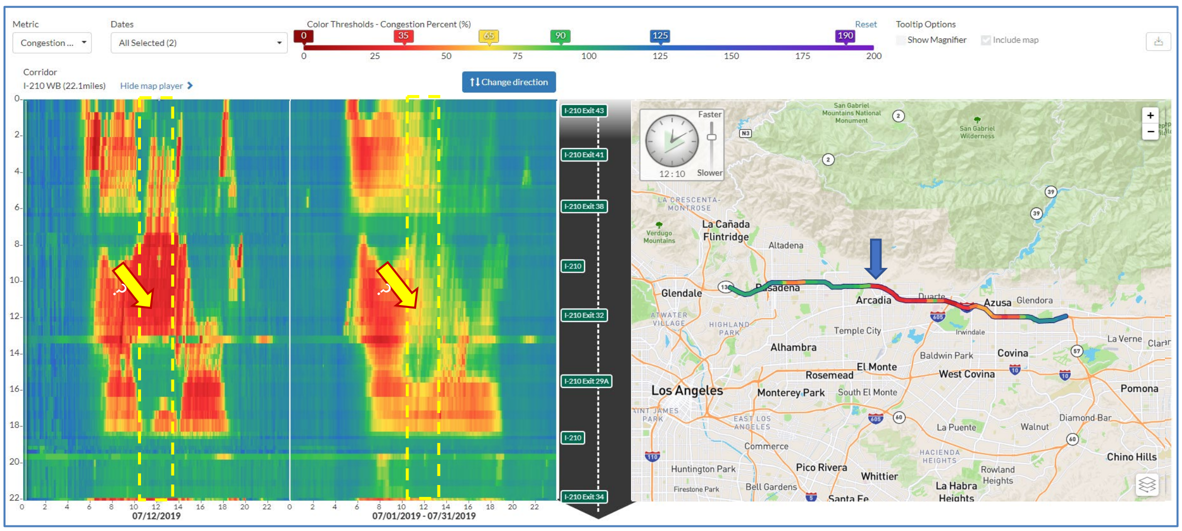

Figure 3-44 – Traffic Conditions on I-210 W for the I-210 W July 12 Incident

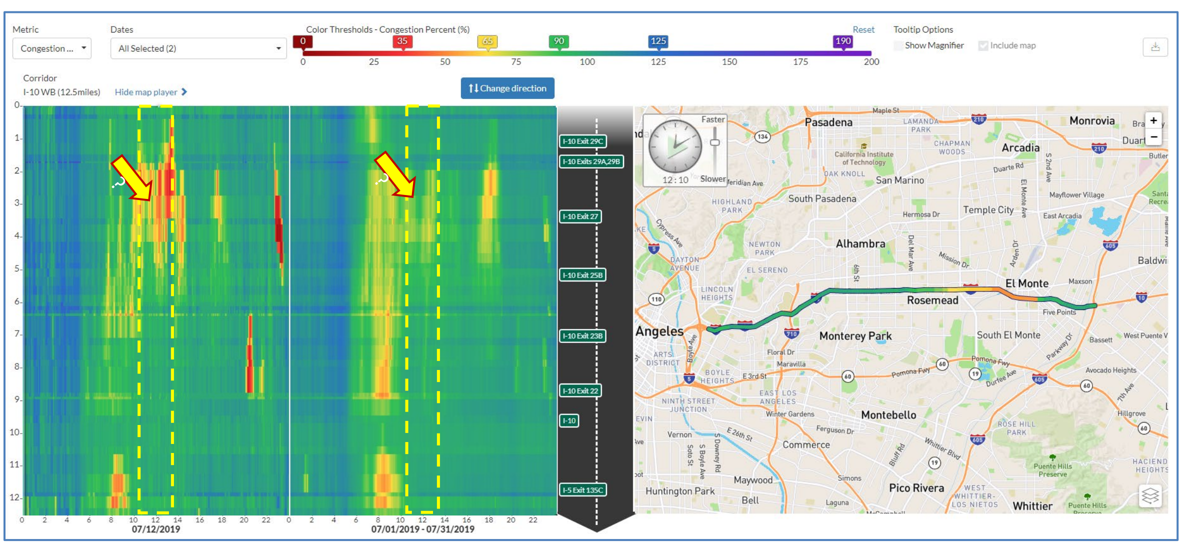

Figure 3-45 – Traffic Conditions on I-10 W for the I-210 W July 12 Incident

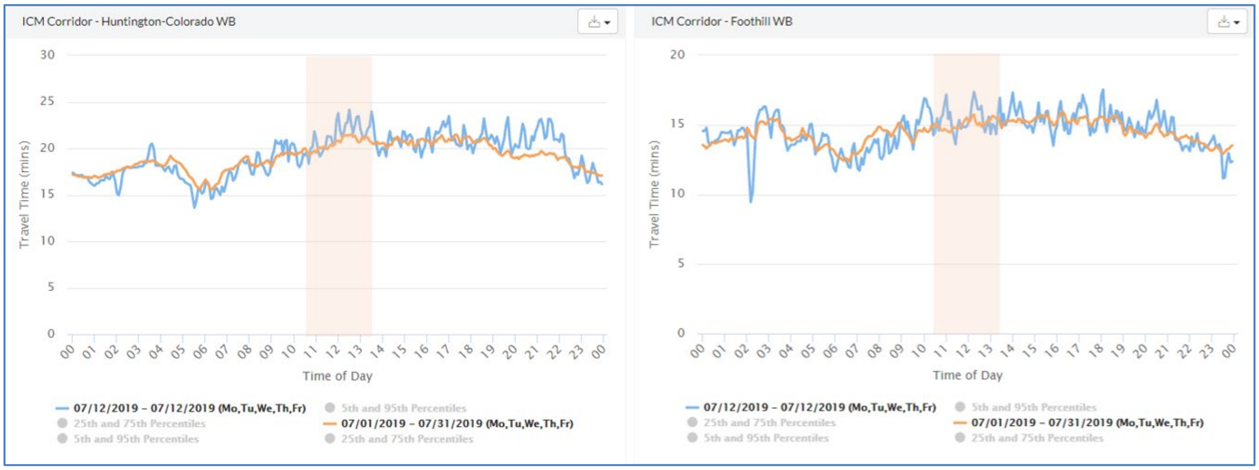

Figure 3-46 – Travel Times along I-210 Parallel Arterials for the I-210 W July 12 Incident

3.9. I-210 W – FRIDAY, JULY 26, 2019

An incident blocking the HOV lane and three of the four mainline lanes occurred at milepost 31.73 near Baldwin Ave., from a reported time of 5:05 AM to 7:17 AM (2.25-hour duration).

The impact on traffic of this incident can clearly be viewed in Figure 3-47, which compares the congestion map extracted from INRIX for the day of the incident to the average weekday conditions for July 2019. Because this incident occurs early in the morning, only limited impact is observed on I-10 W. As shown in Figure 3-48, slightly unusual congestion is observed for a short duration near the end of the incident period for a short section of I-10 W. As shown in Figure 3-49, an analysis of the traffic on the connector from I-210 WB to I-605 SB does indicate that higher traffic volumes were observed exiting I-210 W on July 26 compared to an average day between 5 AM and 7 AM. This increase in flow rate is on the order of 500

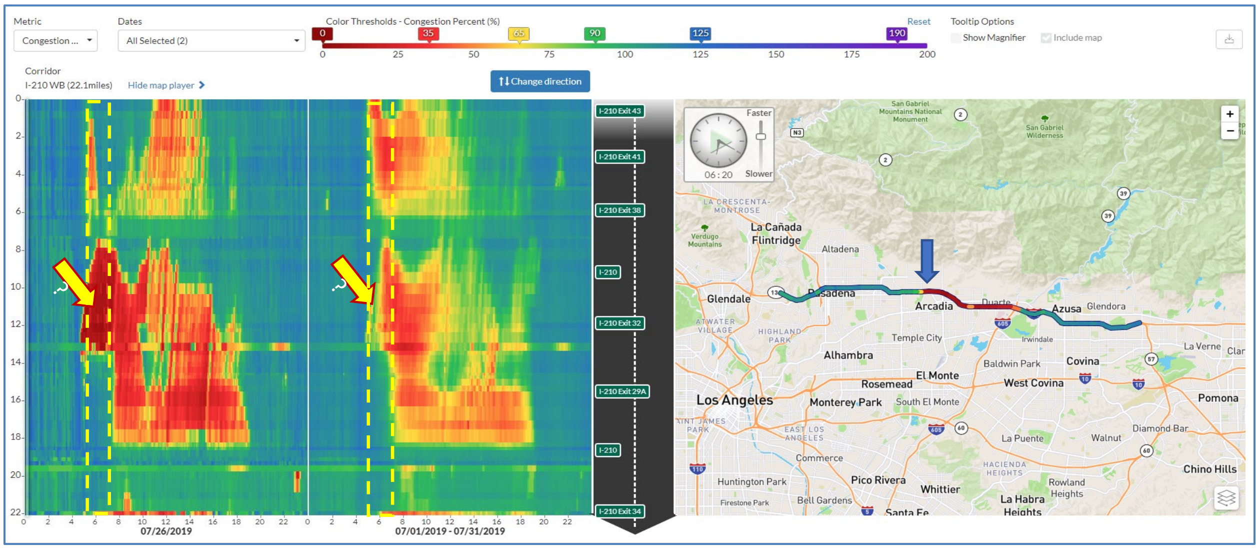

Figure 3-47 – Traffic Conditions on I-210 W for the I-210 W July 26 Incident

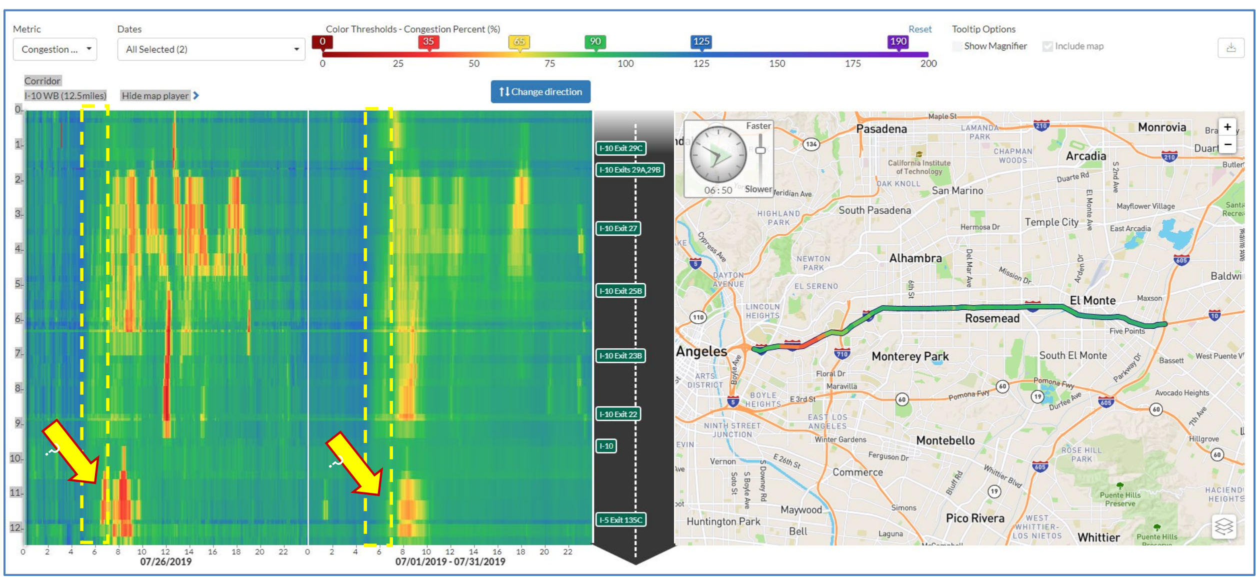

Figure 3-48 – Traffic Conditions on I-10 W for the I-210 W July 26 Incident

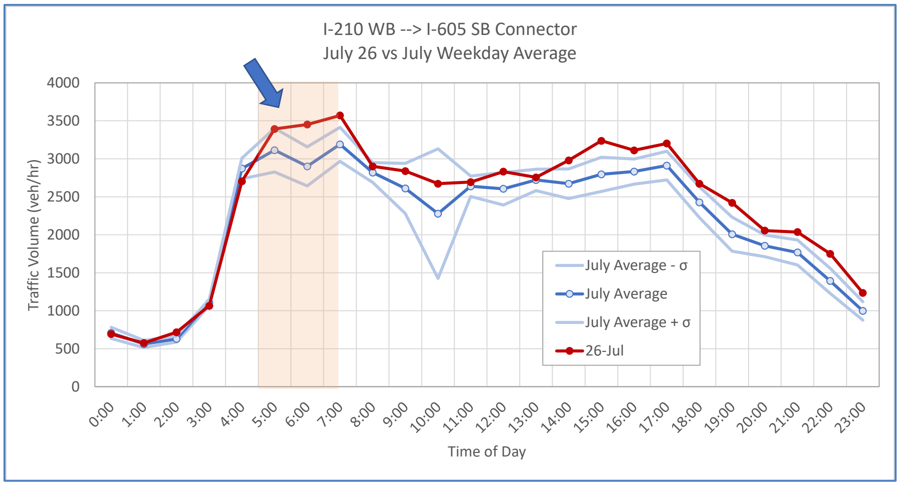

Figure 3-49 – Traffic Volume on the I-210 W to I-605 S Connector for the I-210 W July 26 Incident

vph for three hours. This is likely due to the congestion from the incident reaching the interchange at a time when there is usually no such congestion. However, the availability of space capacity along the I-10 W at that early time in the day likely explains the small traffic impacts from the incident.

While there were small impacts on I-10W, this incident did produce significant impacts on the two arterials running parallel to I-210. As shown in Figure 3-50, travel times along Huntington/Colorado were 5-10 minutes higher than normal between 5 AM and 7 AM. Travel times along Foothill were roughly 5 minutes longer than normal. Evidence of traffic exiting the freeway to take the local arterials can be seen from the off-ramp traffic counts from the four ramps upstream of the incident (Santa Anita, Huntington, Myrtle, and Buena Vista) in Figure 3-51.

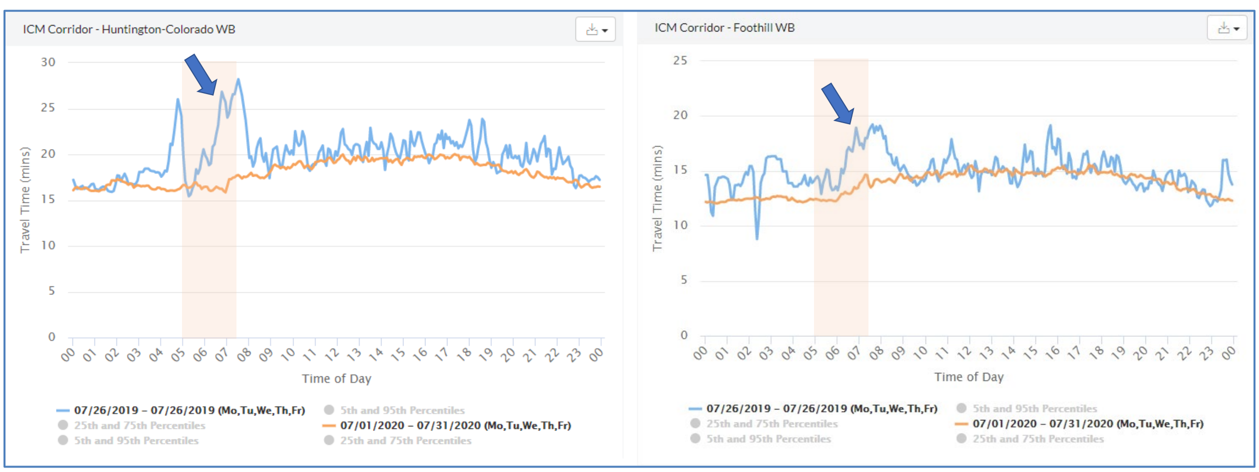

Figure 3-50 – Travel Times along I-210 Parallel Arterials for the I-210 W July 26 Incident

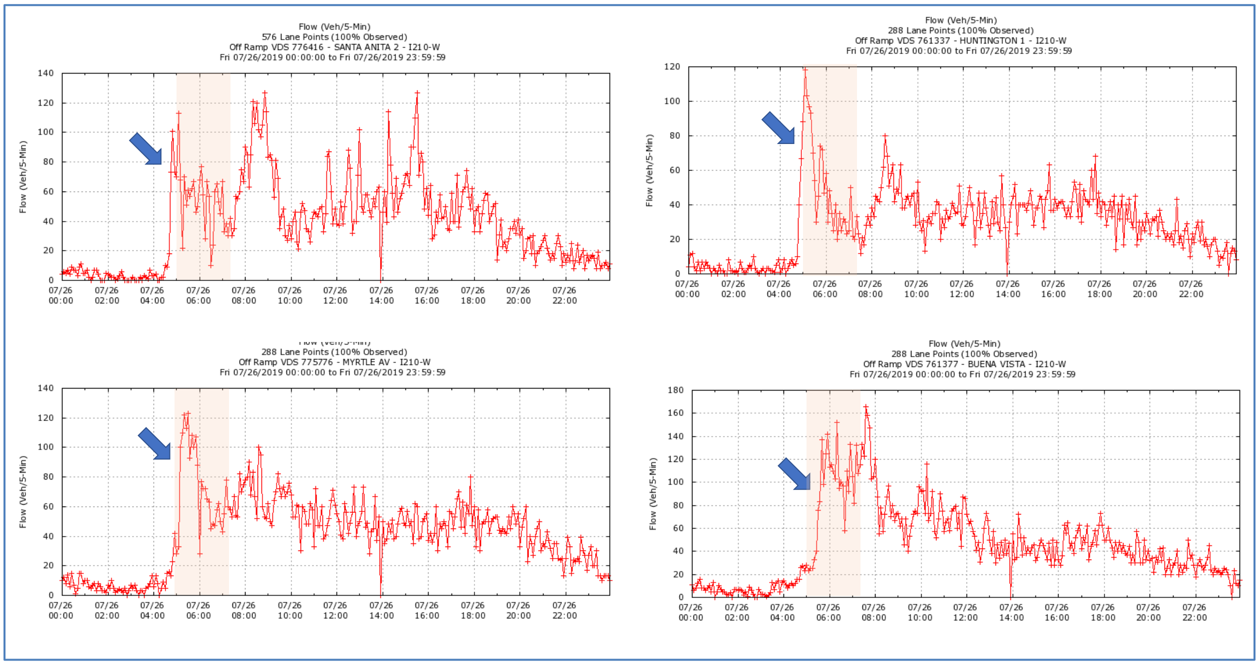

Figure 3-51 – Off-Ramp Flows for July 26 on I-210 W

Figure 3-52 displays a StreetLight top routes analysis from Azusa to Glendale the Friday before the incident (Friday, July 19, 2019), while Figure 3-53 displays the same analysis for the incident day. As can be observed, the two figures are very different. Figure 3-53 shows substantial dispersion of routes. Vehicles appear to use I-605, Live Oak, Longden, Duarte, and Foothill to reroute around the incident. In addition, some vehicles appear to use Baldwin to get back onto the I-210 downstream of the incident.

Figure 3-54 further displays a StreetLight large zone analysis for a typical day from origins in Riverside and San Bernardino to destinations in Pasadena and Glendale on Thursday, July 25, 2019, the day before the incident, while Figure 3-55 displays the same analysis for the incident day. This comparison reveals a notable increase in volume for these trips along I-10 on the day of the incident. Increased usage of Foothill and Colorado Boulevards to avoid the incident can also be observed. These findings are consistent with the increased travel times reported along Foothill and Colorado using INRIX data.

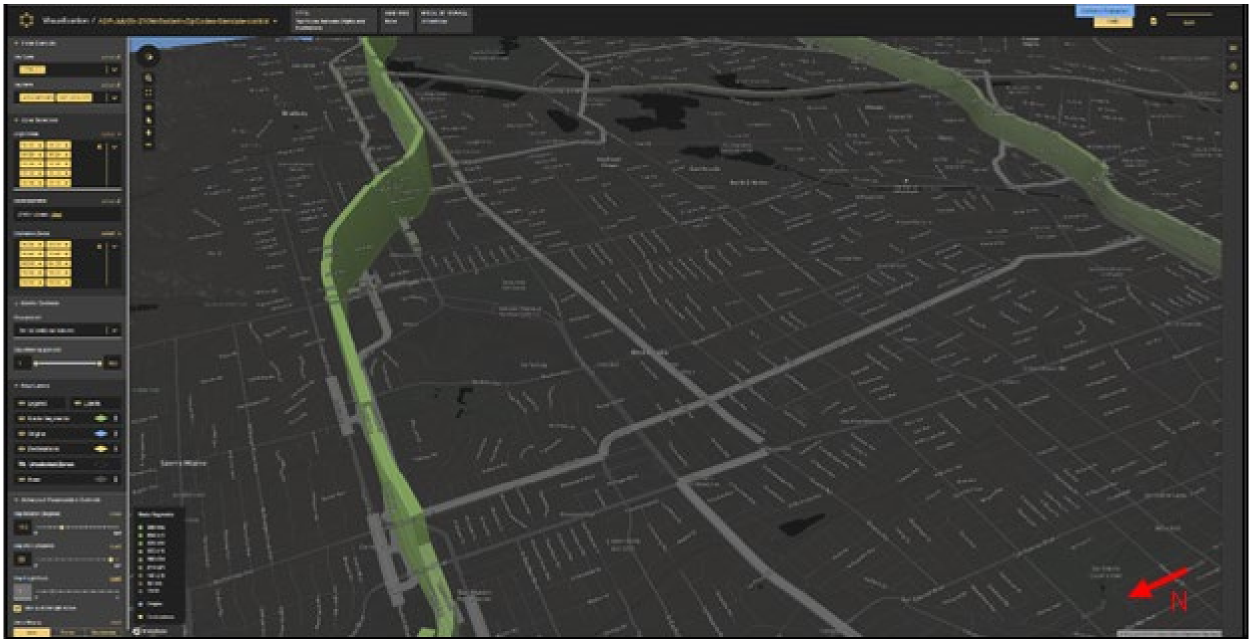

Figure 3-52 – Top routes from Azusa to Glendale on Friday, July 19, 2019

Figure 3-53 – Top routes from Azusa to Glendale on Friday, July 26, 2019

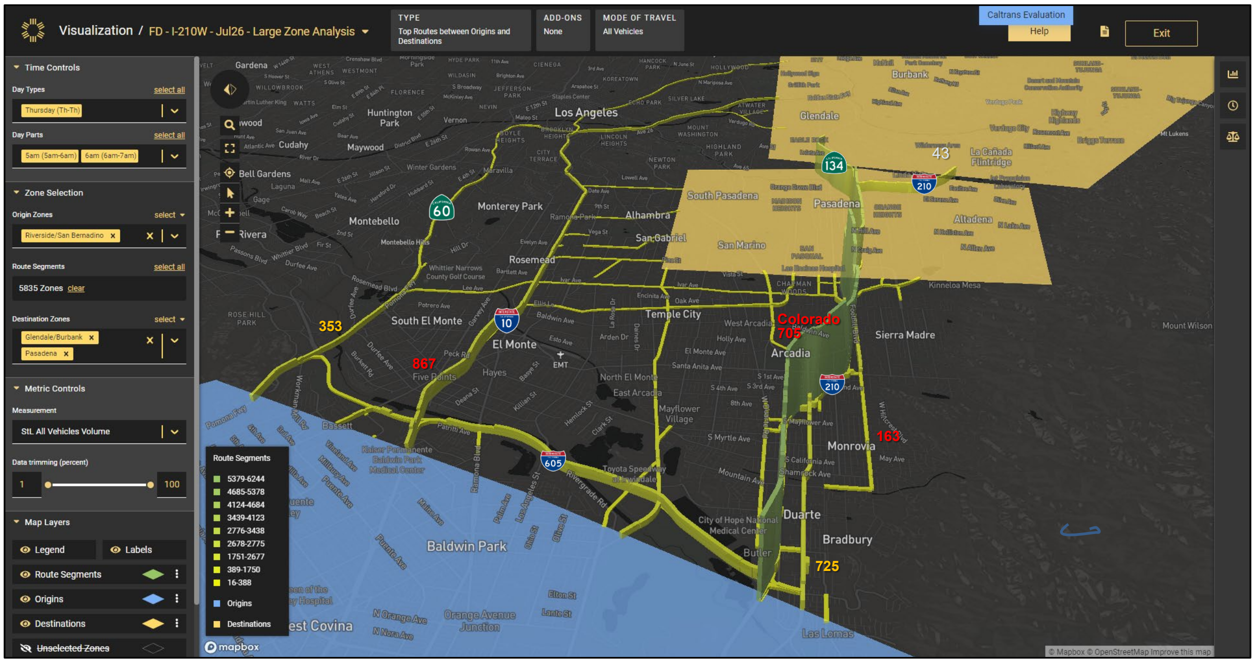

Figure 3-54 – Top westbound routes on Thursday, July 25, 2019

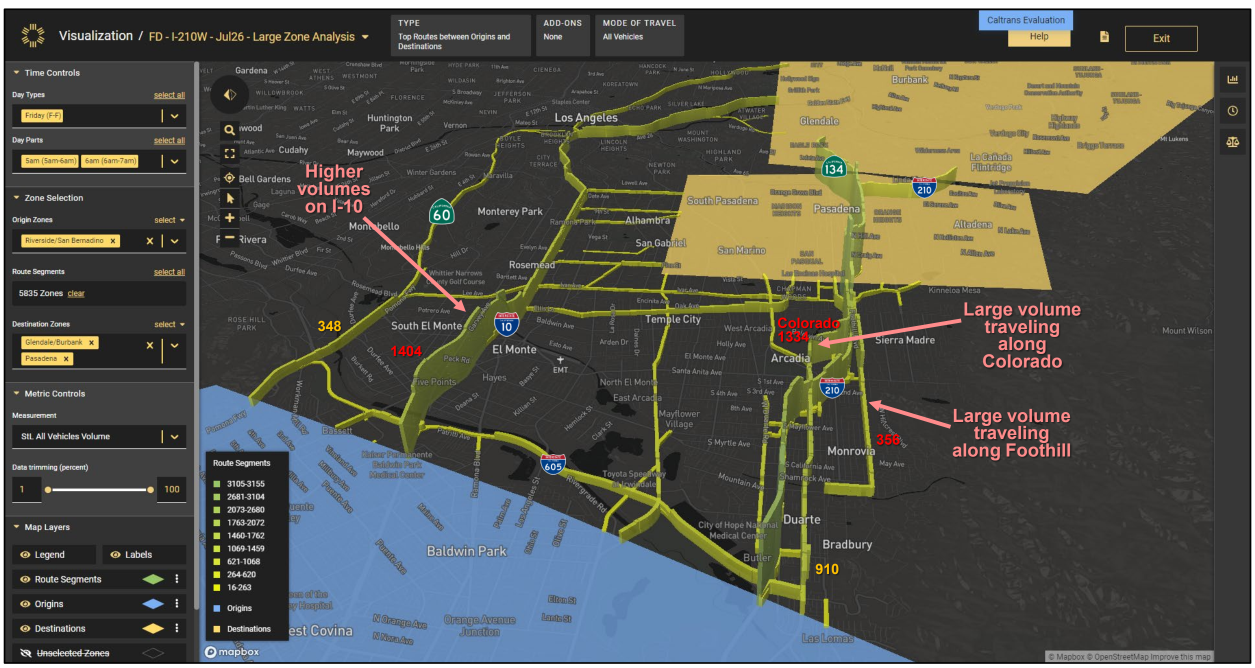

Figure 3-55 – Top westbound routes on Friday, July 26, 2019

3.10. I-210 W – THURSDAY, NOVEMBER 14, 2019

This section analyses an emergency closure of three of the five traffic lanes available along I-210 W near Rosemead Boulevard from approximately 9:30 AM to 1:30 PM on November 14, 2019 (nearly five hours).

The impact on traffic of this long incident can clearly be viewed in Figure 3-56, which compares the congestion on the day of the incident to the average weekday conditions for November 2019. The congestion scans from INRIX on the left clearly show the impact of the closure, which occurs in the same direction as the morning peak traffic. The map on the right shows that the congestion created by the event extended several miles upstream by noon.

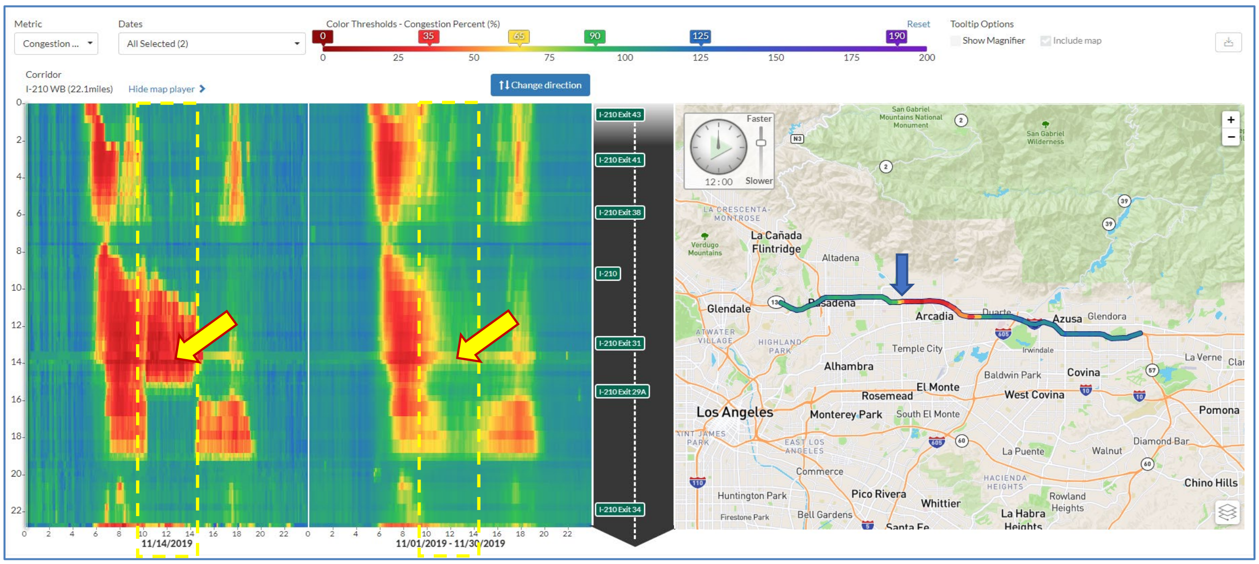

Figure 3-56 – Traffic Conditions on I-210 W for the I-210 W November 14 Incident

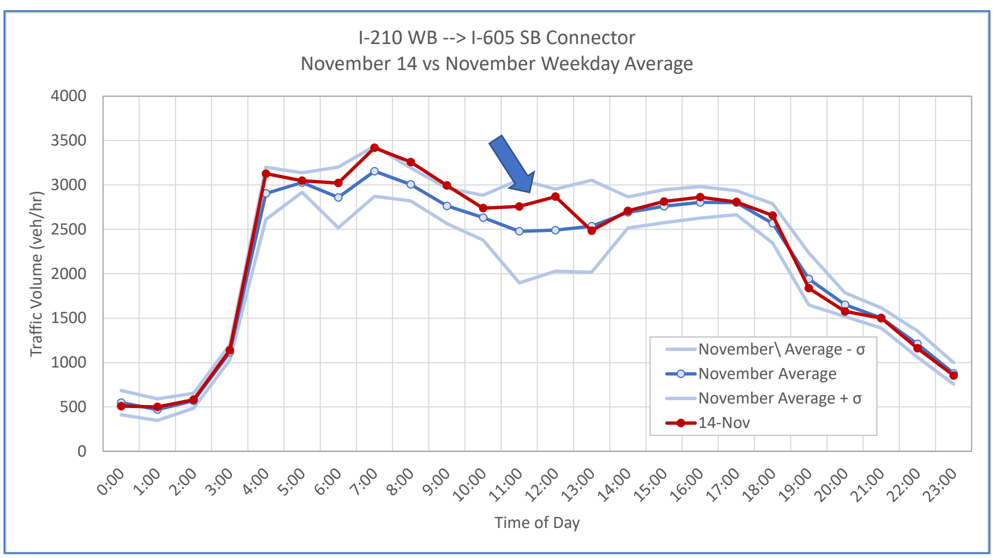

Figure 3-57 – Traffic Volume on the I-210 W to I-605 S Connector for the I-210 W November 14 Incident

As shown in Figure 3-57, there is strong evidence in this case that traffic is diverting from I-210 W to I-10 W as a result the incident. This is illustrated by the significantly higher traffic flow compared to the November average between 10 AM and 1 PM. This increase in flow rate was 400 vph for about two hours. However, because this closure occurs off-peak, there are relatively small impacts that can be observed on I-10W in Figure 3-58, with only some unusual congestion observed near Rosemead, mainly around 12 Noon.

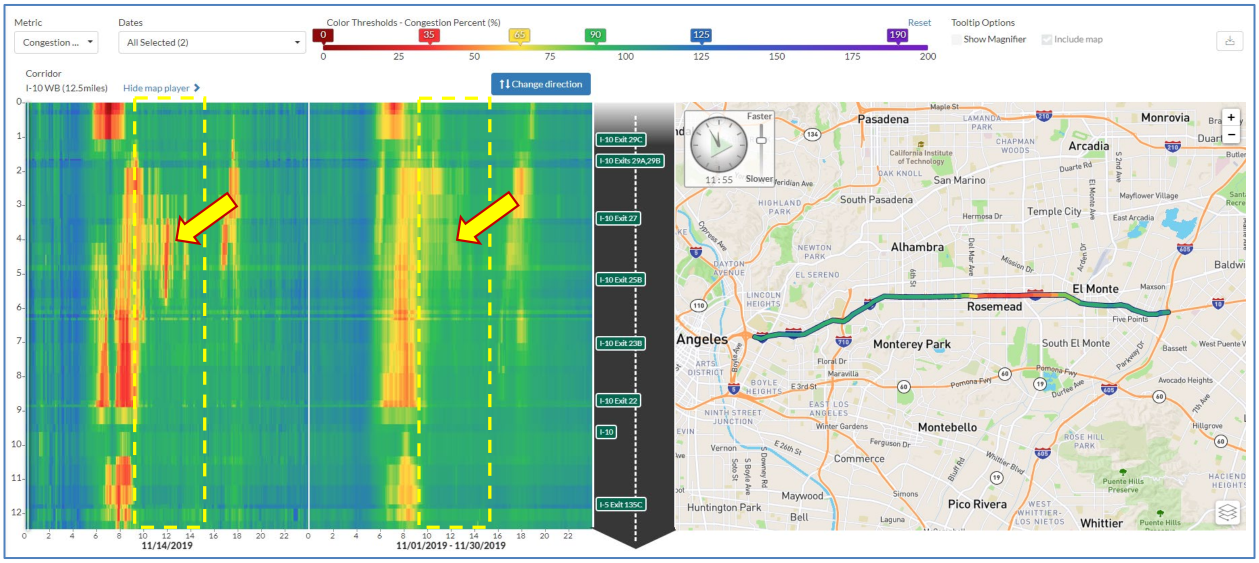

Figure 3-58 – Traffic Conditions on I-10 W for the I-210 W November 14 Incident

While there were only small impacts on I-10W, this incident resulted in increased travel times along Foothill Blvd on the north side of the freeway as traffic exited the freeway to bypass the closure. This is evidenced in Figure 3-59 by the noticeable increase in travel time along Foothill Blvd from approximately 10:30 AM to 3:00 PM. However, no noticeable increase in travel times were observed along Huntington Blvd / Colorado Blvd, the other parallel arterial to the south. This is not an indication that very few motorists elected to use this second alternate route, but that that there was sufficient spare capacity along this detour to accommodate the added flow. Utilization of both detours is demonstrated in Figure 3-60, which illustrates the off-ramp flows on I-210 W upstream of the closure location. Increases in traffic exiting the freeway can be see at all the illustrated ramps between 10:00 AM and 2:30 PM. The increases are particularly notable at the Santa Anita Avenue off-ramp, which provides a close access to Foothill Blvd, and at the Huntington Blvd. off-ramp, which crosses the second detour.

Further investigation into whether traffic that diverted to I-10 W may use some local arterials to get back to I-210 W did not provide strong evidence of such returns on the on-ramp and off-ramp flows along both freeways. This might be because most the diverting traffic could use I-10 W and I-5 N instead of I-210 W / SR-134 W to reach areas around Glendale, or access areas around downtown Los Angeles using I-10 W instead of I-210 W and SR-110 S. Alternatively, many trips may have ended in Pasadena.

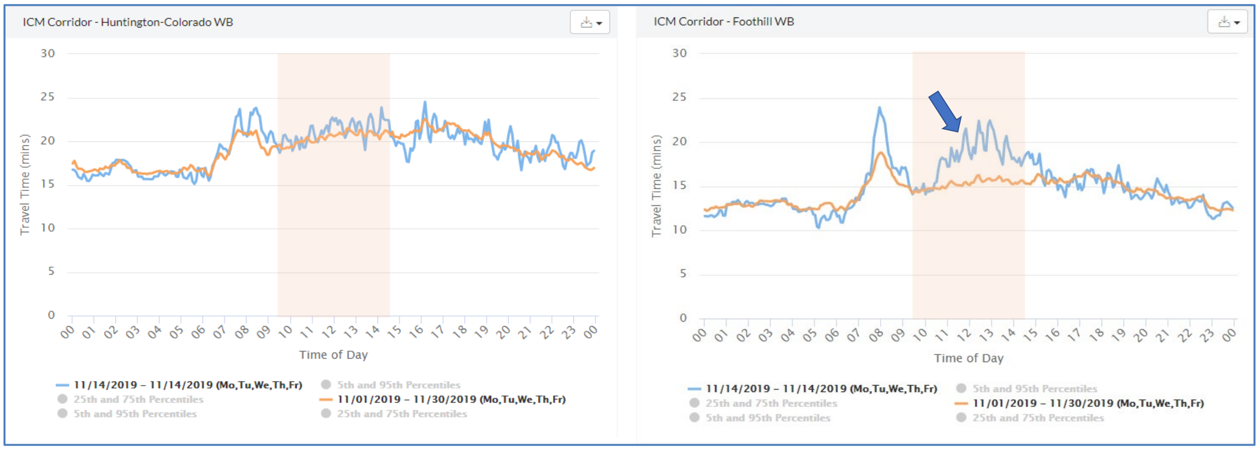

Figure 3-59 – Travel Times along I-210 Parallel Arterials for the I-210 W November 14 Incident

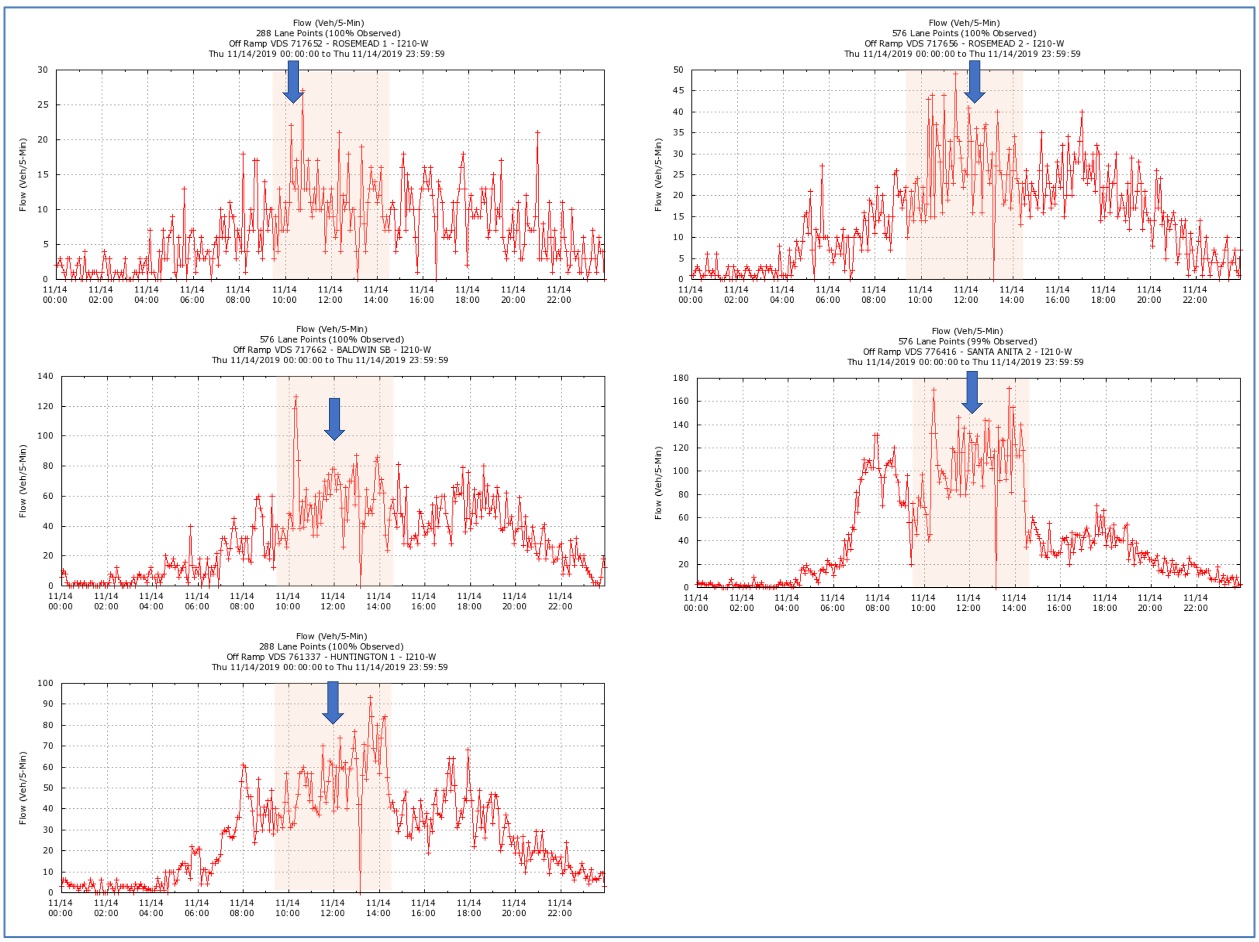

Figure 3-60 – Off-Ramp Flows Upstream of Closure Location for the I-210 W November 14 Incident

Figure 3-61 illustrates the routing patterns captured by StreetLight on the day of the incident. This analysis looks at traffic coming from the I-210 Extension and SR-134 freeway and aiming to travel past the I-605 interchange along the freeway. As can be observed, relatively few detouring activities were observed. This might be due to the occurrence of the incident off-peak. As could be anticipated, some traffic is seen using local arterials to bypass the incident location, as shown in red. Some vehicles detouring to I-10 were also observed, but their number is relatively small.

In this case, the lack of significant impacts across freeways may again be due to the perceived high cost of traveling several miles to the south to use an alternate freeway to avoid a roughly 10-minute delay along I-210. It is highly likely that the added time required to take the detour would be similar, if not greater, than the expected delay. Another key observation is that the back of the queue associated with this incident did not reach the I-605 interchange. Before travelers could visually determine that unusual conditions exist, they had already committed to traveling along I-210. By the time they reached the back of the congestion, their only reasonable alternative option to reach I-5 would be to travel along local arterials.

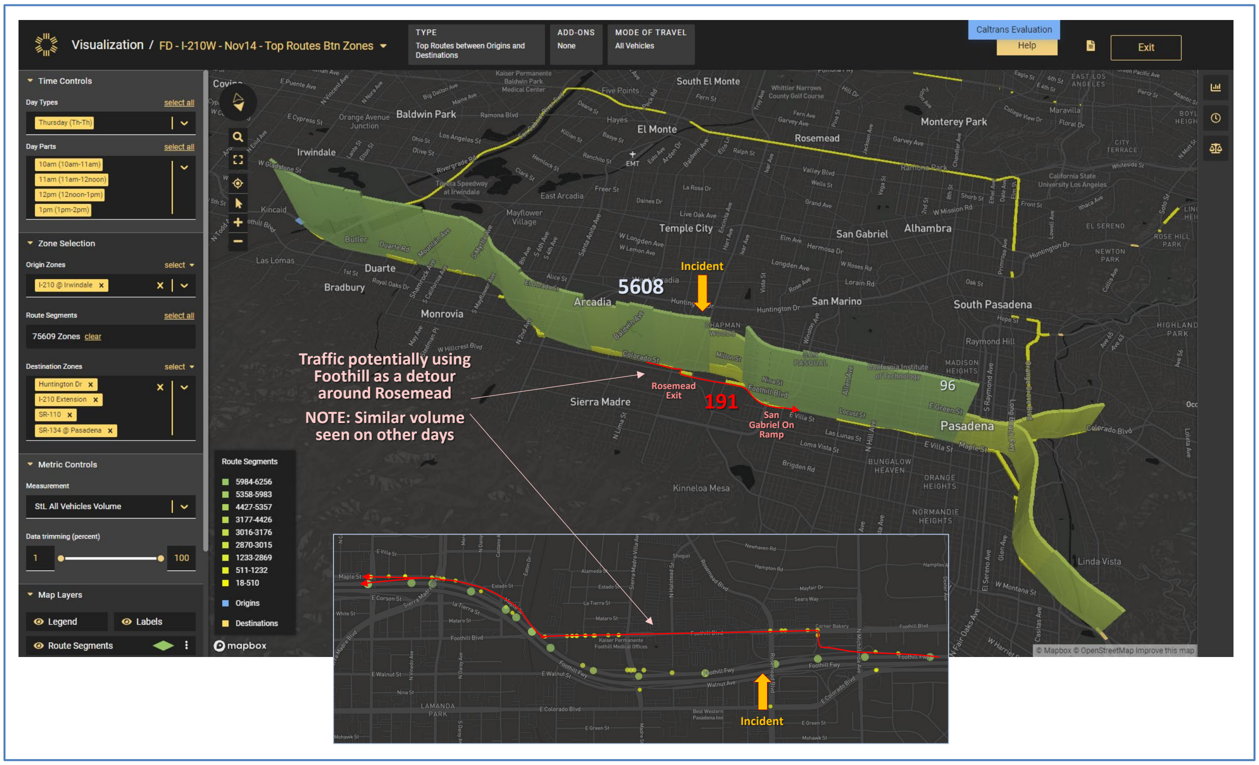

Figure 3-61 – Top routes between zones analysis for I-210 W traffic

3.11. I-210 W – TUESDAY, NOVEMBER 26, 2019

An incident blocking the HOV lane and three of the five mainline lanes was reported at milepost 26.54 near Lake Avenue in Pasadena, from a reported time of 11:54 AM to 2:37 PM (2.75-hours). However, there is some evidence in Figure 3-62 that the incident may have started some significant time before the reported time.

The impact of this incident can clearly be viewed in Figure 3-62, which compares the congestion on the day of the incident to the average weekday conditions for November 2019. For this incident, some usual congestion is observed along I-10 W near El-Monte during the incident period. This suggests that some traffic diverted from I-210 W to I-10 W, but not to a point as to cause major congestion. This is likely because this incident occurs during midday, at a time when extra space capacity is available along I-10 W. Evidence of diversion is further shown in Figure 3-64, which indicates a usually higher volume on the I-210 W to I-605 S connector between 11 AM and 3 PM. While the increase in volume occurs before the reported time of the incident, as indicated above there is strong evidence that incident started well before its reported time. Once again, the increase in flow rate is about 400 vph for several hours.

A review of off-ramp and on-ramp traffic, as well as travel times along arterials parallel to I-210 W did not uncover for this incident any strong evidence of significant diversions using local arterials.

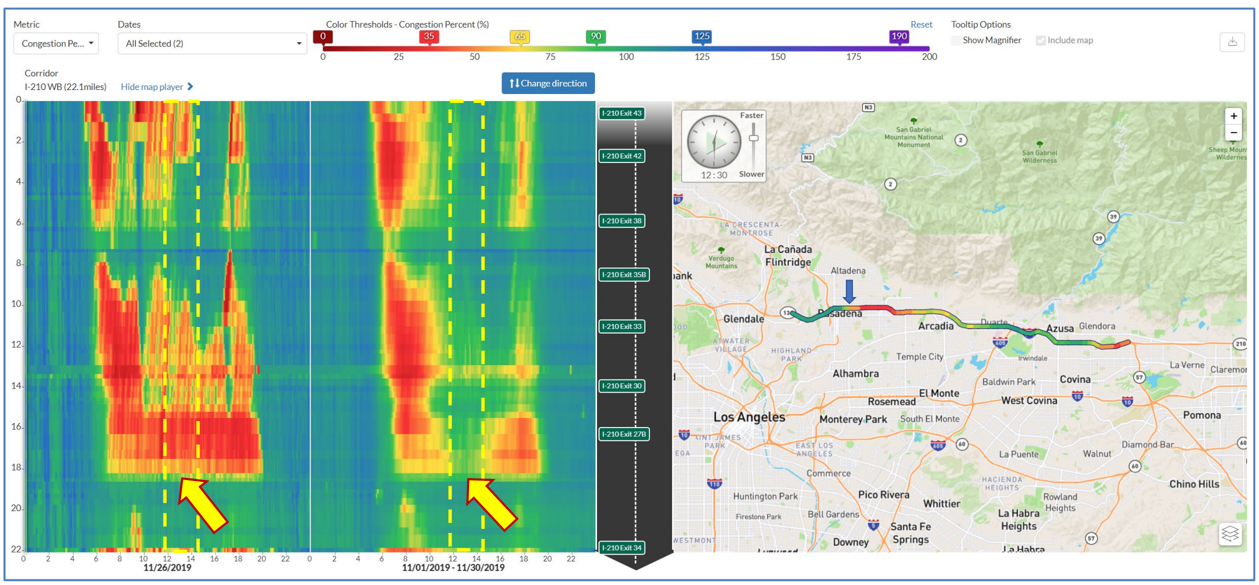

Figure 3-62 – Traffic Conditions on I-210 W for the I-210 W November 26 Incident

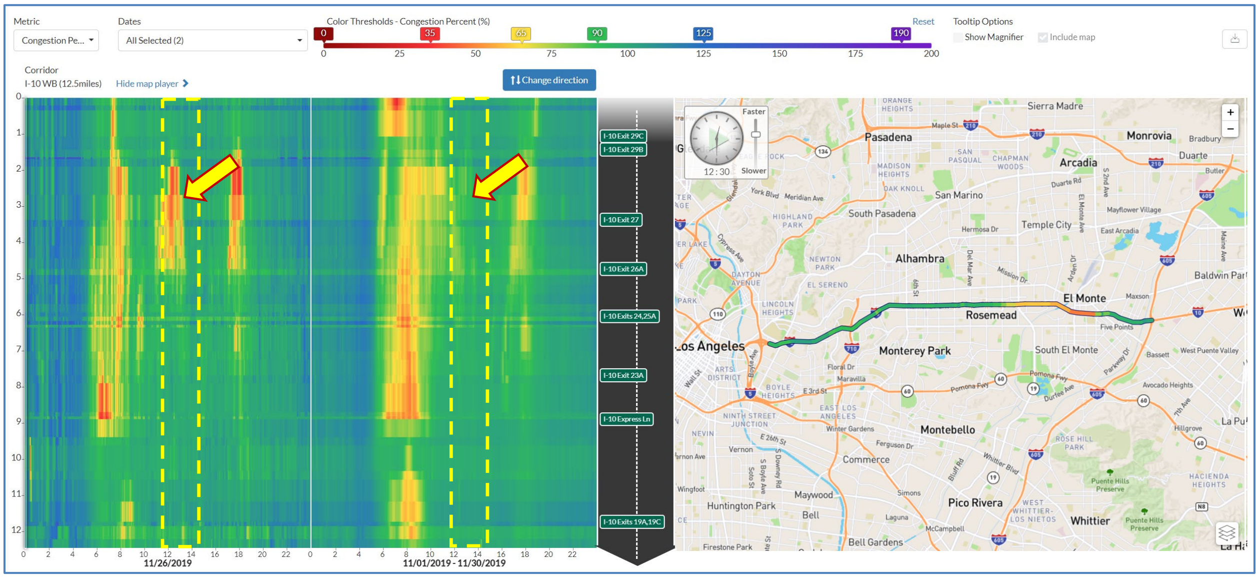

Figure 3-63 – Traffic Conditions on I-10 W for the I-210 W November 26 Incident

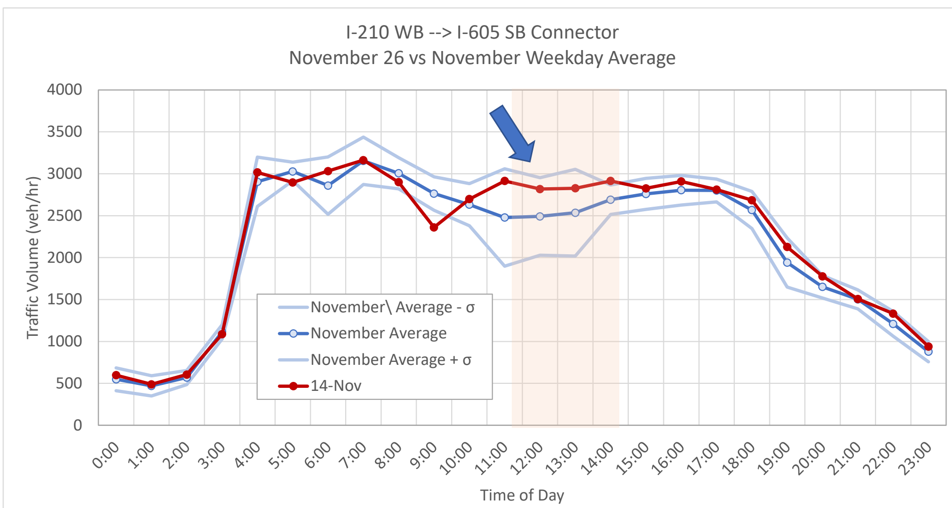

Figure 3-64 – Traffic Volume on the I-210 W to I-605 S Connector for the I-210 W November 26 Incident

3.12. I-210 E – TUESDAY, JANUARY 22, 2019

An emergency closure blocking the HOV lane and two of the five mainline lanes occurred on I-210 E at milepost 29.46 near the Madre St interchange in Pasadena, from a reported time of 10:30 AM to 1:53 PM (3.5-hour incident).

Figure 3-65 indicates that this emergency closure had some significant impacts on traffic conditions along I-210 E, with congested conditions extending over 5 miles. Despite this noticeable impact, no unusual congestion is observed along I-10 E. However, as shown in Figure 3-67, slightly higher than usual flow is observed on I-605 N and the I-605 N to I-205 E connector during the closure period, indicating that some traffic may have used alternate freeways to avoid the closure. In this case, the absence of unexpected congestion along I-10 E or I-605 N is due to the availability of sufficient space capacity to accommodate the increase in traffic.

A review of traffic conditions along the arterials parallel to I-210 further reveals that some traffic may also use local arterials to try to bypass the unusual congestion. As shown in Figure 3-68, slightly longer travel times than the weekday average for January can be observed along Corson St, Colorado Blvd and Foothill Blvd between 1:00 PM and 2:00 PM, as well as Walnut St between 10:30 AM and 12 Noon. While this could be the results of other factors, increases in exit volumes can be observed at the Lave and Altadena off-ramps between 10:30 AM and 2:00 PM. This suggests that traffic may be exiting the freeway to use local arterials as a detour.

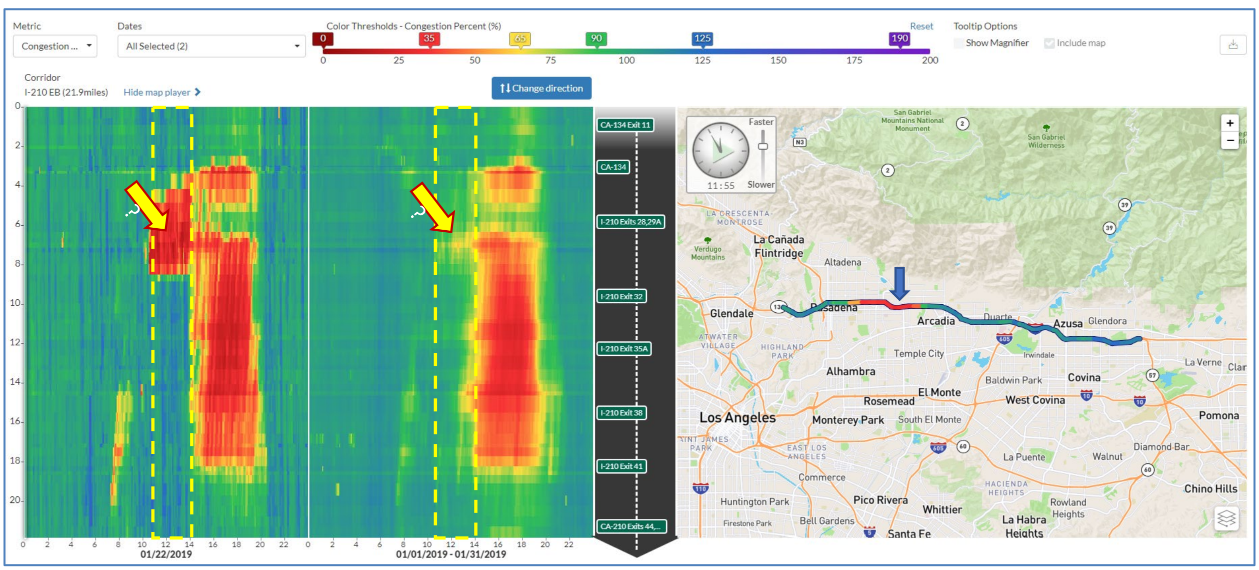

Figure 3-65 – Traffic Conditions on I-210 E for the I-210 E January 21 Incident

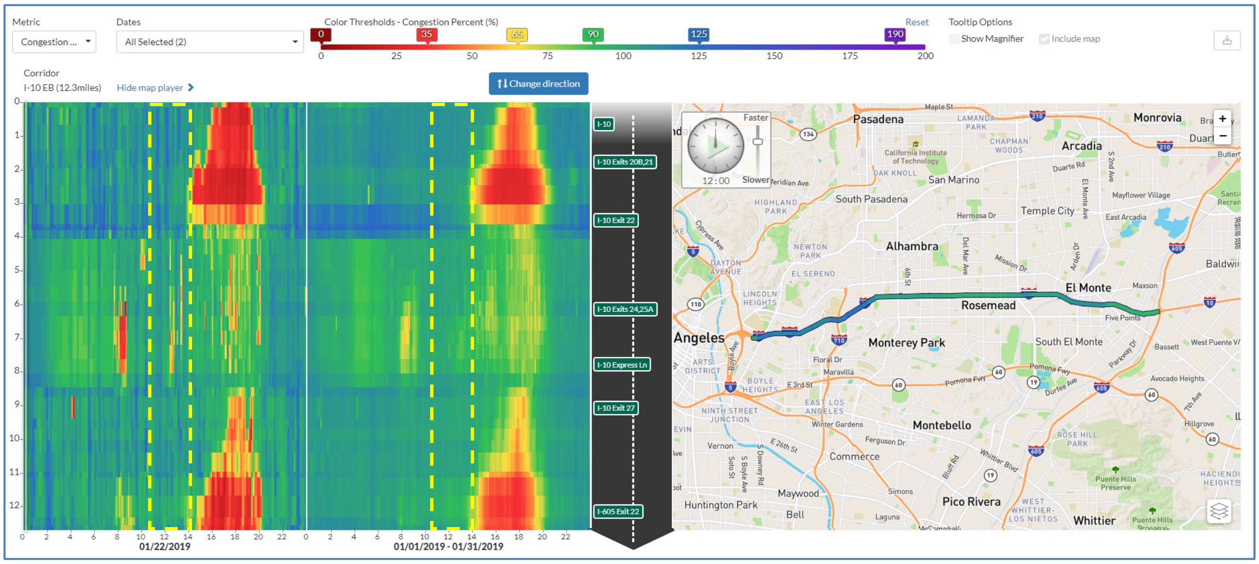

Figure 3-66 – Traffic Conditions on I-10 E for the I-210 E January 21 Incident

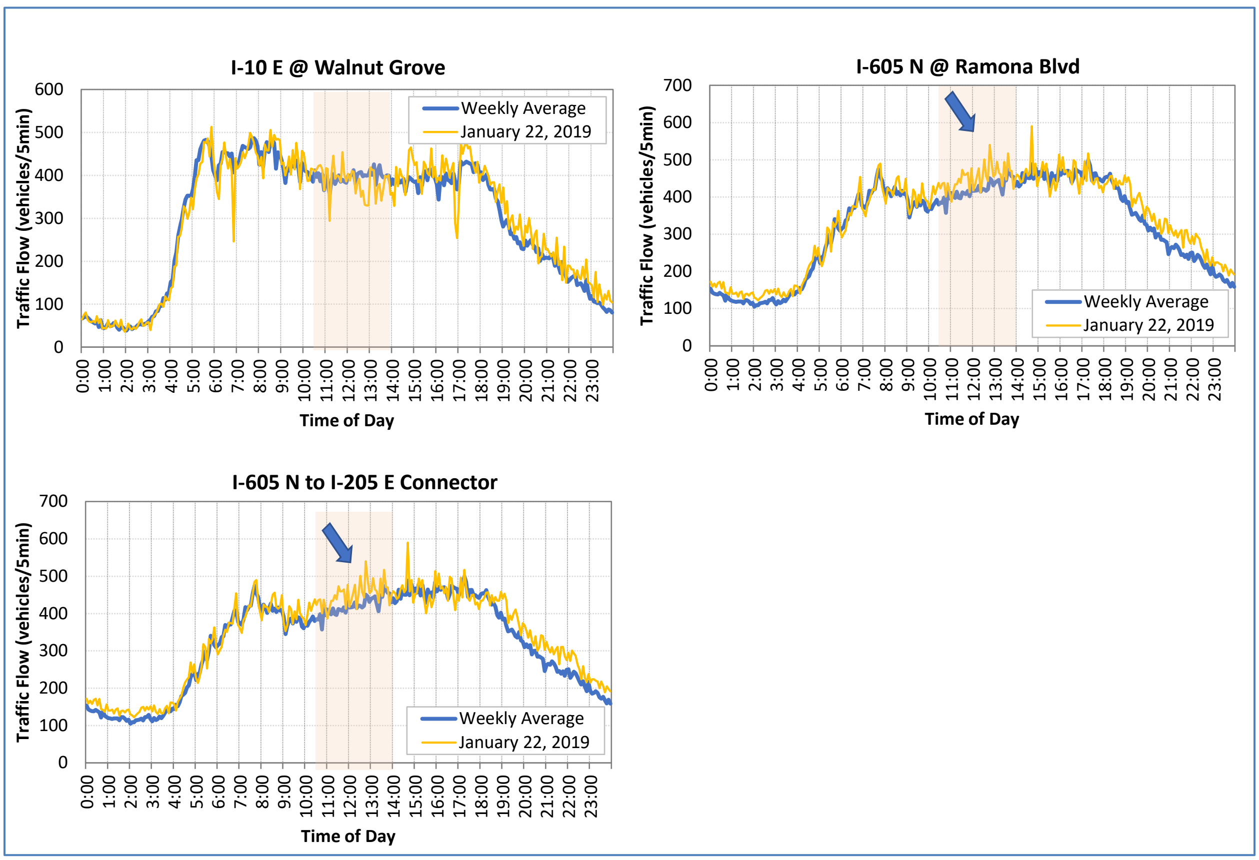

Figure 3-67 – Traffic Flow on I-10 E and I-605 N for the I-210 E January 21 Incident

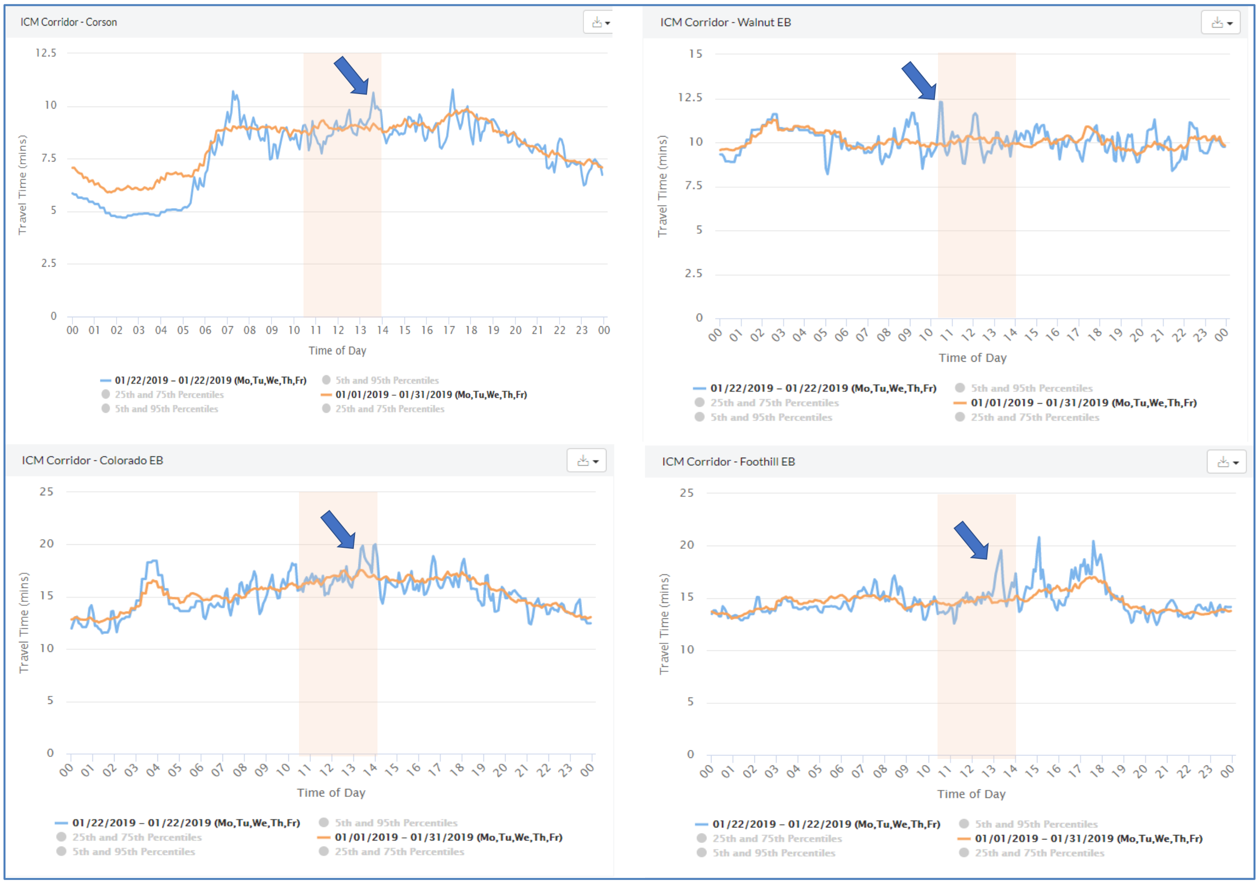

Figure 3-68 – Travel Times along I-210 Parallel Arterials for the I-210 E January 21 Incident

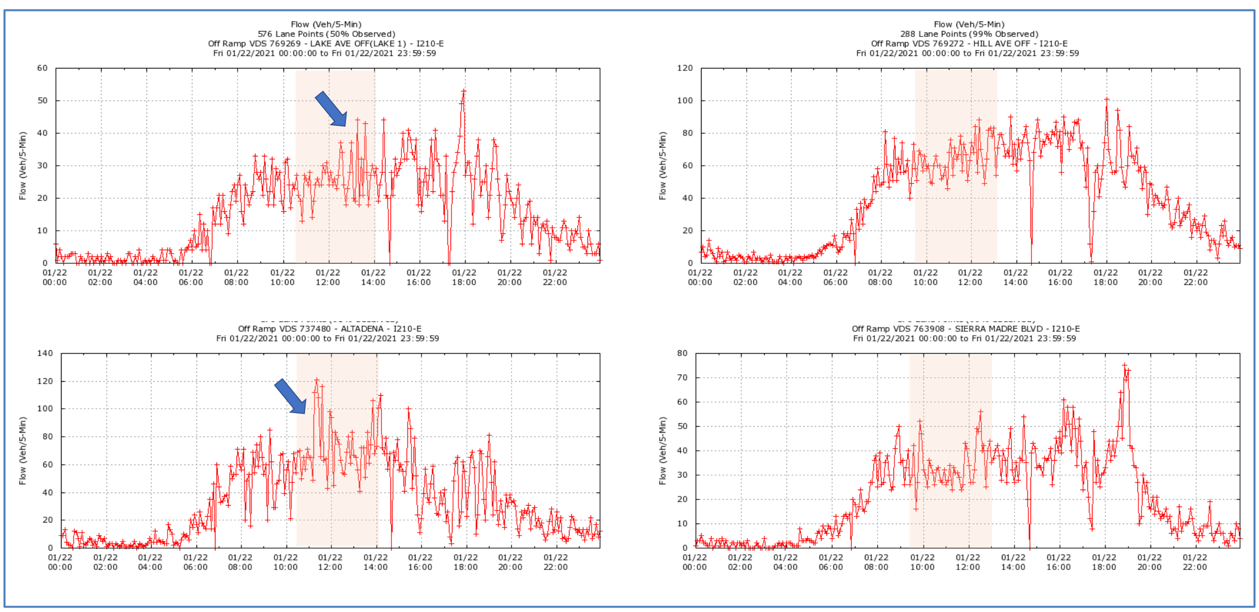

Figure 3-69 – Off-Ramp Flows Upstream of Closure Location for the I-210 E January 21 Incident

3.13. I-210 E – MONDAY, OCTOBER 21, 2019

An emergency closure blocking the HOV lane and one of the five mainline lanes occurred on I-210 E at milepost 36.65 in the middle of the I-210/I-605 interchange, from a reported time of 11:00 AM to 2:00 PM (3-hour incident).

Figure 3-70 shows that this emergency closure had a relatively small impact on traffic conditions on I-210 E. Some additional congestion is observed at the I-605 interchange, but this unusual congestion remains localized. This incident was therefore unlikely to push motorists to seek alternate routes around the closure. While Figure 3-71 shows some unusual congestion along I-10 E during the emergency closure,

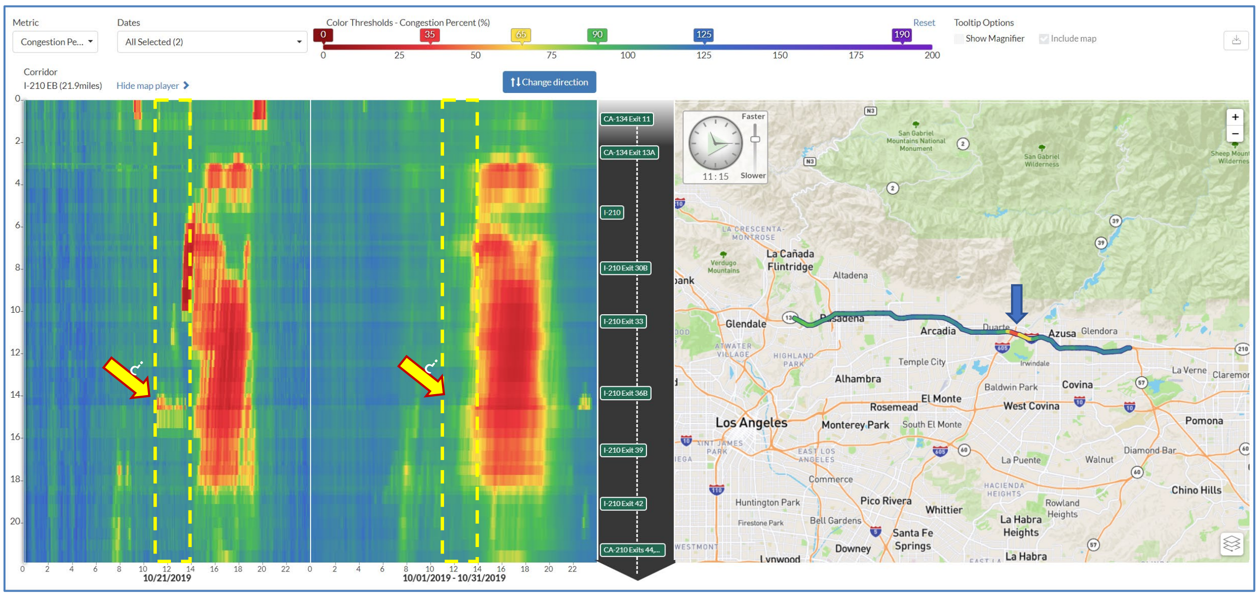

Figure 3-70 – Traffic Conditions on I-210 E for the I-210 E October 21 Incident

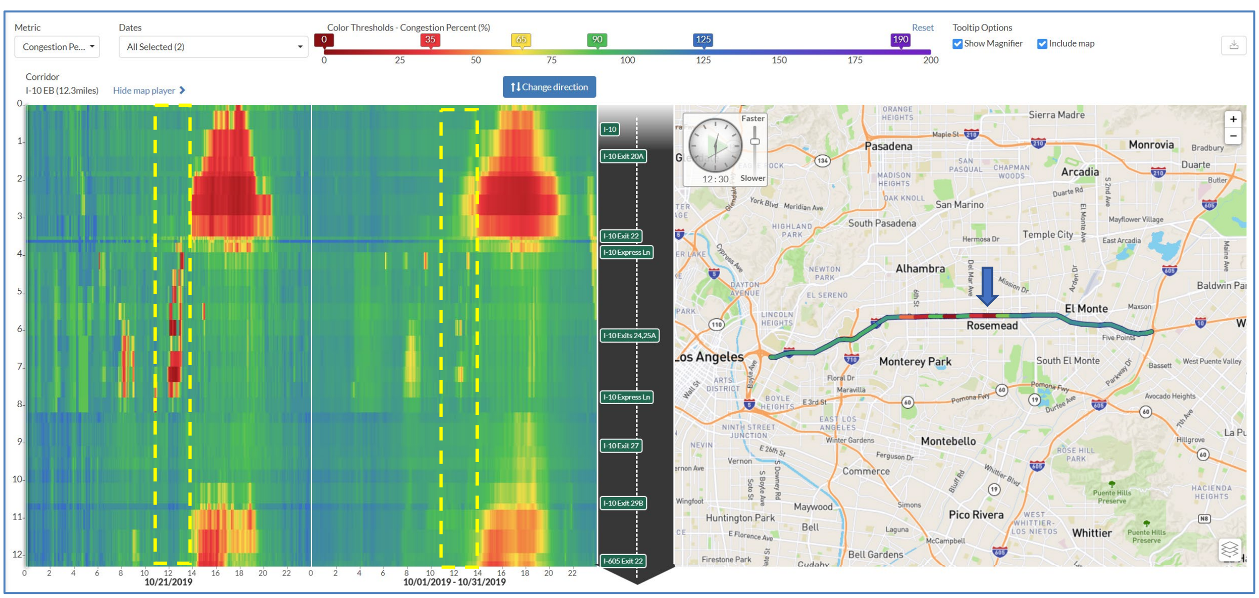

Figure 3-71 – Traffic Conditions on I-10 E for the I-210 E October 21 Incident

this unusual congestion is actually the result of a second incident that closed the HOV lane and three of Figure displaying on the left two time-space diagram comparing traffic congestion on I-210 E on December 19, 2019, the incident day, with the December 2019 weekday average. A yellow rectangle denotes the duration of the incident while yellow arrows highlight key profile differences. On the right, the map shows the freeway segments analyzed, the location of the closure with a blue arrow, and the extent of congestion in shades of red.

3.14. I-210 E – TUESDAY, DECEMBER 19, 2019

An incident blocking the HOV lane on I-210 E at milepost 30.49 occurred near Baldwin Avenue in Arcadia, from a reported time of 11:05 AM to 3:09 PM (4-hour incident).

Figure 3-72 and Figure 3-73 compare traffic conditions along I-210 E and I-10 E on the day of the incident to the average weekday traffic conditions observed in December 2019. As can be observed, this incident produced relatively small impacts on traffic along I-210, and no significant impact on I-10, despite its long duration. Observable impacts appear to be contained to the last hour of the event, at the beginning of the afternoon peak travel period. This can be explained by the event only closing the HOV lane at a time when there is normally sufficient capacity on the remaining lanes to absorb the HOV traffic. An event lasting significantly beyond 3 PM or closing additional lanes would have likely produced more impacts.

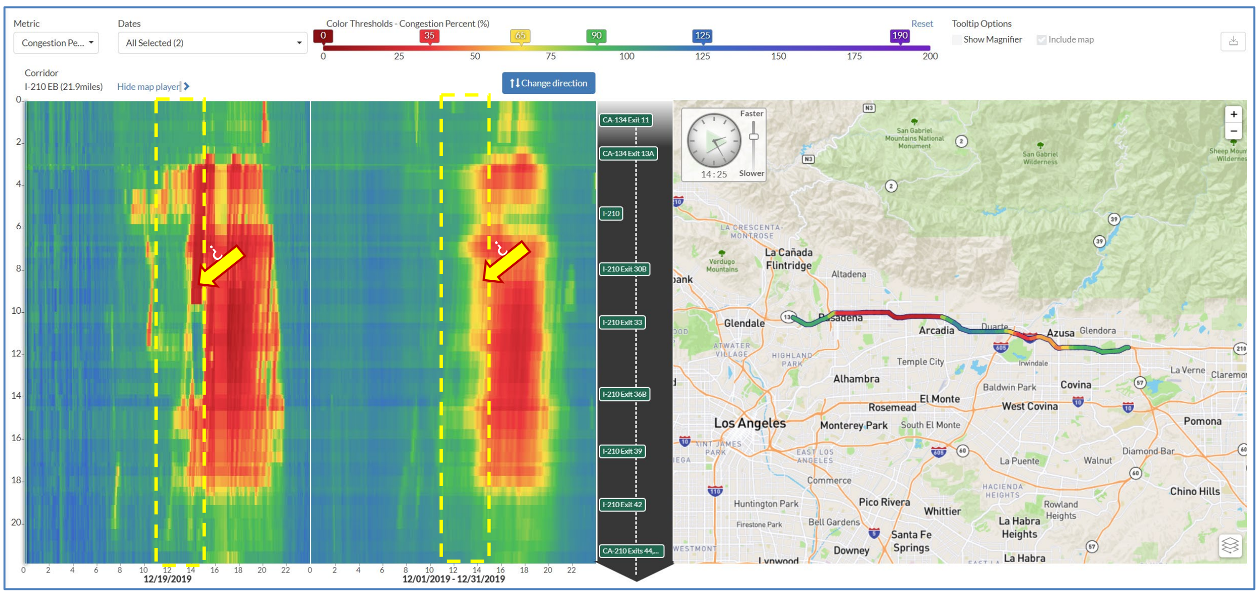

Figure 3-72 – Traffic Conditions on I-210 E for the I-210 E December 19 Incident

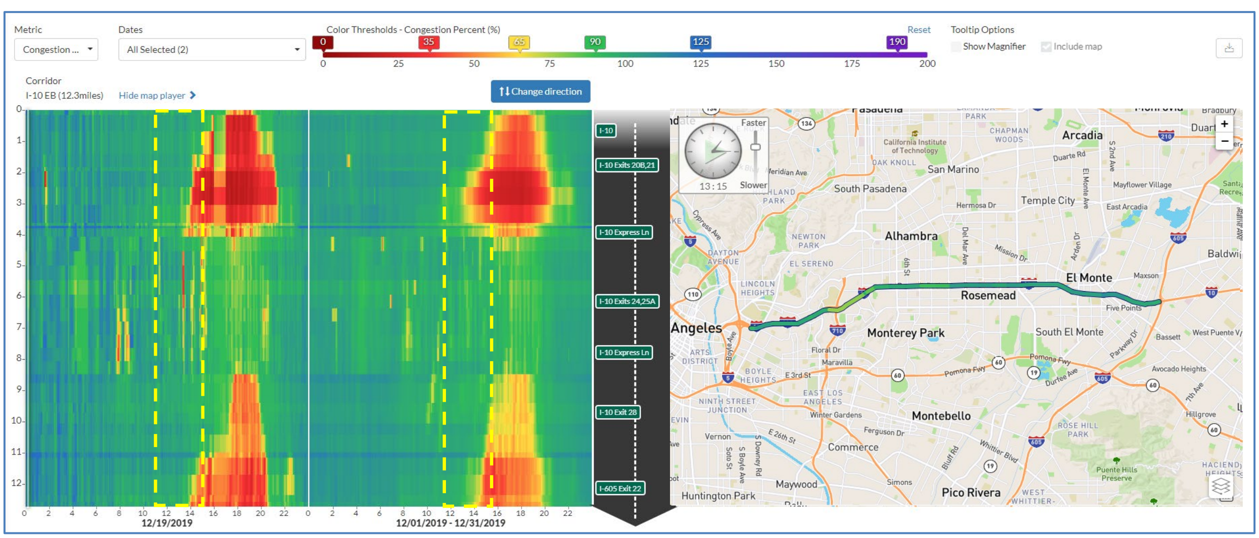

Figure 3-73 – Traffic Conditions on I-10 E for the I-210 E December 19 Incident

Figure 3-74 displays a StreetLight top routes analysis for a typical day along I-210 E from I-210, SR-134, and SR110 on Wednesday, December 18, 2019. Figure **3-75** displays the same analysis for the incident day on Thursday, December 19, 2019. The two figures are very similar.

There is some evidence of rerouting along local streets including Huntingon Drive. However, the rerouting effect appears to be small. This result is consistent with the findings based on INRIX and PeMS data.

Figure 3-74 – Top routes on I-210 E on Wednesday, December 18, 2019

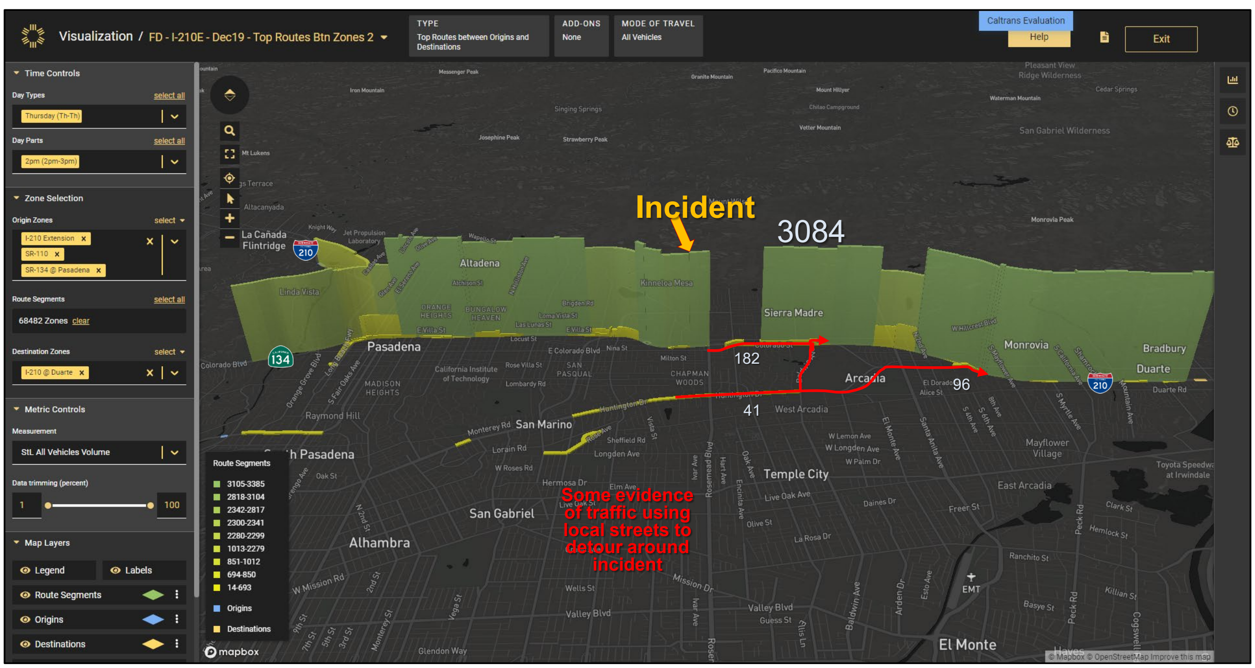

Figure 3-75 – Top Routes on I-210 E on Thursday, December 19, 2019

4. FACTORS AFFECTING ROUTING DECISIONS

This section presents a distillation of findings regarding routing decisions inferred from the analysis. These findings are categorized into considerations for network effects, congestion effects, traveler information system effects, traveler experience effects, and weather. Attributes are suggested with possible metrics that could be used to characterize relationships of nearby freeways and corridors.

Within the scope of this discussion about freeway incidents and response plans, there are several main kinds of trips that deserve special attention:

- **Through-route trips**: Re-routes that avoid the incident by leaving the freeway and returning to the freeway downstream of the incident
- **Deferred entrance trips**: Re-routes that enter the freeway at a downstream on-ramp to avoid the incident
- **Expedited exit trips**: Re-routes that mitigate exposure to the incident-related queue by leaving the freeway at an upstream off-ramp and never return to the freeway
- **Other impacted trips**: Trips that were never routed along the link with the incident, but trips that get caught in incident-related queues that form on the network

The trips that have ultimate destinations downstream of an incident (such as through-route trips) must inevitably pay the cost of the reduced network capacity caused by the incident. However, other impacted trips that are simply caught up in the excess congestion due to unfortunate routing decisions may avoid that cost. Expedited exit trips benefit most from efforts to keep an upstream off-ramp or upstream junction from being blocked. These last two examples are cases where the non-linear deleterious effects of congestion can be reduced.

The data gathered and analyzed in this study focused on the first bullet about through-route trips. Given the available data, these trips were the easiest to extract and to draw conclusions from. The findings suggest that parallel freeways within about 3 miles, and with convenient access, are highly attractive as alternate routes. As the distance increases and the ease of access is reduced, the attractiveness of that freeway as an alternate route falls off quickly. However, the distribution of trip lengths for a given link is also important. Incidents at critical network choke points that service a large proportion of long-distance trips can cause much larger rerouting effects.

4.1. NETWORK EFFECTS

- **Distribution of trip lengths**
    - Incidents that occur on links that tend to serve predominantly longer routes have the potential to trigger longer reroutes. The reasoning is that travelers who intend to take short distance trips are less likely to accept long reroutes that take them far out of their way. However, travelers who have already committed to a long-distance trip may be able to reroute to a completely different freeway; the new reroute may only be a small percentage longer than the original route.
    - METRIC:
        - Distribution of trip lengths for a link estimated from a calibrated demand model.

- **Distance of alternate route from initial route**
    - Alternate freeways located closer to the initial routes are more likely to be used.
    - Freeways at a distance of about 3 miles or less naturally provide strong incentives to be used as alternate routes. Examples for which notable rerouting effects were observed include:
        - I-10 and SR-60
        - SR-57 and SR-55
    - The attractiveness of an alternate freeway falls off quickly beyond a distance of about 3 miles. Part of this is likely due to the increased travel time to reach it and come back. Examples for which little freeway rerouting was observed include:
        - I-210 and I-10, which resulted in mostly local detours
        - I-5 and SR-99 south of Sacramento
        - I-5 and SR-99 near Stockton (separation distance 3.5 to 5.0 miles)
    - METRIC:
        - Average distance, in miles, between the two corridors, or freeways.

- **Parallelism of alternate route**
    - The attractiveness of alternate routes is linked to their parallelism to the initial route. Travelers are more willing to use an alternate freeway generally allowing them to travel towards their destination and in the same general direction.
        - Heavy use of SR-57 and SR-91 together as an alternate to the hypotenuse of I-5 in the triangle. This effect is reinforced by the orientation of the underlying arterial network.
        - Little use of I-5 (the hypotenuse) in combination with one side of the triangle to compensate for the other side.
    - METRIC:
        - Difference in directional heading, in degrees, between the two corridors.

- **Ease of access to destination from alternate route**
    - Alternate routes providing easy travel to an intended destination are more attractive. For instance, detouring from I-210 to I-10 to get to Glendale requires travel back to I-210 using local streets, which is not very attractive. However, downtown Los Angeles might be reached by freeway using either I-10 or I-210/SR-110.
    - METRIC:
        - Does the alternate route allow to return to the original route using freeways, expressways, or arterials with few traffic signals?

- **Known work zones/special events**
    - Knowledge of a work zone or lane closure due to a special event on alternate routes may significantly reduce the desire to use the route as an alternative.
    - METRIC:
        - Presence of scheduled work zones or events affecting the alternate route.

- **Incident on alternate routes**
    - The presence of an incident on an alternate route can significantly reduce the attractiveness of using it as a detour. This possibility is categorized as a network effect, and treated as distinct from congestion effects on the initial route.
    - Attractiveness will typically reduce with:
        - Increases in the number of lanes affected (lower available capacity).
        - Extent of congestion generated by the incident (higher travel time).
    - METRICS:
        - Fraction of lanes affected
            - Would probably need to be greater than about 35% of lanes, as single lane accident on a 6-lane freeway may not generate much congestion, while a single lane accident on a 2-lane freeway may have a significant impact.
        - Extent of congestion upstream of incident
            - Values would need to be greater than a certain threshold (e.g., queue > 1 mile) to negatively impact the attractiveness of a detour.
        - Delay generated by the incident.
            - Values would need to be greater than a certain threshold (e.g., delay > 5 minutes) to negatively impact the attractiveness of a detour.

4.2. CONGESTION EFFECTS

- **Magnitude of anticipated delay on initial congested route**
    - Travelers may decide to stay on a congested route if the estimated delay is relatively small. For instance, freeway motorists may choose to remain on their current route if the estimated delay is less than 5 minutes. This is based on the uncertainty that significant travel time savings may be achieved by attempting to travel on signalized local arterials that may or may not be congested as well.
    - The proportion of travelers considering alternate routes should increase with increases in estimated delays on the initial route.
    - For connected travelers, estimated delays would be provided by their routing application. For non-connected travelers, this would be provided by their assessment of traffic conditions, and if the freeway appears to be unusually congested at the specific time of travel (peak, midday, off-peak, night, etc.).
    - Subject to:
        - Time of day, day of week, weather effects.
    - METRIC:
        - Expected delay, in minutes, along initial route.
            - Must generally be greater than 5 minutes to have meaningful effects.
            - Longer or slightly shorter values may be used depending on location, time of day, day of week.

- **Magnitude of <u>perceived</u> potential travel time savings**
    - The proportion of travelers seeking alternate routes should increase with the perception that significant time savings could be obtained by rerouting.
        - Taking a 10-minute reroute to avoid a 9-minute delay would for instance not be seen as sufficiently beneficial as it increases traveled distance for a little gain in travel times.
        - A big question is: what is the travel time reduction threshold through which using an alternate route becomes beneficial? This is likely to vary across travelers. For short reroutes, a 1-2 minute savings may be perceived as sufficiently advantageous. For longer reroutes, this may be seen as too little of a gain.
    - Subject to:
        - Accuracy of information travelers have on traffic conditions on alternate routes.
    - METRIC:
        - Difference in travel time, in minutes, between detour and initial route.
            - Must be equal or greater than 2 minutes to have meaningful effects.

- **Visible unusual congestion at key decision points**
    - Travelers may be more inclined to make spur-of-the-moment decisions to use alternate routes if unusual congestion is observed at or near a key decision point.
        - This is based on the principle that non-connected drivers will base their route choices on perceived traffic conditions. If traffic conditions appear normal, they will tend to stay on their current route. This may lead them to pass on opportunities to avoid being trapped in freeway congestion downstream and ultimately end up with limited options, i.e., using local streets to get around the congestion.
        - Example: Congestion reaching major freeway-freeway interchange or key freeway-to-freeway connector, such as I-210 West at the I-650 interchange.
    - Subject to:
        - Travelers having knowledge of usual traffic conditions, except when very high densities or very low speeds are encountered.
    - METRICS:
        - Traffic Density, in vehicles/mile.
            - Traffic starting to detour if density > 90-105 veh/miles.
            - High percentage of detours reached when density > 120-135 veh/miles.
        - Speed, in miles/hour.
            - Traffic starting to detour if freeway speed < 35 veh/miles.
            - High percentage of detours reached speed < 15 veh/miles.

- **Time-of-day effects**
    - Travelers may be less likely to seek alternate routes during peak travel times, as there is an increased probability that potential alternate routes are also congested. These considerations would translate into:
        - Potential reduction in fraction of travelers considering a reroute for an incident of a given magnitude.

        - Potential increase in the magnitude of delay threshold needed to trigger the travelers to seek alternate routes.
    - Subject to:
        - Direction of travel. Time-of-day effects may be more pronounced for travel in the peak direction than in the opposite direction.
    - METRIC:
        - Period of day during which incident occurs:
            - Weekday incident during: AM Peak, Midday, PM Peak, Evening, Night.
            - Weekend incident during: Morning, Midday, Afternoon, Evening, Night.

- **Day-of-week effects**
    - Travelers may be more inclined to seek alternate routes on days with less congestion
        - Fewer travelers may seek alternate paths on Mondays and Fridays if such days often have congested traffic conditions.
        - More travelers may seek alternate routes on Saturdays and Sundays than on weekdays based on the perception that local streets may be less congested.
    - METRIC:
        - Day of week during which incident occurs.

4.3. TRAVELER INFORMATION EFFECTS

- **CMS displaying travel time or incident information upstream of major decision point**
    - A CMS displaying travel time information allows travelers to judge the magnitude of potential problems ahead.
    - Signs displaying travel time information upstream of a key decision point may entice travelers to seek alternate routes when unusual conditions exist.
    - This information is consumed differently depending on whether drivers have pre-existing knowledge of what normal conditions may be.
    - In cases where a very large travel time is reported (e.g., 60 minutes of travel time for a location 15 miles distant) knowledge of normal conditions may not matter.
    - Subject to:
        - Percentage of travelers that have pre-existing knowledge of what normal conditions are like.
    - METRIC:
        - CMS within 5 miles of key decision point displaying traveler information.
            - Longer distances may be used if it is believed that drivers may still respond to be information.

- **Percent of connected travelers**
    - A greater proportion of connected travelers having access to real-time routing may increase the use of alternate routes.
        - Access to real-time routing applications allow travelers to receive alternate route suggestions reflecting latest conditions.
        - Accurate real-time information removes guesses or inaccurate biases in route choices.

        - Provision of turn-by-turn directions remove fear of getting lost.
    - Subject to:
        - Driver acceptance of suggested reroutes.
    - Potential problems:
        - Suggested reroutes by application that save only 1 minute.
        - Rerouting suggestions based on inaccurate or outdated travel time information (as this is usually a delay in information processing).
    - METRIC:
        - Percent of vehicles assumed to use real-time information from onboard or cellular phones.
            - This will likely need to be based on regional estimates.

- **Traveler willingness to follow alternate route suggestions**
    - Access to real-time information only affects traveler behavior if individuals are willing to alter their route. There may be cases where travelers ignore recommendations due to unfamiliarity with the alternate route (Does it go through an undesirable part of town?) or a simple preference to stay on freeway. Some travelers may believe they "know better than the application" and decide to override app-based routing suggestions.
    - Subject to:
        - Traveler past experiences with detours, particularly detours suggested by applications in cases where there is a relatively small travel time gain.
    - METRIC:
        - Percent of travelers assumed to respond to detour.
            - This will likely need to be based on historical observations.

4.4. TRAVELER EXPERIENCE EFFECTS

- **Traveler familiarity with an area may be more likely to divert than non-familiar drivers.**
    - Travelers familiar with a local network may be more likely to divert than non-familiar drivers.
        - This may be due to a better understanding of available routes and typical congestion patters.
    - Corridors traveled by regular commuters might see more diversion than other corridors.
        - This implies that the same corridor may have different rerouting responses for incidents occurring during weekday peak periods and, say, weekends.
    - METRIC:
        - Difficult to pinpoint a specific metric, as long-distance commuters along a given route may not necessarily be familiar with the nearby networks. Short distance commuters may have a higher level of knowledge. Perhaps obtaining from travel demand models or other origin-destination study the percentage of motorists traveling less than a threshold number of miles.

- **Traveler past rerouting experiences**
    - Travelers who have used a specific detour are likely to repeat using the detour if they previously successfully saved time going around an incident but are not likely to repeat their use if they ended up taking more time.
    - A higher proportion of regular commuters knowing typical traffic conditions on the freeway and local network may affect (either positively or negatively) the proportion of vehicle rerouting.
    - METRIC:
        - Difficult to quantify as this relies on knowing the past experiences of travelers.

4.5. WEATHER EFFECTS

- **Weather effects**
    - Inclement weather may reduce the attractiveness of alternate routes if it is perceived that traffic conditions are significantly affected by the weather.
        - Slow traffic due to slick pavement following a first rain of the season
        - Heavy rain/hail event causing congestion on SR-60 East observed in case study on May 22, 2019
    - METRIC:
        - Presence of widespread inclement weather in weather report.

5. CONSIDERATIONS FOR LARGE SCALE TRAFFIC MANAGEMENT

There is a great deal of information available about ICM projects, and how to plan them. This brief section does not attempt to represent what is available in the literature. However, it has a focus on large scale traffic management and considerations based on the re-routing patterns identified above.

This discussion only considers freeway incidents. For these incidents, there are two main types of response plans:

- Reroutes using alternate paths on other freeways
- Reroutes that use nearby arterial streets to compensate for some lost capacity on the freeway

These response plans may consist of messages, CMS signage, and changes to the timings of arterial signals and ramp meters. This style of ICM is consistent with past efforts by Caltrans.

5.1. METRICS FOR DECISION MAKING

When considering the deployment of a response plan to mitigate an incident, quantitative metrics must be predetermined to evaluate the benefit of the intervention. This need exists for planning and design efforts as well as the live operation of an ICM.

For freeway incidents, typical metrics may include:

- Flows: upstream off-ramps, downstream on-ramps, screen-lines[1] near the incident capturing flows moving parallel to the freeway near the incident
- Travel times on the freeway and along selected alternate routes
- Area-based statistics, such as VMT and VHT over the affected road network
- Route-based statistics, such as VMT and VHT along the freeway and selected routes
- Freeway queue length, or excess freeway queue length

These metrics may be combined to form a scorecard that summarizes the advantages and disadvantages of a particular response plan for a particular incident situation. In practice, a detailed simulation would be required to calculate all of these metrics. However, since simulation models are expensive to build, calibrate and maintain, some metrics such as excess freeway queue length, might be estimated with a simple historical model of freeway flows and capacity reductions due to blocked lanes.

Each of the metrics listed above reveals separate aspects of performance, and their proper interpretation can be subtle. For example, freeway queue length is a good measure because it relates to the potential blockage of upstream off-ramps and upstream freeway junctions. However, queue estimates may also be subject to noise, or stochastic error in simulation, and measurement or estimation errors in physical systems as the actual end of queue is not always clearly defined. Flow information further helps to quantify the number of vehicles serviced by the system at specific locations in the network. However, the

[1] Screen-lines are defined at or near the location of the incident and aligned perpendicular to the freeway.

flow at downstream on-ramps or across a screen-line placed perpendicularly to a freeway incident location may be lower than expected if a large number of trip destinations happen to lie just upstream of the screen-line.

Performance improvements revealed in area-based statistics such as VMT and VHT might get washed out if the area of the measurement is too large. Alternatively, they may be skewed if not chosen appropriately for the incident in question.

5.2. BOUNDARIES OF SITUATIONAL AWARENESS AND CONTROL

One important finding from the case studies considered in this effort is that the effects of rerouting can be geographically large. If ICM projects are deployed myopically along narrow corridors within 1-2 miles of a freeway, there may be substantial unaccounted (positive or negative) effects beyond the boundaries. The traffic impacts of a disruption within an ICM's control boundaries may extend beyond those boundaries. Likewise, the impacts of any control strategies may extend beyond those control boundaries as well.

In the above context, it is therefore useful to introduce the following distinctions for an ICM project:

- The geographical boundary of situational awareness
- The geographical boundary of control

The geographical boundary of control, schematically represented by the rectangles in Figure 5-1, consists only of the zone that contains the traffic control elements such as traffic signals and ramp meters that may be used during a response plan (CMS do not fit neatly inside of this boundary and are discussed in Section 5.5). However, the geographical boundary of situational awareness, schematically represented by the ellipses in Figure 5-1, must be much larger to include any freeways and arterials that could be affected by a disruption, or a control strategy deployed to mitigate a disruption.

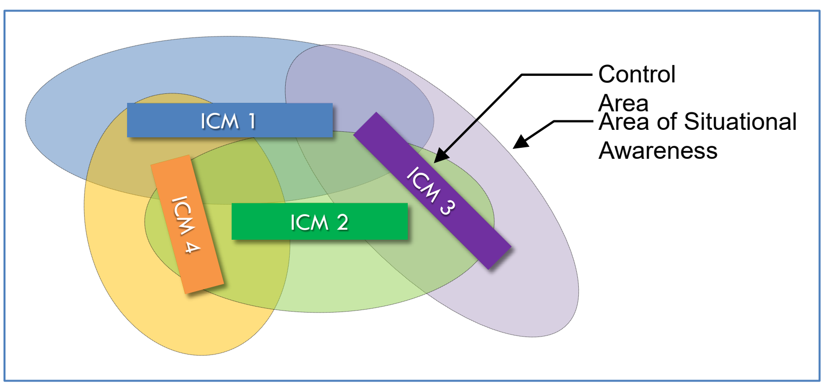

Figure 5-1 – Schematic representation of four ICM regions, control situational awareness boundaries

As an example, in the Orange County Triangle area, it is clear that SR-57, and SR-55 are well coupled freeway corridors. An incident affecting one would naturally result in traffic re-routing on the other. Therefore, a full accounting of benefits and disbenefits for an ICM response plan to mitigate an incident on SR-57 would need to consider its effects on SR-55. Decision making for incidents on both these freeways should be coupled as well. Therefore, an ICM centered on SR-57 to mitigate incidents in and around SR-57 would need to include SR-55 in its geographical boundary of situational awareness, even if SR-55 were not a part of its geographical boundary of control.

Another natural grouping based on the empirical findings is I-10 and SR-60. These freeways are close enough together that they appear to support each other, and a number of longer trips appear to use either freeway. Once again, data-driven decision making would require situational awareness on both freeways in order to manage both freeways effectively. Therefore, an ICM centered on I-10 to mitigate incidents in and around I-10 would need to include SR-60 in its geographical boundary of situational awareness, even if SR-60 were not a part of its geographical boundary of control.

The consequence of these findings is that decision making processes need to integrate situational awareness data beyond the control boundaries. Therefore, the integration of systems needs to extend beyond the control boundaries as well. To do this requires common standards for meta-data and semantics so that TMCs are able to share information, even if they have no intent to cede control during an incident to participate in an ICM response plan.

5.3. STRUCTURES FOR DECISION MAKING

The key question for any ICM system is this: given the information available, what is the best course of action over the next time horizon? The time required for a signalized intersection to transition into a new plan can vary between one and three cycles depending on the magnitude of the change proposed and the signal control systems involved. This translates into possible delays ranging from one to six minutes. There are often additional delays associated with data gathering, state estimation, and evaluation of alternatives. So a reasonable time horizon for an action might be 30 to 45 minutes.

At a minimum, the key courses of action to be evaluated at every decision point are:

- Maintain the current plan (Time-of-day or Response Plan)
- Implement typical time-of-day plan
- Implement one of available response plan alternatives

The current plan could be the current response plan, or the time-of-day plan that is normally scheduled to operate. There are several types of response plan alternatives:

1. *Non-constrained* choice: the best choice in a “perfect world” where there are no communications interruptions, no equipment failures, no work zones, no special events, or any other external factors that limit the choice of Response Plan within the design of the ICM.
2. *Operationally-constrained* choice: the best choice in the “real world” but not considering constraints imposed by other active Response Plans either deployed by the ICM system or by neighboring ICM systems.
3. *Conflict-constrained* choice: The best choice given all existing constraints.

During real-time operation, choices 2 and 3 are the most crucial and both must be considered in cases where multiple incidents are active. The way to distinguish among possible choices is to determine the value of each choice over a suitable time horizon. This requires a scorecard generator capable of calculating the metrics of interest, as described above, making such a scorecard generator a core component of a decision support system.

The scorecard generator should take as input the following elements:

- the current state of the traffic system within the bounds of situational awareness,
- information about the expected duration and magnitude of incidents, and
- the response plans up for consideration.

Based on the available information, a scorecard should then be generated for each possible response plan to allow comparisons across all available solutions. In this process, the response plans for consideration should include both operationally constrained and conflict constrained choices, as it may not always be clear which type of response plan may be best for a given situation.

5.4. SYSTEM SCALE

While previous sections have motivated the need for large scale situational awareness to assess traffic conditions and rerouting effects caused by incidents and mitigation strategies, this section addresses the ability of messaging and communications technology to handle the volume of data that would be required.

The existing Caltrans Performance Measurement System (PeMS) was deployed using late 1990's technology. This system collects data on freeways from across the state of California, from roughly 46,000 individual PeMS detectors, organized into vehicle detection stations. Each station communicates sensor data once per 30 seconds, generating a volume of about 55 million messages per day.

Using a simple rule of thumb, there are approximately 40,000 signalized intersections in California. If each signal were to communicate its status once every 4 seconds, this would correspond to about 864 million messages per day. Assuming a data sizing estimate based on JSON messages with TMDD like structure and content this would correspond to about 16.4TB per day.

Modern messaging systems routinely handle data volumes at greater scales:

- 500 million: Number of tweets processed by Twitter every day[2]
- 2 billion: Number of daily Facebook users[3]
- 5.6 billion: Number of searches processed by Google every day[4]

Cloud technology continues to advance, making it possible to ingest, process, and visualize increasingly larger volumes of data. Therefore, it is technically feasible to bring together traffic management system (TMS) data across geographical regions as large as one state. The true limitations are:

- Political/Social/Legal implications

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[2] https://www.omnicoreagency.com/twitter-statistics/

[3] https://www.theverge.com/2022/2/2/22914970/facebook-app-loses-daily-users-first-time-earnings

[4] https://www.google.com/

- Financial limitations
- Legacy and variety and lack of standardization of infrastructure

As noted elsewhere, it is crucial for future systems to have a basic level of data, data exchange, and situational awareness capabilities. Actionable information is the lifeblood of effective traffic management. Command and control systems/elements may be rather simple or sophisticated. Either way, the critical enabler is having wide-area, and regional access to trustworthy data and information. Current trends are for systems to become even more interconnected, and the data requirements to establish solid situational awareness will only increase. Fortunately, technologies to enable this are well-established in the private sector.

Cloud technologies enable the scaling of systems on-the-fly to handle peak demand for data processing. This is ideal for applications like decision support for traffic management. During the times of day or night when demand is low, the need to constantly evaluate alternative strategies will be much lower. During times of high demand and incident related congestion, the computational demand to evaluate alternatives will be much higher. One benefit of the cloud is to be able to match computational resources according to needs that may increase or decrease. A fixed, on-premises solution would always need to have the capacity to handle the peak load. Another benefit is that cloud technologies will naturally evolve over time, and it is advantageous to allow capabilities of traffic management systems to evolve with those new technologies, thus leveraging other people's innovations.

5.5. CMS MESSAGING

One practical challenge for an ICM is deciding on rules for the suggestion of reroutes on CMS. Typically, CMS are controlled for an entire district at a centralized ATMS. This ATMS will have its own configuration and rules for deploying CMS response plans that include templates for messages. Another consideration is the signing extent, i.e., the number of interchanges upstream of an incident where a CMS message is warranted.

CMS will, in general, not fall neatly within the rigid boundaries of control as described in Section 5.2. The deployment of CMS messages will extend a significant distance upstream because CMS are relatively sparse. In the case of multiple ICMs within a district, it is likely that priority rules will need to be established, perhaps based on projected incident impact, to determine dynamically, which CMS is to be included or excluded from a particular ICM response plan. There are other use cases for CMS, such as amber alerts that will also affect the CMS that are marshalled as a part of a response plan.

One could imagine a future situation in which there are multiple, separate ICMs each making conflicting CMS message requests. The best recommendation is to have a comprehensive priority scheme in place to resolve the conflicts, and for each ICM to know what CMS resources are available in real time.

In the absence of a comprehensive priority scheme, it is possible (but not recommended) to implement an ad hoc coordination strategy where each ICM keeps track of its own last request for each CMS in the system. An algorithm could work like this:

- Read the current message for each desired CMS resource
- Check if one of the following conditions is true:
    - There is no current message

    - The priority of the current message is low
    - The message is the same as the previously requested message from this ICM

- If the above condition is true, then a request for this CMS to update its message is allowed
- Else a request for this CMS to update its message is not allowed

In the case that the current message is different than what was requested, this means that another ICM is using that CMS resource as a part of another response plan, or that a manual change was made at the ATMS level, and the CMS resource in question is no longer available.

6. ORGANIZATIONAL STRUCTURES FOR LARGE-SCALE MANAGEMENT

This section discusses organizational structures for large scale traffic management and considerations for the management of two adjoining or overlapping corridors.

Partners of an ICM likely include city, county, regional, and state actors. These are the actors that may be called up to coordinate their operations through their TMC. While some smaller cities might not have their own TMC, a regional TMC or Caltrans TMC would need to step in to assist where coordination is required.

Each of the above actors would be responsible for managing their traffic infrastructure elements, such as arterial and freeway links, intersection signals, signage, and ramp meters. However, to determine availability, it is crucial that each infrastructure element that could be called into play for the possible implementation of an incident response plan be connected to a traffic management center capable of tracking its status and operational capability. This availability information should indicate whether the element is:

- Available for the implementation of the proposed response plan
- Not available, because of involvement in another active response plan
- Not available due to some other circumstance, such as technical communication problem or other reason

In addition, it is also necessary to have detailed information about the operational status of each element. For example, it may be useful to know the actual signal timing plans that intersections along a proposed route are using or normally using at a given time of the day, or the metering rates used at various nearby onramps.

6.1. TILED STRUCTURE (NOT RECOMMENDED)

A tiled structure is one in which ICMs are arranged so as to divide up a metropolitan region into mutually exclusive, but collectively exhaustive zones. This is possible for infrastructure elements such as roadways, intersection signals, and ramp meters. However, CMS would probably not fit nicely within this structure.

One motivation for a tiled structure might be to seek value or simplicity in breaking up the decision-making complexity of traffic management into smaller geographical zones. However, as discussed below, this approach is not recommended.

Traffic control field elements are already organized into jurisdictional groups. While it is true that collecting jurisdictional groups into larger zones would facilitate cooperation within each zone, it creates new boundaries between multiple zones. Incidents that occur toward the center of a zone could be well handled by the infrastructure belonging to that zone. However, responses to incidents occurring on the boundaries would have limited flexibility unless control authority could be coordinated across zone boundaries. One example might be the desire to implement a long reroute requiring infrastructure elements belonging to two adjacent zones. While feasible, the need to implement coordination across the two zones leads to the following question: why create the boundary in the first place?

As described above, the geographical boundary of situational awareness should extend beyond the boundary of control. In this context, it is therefore highly desirable for ICM tiles to be able to receive information from their immediate neighbors as this information would be valuable for real-time decision making and after-the-fact analysis of system effectiveness. While feasible, this approach adds significant communication requirements and structural complexity. This leads to questioning the utility of a rigid, tiled structure.

6.2. OVERLAPPING STRUCTURE (NOT RECOMMENDED)

An overlapping structure is one in which ICMs could be organized by sets of control responses along a freeway or set of freeways. The advantage over the tiled structure is that (with the exception of CMS) all reroutes and control interventions could be commanded from within a single ICM. There would be no need for a response plan such as a long reroute to be cobbled together using response plan elements from two separate ICMs.

Figure 6-1 illustrates an example with two overlapping ICM systems. ICM A is centered around freeway A and ICM B around freeway B. After an incident occurs within the ICM A control area, a response plan is deployed. Later, a more severe incident occurs along freeway B. When assessing how to response to this second incident, the system of systems needs in this case to have the capability to evaluate the situation holistically and to arrive at a decision that is best for both systems. In the example of Figure 6-1, the first incident is completely outside of the control area of ICM B. However, the queue from the incident may spill into the region covered by ICM B. In addition, resources at the intersection of ICM A and ICM B might be requested by both ICMs for the implementation of competing response plans independently attempting to address incident 1 and incident 2. This example is designed to describe a framework that might help to manage these resources.

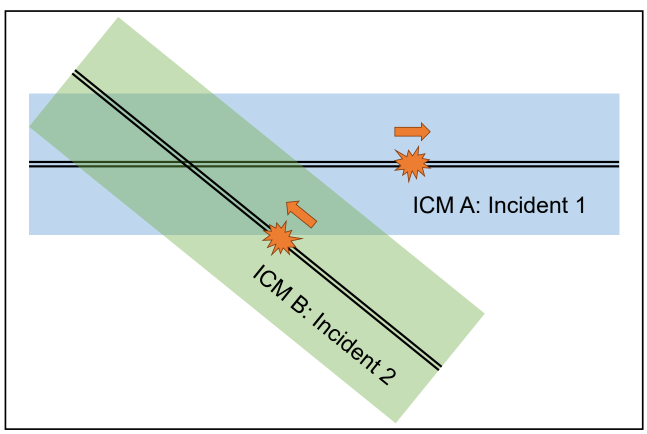

Figure 6-1 – Example of overlapping ICM systems

At the start of the first incident, it can be assumed that there are no other Response Plans in play, and that everything in the region is operating nominally. After receiving relevant information about the incident, ICM A is tasked to select a response from the following four alternatives:

- Maintain the current plan (time-of-day plan)
- Implement Response Plan A-1
- Implement Response Plan A-2
- Implement Response Plan A-3

Since there is no active Response Plan in the area controlled by ICM B, none of the considered response plan alternatives are *conflict-constrained*. ICM A then evaluates the scorecards for each of the four possibilities and finds the improvements offered by each of the three alternatives over maintaining the current plan. This leads to the selection and implementation of the highest scoring response plan, i.e., the plan offering the most benefits. In this example, it assumed that this includes an arterial reroute parallel to the freeway A, and changes to intersection signal plans along the way to improve travel times and increase capacity in the affected direction.

Sometime later, a second incident occurs on freeway B. In general, ICM B would not be directly aware of incident 1, and would have no way to assess the effect of an incident outside of its boundaries. In this case, however, ICM B must be aware of the infrastructure resources within its boundaries. This includes knowing if some of these resources might be participating in an active response plan called by ICM 1. To facilitate this information sharing, each ICM partner should ideally have a traffic management center capable of tracking the status and operational capability of each infrastructure element that could be called into play and should make this information available to all ICMs that may call a particular infrastructure element into play.

Similar to incident 1, ICM B is made aware of the occurrence of incident 2 and is then tasked to evaluate scorecards for the following four alternatives pertaining to incident 2:

- Maintain the current plan (time-of-day plan)
- Implement response plan B-1
- Implement response plan B-2
- Implement response plan B-3

In this case, both *operationally-constrained* and *conflict-constrained* response plans should be considered and evaluated since some of the requested infrastructure elements may already have been committed to servicing incident 1.

After responses to incident 2 have been evaluated, scorecards from both ICM A and ICM B need to be considered to make a holistic decision in how to respond to both incident 1 and incident 2. This is best accomplished if the metrics in the scorecards are compatible, so that an advantage or disadvantage to one ICM is accurately compared to an advantage or disadvantage in another. One way to proceed is to arrange the scorecards in a matrix that also indicates the compatibility of the proposed plans.

ICM A	
The current plan (CP)	+0
Time-of-day plan (TOD)	-3
Response Plan A-1	-2
Response Plan A-2	-1
Response Plan A-3	-1

ICM B	
The current plan (CP)	+0
Time-of-day plan (TOD)	+0
Response Plan B-1	+6
Response Plan B-2	+5
Response Plan B-3	+3

Figure 6-2 – Response Plan Scorecards

For example, the last set of scorecards from ICM A and ICM B could be summarized as shown in Figure 6-2. ICM A has a response plan that is evaluated as the current plan. In this context, the continuation of the current plan as compared against itself will always have a delta equal to zero. In the example, returning to the normal time-of-day plan from the current response plan incurs a negative benefit of size 3, which indicates a worse outcome. Negative benefits are also associated with switching to any of the three other proposed response plans. This shows that with respect to the ICM A alone, the best decision is to stick with the current plan.

In the scorecard for ICM B, the current plan and the time-of-day plan happen to be the same, resulting in a zero score for this particular option. When considering only the area controlled by ICM B, the best course of action is to select the B-1 response plan, which provides a positive benefit of size 6. However, the question at hand is to consider both ICM systems, and the compatibility of the response plans selected by ICM A and ICM B to work together to address both incidents simultaneously.

A way of making a system-wide decision it to consider a matrix of scores similar to the one shown in Table 6-1, in which all combinations of ICM A and ICM B alternatives are represented and evaluated. In the matrix, the second row across the top repeats the scorecard results for ICM B while the second column from the left repeats the scorecard results for ICM A. The values within the core of the matrix correspond to the sum of the scores associated with the corresponding ICM A and ICM B plans. A value of "X" indicates that there is a conflict of resources between the two alternatives, and that they are not compatible. It is important to include both *operationally-constrained* and *conflict-constrained* responses in the alternatives evaluated for ICM B, to provide opportunity to discover the best combination. Since the Current Plan (CP) and the TOD alternatives for ICM B are the same, the columns for the CP and TOD alternative scores are also the same.

Table 6-1 – Matrix of combined scorecards for ICM A and ICM B Plans

		CP	**TOD**	**B-1**	**B-2**	**B-3**
	Scorecard Results	***0***	***0***	***6***	***5***	***3***
CP	***0***	0	0	X	X	3
TOD	***-3***	-3	-3	3	2	0
A-1	***-2***	-2	-2	X	X	1
A-2	***-1***	-1	-1	X	X	2
A-3	***-1***	-1	-1	X	4	X

Note: Rows show ICM A Plans, columns ICM B Plans

Notice that for this particular example, the best holistic choice is for ICM B to select plan B-2, and for ICM A to switch to plan A-3, which result in a combined score of 4, the highest of any combination. Even though the switch to A-3 provides a negative gain within the ICM A control area, this disadvantage is offset by the gain of 5 by moving ICM B into plan B-2.

The above approach assumes that complete scorecards and response plan information needed to calculate resource compatibility are available. In addition, there are challenges involving:

- Double counting of benefits in the overlapping region
- Miscalculation of benefits
- Scores not being additive

To reduce the possibility of double counting, it would be important for scorecard metrics to be defined carefully and compatibly. Ideally, a system should be able to recognize situations where a more severe incident causing a complete freeway closure requires a higher level of priority than a prior, less severe incident.

6.3. SCALEABLE STRUCTURE (RECOMMENDED)

The recommended option is a scalable structure that could do away with arbitrarily drawn boundaries and implement multiple response plans to manage multiple incidents on a regional scale. One advantage of this approach is that it would be able to implement a logic very similar to the scorecard matrix of Section 6.2 above, but with a reduced danger of double counting or miscalculating the benefits. This kind of system would be applicable at a regional level whether or not each corridor in the region is pursuing an ICM. It would also provide a framework for prioritization among ICM response requests across the region.

The proposed integration would also enable a more efficient preselection of response plans for a more detailed evaluation. Consider again the choice to evaluate plan B-1 in Table 6-1. For ICM B, this is a sensible choice if it is operating by itself with its own internal decision support system as plan B-1 is the top performing plan within ICM B. However, this plan is not compatible with any of the plans evaluated by ICM A. In this case, there are several ways to avoid wasted evaluations. One is for the ICMs to pass additional messages back and forth to coordinate what choices of plans to evaluate. The simpler way is to handle this within the logic of a decision support system that is able to avoid *operationally-constrained* plans that have no chance of being implemented. Notice that plan B-2 in Table 6-1 is also *operationally-constrained* as is B-1. The difference is that there exists an A-3 plan compatible with B-2 that makes its evaluation worthwhile as a realistic alternative.

This idea of a scalable structure does not necessarily mean a monolithic structure. There could still exist a logical component that primarily concerns itself with ICM A and another logical component that primarily concerns itself with ICM B. However, the scalability implies that the overall system is sufficiently integrated to streamline decision making and address the challenges of multiple incidents and multiple response plans that may happen simultaneously across a region.

A scalable structure requires that semantics and meta-data standards for data exchange are specified to a degree that enables effective communication of situational awareness, traffic data, and proposed response plans between jurisdictions. At a minimum, these standards need to be implemented at a scale commensurate with the size of the region to be managed. It is likely that data quality is highly variable across a region. Over time, as jurisdictions become "data-compliant" they will acquire capabilities that enable them to participate in cooperative management and response plan deployment.

From the perspective of a commuter, the identity of the owner/operator of a road or intersection is not considered during trip planning. Rather, convenience, travel time and the factors described in Section 4 are at the forefront of decision making. Given these facts it makes sense to anticipate the routing tendencies as observed in the case studies, and to plan ahead by building scalable systems.

From a traffic engineering perspective, it is beneficial to perform a full accounting of benefits and disbenefits of a proposed response plan or ICM strategy. Decisions should be based on data. It is preferred to have the ability to group and split analyses over relevant geographical regions as appropriate for the incidents and disruptions affecting the road network in real time. It is more difficult to do this if boundaries are drawn a priori.

From a systems architecture standpoint, it is preferable to have a single data standard over a state or a large region. Jurisdictions that never intend to be part of an ICM system could still provide their data to ensure that their road networks are not unfairly impacted by the ICM response plans deployed by their neighbors. As ATMS or TMC systems are upgraded over time, jurisdictions could opt in to the system. At first they could just share data, and when ready, expand the library of response plans in the system.

7. RECOMMENDATIONS

Through a series case studies, this project investigated aspects of multi-corridor rerouting, and provided examples of coupled freeways that support each other's operations. Examples were taken primarily from 2019 and a range of freeways across California but with focus on: (1) I-210, I-10, and SR-60 in the Los Angeles area, and; (2) I-5, SR-91, SR-57, and SR-55 in the Orange County Triangle. Using data from PeMS, INRIX, and Streetlight, it is shown that large incidents on one freeway can cause measurable changes and traffic congestion on the coupled freeways. Response plans that are able to increase capacity near and around the incident may result in benefits on the coupled freeways.

Three structures for organizing ICMs are discussed. An example with joint scorecards is used to illustrate how a data-driven decision process could enable two ICMs to work together to determine two response plans that could be deployed while respecting constraints on available resources.

The recommended structure for organizing ICMs is a scalable structure that could implement multiple response plans to manage multiple incidents on the road network at the scale of a region. A vision to achieve effective multi-jurisdictional collaboration for traffic management involves several key ingredients:

- **Commitment**
    - Acceptance that this is a long-term goal that will require decades of consistent effort
    - Recognition that legacy, variety, and lack of standardization of infrastructure are serious barriers
- **Standards**
    - It is crucial to establish modern standards for exchange of traffic management data
    - Standards must specify data semantics
    - Vendors must be included in the standards generation and maintenance process
- **Data**
    - More complete, more representative, and more integrated data is needed for planning and for real-time situational awareness
    - Further studies of emerging data sources are needed
        - To improve the fidelity of traffic studies to determine cost/benefits of large scale traffic management strategies
        - To build fast predictive models to enhance decision support for real-time traffic management
- **Incremental steps**
    - When standards are in place, ATMS and local TMC systems can be updated or replaced to implement them
    - With consistent effort over time, the barriers to data exchange will be reduced