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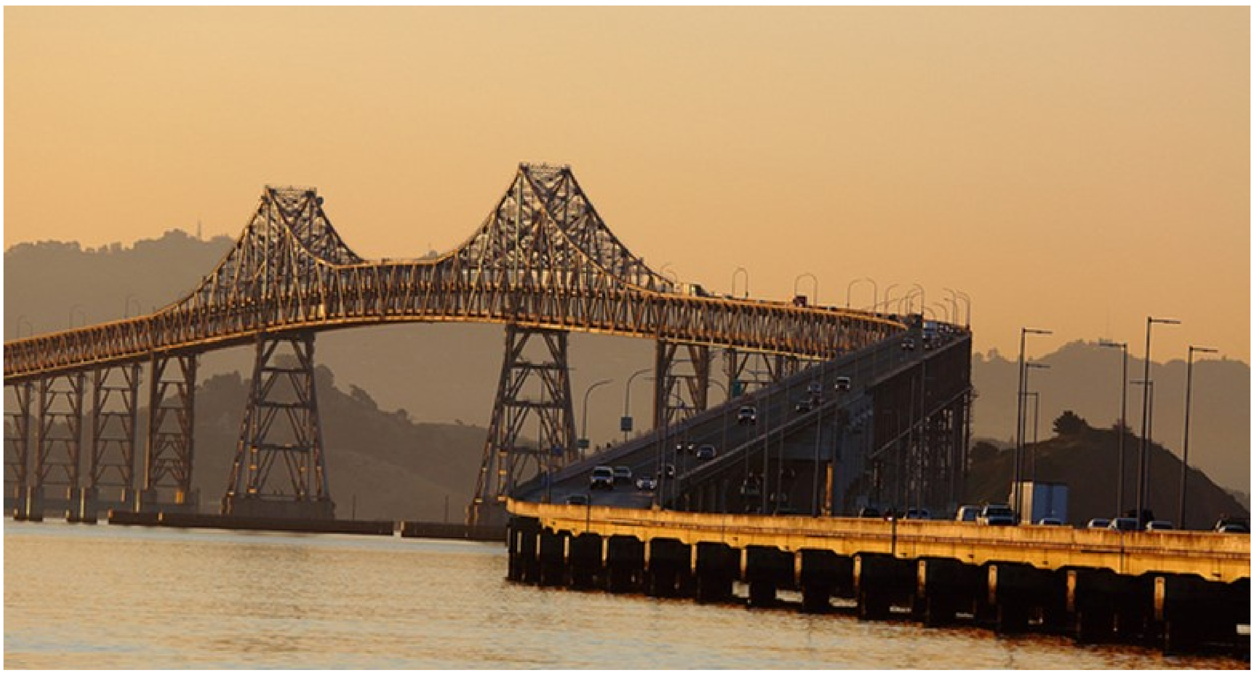
UNIVERSITY OF CALIFORNIA, BERKELEY

After Study for the Richmond-San Rafael Bridge (Phase I)

June 30, 2022



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16. ABSTRACT
This report presents an evaluation of impacts associated with the following changes that were made to the Richmond-San Rafael Bridge as part of a pilot project: (1) opening to traffic of the eastbound shoulder lane on the lower deck of the bridge between 2 PM and 7 PM every day (April 2018) and (2) conversion of the westbound shoulder lane on the upper deck of the bridge into a barrier-separated shared bike/pedestrian (November 2019). Specific elements evaluated include traffic compliance with the shoulder lane open/close periods, use of bridge paths by cyclists and pedestrians, impacts on eastbound and westbound traffic conditions, impacts on incidents, incident clearance times, maintenance activities, and quality of life in Marin County areas near the bridge. These elements are to be used by Caltrans to determine whether the changes should be kept, in whole or in part. Evaluations show that the opening of the eastbound shoulder to traffic has significantly reduced travel times and incidents in Marin County through the elimination of the congestion that used to affect the bridge's I-580 East approach. In terms of usage, between 150 and 300 cyclists are seen using the upper path in each direction on weekend days, and between 50 and 75 cyclists on weekdays. Pedestrian traffic is usually very low, at less than 25 individuals per day. While the addition of the path on the upper deck has slightly decreased peak bridge capacity and increased travel time variability on the Richmond approach, congestion on the approach remains close to historical averages. Some slight impacts were also found on incident response and maintenance activities. A user survey finally shows a positive perception of the path by cyclists, but a more negative view from motorists.

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Part-Time Shoulder Traffic Lane, Bicycle Path, Pedestrian Path, Traffic Impacts, Traffic Safety, User Survey.

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BEFORE EVALUATION REPORT

The work documented in this report is a continuation of a multi-year project aiming to assess the impacts of the modifications made to the Richmond-San Rafael bridge on traffic, safety and bridge operations. Under contract 65A0529 - *Richmond-San Rafael Bridge Access Improvements Project Before Study Evaluation and Report*, a preliminary set of evaluations focusing on operational conditions that existed before the modifications were made in 2015-2016 and detailed in a 2018 report bearing the project name as its title (Report 18CA-2997). This report presents a comparative before/after evaluations of operational conditions around the bridge over the 2015-2022 timeframe.

PHASE II FUTURE WORK

Evaluation results presented in this document cover the first phase of the pilot modifications around the Richmond-San Rafael bridge. Evaluations for the after are to continue through a Phase II after assessment under Contract 65A0804 (Task 3839) - *Richmond San-Rafael Bridge and Sir Francis Drake Pilot (Phase II)*. This phase II assessment will update some of the Phase I evaluations and expand the study to cover modifications made to an existing bike path on a nearby I-580 West off-ramp overpass connecting the bridge path to the Sir Francis Drake Boulevard in Marin County. It may result in some updates in the data presented in this report.

DISCLAIMER

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LIST OF ACRONYMS

ADT	Average Daily Traffic
BAIRS	Bay Area Incident Response System
BATA	Bay Area Toll Authority
Caltrans	California Department of Transportation
CCTA	Contra Costa Transportation Authority
CHP	California Highway Patrol
CHP-CAD	California Highway Patrol Computer-Aided Dispatch
DRISI	Division of Research, Innovation, and System Information
IMMS	Integrated Maintenance Management System
LCS	Lane Closure System
MIDB	Major Incident Database
MTC	Metropolitan Transportation Commission
NDS	National Data and Surveying Services
PeMS	Performance Measuring System
RSR	Richmond-San Rafael
SafeTREC	University of California Safe Transportation Research and Education Center
SWITRS	Statewide Integrated Traffic Report System
TAM	Transportation Authority of Marin
TASAS	Traffic Incident and Surveillance Analysis System
TIMS	Transportation Injury Mapping Systems
VMT	Vehicle miles traveled

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EXECUTIVE SUMMARY

This report presents an evaluation of the operational impacts associated with the following changes that were made to the Richmond-San Rafael bridge:

- Opening to traffic of the eastbound shoulder lane on the lower deck of the bridge between 2 PM and 7 PM every day (April 2018).
- Conversion of the westbound shoulder lane on the upper deck of the bridge into a barrier-separated shared bike/pedestrian (November 2019).

Specific elements that were evaluated include:

- Traffic compliance with the opening period of the eastbound shoulder lane
- Use of bridge paths by cyclists and pedestrians
- Impacts on eastbound and westbound traffic conditions on the bridge and its approaches
- Impacts on frequency, type, and severity of incidents occurring on and around the bridge
- Impacts on incident clearance times
- Impacts on maintenance activities on the bridge
- Impacts on quality of life in Marin County areas near the bridge

Below is a summary of the key findings from the study for the two bridge modifications evaluated.

IMPACTS OF SHOULDER LANE MODIFICATIONS ON BRIDGE LOWER DECK

- **OVERALL ASSESSMENT:**
    - The opening of the lower deck shoulder lane to traffic between 2 PM and 7 PM has had significant positive impacts on westbound traffic across the bridge. Afternoon congestion on I-580 East in Marin County has disappeared, resulting in up to 14 minutes travel time reductions from the US-101 to the toll plaza. Travel times and flow output have also improved along Sir Francis Drake Boulevard, and significantly less traffic is using other local arterials to bypass I-580 East.
    - From a safety standpoint, the frequency of incidents on the approach to the bridge has reduced by 70%. No significant impacts were further observed on the type, severity, duration, and location of incidents.

- **Compliance of traffic with shoulder open/close periods:**
    - On average, 99.6% of traffic observed on the bridge before 2 PM and after 7 PM is compliant with the shoulder closure.
    - Non-compliant use of the shoulder lane is highest 20 minutes before its opening and up to 30 minutes following its closure. Non-compliant use in the 20 minutes to opening varies between 0.3% and 0.6% of traffic, depending on the day of the week, while non-compliance 30 minutes after closing varies between 0.5% and 1.1%.
    - Some vehicles use the shoulder as a passing or travel lane when a red or yellow X is displayed above it. This suggests that current lane control signs, particularly the yellow X, may not be fully understood by all motorists.

- **Impacts on I-580 East and US-101 North traffic:**
  - The availability of an extra traffic lane during peak hours has increased the hourly flow across the bridge by 13-25%, from a range of 3,300-3,600 vehicles/hour before the modification to a range of 3,750-4,500 vehicles/hour after.
  - Less than 25% of traffic is using the shoulder lane during weekday peak periods, and less than 20% on weekends.
  - The added peak-hour capacity has ended congestion on the Marin County approach to the bridge, resulting in peak travel time reductions from the US-101 to the toll plaza by 13-14 minutes on weekdays, 10-14 minutes on Saturdays, and 6-8 minutes on Sundays. Peak travel times are also significantly less variable than before.
  - Traffic improvements along I-580 East may have partly contributed to the observed 1-2 minutes reduction in average peak weekday travel times on US-101 North between the Sir Francis Drake Boulevard and I-580 interchanges since 2017.
  - Fewer vehicles are using the Main Street off-ramp and on-ramp as a congestion bypass. Illegal use of the ramps during the afternoon peak has dropped from an average of 56 vehicles/hour in 2016 to 1 vehicle/hour in 2022.
- **Impacts on Marin County local arterials:**
  - Compared to 2016, weekday afternoon peak travel times along Sir Francis Drake Boulevard have dropped by up to 4 minutes, while traffic volumes have increased by over 300 vehicles/hour.
  - Fewer vehicles are using local arterials as a bypass to I-580 to save time while traveling towards the bridge in the afternoon. Peak traffic on Francisco Boulevard has for instance dropped from 730 to 227 vehicles/hour between May 2016 and March 2022.
- **Impacts on traffic safety on I-580 East:**
  - The opening of the eastbound shoulder lane has reduced by 72% the frequency of incidents occurring on the eastbound approach to the bridge. This includes significant reductions in rear-end collisions, sideswipes, and vehicle hitting objects. This is due to the elimination of the heavy congestion that used to affect traffic along I-580 East from the US-101 interchange to the entrance of the bridge.
  - On the approach, the absence of congestion on the approach to the bridge has resulted in an 82% reduction in the rate of rear-end collisions, a 60% drop in the rate of sideswipes, and a 63% reduction in the rate of vehicles hitting fixed objects.
  - On the bridge, the addition of a traffic lane has led to lower peak traffic densities and a 33% reduction in the rate of rear-end collisions. However, this change is also providing more opportunities for lane changes, which has translated into a 22% increase in the rate of sideswipes and a slight increase (+4%) in vehicles hitting objects.
  - In terms of severity, the modifications have resulted in a reduction from 41% to 32% of the proportion of incidents on the bridge or its approach with severe injury, a complaint of pain, or other visible injuries.

- There is no evidence that the bridge modifications are producing longer crash-related incidents or changing the location where crashes tend to occur on the bridge.
- There is no evidence that the bridge modifications are increasing the time needed to clear crash events. In this case, data measuring more precisely the period during which an incident affects traffic would be required to provide a more definitive answer.

- **Impacts on lower deck incident response times:**
  - Tow truck and CHP dispatch logs do not provide evidence that the modifications may have changed the time needed for responding to incidents on the bridge.
- **Impacts on lower deck maintenance activities:**
  - Because vehicles are occasionally seen using the lower deck shoulder when closed, maintenance crews must always treat it as an active lane to ensure their safety.

IMPACTS OF NEW PATH ON BRIDGE UPPER DECK

- **OVERALL ASSESSMENT:**
  - The upper bridge path has attracted a notable number of cyclists, particularly on weekends, and a relatively small number of pedestrians. Since January 2021, an average of 190 cyclists/direction/day have been traveling on Saturdays and Sundays on the upper deck path, with seasonal highs around 300 cyclists/direction/day and lows around 100. Average weekday use has been 68 cyclists/direction/day. Due to the length of the bridge, pedestrian use is much lower, averaging only 14-24 individuals/day/direction on weekends and 8-11 individuals on weekdays.
  - Due to the shorter merge downstream of the toll plaza and narrower roadway on the bridge, the maximum flow going across the bridge on weekdays has been reduced by 7%, and 4% on weekdays. Peak-hour travel times across the speeds have also increased by less than a minute, due to slightly slower speeds on the bridge and have been made more variable due to the inability of disabled vehicles to move out of a traffic lane. However, these impacts have not yet translated into increased congestion upstream of the bridge, likely because of reduced traffic demand due to lingering Covid-19 effects.
  - From a safety standpoint, the bridge path is generally perceived as being safe by its user, although some concerns exist about the risk of being hit by objects flung over from the adjacent traffic lanes. On the vehicular traffic side, the installation of the path has not affected the frequency, type, and severity of incidents, nor to have significantly affected incident responses.
- **Use of new bridge path by cyclists:**
  - Since January 2021, between 100 and 300 cyclists have been traveling in each direction on the upper deck path on Saturdays or Sundays, depending, with an average of 190 cyclists/direction/day. Saturday traffic is usually the highest.
  - On weekdays, bicycle traffic has ranged between 50 and 75 cyclists in each direction, with an average of 68 cyclists/direction/day.

- Weekend bicycle traffic follows an annual cycle, with the lowest demand during winter and the highest during summer months. Weekday traffic is relatively constant, with only minor seasonal variations.
- Path users mainly travel westbound in the morning and eastbound in the afternoon. On weekends, peak westbound traffic is between 10 AM and 11 AM, and eastbound traffic is between 1 PM and 2 PM. On weekdays, peak westbound traffic is also between 10 AM and 11 AM, but peak eastbound traffic is later, between 3 PM and 4 PM, with notable traffic between 12 Noon and 3 PM.
- A 2021 survey of path users indicated that 1.9% used the path more than four times per week, 10.7% up to four times per week, 29.8% up to four times a month, 31.8% less than once a month, and 25.8% less than four times since its opening.
- 85.1% of path users have indicated using the path for recreation (63.1%) or exercise (22.0%). Only 14.0% have used it for commuting, either to work (4.9%) or other locations (9.1%). The remaining 0.9% used it for other, non-specified, reasons.
- 83.9% of path users indicated having completed one or more round trips on the path while cycling or walking. Of these, 90.6% reported fully crossing the bridge both ways, 6.9% turning back mid-way, and 2.5% having both fully crossed the bridge or turned back mid-way depending on the occasion.
- Between 2015 and 2019, Golden Gate Transit buses typically carried between 465 and 829 bicycles per month across the bridge, depending on the season. Between April 2020 and December 2021, the number of bicycles carried over dropped 40-50% to a 227-466 range. However, between January and May 2022, monthly counts have increased significantly, to a 337-533 range, or 11-17 bicycles per day.
- It is still unclear which part of the drop in bicycles carried over by Golden Gate Transit is due to the opening of the path and which part is due to the Covid-19 pandemic.

- **Use of new bridge path by pedestrians:**
  - Observed pedestrian traffic is relatively low. On average, only 11 pedestrians are seen each weekday crossing the bridge eastbound, and 8 going westbound. Weekend traffic is slightly higher, with 24 pedestrians going eastbound and 14 westbound.
  - Pedestrian use is likely underestimated as the reported counts are based on a single sensor on the Richmond side. This sensor does not capture individuals accessing the path from Marin County and turning back midway.
  - The 4-mile length of the bridge likely explains the low pedestrian demand, and why less than 25% of pedestrians indicated completing a full round trip on the bridge and 57% turned around midway.
  - Fishermen have been observed using the path to access locations from where to cast fishing lines, either on the shore or the path itself. Such individuals are more often seen on the Marin County side, where they use the vista parking lot as a staging area.

- **Impacts on I-580 West traffic:**
  - Average weekday peak-hour flows across the bridge have dropped by 7% following the addition of the path, from a range of 3,500-3,850 vehicles/hour to a range of 3,250-

3,600 vehicles/hour depending on the day considered. Weekend peak-hour flows have similarly dropped by 4%, from 3,200-3,500 vehicles/hour to 3,100-3,300 vehicles/hour.

  - The significantly shorter merge downstream of the toll plaza (325 ft instead of 850 ft) and the perceived narrowness of the roadway on the bridge causing some vehicles to slow down and others to move to the left lane may explain the maximum flow reductions across the bridge. These negative impacts may have partly been compensated by the elimination of the toll cash collection.
  - The closeness of the path's barrier to the right traffic lane appears to have caused 1-2% of peak-hour traffic to shift to the left lane, and up to 20% of the evening and night traffic to do the same. This has resulted in an average 57%/43% split across the left and right lanes during weekday peaks, and a 55%/45% split during weekend peaks.
  - Despite the slight capacity reduction, the extent of the congestion upstream of the toll plaza and average peak travel times from I-80 to the end of the bridge on weekdays, Saturdays, and Sundays have remained similar to the before conditions. This can be explained by traffic demands remaining slightly below before conditions, particularly at the start and end of the peak periods, due to lingering Covid-related factors.
  - Before the modifications, upper deck traffic generally flowed on weekday mornings at or above 50 mph following the first mile of the bridge. In the fall of 2021, speeds between 40 and 50 mph were typically observed across the bridge, resulting in a slight increase in travel time of less than one minute. Some slight speed reductions were also observed on Saturdays and Sundays, but with negligible impacts on travel times.
  - Peak weekday travel times on the bridge's approach are now more variable, i.e., less reliable, than before the path installation, mainly due to the barrier now preventing disabled vehicles to pull out of a traffic lane. The reliability of peak weekend travel times remains similar to before.
  - Many of the traffic impacts described above may still be affected by lingering reductions in traffic caused by an increase in the proportion of individuals working from home following the Covid-19 pandemic.

- **Impacts on local Richmond arterials:**
  - The bridge modifications do not appear to have had significant impacts on local arterials on the Richmond side of the bridge.

- **Safety of new bridge paths for cyclists and pedestrians:**
  - No incidents involving bicyclists or pedestrians were recorded by the CHP or reported on the Street Story platform during the evaluation period. However, anecdotal evidence suggests that some incidents have occurred.
  - Users generally have a positive view of the safety offered by the path, as evidenced by a safety rating of 8.19 out of 10 assigned by users in the summer of 2021.
  - The low height of the barrier put path users at risk of being hit by debris flung from the adjacent traffic lanes, or being blinded at night by vehicle lights when traveling east.
  - Only 3% of surveyed path users commented on its narrowness.

- **Impacts on traffic safety on I-580 West:**
  - There is no straightforward evidence that the modifications have negatively impacted traffic safety on the approach of the bridge or the bridge itself despite the creation of a constrained roadway and a shorter merge downstream of the toll plaza. Scenarios including or excluding the April 2020 to June 2021 interval both point to a 20% reduction in accident rates upstream of the toll plaza but provide opposite conclusions regarding incidents on the bridge and downstream of it.
  - No clear impacts are observed on the types of incidents occurring around the bridge. Rear-end incidents remain dominant on the bridge before and after the modifications, at around 50-55% of all incidents. These are followed by sideswipes (33-42%) and vehicles hitting objects (8-9%). In particular, no increase is observed in the proportion of vehicles hitting a fixed object on the bridge, such as the path's barrier.
  - In terms of incident severity, the upper deck modifications seem to have caused a 23% reduction in the frequency of incidents with a complaint of pain on the bridge and a 71% on the approach. The rate of incidents without injury has further slightly increased on the bridge (+9%) but reduced on the approach (-14%), while no conclusive trend could be identified for incidents with other visible injuries.
  - Based on an analysis of CHP CAD logs, there is no evidence that the bridge modifications are producing longer crash-related incidents or changing the location where crashes tend to occur on the bridge.
  - The analysis of additional data is recommended to more clearly established impacts associated with the modification, the current data only include three quarters with minimal Covid-19 impact. A recommendation is to include at least one additional year of data (January to December 2022).
- **Impacts on upper deck incident response times:**
  - Tow truck and CHP dispatch logs do not provide evidence that the modifications may have changed the time needed for responding to incidents on the bridge.
- **Impacts on upper deck maintenance activities:**
  - The barrier may force maintenance crews to close the right traffic lanes when they need to do maintenance on the bridge.
  - Closing of a traffic lane for path maintenance mainly occurs for routine monthly cleanings, when the barrier must be moved. To minimize traffic impacts, this is typically done at night, with bulletins published by MTC/511 well ahead of time.
  - Emergency realignment to the barrier is only conducted if an accident causes the barrier to leave less than 10 feet of width on the path. This has only occurred twice between November 2019 and April 2022. In other cases, maintenance crews either try to use tools to manually realign the barrier or wait for the monthly machine re-alignment of the barrier to fix the issue.

OTHER ASSESSMENTS

- **Impacts on businesses in Marin County**
  - According to 8 surveyed businesses in March 2022, morning congestion on the Richmond side of the bridge continues to affect the ability of businesses in Marin County to hire and retain staff from the East Bay. This is a problem that pre-existed the upper bridge modifications. However, travel time reductions to access Richmond from the Marin side during the afternoon peak following the lower deck improvements may have helped reduce the impacts of the morning commute.
  - For one business, less traffic using local streets to bypass I-580 East in the afternoon is significantly easing fleet movements around San Rafael and Larkspur.
  - None of the few surveyed business managers were aware of employees using the new bridge bike path for commute purposes.

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1. INTRODUCTION

This report presents an evaluation of the operational impacts associated with changes that were made to the Richmond-San Rafael bridge in the northern portion of the San Francisco Bay Area between 2018 and 2020 as part of a four-year pilot project. Two specific changes are evaluated:

- The opening to traffic of the eastbound shoulder lane on the bridge lower deck between 2 PM and 7 PM every day in April 2018.
- The conversion of the westbound shoulder lane on the upper deck into a barrier-separated bike/pedestrian path in November 2019.

The impacts associated with the listed modifications are evaluated through a study comparing operational conditions around the bridge before and after the changes. Before conditions were assessed in 2015-2016, at the beginning of the project, while the after conditions were assessed between 2019 and 2022. Efforts were made to avoid conducting evaluations between March 2020 and June 2021 due to the significant impacts of the Covid-19 pandemic on business activities and travel.

Specific elements that were evaluated through the before/after study include:

- Level of utilization of the eastbound shoulder lane and upper deck multi-use path during typical weekdays and weekend days
- Changes in traffic conditions around the bridge during peak weekday and weekend traffic conditions
- Impacts on the number, type, and severity of incidents occurring within the study area
- Impacts on the ability to respond to incidents occurring on the bridge
- Impacts on bridge maintenance activities
- Impacts on business activities in Marin County

The results of the above evaluations are to be used by Caltrans at the end of the pilot project to determine whether the various modifications should be kept, modified, or removed. It is not the goal of this study to provide recommended courses of action. Its goal is simply to report on the impacts of the modifications.

The remainder of this report is divided into the following sections:

- **Section 2:** Project background
- **Section 3:** Evaluation objectives
- **Section 4:** Description of study area and roadways of interest
- **Section 5:** Description of data collected and analyzed
- **Section 6:** Bicycle traffic on new bridge path
- **Section 7:** Pedestrian traffic on new bridge path
- **Section 8:** Impacts on traffic conditions along I-580 and key nearby local streets
- **Section 9:** Safety of new bridge path and modified overpass path for cyclists and pedestrians
- **Section 10:** Impacts on traffic safety
- **Section 11:** Impacts on incident response activities
- **Section 12:** Impacts on maintenance activities
- **Section 13:** Evaluation of impacts on quality of life through business and user surveys
- **Section 14:** Summary of observations

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2. PROJECT BACKGROUND

This section provides background information about the pilot project that is the subject of the evaluations reported in this document. Specific elements covered include:

- Description of Richmond-San Rafael Bridge
- Initial traffic setup across the bridge
- Initial pedestrian/cyclist access to the bridge
- San Francisco Bay Trail project
- Pilot modifications to the bridge
- Project stakeholders

2.1. RICHMOND-SAN RAFAEL BRIDGE

Figure 2-1 shows the location of the Richmond-San Rafael Bridge within the context of the San Francisco Bay Area. The bridge connects the city of Richmond in Contra Costa County with the city of San Rafael in Marin County, through a narrow section of water between the San Francisco and San Pablo bays. It opened to traffic in September 1956 as the second-to-last major bridge to be constructed in the Bay Area. It remains the second-longest bridge in California, with a length of four miles, behind the San Mateo-Hayward crossing further south.

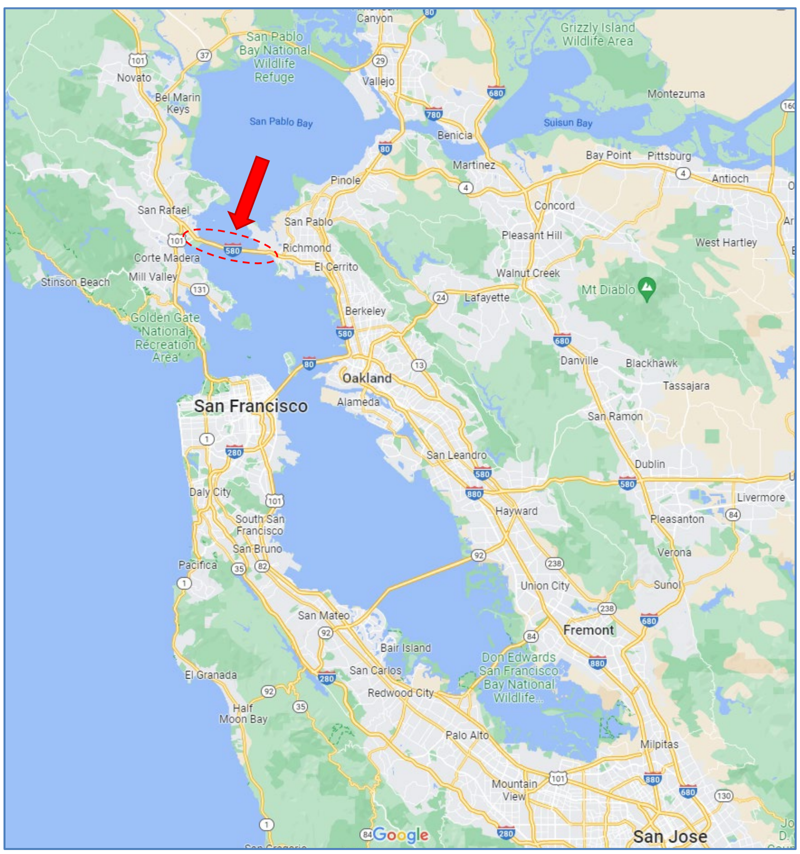

Figure 2-1: Location of Richmond-San Rafael Bridge within the San Francisco Bay Area

Figure 2-2 provides a picture of the bridge. The bridge features two identical cantilever spans with a lower section in between. Both spans are 1,070 feet long, with a 185-feet clearance over water at the highest point. For much of its length, the structure has upper and lower decks rather than side-by-side decks. Westbound traffic is carried on the upper deck while eastbound traffic is carried on the lower deck. As a result of these features, the bridge has often been compared aesthetically to a roller coaster, a sea serpent, or a bent coat hanger.

Figure 2-2: Richmond-San Rafael Bridge

2.2. INITIAL TRAFFIC SETUP ACROSS BRIDGE

Although the bridge was originally part of State Road 17, it is currently signed as Interstate 580. In 2015, it carried an average peak daily traffic flow (ADT) of approximately 82,000 vehicles. This increased to 87,000 vehicles in 2017. As indicated in Table 2-1, which compares AADT with other Bay Area bridges, this is noticeably lower than other bridges, in great part due to the lower number of lanes on the bridge and its location relative to the main traffic destinations in the region. During a typical weekday, travel demand on the bridge is highly directional, with traffic mainly moving westbound towards Marin County in the morning and eastbound towards the city of Richmond during the afternoon peak.

Table 2-1: ADT of Sample Bridges in the San Francisco Bay Area (North to South)

Bridge Name	Connections	Lanes per Direction	2015 Peak ADT	2017 Peak ADT
Carquinez Strait	Vallejo – Contra Costa County	4	123,000	131,000
Richmond-San Rafael	Richmond – San Rafael	2	82,000	87,000
San Francisco Bay	Oakland – San Francisco	5	268,000	290,000
Golden Gate	Marin County – San Francisco	3	119,000	125,000
San Mateo	Hayward – San Mateo	3	110,000	119,000
Dumbarton	Fremont – Palo Alto	3	71,000	76,000

(Source: 2015 and 2017 Caltrans Traffic Census)

Like other east-west Bay Area bridges, a toll is currently assessed for vehicles crossing in the westbound direction, while no toll is charged in the reverse direction. The toll is collected at a plaza located in Richmond, approximately 500 feet from the foot of the bridge. Figure 2-3 provides an aerial view of the plaza, while Figure 2-4 provides a close-up view of the toll booths. On the approach to the toll plaza, the number of traffic lanes increases from three to seven. Before March 2020, the left lane within the toll booths was initially dedicated to high-occupancy vehicles with an electronic Fastrak toll transponder and the following two lanes to all vehicles equipped with an electronic transponder. The last four lanes on the right were dedicated to the general traffic and had toll collectors to handle cash payments. Since then, tollbooth operators have been eliminated and replaced with a license-plate reading electronic toll collection system. Downstream of the toll booths, the number of traffic lanes quickly drops from seven to two over 325 feet.

Figure 2-3: Aerial View of Richmond-Toll Plaza Before Modifications

Figure 2-4: Approach to Richmond-Toll Plaza before March 2020

The width of the bridge can accommodate three lanes of traffic in each direction with no emergency shoulder. For safety reasons, however, Caltrans had striped each direction for only two lanes, leaving the third lane for emergencies or maintenance vehicles. The extra shoulder lane proved particularly helpful during the 1976-1977 drought when the East Bay Water District was able to lay a temporary water pipe to Marin County without disrupting traffic.

Over time, increased volumes have led to increasing congestion on the westbound approach to the bridge. As indicated in Figure 2-5, the two main congestion-contributing factors were the toll collection activities and the fact that the bridge only carried two lanes of traffic while the freeway leading to it had three lanes. While it was often hypothesized that the toll collection activities were the primary cause of congestion, merging activities downstream of the plaza was the real culprit. Following a continuous reduction in the number of vehicles paying the toll with cash, the expectation was that congestion upstream of the plaza would reduce. This is not what happened. By increasing the rate at which vehicles were able to go through the toll plaza, the adoption of electronically toll transponders by motorists resulted in more vehicles entering the merge area downstream of the plaza. This, in turn, caused increased frictions and slower speeds at the entrance of the bridge that propagated back through the toll booths.

The eastbound approach in Marin County, shown in Figure 2-6, had also experienced a significant increase in congestion during the PM peak period due to increased traffic. In this case, the congestion was primarily caused by a reduction in the number of traffic lanes from three to two as the right-most lane converts to an exit lane approximately 2,000 feet from the foot of the bridge. Traffic merging from Main Street merging onto the freeway through a very short acceleration lane also contributed to the problem.

Figure 2-5: Initial Conditions – Westbound Bridge Approach in Richmond

Figure 2-6: Initial Conditions – Eastbound Bridge Approach in Marin County

2.3. INITIAL PEDESTRIAN/CYCLIST BRIDGE ACCESS

Before the pilot project, there were no physical accommodations on the bridge for bicycles or pedestrians. To cross the bridge, the only option had been to take transit buses.

The only regular transit service across the bridge was, and is currently still, offered by Golden Gate Transit, a local transit agency serving servicing Marin and Sonoma counties, with limited service to San Francisco and Contra Costa County. To accommodate cycles, most Golden Gate Transit buses are equipped with exterior bike racks at the front of the bus or with underbelly bike racks, as shown in Figure 2-7.

Figure 2-7: Golden Gate Bus Carrying Bikes on Front Rack

Between 2015 and December 2021, primary service across the bridge was offered by buses on Route 40. As shown in Figure 2-8, this route provided service between the El Cerrito Del Norte BART Station on the east side of the bay to the San Rafael Transit Center on the west side. A Route 40X, running from the same origin to destination as Route 40 only during the afternoon peak, but with fewer stops, also existed. Before January 2016, two other routes also ran across the bridge: Route 42 and Route 580. Route 42 was merged with Route 40, while Route 580 was a pilot route that ran only from December 2014 to December 2015, from Emeryville to the San Rafael Transit Center via San Pablo Avenue in Berkeley and I-580, as shown in Figure 2-9.

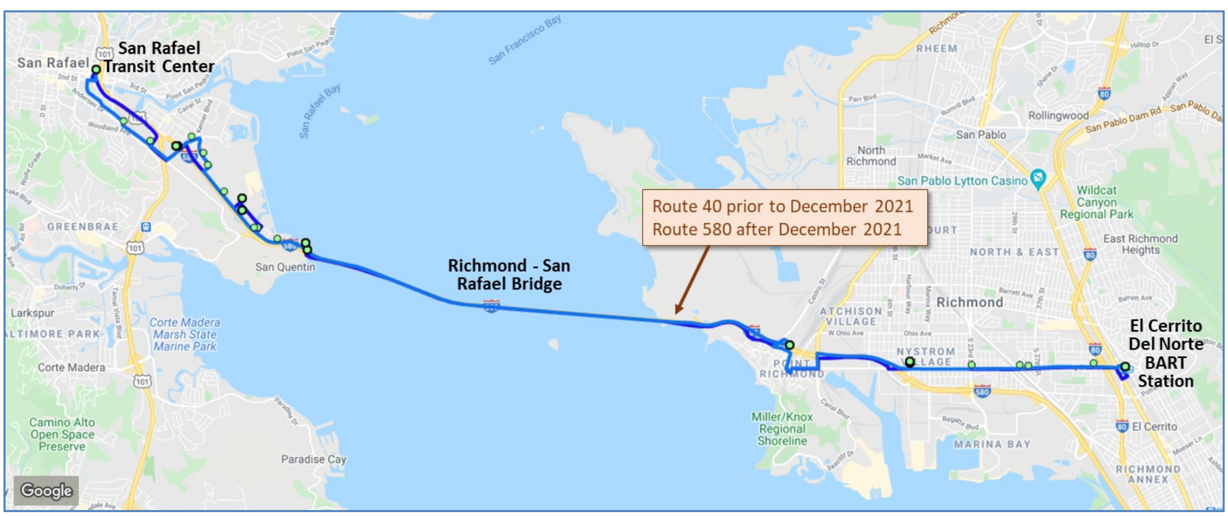

Figure 2-8: Golden Gate Transit Service across the Richmond-San Rafael Bridge

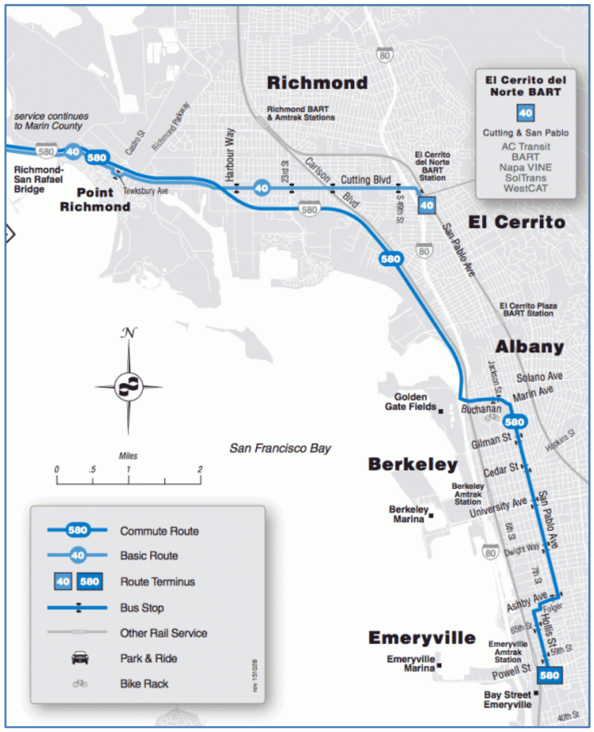

Figure 2-9: Golden Gate Transit Pilot 2015 Route 580 Service

In response to a significant drop in demand due to the Covid-19 pandemic, service on Route 40 was reduced in the summer of 2020, while route 40X was suspended. In December 2021, to help the customers better distinguish between routes offered by Golden Gate Transit and those offered by other Bay Area bus systems, Route 40 was renamed Route 580, without any service change. As of May 2022, Route 40x appears to have been permanently discontinued, likely because transit demand remains low, leaving only one route crossing the bridge.

2.4. SAN FRANCISCO BAY TRAIL PROJECT

The San Francisco Bay Trail is a project from the Metropolitan Transportation Commission (MTC) and the Association of Bay Area Governments that calls for the development of a continuous 500-mile network of biking and hiking trails encircling the San Francisco Bay, San Pablo Bay, and Carquinez Strait. As of 2021, the development of about 350 miles of trails had already been completed. As shown in Figure 2-10, plans were made, if possible, to use all Bay Area bridges to connect various sections of the networks on each side of the bay. This vision provided strong advocacy for converting one of the shoulder lanes on the Richmond-San Rafael bridge into a bike/pedestrian path.

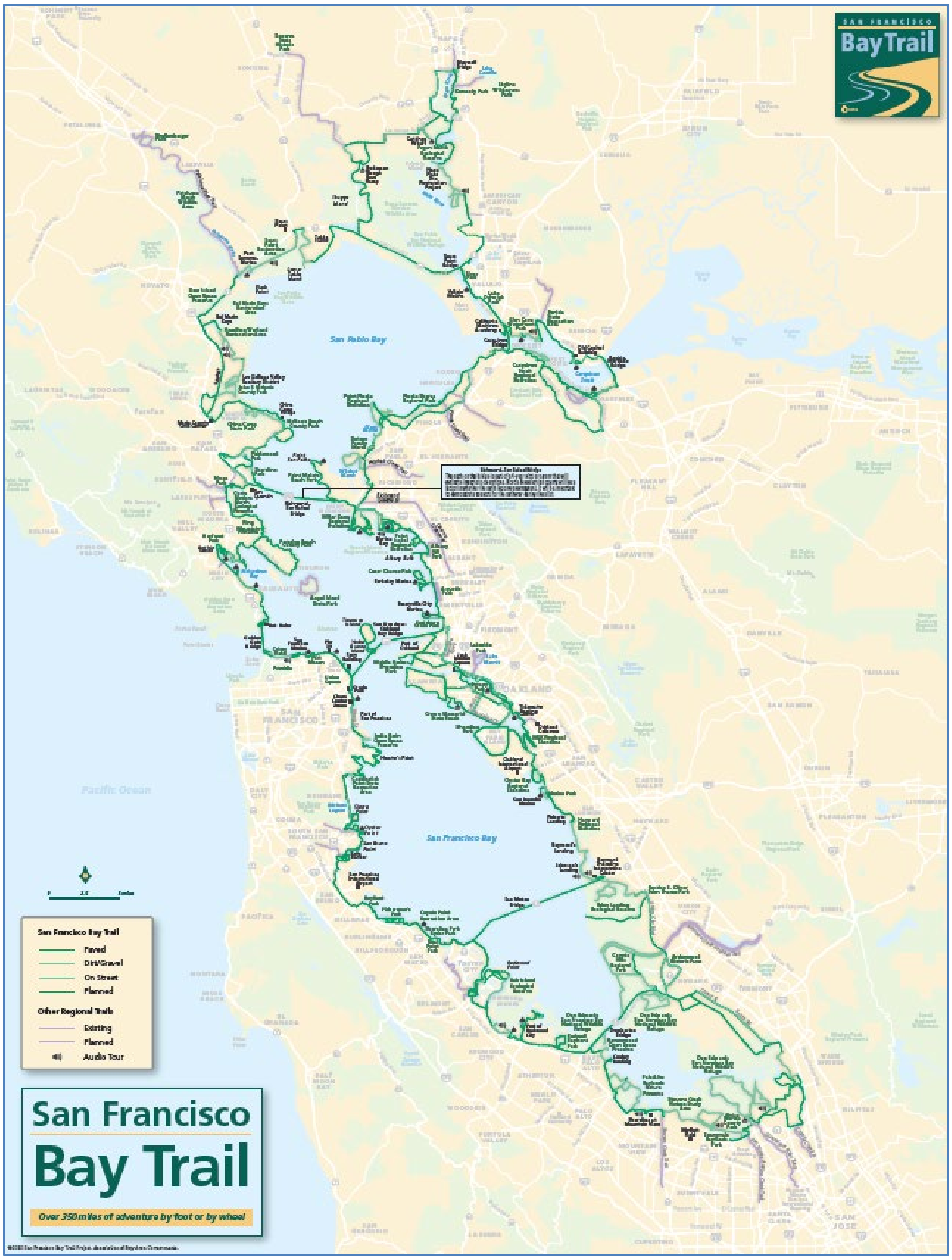

Figure 2-10: San Francisco Bay Trail Network (2020 Brochure)

2.5. BRIDGE MODIFICATIONS

To address the traffic and pedestrian/bicycle issues identified above, a consortium comprised of Caltrans, the Bay Area Transportation Authority (BATA), the Metropolitan Transportation Commission (MTC), and local jurisdictions started in 2014 formulating a pilot project that would allow for vehicular traffic to use the eastbound shoulder on the bridge lower deck during the afternoon peak periods while at the same time constructing a multi-use path for bicycles and pedestrians on the westbound shoulder on the upper deck. The objectives of this pilot were twofold: (a) to reduce congestion on eastbound I-580 and (b) to provide a bike/pedestrian link between the two counties.

The proposed pilot, known as the *Richmond-San Rafael Bridge Access Improvements Pilot Project*, was formally approved in the summer of 2015. As illustrated in Figure 2-11 and Figure 2-12, it included the following key modifications to be made to the bridge and its approaches:

- **Westbound direction (upper deck):**
    - Conversion of the existing shoulder into a two-way bike/pedestrian path.
    - Addition of a movable zipper barrier from the foot of the bridge in Richmond to the Main Street intersection in Marin County, to separate the multi-use path from the vehicular traffic while allowing maintenance vehicles to retain the ability to access the path.
    - Shortening of traffic merge area downstream of the toll plaza from 850 ft to 325 ft.
    - Construction of a connecting bike path separated by a fixed barrier between Marine Street in Richmond and the bridge, along the right side of the freeway and the Stenmark Drive off-ramp.

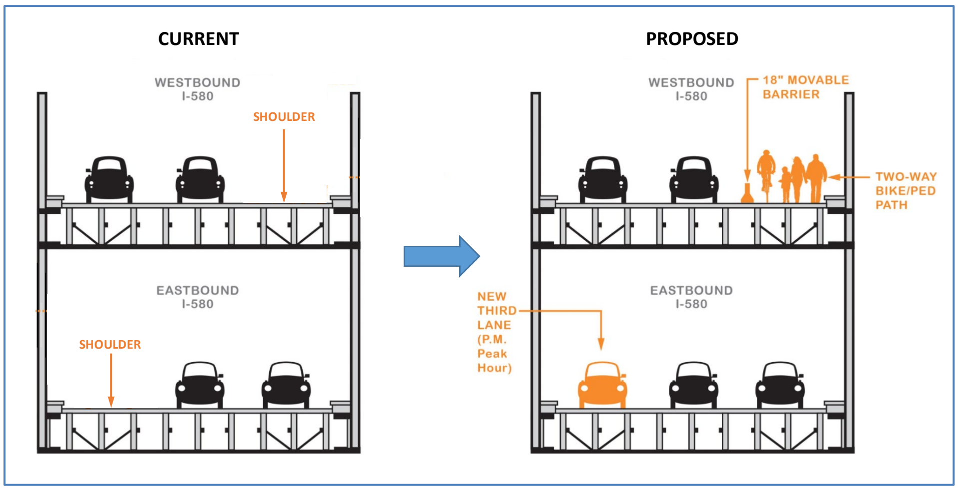

Figure 2-11: Proposed Bridge Modifications

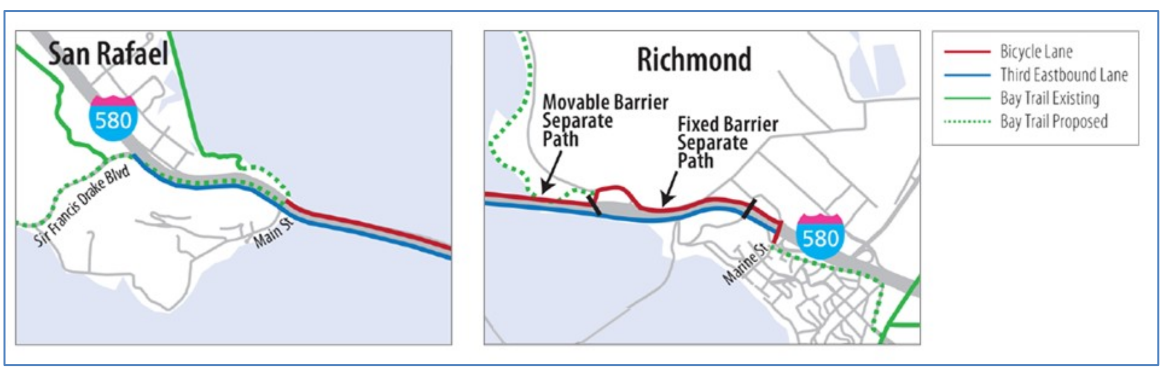

Figure 2-12: Bike Trail Modifications on Eastern and Western Bridge Approaches

- **Eastbound direction (lower deck):**
    - Conversion of the existing shoulder lane into a part-time regular traffic lane, opened each week and weekend day between 2 PM and 7 PM.
    - Installation of electronic traffic signs above the traffic lanes on the lower deck of the bridge indicating whether a lane is opened (green arrow), closed (red X), or still open at the entrance of the bridge but closed at some point further down (yellow X indicating that traffic should merge to the next lane).
    - Installation of electronic traffic signs on the bridge approach to indicate when the shoulder lane is opened.
    - Conversion of the exit lane between Sir Francis Drake and the Main Street off-ramp in Marin County into a regular traffic lane.
    - Addition of a third traffic lane between the Main Street exit in Marin County and the bridge.
    - Addition of a third traffic lane between the bridge and the Marine Street on-ramp in Richmond.

The eastbound modifications on the bridge were completed in early 2018, with the shoulder lane formally opening to traffic on Friday, April 20, 2018. Construction of the multi-use path on the upper deck was completed in March 2019, with the path officially opened for use on Monday, November 18, 2019.

Figure 2-13 through Figure 2-19 present illustrations of the completed work. Figure 2-13 provides a Google Street View snapshot of the bridge lower deck with the installed overhead lane control signs, while Figure 2-14 provides a snapshot of the roadside sign explaining the lane control symbols used. Figure 2-15 presents snapshots of the electronic message signs that have been installed on the eastbound approach to indicate whether the shoulder lane is open or closed. Figure 2-16 further presents a snapshot of the upper deck of the bridge with the bikeway and moveable barrier, while Figure 2-17 presents a snapshot of the western end of the path along the Main Street off-ramp in Marin County. Figure 2-18 and Figure 2-19, finally, highlight aerial pictures of the various modifications that were made to the eastern and western approaches to the bridge.

Figure 2-13: Electronic Lane Control Signs on Lower Deck

Figure 2-14: Sign Explaining Electronic Lane Control Displays

Figure 2-15: Dynamic Sign Indicating Shoulder Lane Open Status

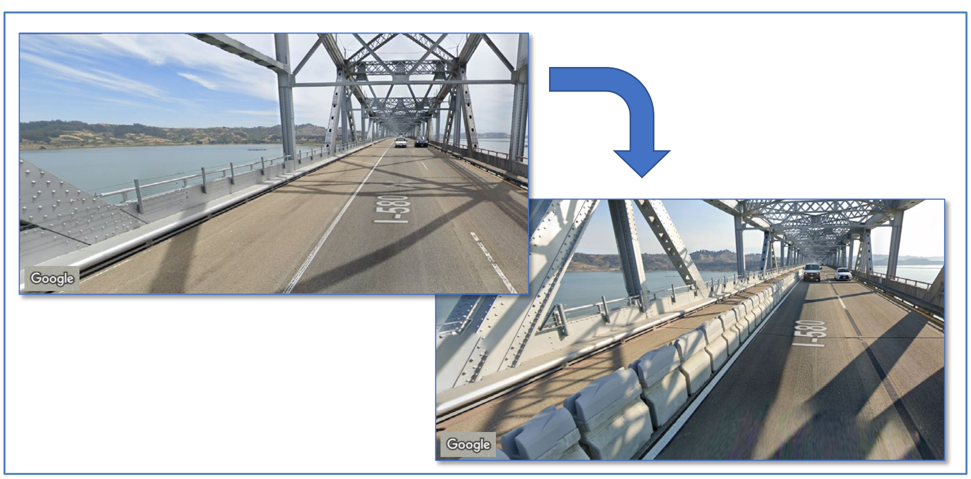

Figure 2-16: Upper Deck Modifications for Bike/Pedestrian path

Figure 2-17: Bike Path Western End Along Main Street Off-Ramp

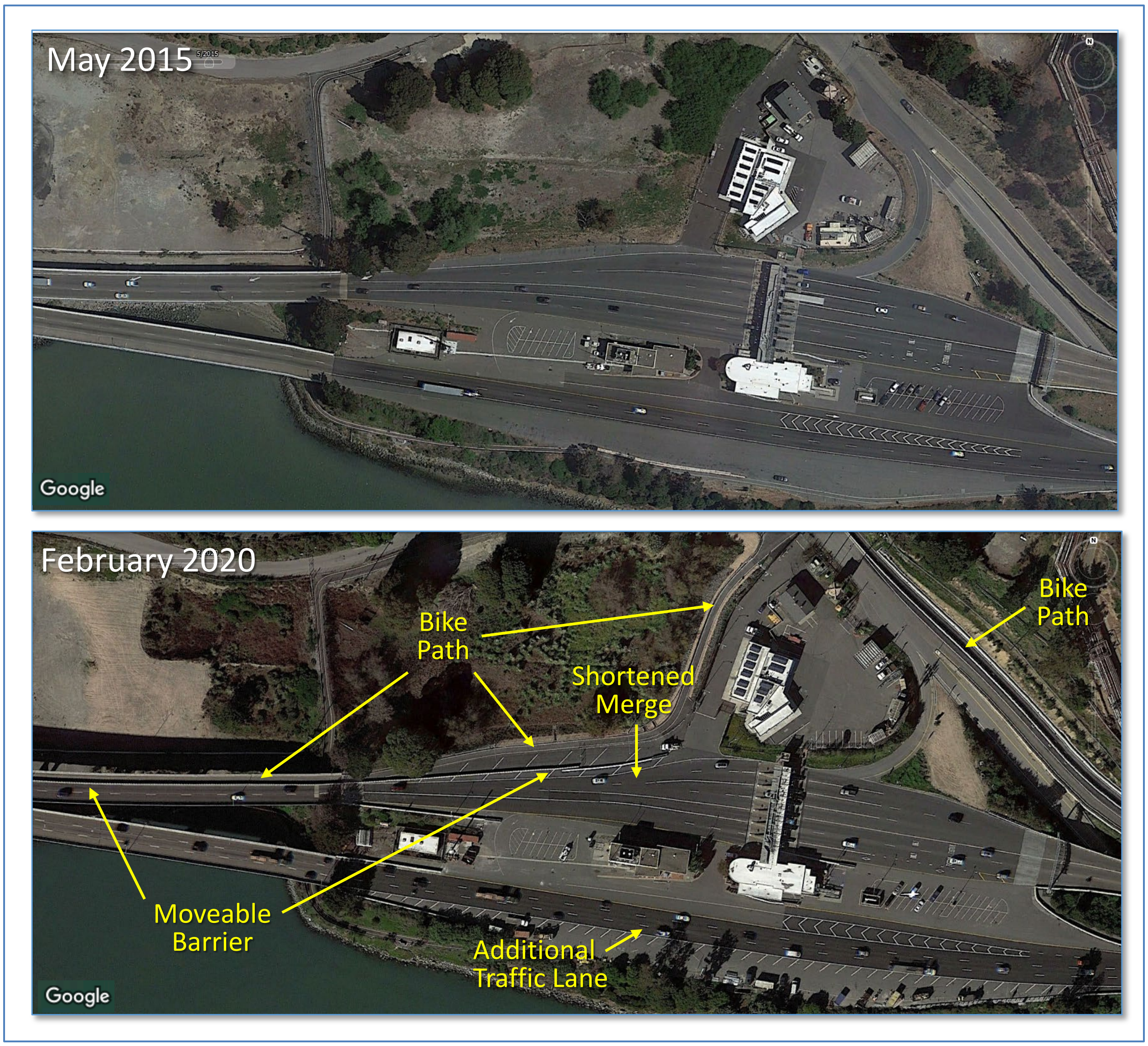

Figure 2-18: Modification of Richmond Approach

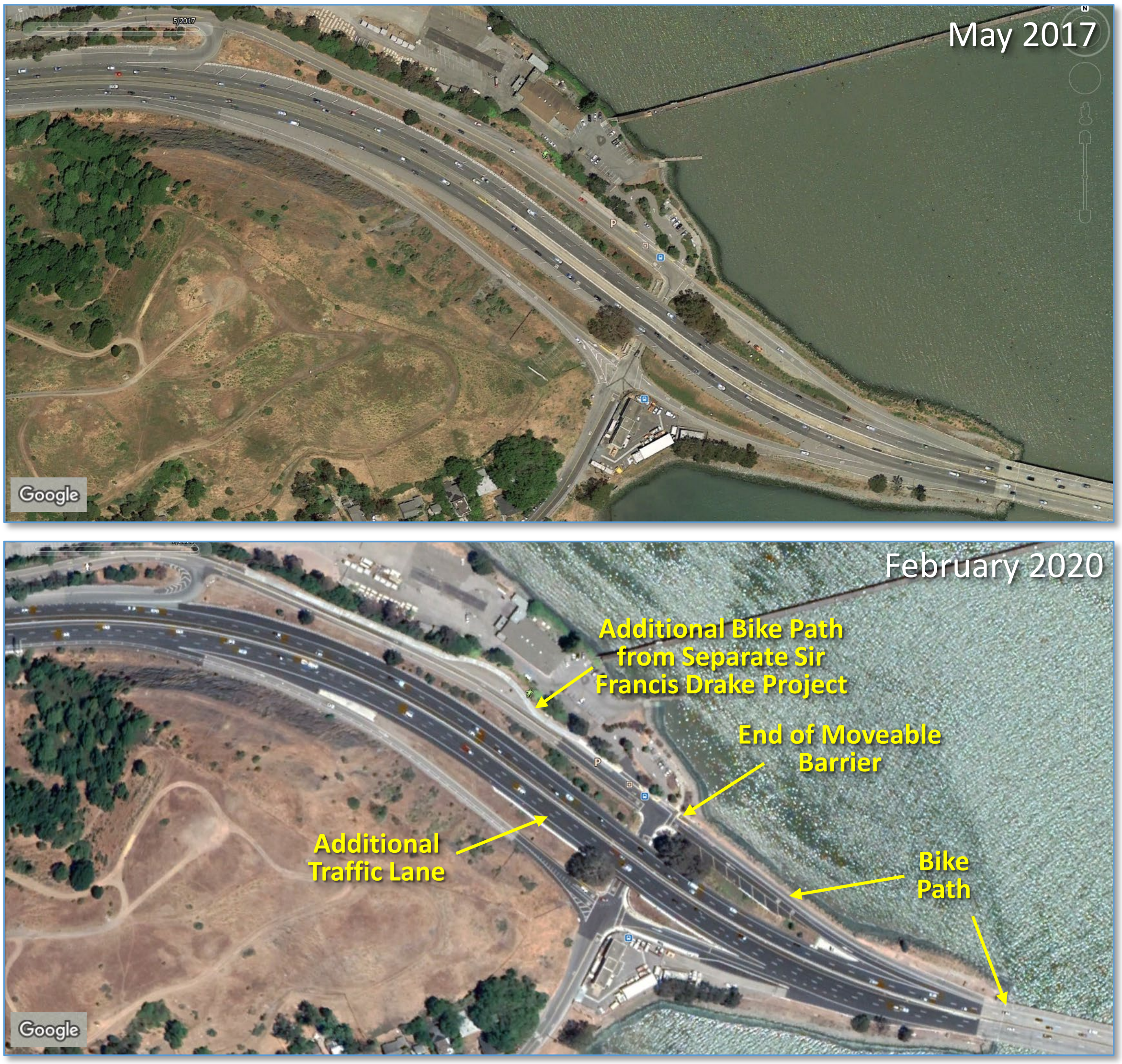

Figure 2-19: Modifications of Marin County Approach

2.6. PROJECT STAKEHOLDERS

In addition to the University of California being responsible for performing the evaluation study contained in this report, stakeholders in the pilot project included the following entities:

- **Project Proponents:** Bay Area Toll Authority (BATA), Contra Costa Transportation Authority (CCTA), and Transportation Authority of Marin (TAM). These organizations have provided the funding for the modifications, in addition to having expedited the permitting process.
- **Project Overseer:** Caltrans District 4, responsible for approving the design and providing quality assurance during construction.
- **Project Designer:** CH2M Hill (formerly HNTB Corporation), responsible for the design and implementation of the improvements.

3. EVALUATION OBJECTIVES

The conversion of the eastbound shoulder lane into an additional traffic lane and the conversion of the westbound shoulder lane into a barrier-separated bike/pedestrian path was expected to change how the bridge operates. In both directions, a key concern was the fact that the loss of the shoulder could significantly reduce bridge accessibility for emergency and maintenance vehicles. Another potential concern was that the installation of a physical barrier on the upper deck could cause the westbound traffic to travel slower on the bridge and thus lead to more congestion in the westbound direction. Finally, some individuals argued that opening the bridge to pedestrians and cyclists could also generate additional emergency responses on the bridge and negatively impact westbound traffic, particularly if the problems occur during peak traffic periods.

To assess the extent of these potential impacts, Caltrans commissioned the University of California, Berkeley to monitor the changes in bridge operations that may result from the modifications. Results of this evaluation are to be used by Caltrans to assess whether the improvements are to be kept, in whole or in part, at the end of the four-year evaluation period, or removed altogether. This meant first assessing operations before the changes and then reassessing them at various points in time after completion of the modifications.

Specific elements that were to be evaluated included:

- The utilization of the eastbound shoulder lane on the bridge lower deck during periods of authorized and unauthorized use
- Utilization by cyclists and pedestrians of the new multi-use path on the bridge's upper deck
- Congestion on the eastbound and westbound approaches to the bridge, as well as on the bridge itself
- Traffic on local arterials near the freeway
- Rate and severity of major traffic incidents occurring on the bridge and its approaches
- Clearance time of incidents occurring on the bridge
- Impacts on maintenance activities on the bridge
- Impacts on quality of life in Marin County areas near the bridge

A “before evaluation” report covering the first part of the evaluation was completed and released in September 2017. This report presents findings associated with the first phase of the “after evaluation,” which focuses on an assessment of impacts on bridge operations up to mid-2022. A later report is expected to update the assessments with observations from late 2022, 2023, and early 2024, and add an evaluation of impacts associated with additional modifications that were made to the Sir Francis Drake off-ramp overpass near the bridge along I-580 West in Marin County.

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4. STUDY AREA

The evaluation of the changes brought over by the bridge modifications was not strictly limited to what happened on the bridge itself and both its eastern and western approaches. It also included an assessment of potential impacts on important local arterials on both the Marin County and Richmond sides of the bridge. Below is a more detailed listing of the roadway segments that were considered in the evaluation:

- **I-580 segments (Figure 4-1):** Segment in Marin County from US-101 to bridge, the bridge itself, segment around the toll plaza, segment in Richmond from the Bridge to Cutting Boulevard, and segment in Richmond from Cutting Boulevard to I-80.
- **US-101 segments (Figure 4-1):** Segments from Madera Boulevard to Second Street interchanges, covering the I-580 and Sir Francis Drake Boulevard interchanges.
- **Local streets in Richmond (Figure 4-2):** Stenmark Drive, Marine Street, Castro Street, Richmond Parkway, Cutting Boulevard, and Harbour Way.
- **Local streets in Marin County (Figure 4-3):** Stenmark Drive, Marine Street, Castro Street, Richmond Parkway, Cutting Boulevard, and Harbour Way.

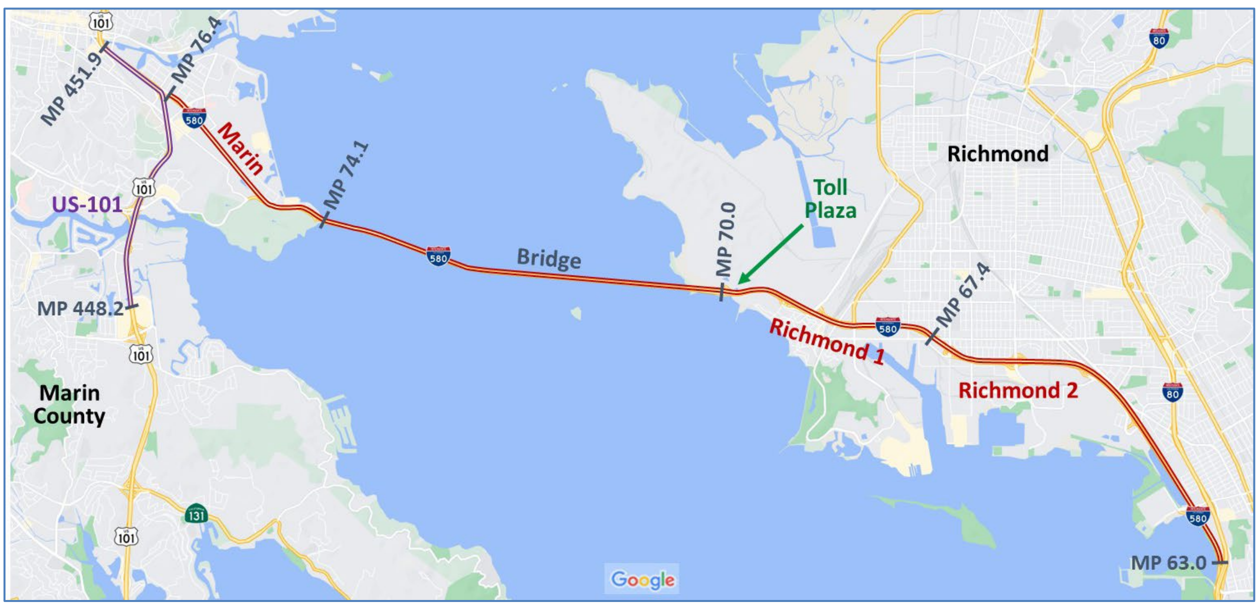

Figure 4-1: Freeway Segments of Interest

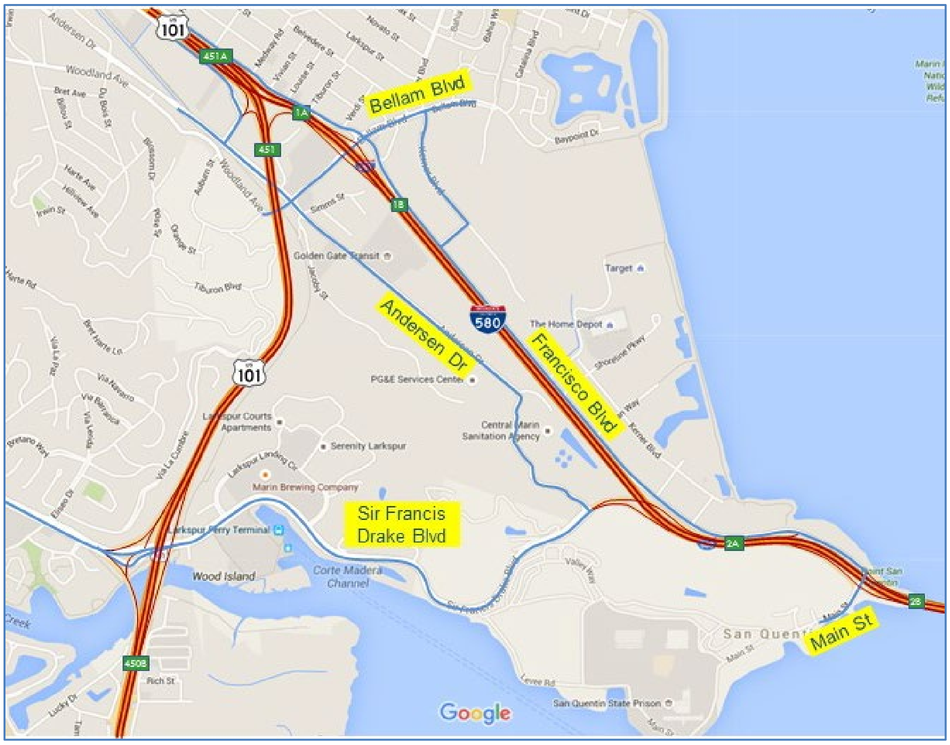

Figure 4-2: Arterials of Interest on Marin County Side

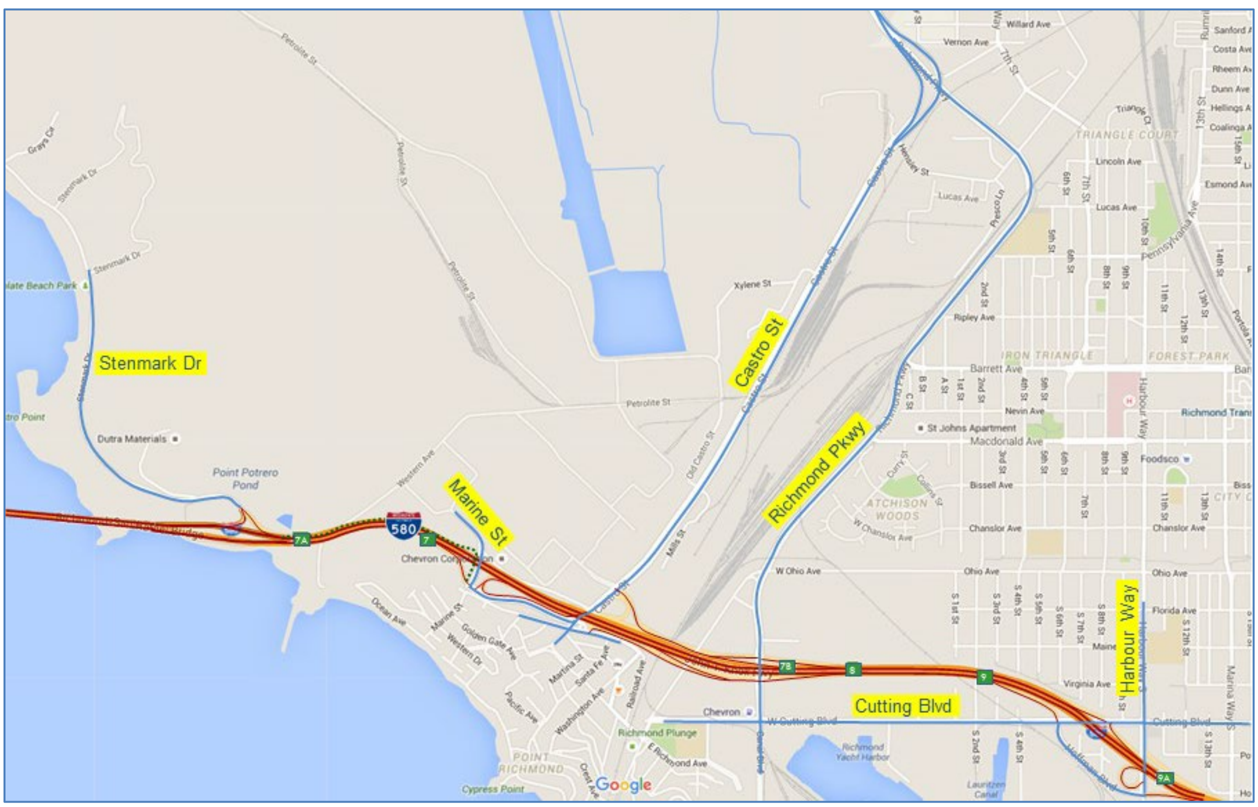

Figure 4-3: Arterials of Interest on the Richmond Side

5. DATA COLLECTED

This section presents a summary of the data that was collected to evaluate the impacts of the implemented modifications on traffic, safety, maintenance, and quality of life. The following sections provide more detailed information about:

- Data collection periods
- Traffic count data
- Travel time data
- Bike and pedestrian counts
- Incident data
- Incident response data
- Maintenance activity data
- Bike path user survey
- Business surveys

5.1. DATA COLLECTION PERIODS

With the beginning of construction initially scheduled to start in late 2016 or early 2017, the period between July 2015 and June 2016 was selected as the preferred period for assessing bridge operations before the implementation of the proposed changes. This was the closest one-year period during which bridge operations would not have been disturbed by construction activities. However, the selection of this period did not preclude the collection of additional data outside this period should the need arise.

For the after period, data collection was initially set to start approximately 6 months after completion of construction activities, to allow enough time for traveler behavior to settle following the introduction of the new elements. This evaluation was again set to cover at least one year. Based on the expected April 2018 shoulder lane opening, this meant starting data collection for the lower deck evaluation no earlier than October 2018. For the upper deck, this further meant starting data collection no earlier than May 2020 based on the path's anticipated November 2019 opening.

The above data collection plans were derailed by the Covid-19 pandemic. Following the imposition of a stay-at-home order in mid-March 2020, vehicle traffic across the bridge dropped by more than 50% in April and May 2020. This likely affected bicycle and pedestrian traffic across the bridge as well. Because of these unusual changes, the data collection for the after period had to be postponed until traffic would return close to pre-Covid conditions. By the end of June 2021, most work-related Covid restrictions had been lifted and both weekday and weekend peak time traffic had returned close to pre-Covid levels, even slightly exceeding them in some time intervals. However, off-peak traffic remained significantly below pre-Covid levels, with night traffic still being 30-50% below. This allowed considering any peak period data collection conducted after June 2021 to be deemed valid for the after evaluations.

5.2. TRAFFIC COUNTS

The following is a summary of the several types of traffic data that were gathered, or attempted to be gathered, to support the intended evaluations. These include:

- PeMS sensor data
- Toll plaza counts
- Traffic counts for local jurisdictions
- Manual traffic counts executed as part of the project

5.2.1. PEMS DATA

Vehicle counts were obtained from the Caltrans Performance Measurement System (PeMS) online application. While it was initially thought that PeMS could provide most of the data needed, an assessment of the data supplied by the system revealed several issues:

- Most of the stations along I-580 had significant reliability problems. This is illustrated in the diagrams in Figure 5-1, Figure 5-2, and Figure 5-3, which show the quality of the data supplied by each station within the study area between January 2016 and December 2021. Data quality is represented by the percentage of direct measurements, ranging from 0% (red) to 100% (green), as opposed to estimated data based on an analysis of information from surrounding sensors. Because of potential errors associated with estimated data, only counts having at least 80% observed data were considered valid.

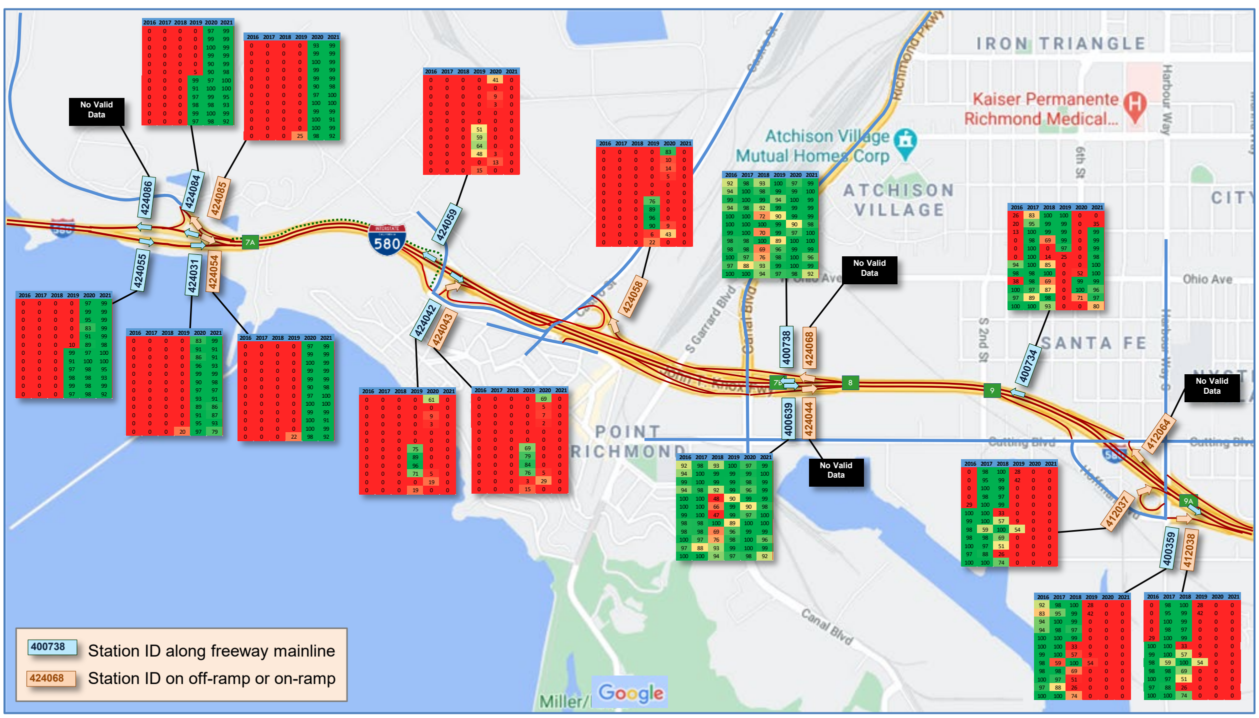

Figure 5-1: Percentable of Observed Data from PeMS Stations on I-580 in Richmond, 2016-2021

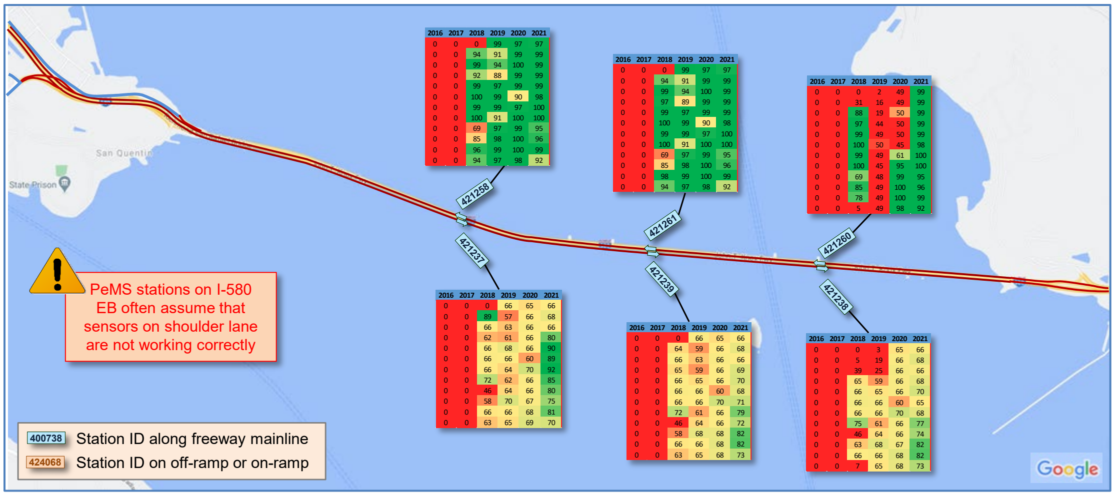

Figure 5-2: Percentable of Observed Data from PeMS Stations on Bridge, 2016-2021

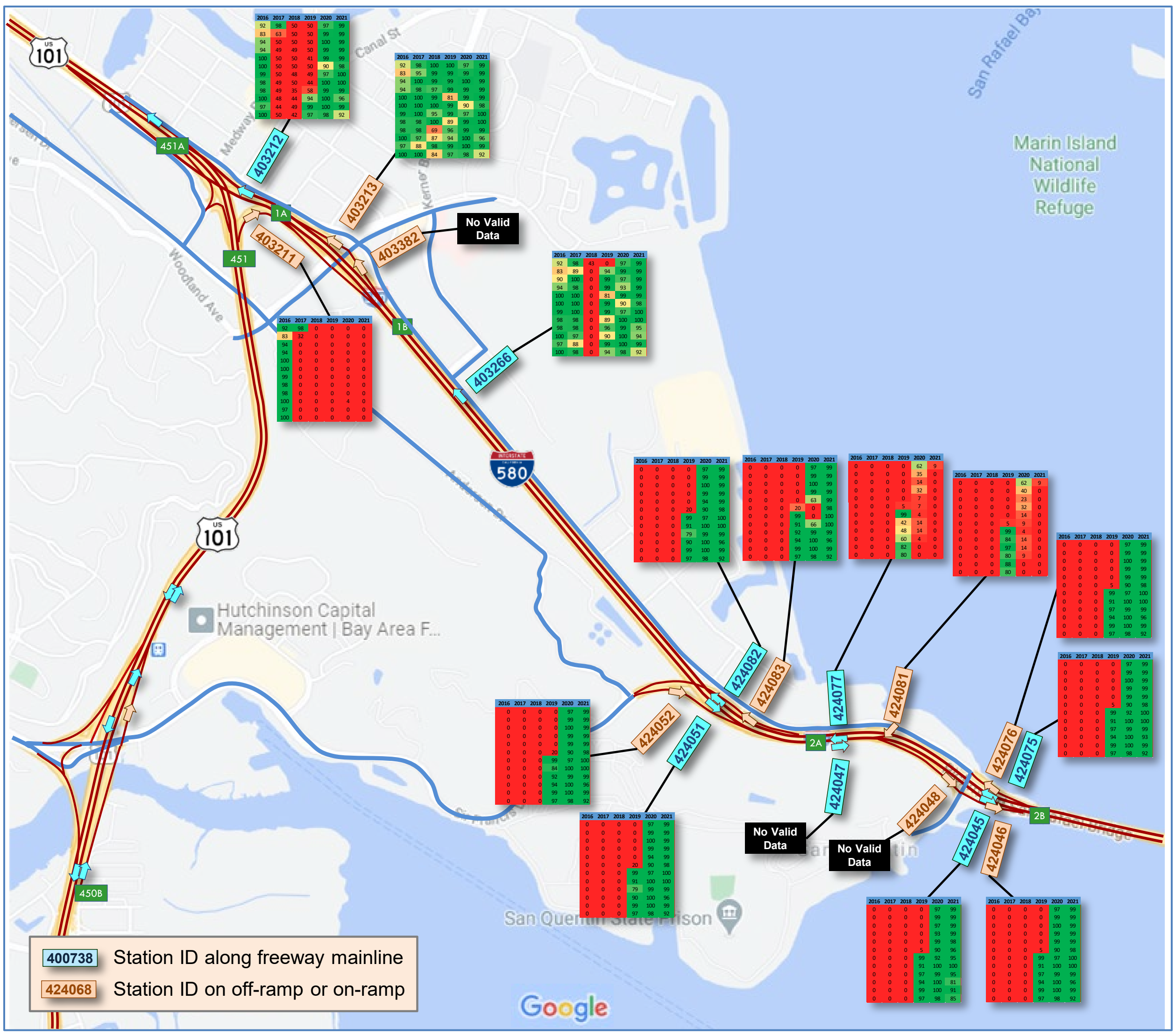

Figure 5-3: Percentable of Observed Data from PeMS Stations on I-580 in Marin County, 2016-2021

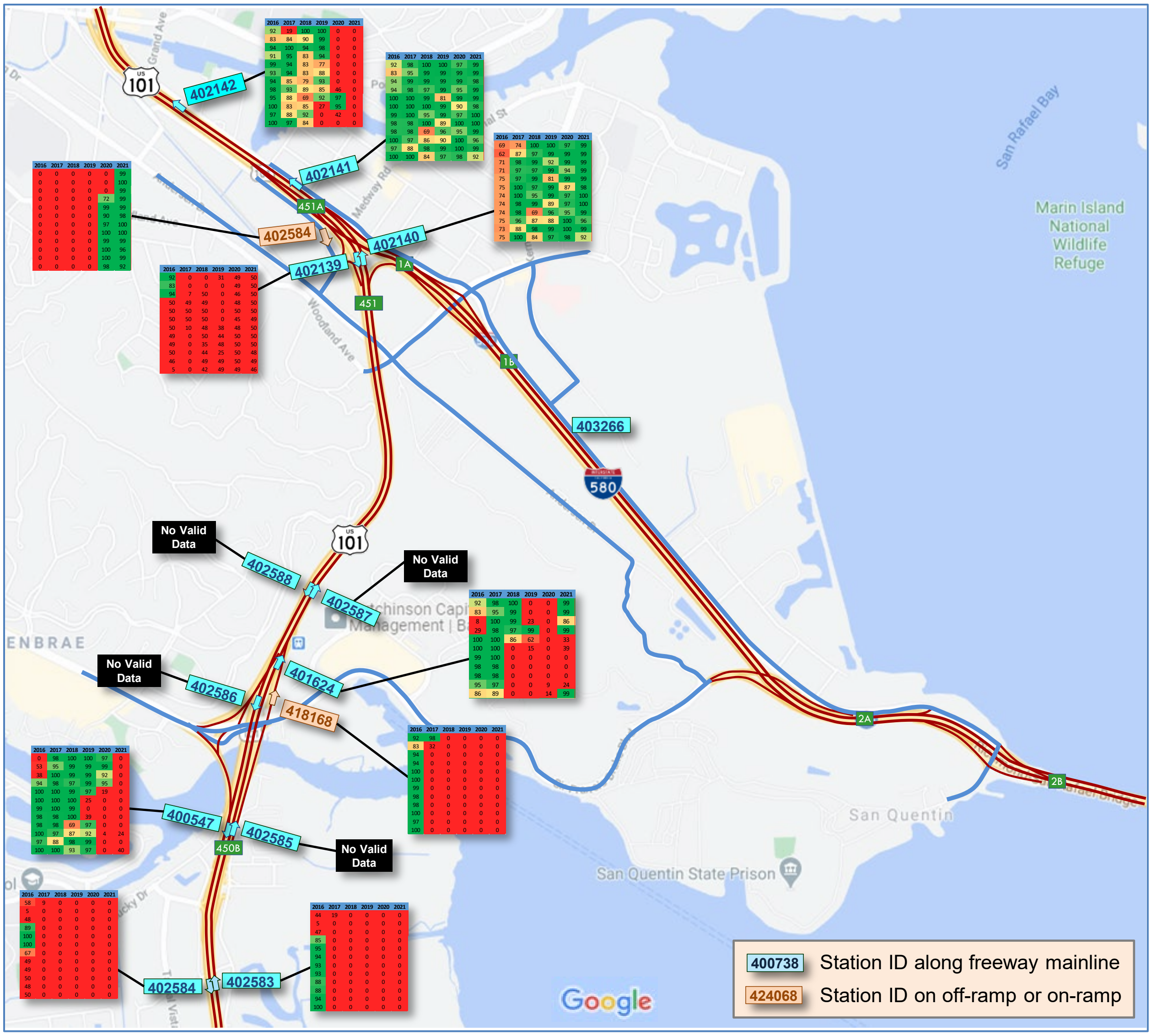

Figure 5-4: Percentable of Observed Data from PeMS Stations on US-101, 2016-2021

- The two mainline stations on I-580 near Canal Boulevard (stations 400638 and 400739) were found to be the only ones on the Richmond side to consistently provide reliable data. In Marin County, the station on I-580 West upstream of the Bellam Boulevard off-ramp (station 403266) was the only reliable one.
- The three new stations that were installed on the bridge as part of the pilot project only started to produce data in February 2018. This restricted the use of this data source to the after evaluation only.
- The detectors installed on the shoulder lane on the bridge lower deck have difficulty recognizing that the lane is opened to traffic only during specific periods. Since the system assumes that a zero volume might be an error, estimated flows are often provided for the lane when it is closed, resulting in an overestimation of the overall bridge traffic. This problem was remedied by retrieving and processing the raw data instead of the processed data.

- Stations along I-580 and US-101 that produced data in 2016-2017, during the before evaluation, generally ceased to produce data by 2019.
- As a result of the installation of new sensors along the I-580, several mainline and ramp stations on each side of the bridge started to produce data in the fall of 2019. Similar to the bridge sensors, this meant that the collected data could only support the after evaluation.

5.2.2. TOLL PLAZA COUNTS

The number of vehicles crossing the Richmond toll plaza on I-580 West for each hour of the day between January 2010 and mid-June 2022 was provided by the Bay Area Toll Authority. These counts are from the vehicle detection system used to detect and categorize vehicles across each of the seven toll lanes at the plaza. Because the data can be considered fully accurate, it was used as a reference for the assessment of the westbound traffic accessing the upper deck of the bridge.

5.2.3. TRAFFIC COUNTS FROM LOCAL JURISDICTIONS

Neither Richmond nor the multiple jurisdictions in Marin County had detailed information about traffic on local streets.

5.2.4. MANUAL TRAFFIC COUNTS

To supplement existing data and cover areas without information, National Data and Surveying Services (NDS) was contracted by PATH to conduct manual traffic counts at strategic locations within the study area. The same firm was used for both the before and after data collection as follows:

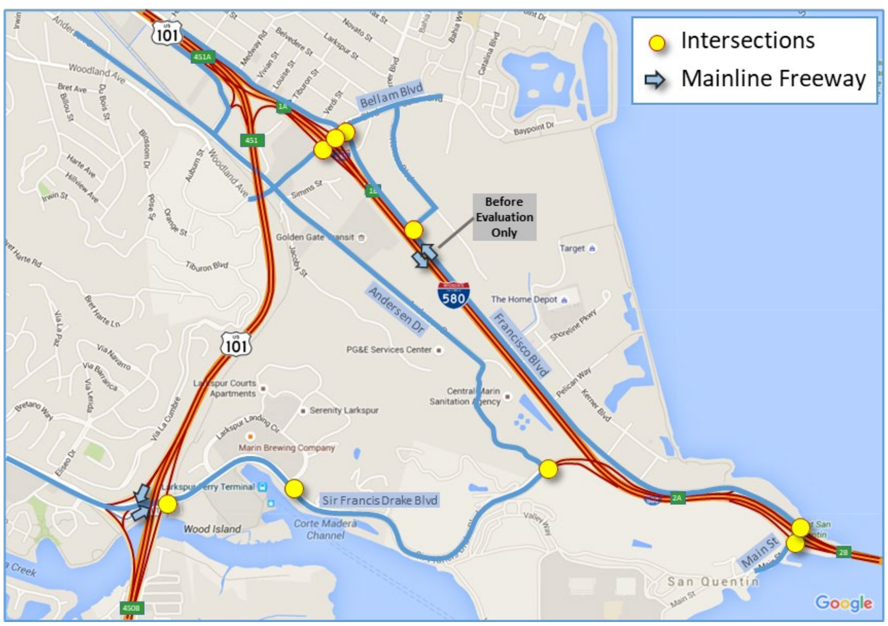

Figure 5-5: Before/After Marin County Manual Count Locations

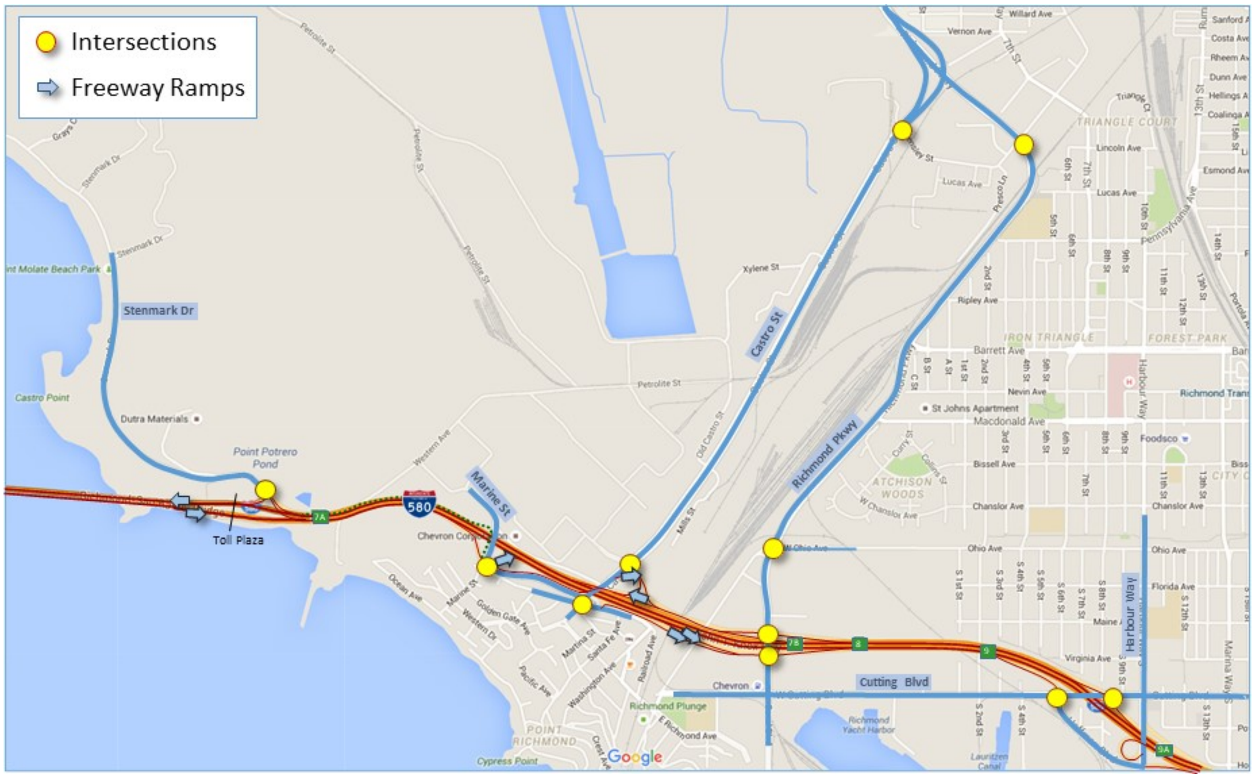

Figure 5-6: Before/After Richmond Manual Count Locations

- For the before evaluation, data were collected between May 10 and May 19, 2016, at the locations shown in Figure 5-5 and Figure 5-6. This included 9 intersections and 4 freeway ramps in Marin County, in addition to 11 intersections and 7 freeway ramps in Richmond.
- For the after evaluation, data were collected at the same locations shown in Figure 5-5 and Figure 5-6, except for the two I-580 mainline sites in Marin County, between March 22 and March 24, 2022. Data collection was not repeated at the two I-580 sites in Marin County as traffic detectors installed along the freeway mainline in the summer of 2019 near the Sir Francis Drake Boulevard and Main Street interchanges could provide the desired freeway volumes.

5.3. TRAVEL TIME DATA

Travel times along key freeway and arterial segments were obtained from the INRIX online data analysis platform through a login provided by the MTC. Specific segments for which travel times were collected are shown in Figure 5-7. This includes various segments along I-580, US-101, and key arterials within the study area.

While the project team initially hoped that Bluetooth data would be available to supplement speeds and travel times obtained from PeMS and INRIX, no such data were found to be available for the study area.

Figure 5-7: INRIX Travel Time Study Segments

5.4. BIKE/PEDESTRIAN DATA

The following data were collected to characterize the bike and pedestrian demand for the multi-use path on the upper deck of the bridge:

- **Automated bicycle and pedestrian counts:** Data from automated counters installed on the multi-use path as part of the pilot project (available only for the after portion of the evaluation).
- **Bicycle Counts from Golden Gate Transit:** Information about the number of bicycles that were carried over the bridge by Golden Gate Transit buses on their front rack (see Figure 2-7).

To measure bicycle and pedestrian traffic along the pilot corridor, Eco-Counter devices were installed at both ends of the bridge. Figure 5-8 indicates the location of the various sensors from which data were collected, while Figure 5-9 illustrates a typical sensor installation.

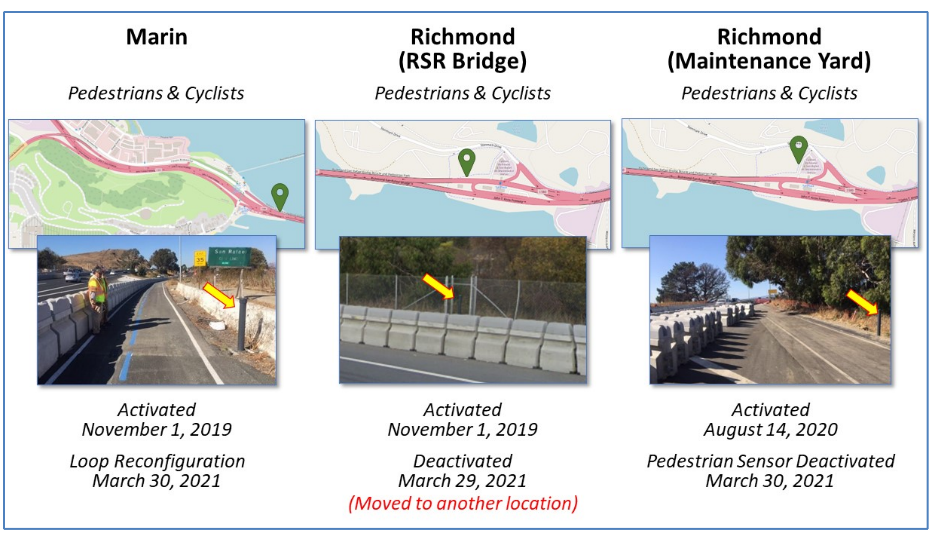

Figure 5-8: Locations of Bike/Pedestrian Eco-Counter Sensors

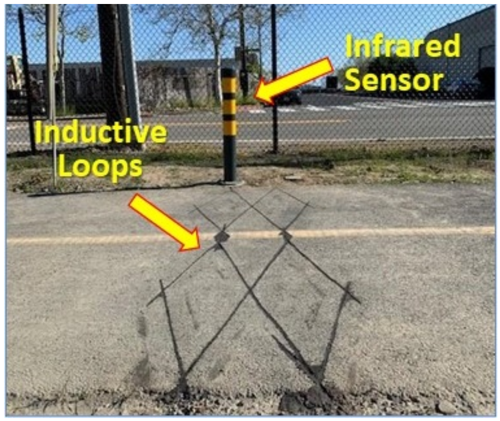

Figure 5-9: Typical Eco-Counter Sensor Installation

The Eco-Sensor devices rely on a combination of in-pavement loops and a passive infrared sensor to detector bicycles and pedestrians:

- Inductive loops embedded in the pavement are used to detect the metal in bicycles passing in front of them. Following a detection, an algorithm then analyzes the recorded bicycle's electromagnetic signal to determine whether a bicycle should be counted and its direction of travel. This is like systems using pavement loops to detect and count traffic.
- The passive infrared sensor is used to detect the heat of human bodies passing in front of the sensor. Like the bicycle data, an algorithm is then used to determine how many pedestrians have been observed and their direction of travel.

As indicated in the bottom of Figure 5-8, various changes were made to the layout of detectors around the bridge throughout the study:

- The first two Eco-Counter sensors, the "Marin" and "Richmond (RSR Bridge)" sensors, were installed on each side of the bridge in November 2019.
- In August 2020, an additional sensor was added near the Caltrans Maintenance Yard at the Richmond toll plaza.
- In March 2021, the initial Richmond sensor was removed to be used along another path going across the Sir Francis Drake of-ramp overpass on I-580 West in Marin County, leaving only the Maintenance Yard sensor on the east side of the bridge.
- During the March 2021 reconfiguration, the Marin sensor had its bicycle loop reconfigured to address an eastbound/westbound misdetection issue that was identified through the analysis of the collected data. The pedestrian sensor for the Maintenance Yard sensor was also deactivated, leaving the Marin sensor to be the only remaining one recording pedestrians.

A comparison of the sensor data to video recordings has shown that the sensors generally produce reliable counts. The only identified issue was a potential undercounting of bicyclists traveling in tight groups. This indicates that the actual number of cycles passing in front of each station may be slightly higher than what is reported, particularly on Saturdays and Sundays, when groups of cyclists are more frequently observed.

5.5. INCIDENT DATA

To assess the impacts of the bridge modifications on the frequency, type, and severity of incidents occurring on the bridge and its approaches, data were collected from the following sources:

- Statewide Integrated Traffic Report System (SWITRS)
- Traffic Incident and Surveillance Analysis System (TASAS)
- Transportation Injury Mapping Systems (TIMS)
- California Highway Patrol Computer-Aided Dispatch (CHP CAD) log data within PeMS
- Processed data from Bay Area Traffic Incident Management Dashboard
- Incident reports logged by travelers on the Street Story online platform

Attempts were also made to collect and use data from the following sources:

- Bay Area Incident Response System (BAIRS)
- Major Incident Database (MIDB)
- Call Box data
- Incident data from local police agencies

The subsections below describe in more detail the data collection efforts, or issues, associated with each of the above sources.

5.5.1. STATEWIDE INTEGRATED TRAFFIC REPORT SYSTEM (SWITRS) DATA

SWITRS is a CHP database containing information about highway incidents. This database essentially aggregates information about incidents that have been submitted by officers on Traffic Collision Reports. It is generally considered to be the definitive source of incident data for state highways. For each collision, this details its location, time of occurrence, severity, type, number of vehicles implicated, and roadway condition at the time of the incident, among many other parameters. However, incident duration is normally not included.

Where needed, information about specific incidents was retrieved from the CHP's iSWITRS online portal at https://iswitrs.chp.ca.gov/Reports/jsp/CollisionReports.jsp. A snapshot of the incident query page is shown in Figure 5-10. Access to this query tool is open to the public but requires obtaining login credentials from the CHP. It allows obtaining reports in PDF format detailing all the incidents occurring between specific dates, within a specific county, city, or police jurisdiction. However, it does not allow to perform queries for specific roads. To retrieve incidents associated with I-580, a manual scan of all reported incidents must be performed.

An element of note with this dataset is that a significant lag can exist between the time an incident occurs and the time it shows up in the database. This is due to the time taken by the CHP to verify all the submitted information. Information about incidents typically becomes public one to one-and-a-half years after their occurrences.

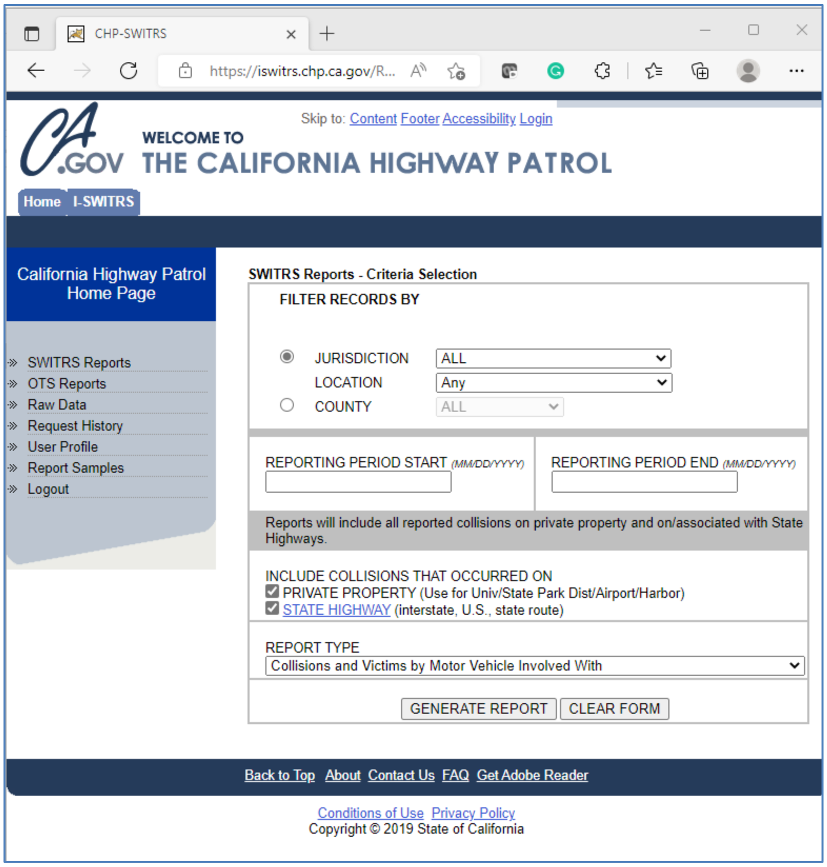

Figure 5-10: iSWITRS Incident Query Webpage

5.5.2. TRAFFIC ACCIDENT AND SURVEILLANCE ANALYSIS SYSTEM (TASAS) DATA

The Traffic Accident and Surveillance Analysis System (TASAS) is a database developed by Caltrans based on information contained in SWITRS. This database links incident data from SWITRS to a database of roadway features to facilitate the analysis of traffic impacts associated with incidents.

This is the primary database that was used to compile incident statistics for the project. Data for mainline and ramp incidents along sections of I-580 within Contra Costa County and Marin County between January 2016 and December 2021 were graciously compiled by Caltrans staff and provided to the research team in Excel format.

5.5.3. TRANSPORTATION INJURY MAPPING SYSTEM (TIMS) DATA

The Transportation Injury Mapping System (TIMS) is an online analytical tool developed by SafeTREC at the University of California, Berkeley to provide quick, easy, and free access to crash data contained in the SWITRS database and facilitate the display of incidents on maps. This tool can be accessed at https://tims.berkeley.edu, but requires obtaining login credentials from the manager of the site. Its focus is on crashes with injury. As such, it does not map crashes with no reported injuries. A particularly useful feature of this data source is that it allows mapping incidents that have occurred in a specific direction on a specific roadway, as illustrated in the snapshot of Figure 5-11.

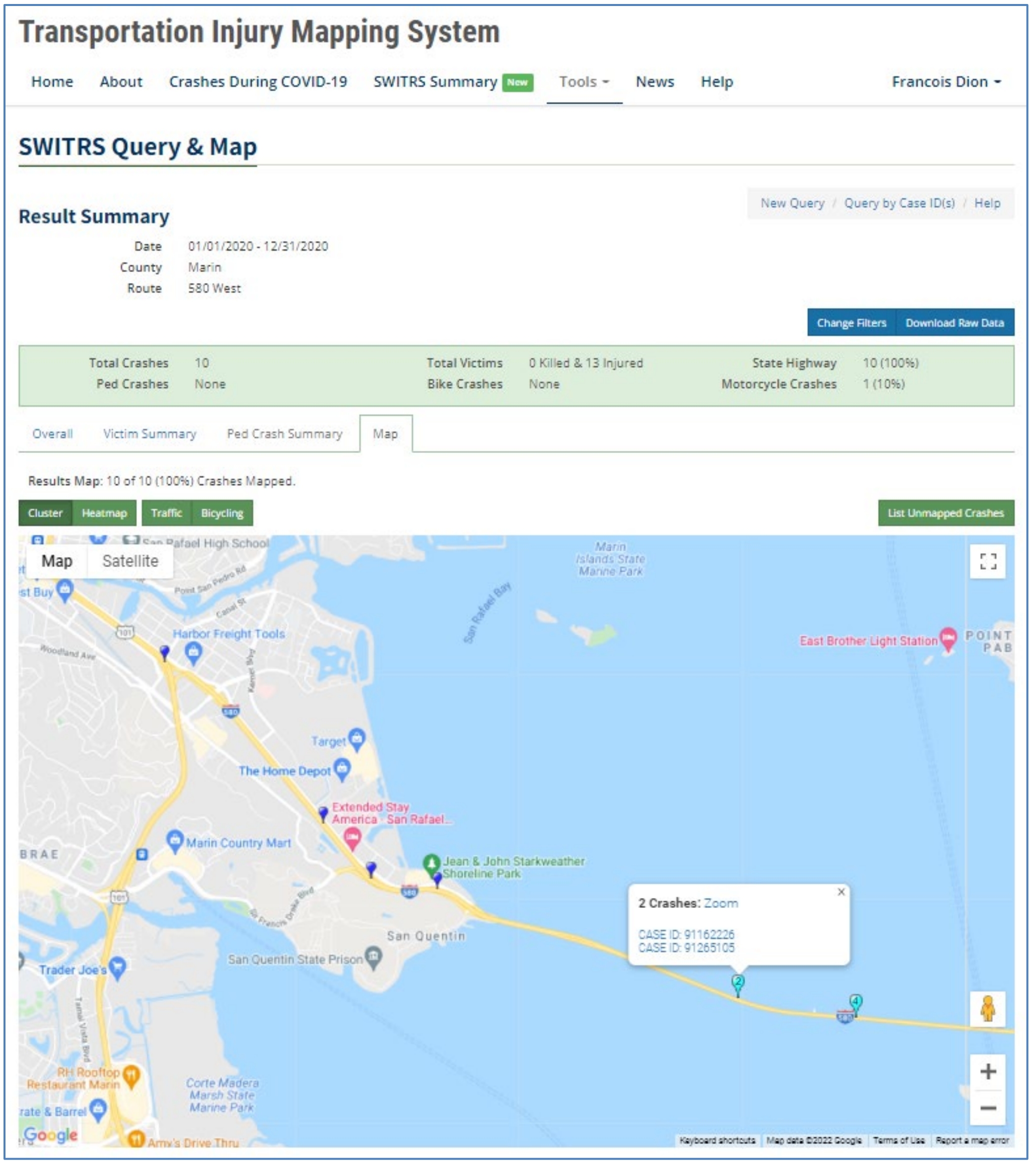

Figure 5-11: TIMS I-580 Incident Query Result Example

5.5.4. CALIFORNIA HIGHWAY PATROL COMPUTER-AIDED DISPATCH (CHP CAD) LOGS

Data from the CHP Computer-Aided Dispatch system (CAD) were used to supplement incident information obtained from the SWITRS and TASAS databases. This data can be retrieved from the California Performance and Monitoring System (PeMS), as illustrated in Figure 5-12. It details the time of occurrence, location, duration, and type of all events for which a dispatch log exists. This not only includes information about traffic collisions, but also information about roadway hazards, weather events, maintenance activities, and roadway closures that involved the dispatching of CHP officers.

An item of particular interest in this database is the ability to access the detailed messages that were posted to manage incidents. An example is shown in Figure 5-13. These message logs are used by various applications as the basis for estimating incident durations. In most cases, incident durations are simply estimated as the interval between the first and last recorded messages.

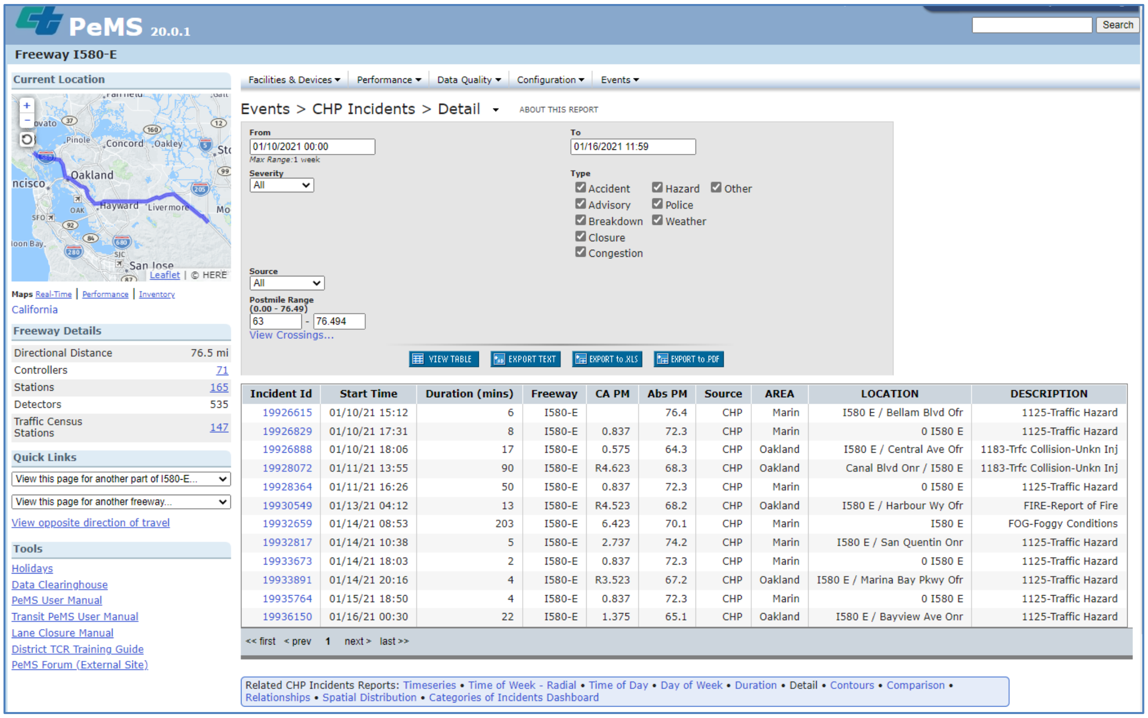

Figure 5-12: CHP-CAD Query Output Example

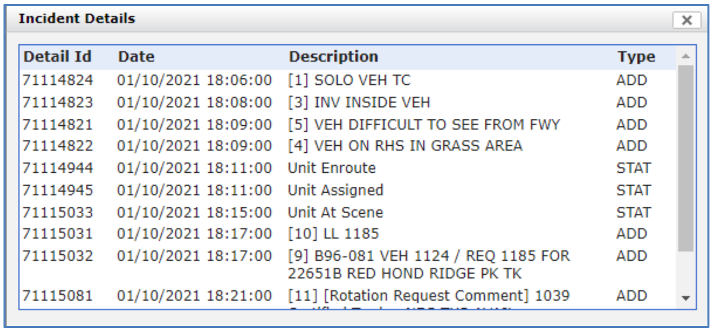

Figure 5-13: CHP-CAD Incident Log Example

While useful, the logs must always be considered carefully as their accuracy is subject to the diligence of CHP dispatchers in recording the various actions taken. For instance, actual event start times are generally not captured. The incident star time is usually the time a dispatcher was notified of an existing event. Event end times are also often missing or not clearly identified in the chain of messages, making it difficult to determine accurately the actual time taken to clear an incident. The last recorded message may correspond to the moment a note has been entered to indicate when the congestion generated by an incident has dissipated when the last incident-related message has been turned off on nearby changeable message signs, or to the last remark about the location where a vehicle has been towed. Some feeds also terminate abruptly, with no information about how an incident was cleared.

While the logs do not necessarily provide clear incident start and end times, they are the only source of information allowing to ascertain incident durations. To reduce possible biases, the message logs associated with all incidents considered in the analyses were reviewed to determine whether an adjustment should be made to the reported durations to more accurately reflect the period during which an incident affected traffic, particularly in the case of incidents with very long reported durations.

5.5.5. BAY AREA TRAFFIC INCIDENT MANAGEMENT DASHBOARD DATA

The Bay Area Traffic Incident Management Dashboard is a web-based application developed by the MTC to facilitate the viewing of crash-related data associated with various Bay Area corridors. Access to this dashboard requires obtaining credentials from the MTC. A snapshot of the page associated with the Richmond-San Rafael bridge corridor is shown in Figure 5-14, with the map at the bottom illustrating the area for which incident statistics are compiled.

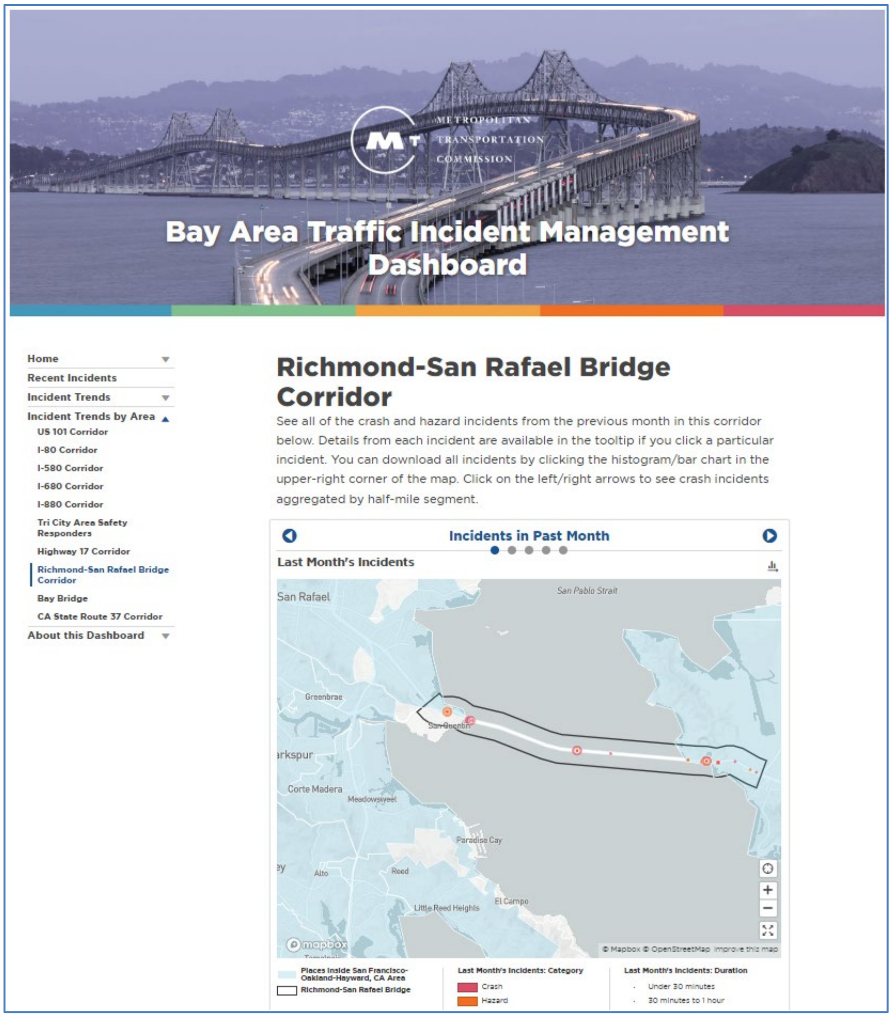

Figure 5-14: Bay Area Traffic Incident Management Dashboard

This dashboard uses CHP CAD data contained within PeMS to identify crash-related incidents within each corridor, estimate their clearance time, and produce summary monthly statistics. Similar to the CHP CAD data processed by PeMS, incident clearance times are estimated based on the first and last messages associated with a particular event. The first message generally corresponds to the time an incident is reported. While the last message often corresponds to a note that a unit has left the scene, this is not always the case. As indicated in the previous section, some incident feeds terminate abruptly while others may include messages posted after an incident has been cleared. As a result, the reported clearance times do not necessarily correspond to actual incident clearance times. To reduce potential large discrepancies, messages associated with all incidents lasting more than one hour were reviewed to verify the accuracy of their reported duration and adjust them if necessary.

5.5.6. STREET STORY ONLINE PLATFORM DATA

StreetStory is an online platform created by the University of California Safe Transportation Research and Education Center (SafeTREC) on the Berkeley campus. This tool allows residents, community groups, and agencies to collect community input about transportation crashes, near-misses, general hazards, and safe locations to travel. Figure 5-15 shows a screenshot of the page used to enter new reports, while Figure 5-16 shows the maps that can be used to explore logged reports. For the evaluations, all reports about the bridge logged between October 2018, when the site was activated, and February 2022 were retrieved and analyzed.

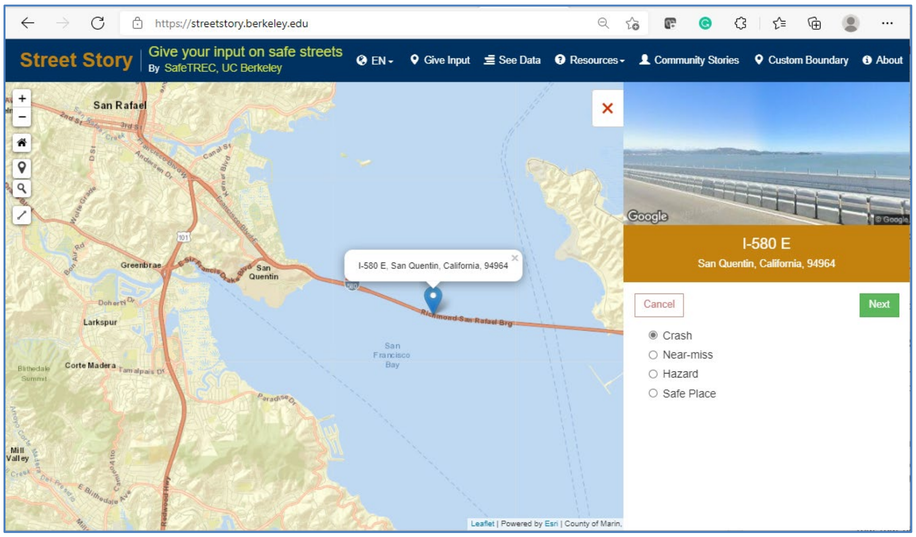

Figure 5-15: SafeTREC Street Story Incident Reporting Online Platform

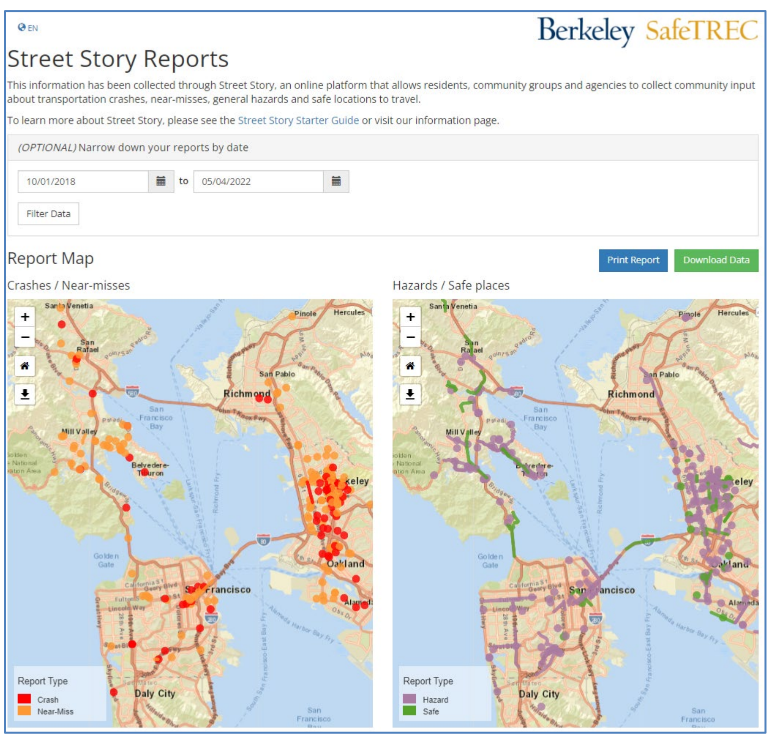

Figure 5-16: SafeTREC Street Story Online Platform for Exploring Reports

5.5.7. BAIRS DATA

BAIRS data were initially obtained for 2015 and 2016. After reviewing the data, it was determined that the information contained in this dataset often duplicated what could be retrieved from SWITRS and the CHP-CAD system. For this reason, no further data were collected from this dataset.

5.5.8. MIDB DATA

Attempts were made to retrieve data from the Major Incident Database (MIDB) in 2015 and 2016. However, these attempts were unsuccessful, in great part due to the difficulty of extracting electronic data from the system. Additional efforts to retrieve data were abandoned after it was determined that the SWITRS data would provide a comprehensive enough record of incidents occurring within the study area.

5.5.9. CALL BOX DATA

A summary of calls made from Call Boxes was obtained for 2011, 2012, 2013, and 2014. While the Call Box data provided information about how frequently the boxes were used to report incidents on each bridge within the Bay Area, the data was found of relatively little use as it did not provide information about the location of the specific box that was used to report each incident, or the type of incident reported. This made it difficult to try to correlate the incidents contained in the database with incidents included in other databases. For these reasons, no further effort was made to use this type of data in the analyses.

5.5.10. DATA FROM LOCAL POLICE DEPARTMENTS

To obtain information about incidents occurring outside the freeway, the police departments of the cities of Richmond and San Rafael as well as the Sheriff's Office of Marin County were contacted in 2016 and 2017. Since electronic data could only be obtained from the San Rafael Police Department, and since the primary focus of the evaluations was on incidents occurring on the freeway, this potential source of incident data was not pursued further.

5.6. INCIDENT RESPONSE DATA

In addition to information about the number and type of incidents, attempts were made to collect data characterizing the time taken by emergency or service vehicles to respond to incidents on the bridge. The goal was to collect data enabling an assessment of the difficulty that emergency services faced reaching incident locations under the various bridge configurations. Efforts were more specifically directed at exploring how such information could be retrieved from the following two sources:

- Caltrans tow truck activity logs
- CAH CAD log data

5.6.1. CALTRANS TOW TRUCKS LOGS

Tow truck activity reports were sought from Caltrans to obtain information about instances in which tow trucks were dispatched to help vehicles on the bridge. This did not include information about towing activities on the approaches to the bridge, as these activities would be provided by the Freeway Service Patrol and would not have been significantly impacted by the bridge modifications.

Collected data include tow truck activity reports for the following periods:

- Before modifications:
  - January to July 2016 (75 logs, 75 with dispatch times)
  - January to September 2018 (244 logs, none with dispatch times)
  - March 21-31, 2019 (26 WB logs, 12 with dispatch times)
- After modifications:
  - March 21-31, 2019 (100 EB logs, 9 with dispatch times)
  - January to February 2020 (119 logs, none with dispatch times)
  - February and March 2022 (645 logs, 77 with dispatch times)

Almost all collected log records include the time a vehicle arrive on the scene (10-97 code) and completed service (10-98 code). However, only a fraction of the logs also includes a dispatch time allowing to assess the time that was needed to reach the location of the requested service. While service locations were generally entered, there were often entered as a general reference location, such as “midspan bridge”, “just east of Toll Plaza”, “just west of San Quentin”, etc.

2019 to 2022 data were provided as scans of handwritten log sheets covering all bridges within the Bay Area. Each sheet had to be visually inspected to determine which logs were relevant. Identified relevant logs then had to be manually transcribed into an electronic format to enable further analyses.

5.6.2. CHP CAD LOGS

Explorations were made into the ability to use the CHP CAD logs to determine the time taken by response vehicles to reach an incident since many logs indicate when a unit has been assigned to an incident, is en route, and has arrived at the scene. As an example, in the log snapshot of Figure 5-13 presented earlier, it could be determined that a unit was assigned to the incident at 6:11 PM, started to travel towards it at that time, and reached the incident location four minutes later at 6:15 PM.

While the “Unit Assigned,” “Unit Enroute” and “Unit at Scene” logs provide some insights about response times, they do not indicate from where a unit has been being dispatched. This makes it difficult to assess whether long recorded travel times are due to difficult traffic conditions on the way to an incident or simply because of a farther starting point. For many incidents, multiple vehicle dispatches and arrivals are also recorded in short succession. Since the logs do not provide information about the specific vehicles being dispatched, it is often unclear to which dispatch each scene arrival corresponds, making it difficult to determine actual response times. Many logs also indicate an assignment but no subsequent arrival time, or an arrival without a prior logged assignment. As a result, estimated response times based on incident logs can only be viewed as crude, potentially inaccurate, estimates.

5.7. MAINTENANCE DATA

Maintenance activity data were sought to assess the frequency at which repairs would be required on the new barrier and, if possible, the time taken by maintenance crews to reach a given site and complete a given task. For this purpose, the following two data sources were considered:

- Caltrans Lane Closure (LCS) System
- Integrated Maintenance Management System (IMMS)

5.7.1. CALTRANS LANE CLOSURE SYSTEM (LCS) DATA

The LCS is used by Caltrans staff to report all approved closures planned for the next seven days, in addition to all lane, ramp, and road closures that are currently in place due to maintenance, construction, special event, or other reason. The system also retains a record of all past closures.

As shown in Figure 5-17, LCS data can be retrieved directly from PeMS. For each closure request, the data indicates whether the request was approved, rejected, or canceled, the proposed start and end locations, the proposed start and end times, the actual start and end times if implemented, as well as the number of lanes closed. The reason for the closure may also be provided in the remarks section.

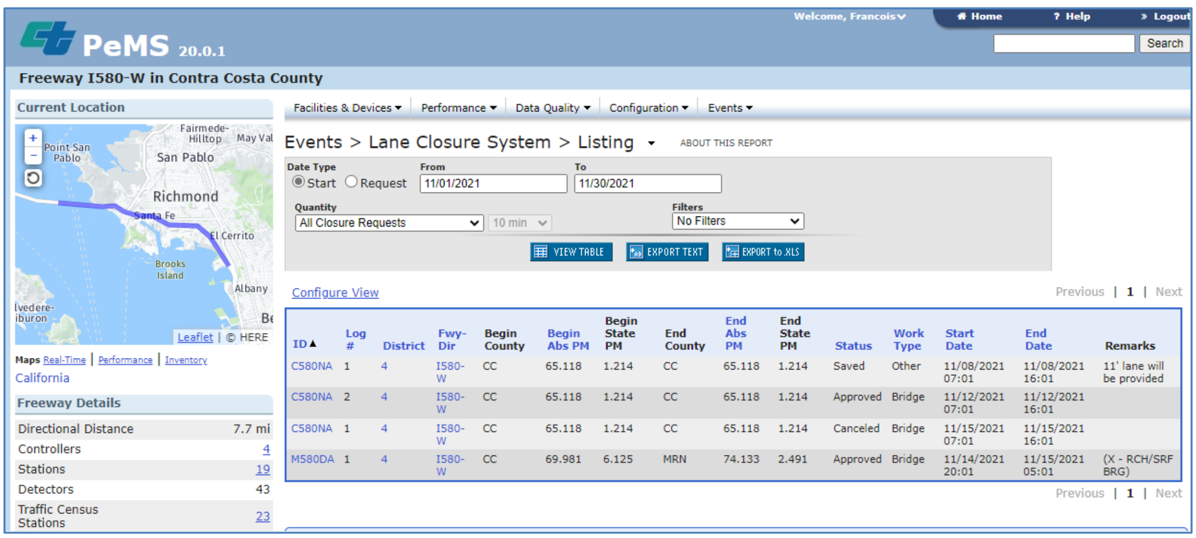

Figure 5-17: Lane Closure System Data Retrieval within PeMS

5.7.2. INTEGRATED MAINTENANCE MANAGEMENT SYSTEM (IMMS) DATA

The Caltrans Integrated Maintenance Management System (IMMS) is used to record, report, and monitor maintenance work planned and performed. A log is normally created for each incident for which maintenance is required. This includes an assessment of the damage to any state property.

An analysis of an IMMS data sample that was provided to the team in 2016 only showed the total number of hours needed to complete a given task and the associated cost to the agency. While this information could be used to assess the magnitude of maintenance work completed, there was no specific information about the time needed to reach a given site. For this reason, it was determined that data from this system would likely not provide useful information for the evaluation and no additional data were sought.

5.8. BIKE PATH USER SURVEY

This section provides information about a user survey that was conducted from June 16, 2021, to August 13, 2021, to assess how users of the new bike/pedestrian path on the bridge view its usefulness and safety. Specific information presented includes:

- Survey development
- Survey dissemination
- Survey results

5.8.1. SURVEY DEVELOPMENT AND DISSEMINATION

The user survey was developed in TypeForm, an application allowing for posting online surveys. A key criterion behind the setup was for path users to be able to answer questions on their mobile phones or at home. Table 5-1 and Table 5-2 detail the questions that were asked within the survey. The first set of

Table 5-1: Survey Questions Related to Improvements on the Richmond-San Rafael Bridge

Question	Answer Choices
1. Have you used the bike/pedestrian path on the upper deck of the Richmond-San Rafael Bridge since its opening in November 2019?	• Yes, as a bicyclist • Yes, as a pedestrian • Yes, as both a bicyclist and pedestrian • No
2. If yes, how frequently do you use the path?	• 1-4 times a week • More than 4 times a week • 1-4 times a month • Occasionally (less than once a month on average) • Seldom (Used only 1-4 times total since opening)
3. Which day(s) do you predominantly use the path (check all that apply)?	• Weekdays • Saturdays • Sunday
4. Which of the following is the most likely reason you currently use the ped/bike path?	• Commuting/traveling to or from work • Commuting/traveling to locations other than work • Recreation • Exercise • Other (please specify)
5. When using the bike/ped path, do you usually (check all that apply)	• Complete a round trip on the path • Use the path one way and return home on a different route • Use the path one way and use a motor vehicle or bus for the other way across the bridge to complete your trip • Do not go completely across the bridge, but turn around mid-way
6. How safe do you feel on the Richmond San Rafael Bike/Pedestrian Path?	• A number between 1 and 10, with 1 being not safe at all and 10 very safe
7. What is the primary factor you think of when considering your safety:	• Open text box
8. How beneficial do you think the Richmond San Rafael Bike/Pedestrian Path improvements are to you?	• A number between 1 and 10, with 1 being not beneficial at all and 10 very beneficial

Table 5-2: Additional Survey Questions

Question	Answer Choices
9. When making your trip across the Richmond-San Rafael Bridge, is your **starting destination** on the	• Richmond/Contra Costa side of the bridge • San Rafael/Marin side of the bridge
10. Please provide the closest intersection or neighborhood to describe your usual starting destination	• Open text box
11. When making your trip across the Richmond-San Rafael Bridge, is your **ending destination** on the:	• Richmond/Contra Costa side of the bridge • San Rafael/Marin side of the bridge
12. Please provide the closest intersection or neighborhood to describe your usual ending destination	• Open text box
13. Any comments you would like to add about your experience with the bike/pedestrian improvements?	• Open text box
14. Any comments you would like to add about your experience with Richmond-San Rafael Bridge?	• Open text box
15. How did you hear about the survey?	• Sign on bike/ped path • Social media post • Local news source • Caltrans or MTC press release • Bike advocacy groups or other community groups • Other

questions specifically pertained to the new bike/pedestrian path on the bridge, while the second set was included to gain some insights about the trips made on the bridge or overpass and how users have heard about the survey. Survey respondents did not necessarily have to answer all the questions. For instance, respondents who indicated on Question #1 that they did not use the new bridge path were not shown questions #2 to #7.

5.8.2. SURVEY DISSEMINATION

Information about the survey was disseminated to the public through:

- A formal Bay Area Toll Authority / Caltrans press release (Figure 5-18)
- Posts on websites maintained by the Metropolitan Transportation Commission/Association of Bay Area Governments and University of California Berkeley (Figure 5-19)`
- Mention of the survey on local news outlets, such as on Kron 4 television channel
- Email blast to bike advocacy groups
- Signs posted at various key locations along the path (Figure 5-20 to Figure 5-23)

A QR code linked to the survey was embedded in press releases and posters to facilitate access from mobile phones. On web pages, a hyperlink was used instead to bring users to the survey.

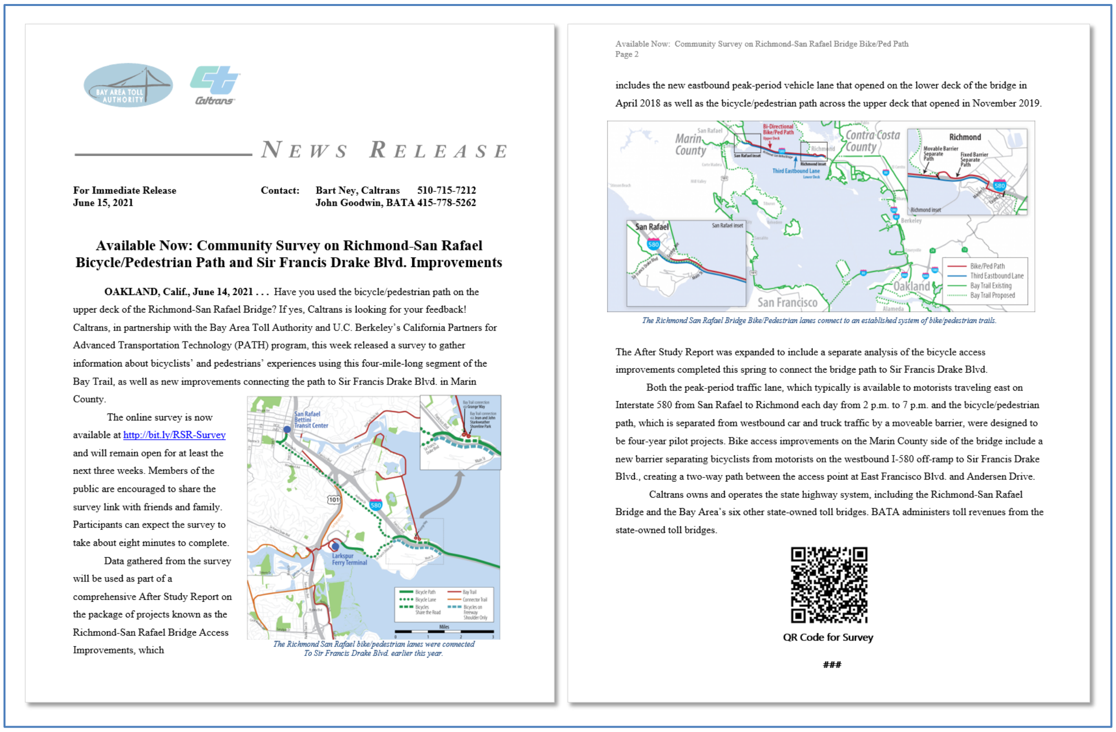

Figure 5-18: BATA/Caltrans Press Release for the User Survey

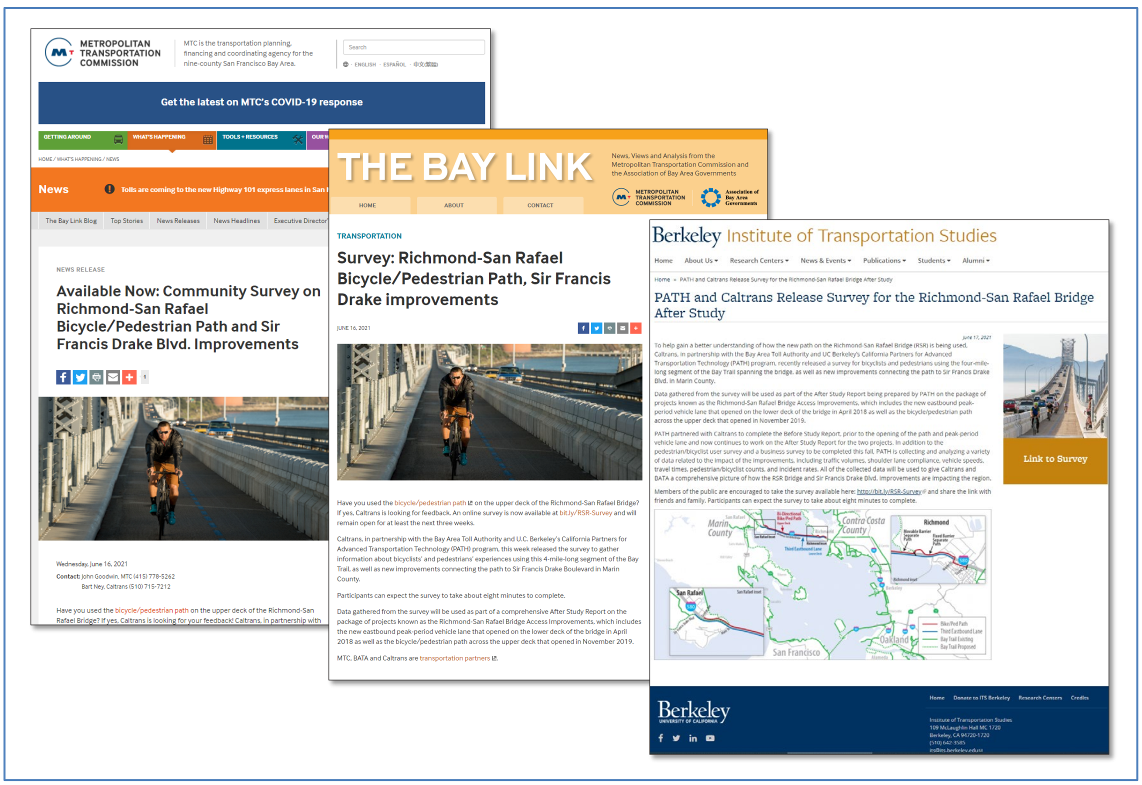

Figure 5-19: Online Posts for the User Survey

Figure 5-20: User Survey Signs Along Path – Richmond Side

Figure 5-21: User Survey Signs Along Path – Marin County Side

Figure 5-22: User Survey Signs Along Path – Vista Point on Marin County Side

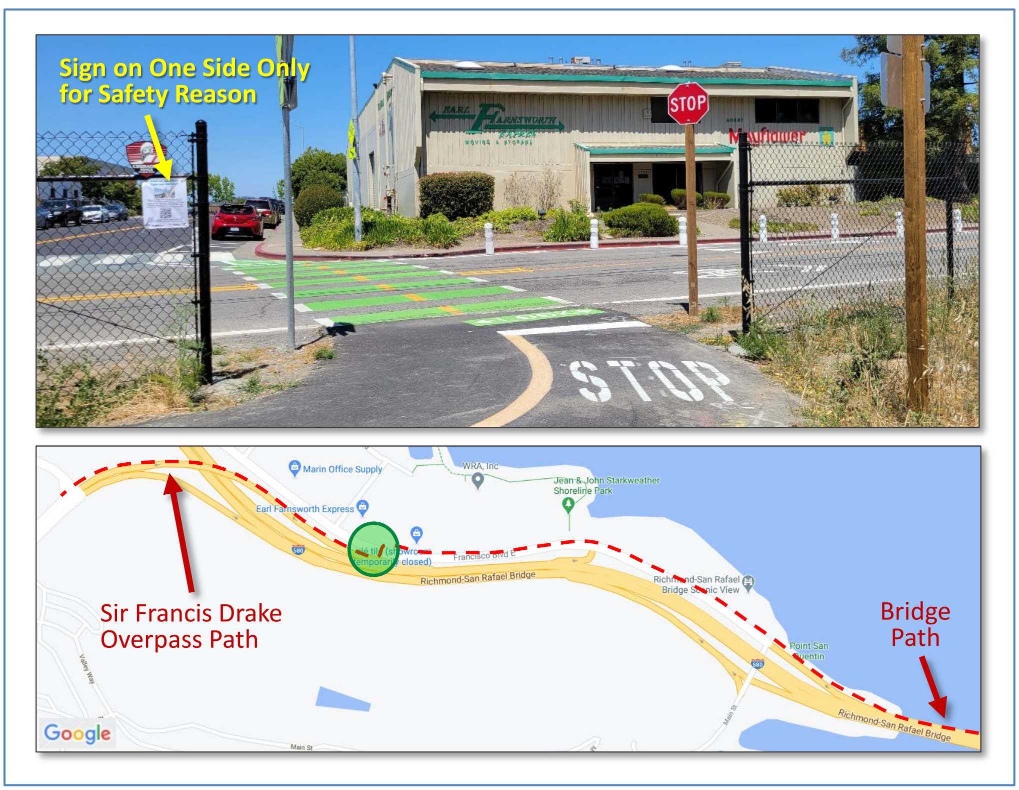

Figure 5-23: User Survey Signs Along Path – Sir Francis Drake Overpass Access

5.8.3. SURVEY RESPONSE RATE

A total of 4,608 individuals viewed the survey splash page over its 8-week active period. Of these individuals, 2,833 started answering questions but only 2,166 individuals completed the survey. This means that 76% of respondents who started answering the survey completed it and 47% of individuals who became aware of it completed it.

A summary of the responses provided by the individuals who completed the survey is provided in Appendix A. More detailed discussions of the survey results are provided in Section 0

5.9. BUSINESS SURVEY

To assess the impacts on business activities associated with the bridge modifications, a series of interviews were conducted with businesses in Marin County located on local streets that were extensively used as alternate routes to the bridge before the modifications. These interviews focused primarily on assessing how congestion leading to the bridge affected the businesses and their employees. No interviews were conducted on the Richmond side as very few businesses were located on streets exhibiting significant bridge-related congestion.

Interviews for the before evaluation were conducted between April, August, and December of 2016. Interviews for the after-evaluation were conducted in the first week of May 2022. The following subsections provide more details about the businesses that were visited, and the questions asked.

5.9.1. BUSINESSES INTERVIEWED – BEFORE STUDY

A total of sixteen businesses were visited for the before study. Table 5-3 lists the various business visited and the date the visit occurred. These businesses were selected based on their high number of employees or customers and their location along key local arterials running parallel to I-580. In each case, efforts were made to talk to managers.

Table 5-3: Businesses Visited in 2016

Date of Visit	Name of Business	Street Location
April 21, 2016	Target	Shoreline / E. Francisco
April 21, 2016	Home Depot	Shoreline / E. Francisco
April 21, 2016	FedEx	E. Francisco
April 21, 2016	Ace Printing	E. Francisco
April 21, 2016	Bay Café	E. Francisco
August 3, 2016	Orchard Supply Hardware	Andersen
August 3, 2016	Smart and Final	Andersen
August 3, 2016	West America Bank	E. Francisco
August 3, 2016	Marin Airporter	Andersen
August 3, 2016	United Parcel Service (UPS)	Kerner
August 3, 2016	US Postal Service	Bellam
December 1, 2016	Extended Stay America	E. Francisco
December 1, 2016	Marin Honda	Shoreline / E. Francisco
December 1, 2016	U-Haul	E. Francisco
December 1, 2016	PG&E Service	Andersen
December 1, 2016	Central Marin Sanitary District	Andersen

5.9.2. QUESTIONNAIRE – BEFORE STUDY

The following questions were asked of each business during the before survey. Since some questions were repetitive or answered in another question, every question did not necessarily have complete information in the answer tables.

1. How do traffic on I-580 and the surrounding roads affect your business and customer/employee access?
2. What days/times are the worst (i.e., weekdays, weekends, specific days, and/or specific times)?
3. Does freeway traffic back up or divert onto local roads surrounding your business?
4. What, if any, types of comments do you hear from employees or customers regarding traffic issues?
5. Do you know where employees live and which on-ramps they use?
6. Do you know of any employees that may bicycle to work once the improvements on the bridge are constructed?

5.9.3. BUSINESSES INTERVIEWED – AFTER STUDY

For the after study, attempts were made to revisit the same businesses that were targeted for the before study. Visits were made in the first week of May 2022. As shown in Table 5-4, comments were obtained from only 8 businesses. First, not all businesses could be revisited as some had permanently closed since 2016. One was still listed as temporarily closed due to the Covid-19 pandemic. Two businesses where a questionnaire was dropped due to managers being unavailable ended up not responding to the survey. The remaining businesses that declined to participate in the after survey did so because of corporate policies preventing employees not working at a corporate office to comment on questions submitted to them.

Table 5-4: Businesses Visited in May 2022

Name of Business	Street Location	Response Provided
Target	Shoreline / E. Francisco	Yes
Home Depot	Shoreline / E. Francisco	No – Did not return the questionnaire
FedEx	E. Francisco	No – Did not return the questionnaire
Ace Printing	E. Francisco	No – Permanently closed
Bay Café	E. Francisco	No – Temporarily closed
Orchard Supply Hardware	Andersen	No – Permanently closed
Smart and Final	Andersen	No – No soliciting policy
West America Bank	E. Francisco	No – No soliciting policy
Marin Airporter	Andersen	Yes
United Parcel Service (UPS)	Kerner	Yes
US Postal Service	Bellam	Yes
Extended Stay America	E. Francisco	Yes
Marin Honda	Shoreline / E. Francisco	Yes
U-Haul	E. Francisco	Yes
PG&E Service	Andersen	No – No soliciting policy
Central Marin Sanitary District	Andersen	Yes

5.9.4. QUESTIONNAIRE – AFTER STUDY

The after survey was conducted more like a discussion than an administration of specific questions. The goal of the discussion was to try to obtain answers to the following questions:

1. Does traffic on I-580 and the surrounding roads affect your business and customer/employee access?
2. What days/times are the worst (i.e., weekdays, weekends, specific days, and/or specific times)?
3. Have there been noticeable changes in travel times to come from Richmond since the addition of the bike path on the upper deck (November 2019), particularly in the morning?
4. Have there been noticeable changes in travel times to get to Richmond since the opening of the lower deck shoulder lane (April 2018), particularly in the afternoon?
5. Does freeway traffic still back up onto local roads surrounding your business?
6. Do you know if some freeway traffic still uses local roads as a freeway bypass?
7. Do you know if some employees live on the Richmond side of the bridge?
8. What, if any, types of comments do you hear from employees or customers about traffic issues?
9. Do you have to consider potential delays due to bridge congestion when planning business activities or employee schedules?
10. Do you know of any employees using the bicycle path on the Richmond-San Rafael Bridge to come to work?
11. Any comments you would like to add about your experience with the bridge improvements?

Not all questions were necessarily answered with each discussion as some of the responses provided may have indicated that some questions were not relevant. Some businesses indicated for instance that they do not have employees coming from the Richmond side of the bridge or do not have business activities requiring them to use the bridge. In such cases, it would have been difficult for the businesses to comment on the impacts that the bridge modifications may have had on their activities or employees. The two-year covid-related delay in administering the after survey has also made it harder for interviewed individuals to recall all the specific conditions that existed in the corridor before the bridge modifications. Many businesses have also had a significant turnover of personnel in the past few years, resulting in many employees being unaware of previous traffic conditions in the corridor.

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6. BICYCLES TRAFFIC

This section presents the results of the evaluations assessing the demand for bicycle travel across the new path installed on the upper deck of the bridge. The following specific elements are discussed:

- Daily directional bicycle traffic on the bridge path
- Bicycles carried across the bridge on Golden Gate Transit buses
- Daily directional bicycle flow profiles on the bridge path
- Summary of observations

6.1. BICYCLE TRAFFIC - BRIDGE PATH

Figure 6-1 and Figure 6-2 illustrate the average daily eastbound and westbound bicycle traffic that was recorded by the sensors around the bridge between November 2019, when the path was opened, and mid-June 2022. Both figures distinguish three data collection periods based on the number of sensors used to calculate the average bicycle counts for each direction (see Figure 5-8):

- **November 2019 – August 2020:** Counts based only on the Richmond and Marin sensors.
- **August 2020 – March 2021:** Counts based on the Maintenance Yard, Richmond, and Marin sensors.
- **April 2021 – Present:** Counts based only on the Maintenance Yard and Marin sensors, as the Richmond sensor was relocated to another location in March 2021. This period also marks a change in the placement of in-pavement sensors at the Marin location in response to an analysis suggesting that the eastbound and westbound counts might be inverted.

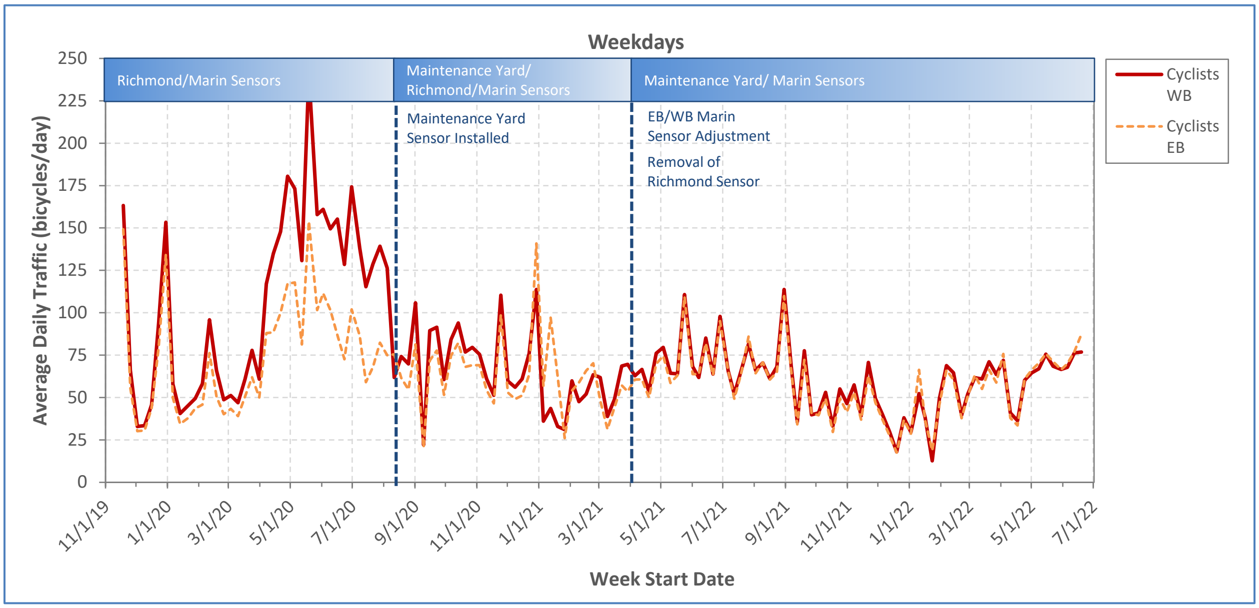

Figure 6-1: Daily Bicycle Traffic – Bridge Path – Weekdays, 2020-2022

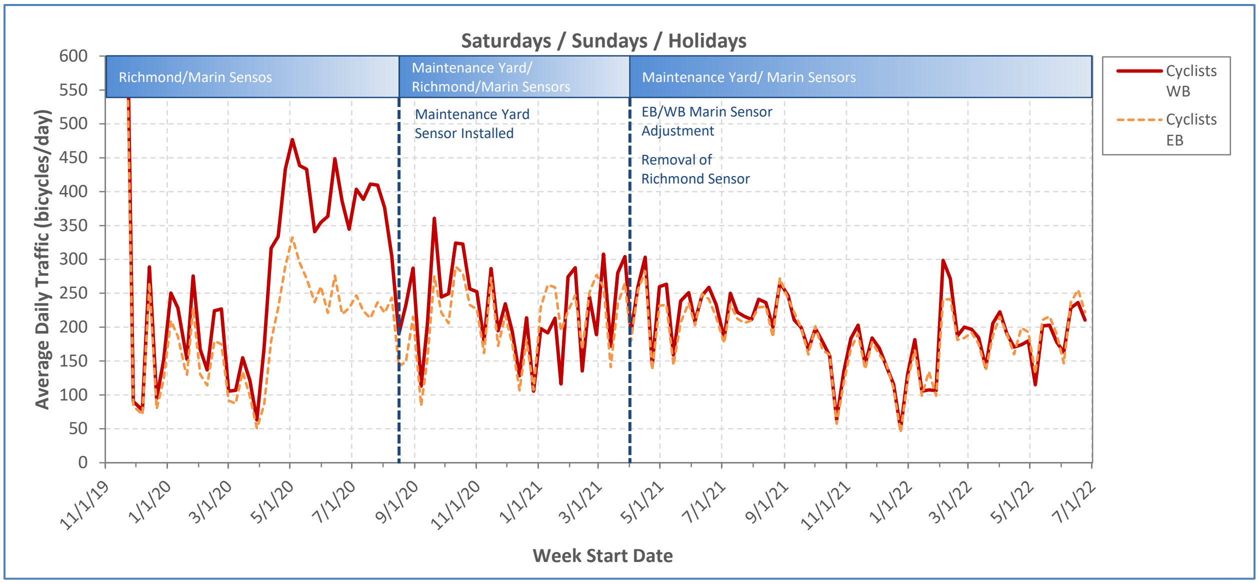

Figure 6-2: Daily Bicycle Traffic – Bridge Path – Weekends, 2020-2022

Based on the illustrated data, the following observations can be made regarding the path utilization by cyclists:

- Since January 2021, between 150 and 300 cyclists have been observed traveling in each direction on the bridge path on Saturdays, Sundays, and weekday holidays, for a westbound average of 235 cyclists and an eastbound average of 213 cyclists.
- Over the same period, between 50 and 75 cyclists have typically been observed crossing the bridge in each direction during weekdays, for a daily average of 68 cyclists in both directions.
- The highest reported weekday and weekend traffic occurred between April and August 2020, during the path's first summer. Initial curiosity may have contributed to this high traffic. Following the March 2020 Covid-19 stay-at-home order, some individuals may also have decided to go on bike rides to break the monotony of staying home. Sensor issues may have further affected the early measurements. This is suggested by the significant drop in measured traffic, particularly in the westbound direction, after the sensor at the Caltrans Maintenance Yard was activated and adjustments were made to the other sensors to reduce the capture of nearby vehicular traffic.
- Weekend traffic shows significantly more variations on a week-by-week basis than weekday traffic. This is likely due to variations in the nature of the bicycle traffic. During weekends, traffic is primarily recreational, and thus heavily influenced by the weather. During weekdays, a portion of path users may be individuals commuting to work. While the weather may still affect the decision to ride, weekday riders may be more accustomed to inclement weather and thus less inclined to ditch their bike on rainy or windy days.
- Following the March 2021 adjustments to the Marin sensor, eastbound and westbound counts generally appear to follow similar patterns. While some discrepancies remain, this may be due to some riders traveling only along a section of the bridge before turning back. This is likely to occur more often with recreational weekend riders than work-related weekday riders, thus explaining the larger observed weekend discrepancies compared to the weekday data.

- The more recent data suggests that there are generally slightly more riders traveling westbound towards Marin County than eastbound towards Richmond during the day. This imbalance is observed at all counting locations. Based on data collected from path users in the summer of 2021 (see Section 0) and the fact that morning trips tend to be westbound crossings, this unbalance can be explained by a proportion of riders following a circuit not taking them back to the bridge or using a different mode of transportation to return to their starting point.

6.2. BICYCLES CARRIED ON GOLDEN GATE TRANSIT BUSES

Before the opening of the bridge path, cyclists wishing to cross the Richmond-San Rafael bridge only had the option of using Golden Gate Transit buses to cross the bridge. To help assess the impact of the new bridge path on the need to use buses to cross the bridge, Golden Gate Transit provided monthly counts of bikes carried by buses on routes crossing the bridge between May 2015 and May 2022. These counts are summarized in Figure 6-3. Monthly counts before the opening of the bike path in November 2019 are linked by a solid line, while counts following the path opening are linked with a dotted line.

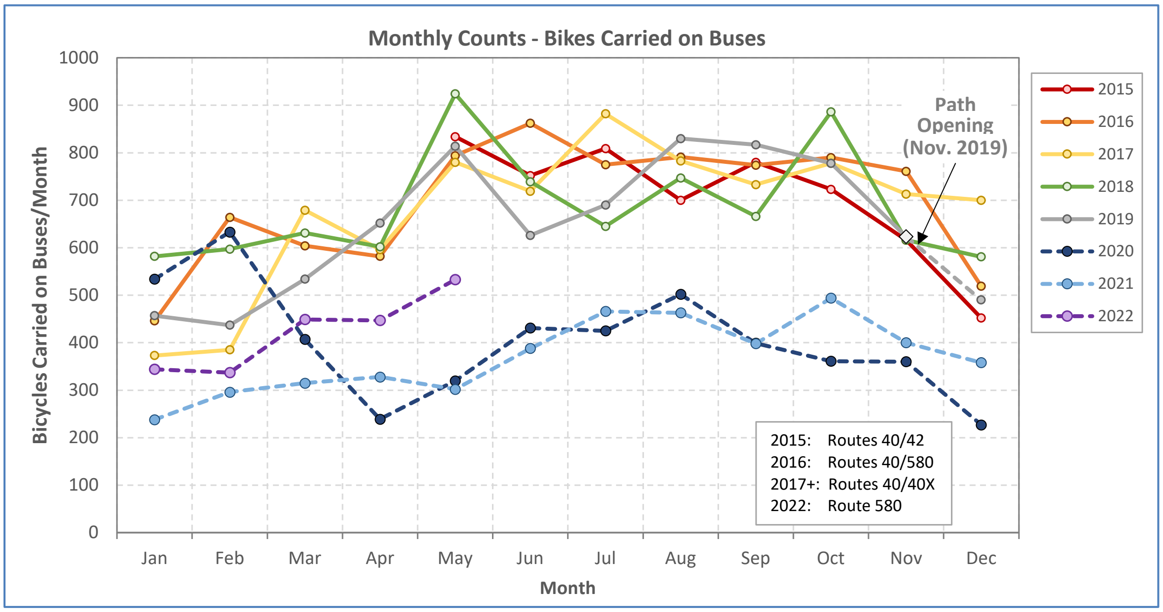

Figure 6-3: Bicycles Carried across Bridge on Golden Gate Transit Buses, 2015-2022

The following key observations can be made from the data:

- Before the bike path opened, buses crossing the bridge carried between 780 and 925 bikes during May, typically the month with the highest demand, and between 375 and 580 bikes in December/January. This corresponds to monthly averages ranging between 465 and 829 bicycles, or 15 to 28 bicycles per day.
- Following the bridge path opening in November 2019, the number of bikes carried across the bridge for December 2019, January 2020, and February 2020 appear to stay within the 2015-2019 historical range.
- A significant drop in counts occurred in March/April 2020, corresponding to the imposition of the first Covid-19 stay-at-home order. Following this drop, counts have remained below previous years while generally mirroring the previously observed annual cyclic pattern.

- Between April 2020 and December 2021, counts corresponded to 50-60% of the 2015-2019 average, with a range between 227 and 466 bicycles/month. However, counts from 2022 show a notable increase. While still being 35% below the 2015-2019 average, the 533 bikes carried in May 2022 represents a 76% increase over the May 2021 counts.
- Since a portion of the reduction in the monthly number of bikes carried over the bridge since 2019 can be associated with Covid-19 effects, it cannot yet be accurately ascertained what portion of the drop may be directly related to a shift in demand from buses to the bridge path. More data needs to be collected to reach a more definitive conclusion.

6.3. TIME-OF-DAY USE PROFILES – BRIDGE PATH

Figure 6-4 illustrates the daily eastbound and westbound bicycle traffic profiles across the bridge for an average weekday, Saturday, and Sunday between April 2021 and May 2022. This is an average of the data recorded by sensors at both ends of the bridge. For each day, the diagrams show the fraction of the total daily flow within each hour. The dotted line further represents the eastbound traffic and the solid line the westbound traffic.

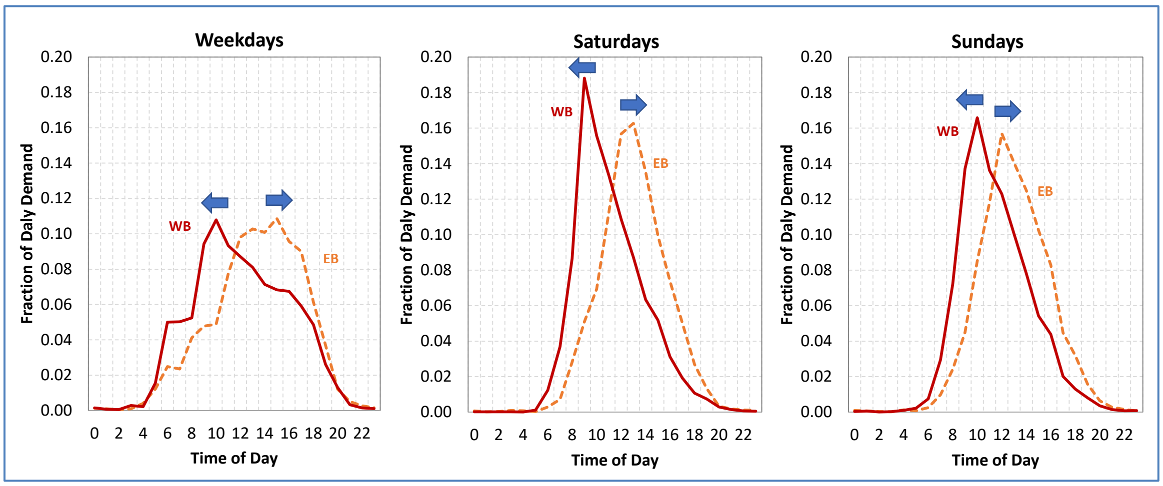

Figure 6-4: Time-of-Day Bicycle Traffic Profiles – Bridge Path

The following observations can be made from the illustrated data:

- On all day types, cyclists mainly travel westbound in the morning and eastbound in the afternoon.
- Westbound traffic generally peaks between 9 and 11 AM, while the eastbound traffic typically peaks around 3 PM on weekdays and around Noon on weekends.
- Weekday bicycle traffic is more spread out across the day, while both Saturday and Sunday traffic show very pronounced peaks.

6.4. SUMMARY OBSERVATIONS

The following are key summary observations from the analysis of bicycle counts:

- Since January 2021, an average of 235 cyclists have traveled eastbound across the bridge on Saturdays, Sundays, and weekday holidays while 213 cyclists have traveled westbound. Depending on the season, daily directional traffic could be as low as 150 or as high as 300 cyclists/direction. On weekdays, daily directional traffic is around 68 cyclists, with lows around 50 and highs around 75 cyclists/direction.
- Weekday traffic is relatively constant, with only minor seasonal variations. Weekend traffic is expectedly highest in summer and lowest during the winter months, and more noticeably affected by weather conditions.
- Path users generally appear to be traveling westbound in the morning and eastbound in the afternoon.
- Golden Gate Transit buses going across the bridge have carried between 337 and 533 bicycles per month from January to May 2022. This corresponds to between 11 and 17 bikes per day. While these counts represent 65-75% of the bikes typically carried over each month during the same period from 2015 to 2019, which averaged between 465 and 829, they are a significant increase over the 2021 counts, which ranged between 238 and 315 bicycles/month.
- While there has been a drop in the number of bicycles carried across the bridge by Golden Gate Transit buses, it is still unclear what part of this drop can be linked to the opening of the path and what part might be a byproduct of the Covid-19 pandemic.

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7. PEDESTRIAN TRAFFIC

This section presents the results of the evaluations assessing the pedestrian traffic across the bridge. The specific elements discussed include:

- Daily pedestrian traffic volumes on the bridge path
- Time-of-day pedestrian flow profiles on the bridge path
- Summary observations

7.1. PEDESTRIAN TRAFFIC – BRIDGE PATH

Figure 7-1 and Figure 7-2 illustrate the average daily eastbound and westbound pedestrian traffic that was recorded by the sensor near the Caltrans Maintenance Yard on the east side of the bridge between August 2020, and mid-June 2022. This is the only sensor that provides valid pedestrian data during the study. Both figures distinguish two data collection periods based on which sensors returned valid pedestrian data (see Figure 5-8):

- **November 2019 – Mid-August 2020:** No valid pedestrian data available.
- **Mid-August 2020 – Present:** Pedestrian counts from the Maintenance Yard counter only.

While pedestrian data were collected from both the initial Richmond and San Rafael sensors between November 2019 and Mid-August 2020, the counts that were returned during this period were unrealistically high, often in the thousands of pedestrians per day. This problem was attributed to placements that caused both sensors to capture some vehicles passing in the nearby traffic lane. The pedestrian counting capability was disabled are both stations in March 2021, leaving only data collected by the Maintenance Yard station from August 2020 onward.

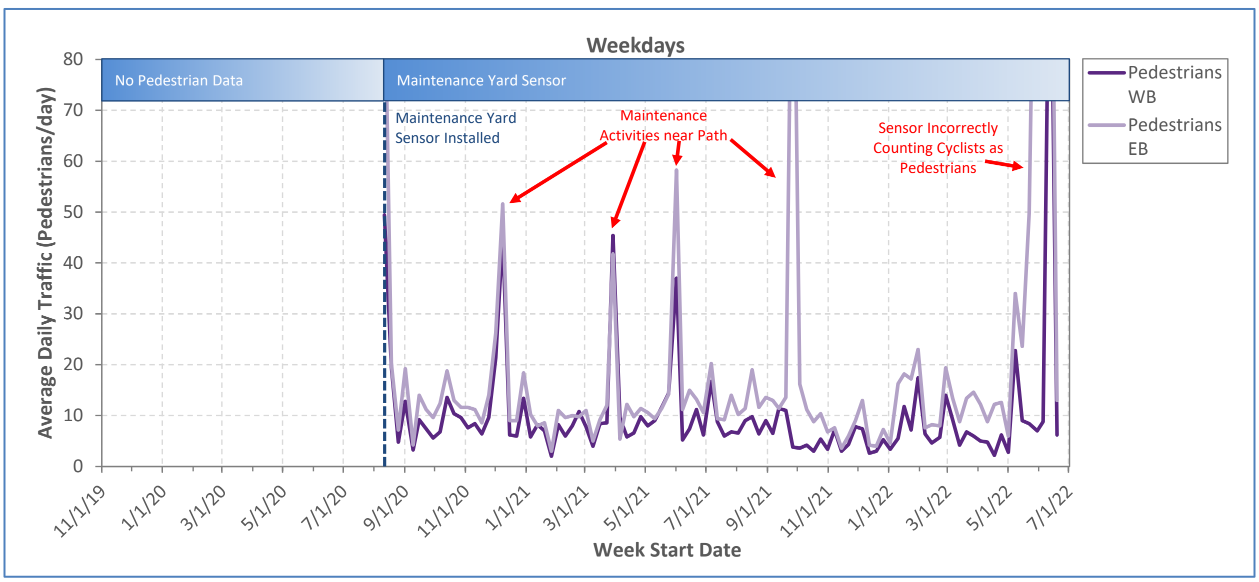

Figure 7-1: Daily Pedestrian Traffic – Richmond Bridge – Weekdays, 2020-2022

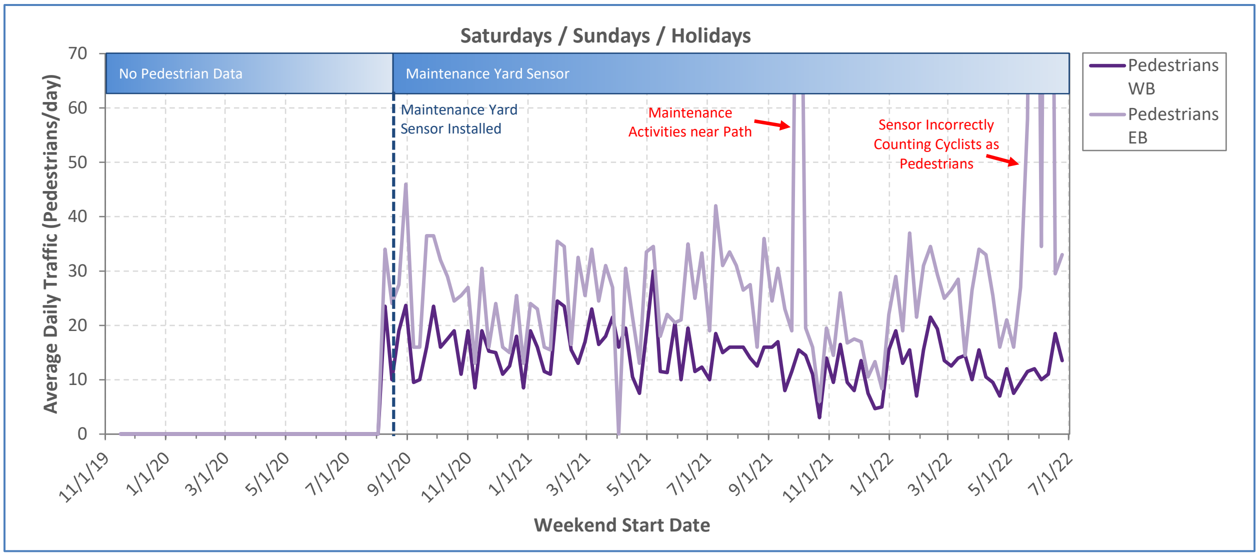

Figure 7-2: Daily Pedestrian Traffic – Richmond Bridge – Weekends, 2020-2022

Comparisons of the eastbound travel profiles captured by the Maintenance Yard counter to the eastbound profile extracted from the San Rafael counter in the fall of 2020 further suggested that the assumed travel direction might be incorrect at one of the two counters. This led to further adjustments being carried out at the end of March 2021 on both the Marin and Maintenance Yard stations to correct the recorded direction of travel and adjust the compiled data.

Finally, the four spikes in pedestrian traffic highlighted in Figure 7-1 in addition to the one in Figure 7-2 are attributed to construction or maintenance activities occurring near the Caltrans Maintenance Yard. In all instances, the sensors likely captured workers walking nearby them. For this reason, data from all marked days have been excluded from all the analyses further reported.

Based on the illustrated data, the following observations can be made about the observed pedestrian use of the bridge path:

- Relatively few pedestrians use the path. Since August 2020, daily weekday traffic has typically ranged between 5 and 20 pedestrians/direction, for an eastbound average of 8 pedestrians/day and a westbound average of 11 pedestrians/day.
- Weekend traffic has ranged between 10 and 40 pedestrians/direction, with occasional higher and lower peaks in both cases. for an eastbound average of 14 pedestrians/day and a westbound average of 24 pedestrians/day.
- The 6-mile length of the bridge may explain the relatively low pedestrian use of the path, as this length may be longer than what most people are willing to walk. It may also explain why some pedestrians may only walk a portion of the bridge.
- Based on field observations, some of the travelers seen going in one direction may be the same individuals seen traveling in the opposite direction, such as individuals using the path to access fishing locations on the path or near the bridge.
- Eastbound pedestrian counts are generally higher than westbound counts. It is unclear whether this is due to different directional volumes or some sensor setup.

- Weekday pedestrian traffic appears to be relatively stable throughout the year, suggesting that a significant portion of the observed pedestrians may be regular users.
- Both weekday and weekend traffic exhibit some cyclical pattern, with slightly higher observed traffic in the summer than in winter. This may likely be due to weather effects.

In the above assessment, the number of pedestrians using the path is likely to be underestimated. This is because all the collected data is based on a single sensor located on the Richmond side of the bridge. Due to the presence of the vista point and its parking area, some individuals likely access the path from the Marin County side and walk a portion of the bridge before returning to the vista point. Unless they have reached the Caltrans Maintenance Yard on the other side of the bridge, none of these individuals were therefore captured in the statistics.

Another unknown is the proportion of individuals walking on the path to reach a fishing location near the foot of the bridge. On the Marin County side of the bridge, individuals are frequently observed walking along the path to go set up fishing stations along the shoreline, on or off the path. These individuals would usually park their vehicle at the nearby vista point and would rarely fully cross the bridge. Since the only pedestrian counter is located on the Richmond side, these individuals were likely not captured in the pedestrian statistics. Some fishermen are also observed walking on the path on the Richmond side but to a much lower frequency than on the Marin County side.

7.2. TIME-OF-DAY USE PROFILES – BRIDGE PATH

Figure 7-3 illustrates the average eastbound and westbound daily pedestrian traffic profiles near the Caltrans Maintenance Yard in Richmond for weekdays, Saturdays, and Sundays. This is based on data recorded between April 2021 and May 2022. As indicated in the previous section, no valid pedestrian data were collected from the other sensors around the bridge. For each day, the diagrams show the fraction of the total daily flow seen within each hour compared to the total daily flow.

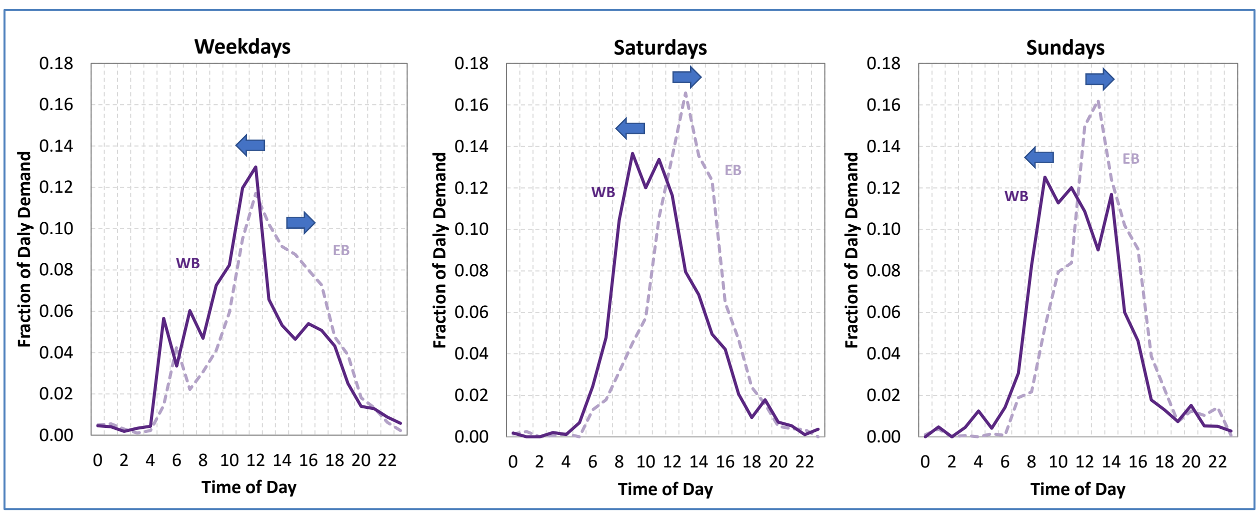

Figure 7-3: Average Daily Pedestrian Traffic Profiles, Maintenance Yard

The following observations can be made regarding the pedestrian traffic on the Richmond side of the bridge:

- More pedestrians travel westbound towards Marin County in the morning and eastbound towards Richmond in the afternoon. This is like the observed bicycle traffic.
- Westbound pedestrian traffic typically peaks around 11 AM on weekdays and around 9-10 AM on weekends, while eastbound traffic generally peaks around 1 PM.
- Pedestrian traffic is generally more spread out over time during weekdays than on weekends.

7.3. SUMMARY OBSERVATIONS

The following is a summary of key observations from the analysis of pedestrians counts on the Richmond side of the bridge:

- Pedestrian traffic on the bridge is relatively low. Average weekday eastbound traffic is only 11 pedestrians/day while westbound traffic is around 8 pedestrians/day. Weekend eastbound traffic averages 24 pedestrians/day while westbound traffic averages 14 pedestrians/day.
- A daily directional pattern appears to exist, with pedestrians mainly traveling westbound in the morning and eastbound in the afternoon.
- Both weekday and weekend traffic exhibit some cyclical pattern, with slightly higher observed traffic in the summer, compared to winter. This may likely be due to weather effects.
- The estimated pedestrian use is likely underestimated as the counts are based on a single sensor located on the Richmond side of the bridge. This sensor would not have captured individuals accessing the path from the vista point in Marin County and turning back before having fully crossed the bridge.
- The 4-mile length of the bridge may explain the low pedestrian demand.
- Fishermen have been observed using the path to access a location to cast their fishing lines, either on the shore or the path itself. Such individuals are more often seen on the Marin County side of the bridge, where they use the vista parking lot as a staging area.

8. TRAFFIC IMPACTS

This section presents the results of the evaluations that were conducted to assess the impacts on traffic of the modifications made to the bridge. Specific items covered in the section include:

- Observed changes in traffic demand over the evaluation period
- Impacts of opening the lower deck shoulder lane on eastbound traffic in Marin County
- Impact of converting the upper deck shoulder lane into a barrier-separated bike/pedestrian path on westbound traffic in Richmond and on the bridge

8.1. CHANGES IN BRIDGE TRAFFIC OVER THE EVALUATION PERIOD

Before evaluating the impacts of the various modifications made, traffic volumes around the bridge were reviewed to determine to which extent observed changes in speeds and travel times could be the result of underlying changes in traffic demand. Two specific aspects of traffic demands are evaluated below:

- Changes in daily total traffic volumes
- Changes in daily traffic profiles

8.1.1. DAILY TRAFFIC VOLUMES

Changes in traffic volumes were first analyzed using data from PeMS stations on I-580 near Canal Boulevard in Richmond (stations 400639 and 400738 in Figure 5-1), as these are the only stations having continuously provided good data between 2015 and 2021. While the data do not technically represent traffic on the bridge, most vehicles traveling at this location either come from it or travel towards it. Any changes in traffic there will thus be indicative of changes in traffic across the bridge. The westbound station is also sufficiently far from the bridge to be less affected by the congestion that frequently builds up upstream of the toll plaza.

Figure 8-1 to Figure 8-3 illustrates the eastbound and westbound daily flows that were measured near Canal Boulevard on weekdays, Saturdays, and Sundays from January 2015 to mid-December 2021. Data from 2022 are not included as the sensors stopped working in December 2021. In each figure, the dots represent specific day measurements while the solid lines represent moving averages across two weeks for weekdays and four weeks for Saturdays and Sundays. Only days with 90% or more observed data are included to avoid biasing results with less accurate estimates from the PeMS imputation process. Days affected by known major incidents are also ignored.

Before the Covid-19 pandemic, traffic volumes were slowly increasing year-over-year, with some seasonal patterns. Pre-pandemic volumes typically ranged between 30,000 and 43,000 vehicles/day, depending on the direction and day of the week. Through March and April 2020, daily traffic dropped by roughly 55% on weekdays and 66% on Saturdays and Sundays because of imposed Covid-19 travel restrictions. Following a quick partial rebound through June and July 2020, traffic demand went through another dip from December 2020 through February 2021 as the country experienced a second wave of Covid-19 infections. Since then, daily traffic volumes have rebounded significantly but have generally remained below pre-Covid levels, particularly on weekdays.

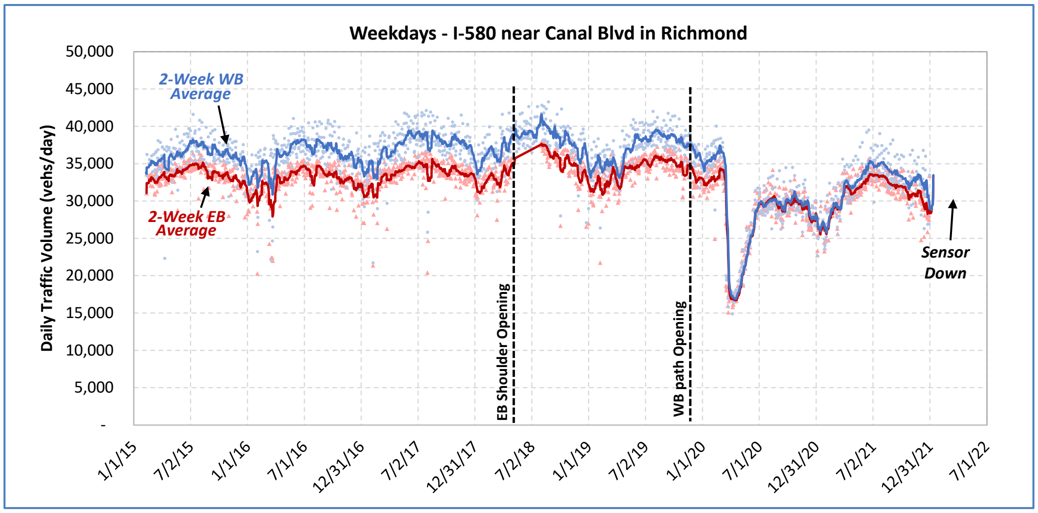

Figure 8-1: Traffic Volumes on I-580 near Canal Boulevard in Richmond – Weekdays, 2015-2022

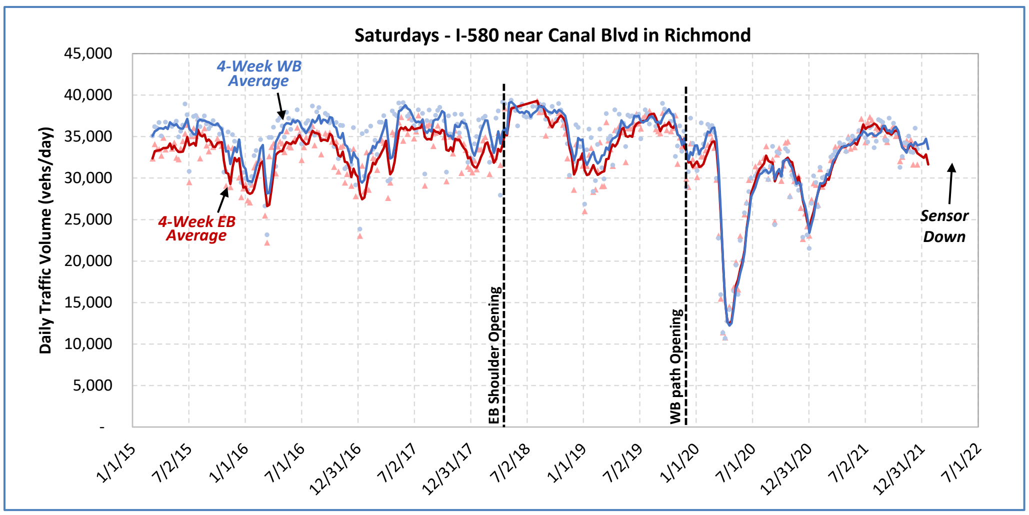

Figure 8-2: Traffic Volumes on I-580 near Canal Boulevard in Richmond – Saturdays, 2015-2022

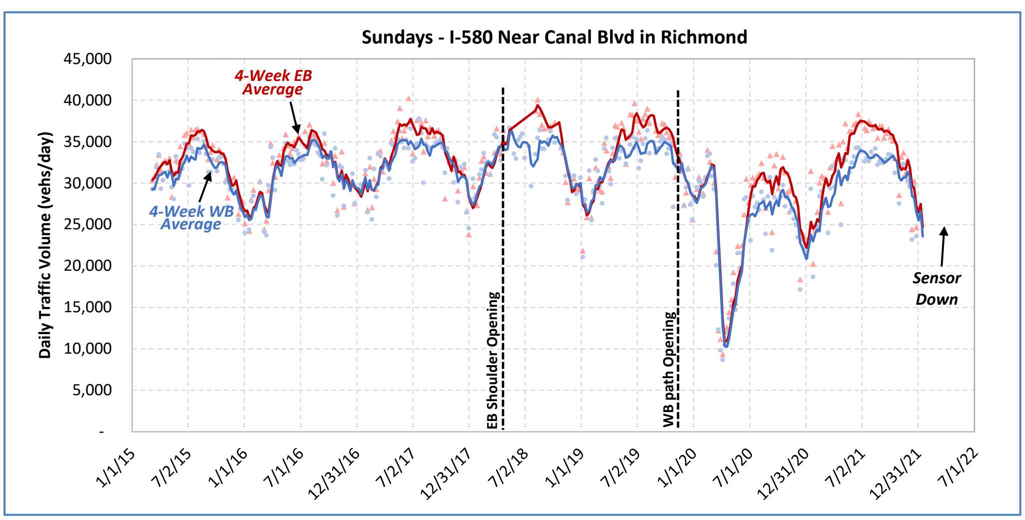

Figure 8-3: Traffic Volumes on I-580 near Canal Boulevard in Richmond – Sundays, 2015-2022

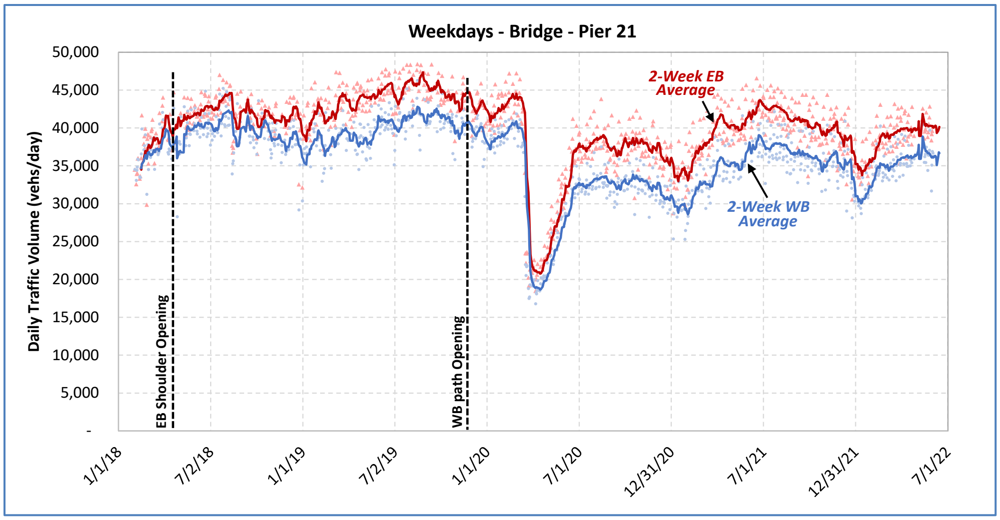

Figure 8-4: Traffic Volumes on Bridge – Weekdays, 2018-2022

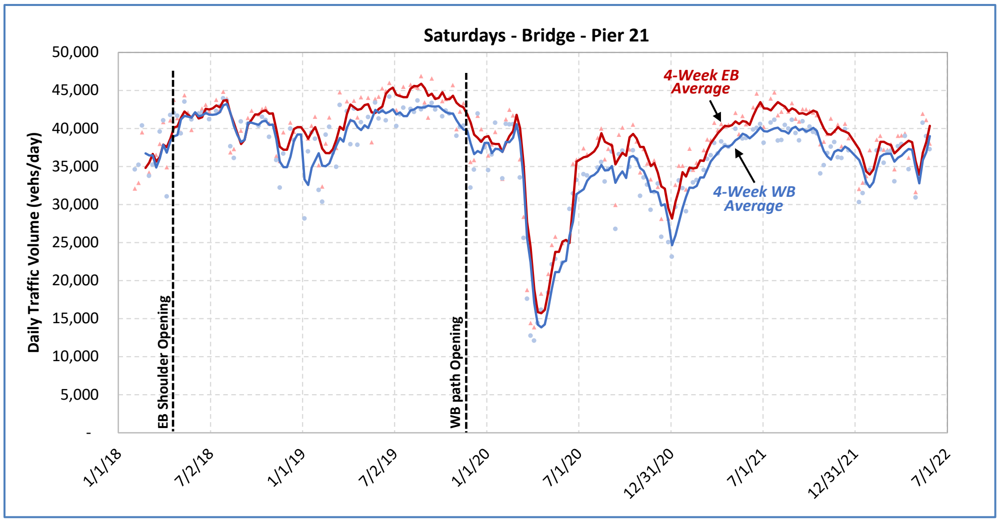

Figure 8-5: Traffic Volumes on Bridge – Saturdays, 2018-2022

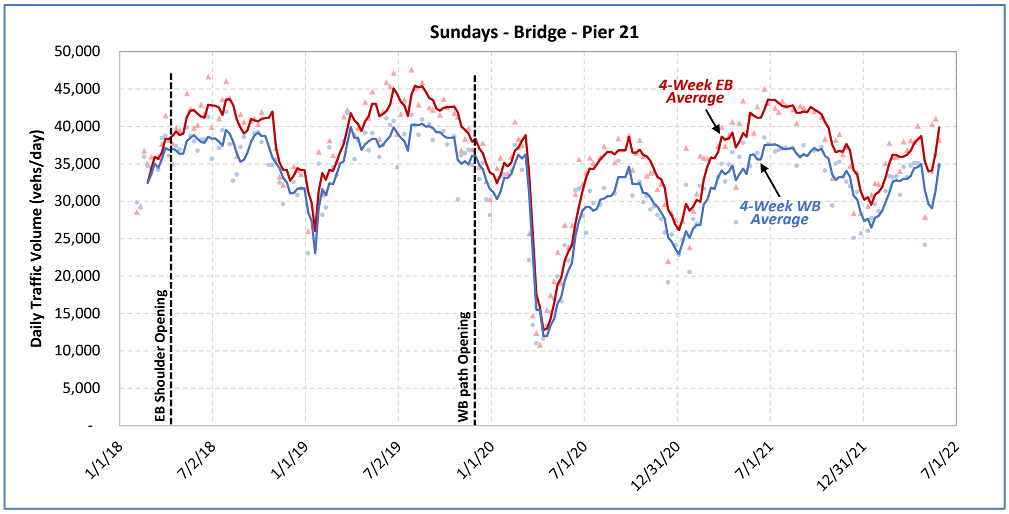

Figure 8-6: Traffic Volumes on Bridge – Sundays, 2018-2022

For comparison purposes, Figure 8-4 through Figure 8-6 illustrate observed traffic volumes near Pier 21 on the west end of the bridge between February 2018 and May 2022. Earlier data are not plotted as this is the only period for which data has been automatically collected by PeMS sensors on the bridge. While data from Pier 35 in the middle of the bridge were initially thought to be ideal for the assessment, a comparison to counts from the toll plaza revealed that sensors at this location were likely undercounting traffic, leading to the choice to use data from Pier 21 instead. Similar patterns to those observed near Canal Boulevard are observed, but with daily traffic ranging between 35,000 and 48,000 vehicles. This increase in traffic compared to the Canal Boulevard location is mainly the result of vehicles entering or exiting the freeway at the Castro Street/Richmond Parkway interchange.

8.1.2. TIME-OF-DAY TRAFFIC PATTERNS

Figure 8-7 to Figure 8-12 present average daily flow profiles across the bridge for weekdays, Saturdays, and Sundays for each year with available data between 2015 and 2022. For the eastbound direction, data are from the PeMS station in the middle of the bridge (Pier 35), which only started to produce data in February 2018. For the westbound direction, data are from the toll plaza counts. Each figure presents two average profiles: one covering February, March, and April, and the other covering late September, October, and early November. All profiles cover the same weeks year after year, except for Spring 2020, where data past March 15 were not considered to avoid including the sudden drop in traffic related to the newly imposed Covid-related stay-at-home order. In each diagram, dotted lines are further used to mark data associated with the before evaluation period and solid lines to mark data for the after period.

The following key observations can be made from the illustrated daily profiles:

- While data from Figure 8-1 to Figure 8-6 presented in Section 8.1.1 all indicate that 2021 and 2022 daily traffic volumes remain below pre-Covid levels, the profiles presented here indicate that this is largely due to off-peak flows remaining below pre-Covid levels.
- Daily peak traffic flows for 2021 and 2022 are generally back close to pre-pandemic levels, if not already exceeding them as in the case of the Saturday and Sunday profiles from February/March/April. The only exception is for westbound morning peak flows, which remain below the 2015-2019 historical averages.
- The fact that westbound weekday peak morning flows remain below levels observed before the November 2019 upper deck modifications will be explained in 8.3.2. This is likely a consequence of a reduced carrying capacity across the bridge due to effects associated with the installation of the multi-use path barrier and a shorter merge area at the foot of the bridge.
- The spring eastbound profiles show significantly higher afternoon peak flows for 2019-2022 than for 2016 and 2018, the only two years for which data is available before the lower deck modifications. This is due to the availability of an additional lane to cross the bridge. A similar observation cannot be made on the fall profiles as bridge sensors only started to produce data after the April 2018 modification. While some eastbound flow data were also collected at the toll plaza in May 2016 using radar detectors, these were deemed unrealistically too high in relation to the bridge carrying capacity and assumed to be invalid.

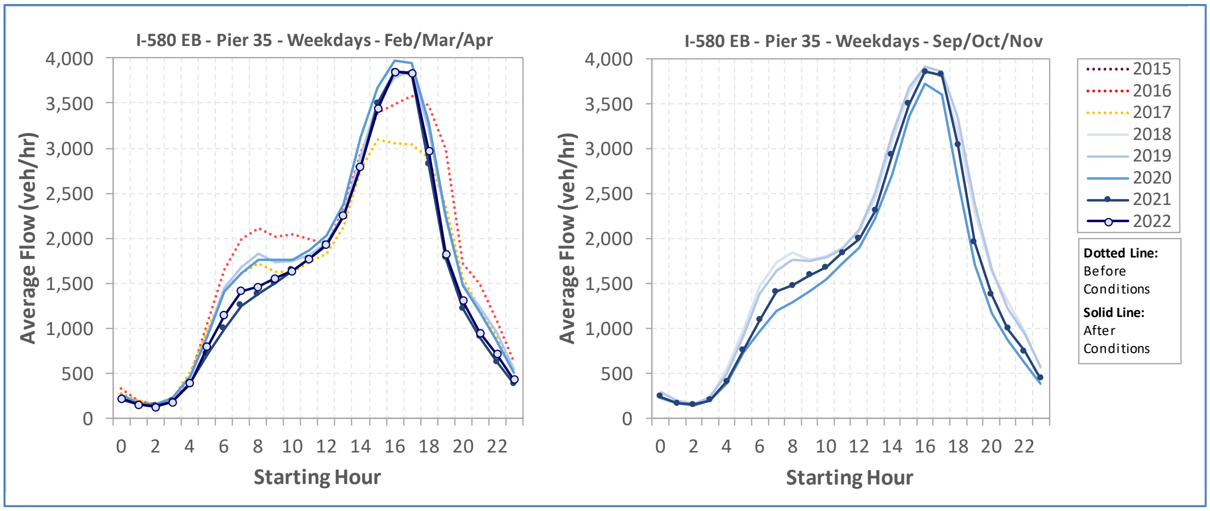

Figure 8-7: Daily Traffic Flow Profile – Bridge EB – Weekdays, 2015-2022

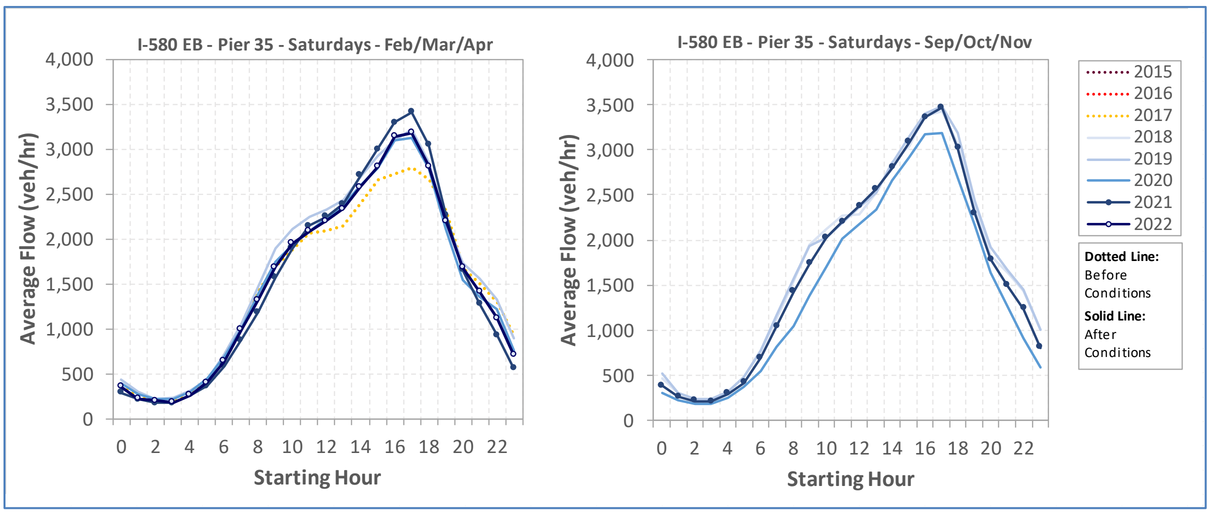

Figure 8-8: Daily Traffic Flow Profile – Bridge EB – Saturdays, 2015-2022

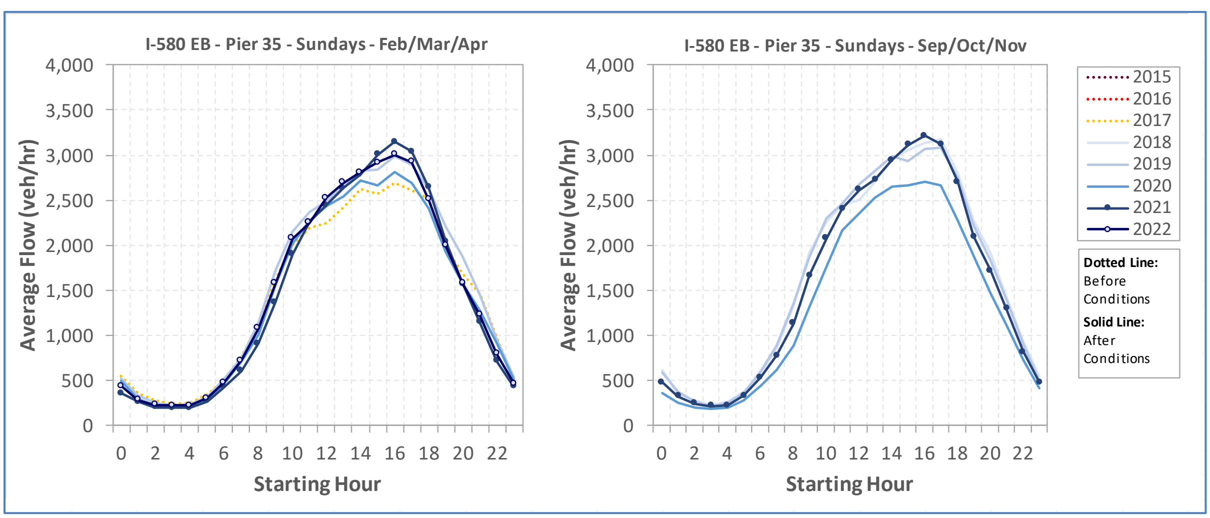

Figure 8-9: Daily Traffic Flow Profile – Bridge EB – Sundays, 2015-2022

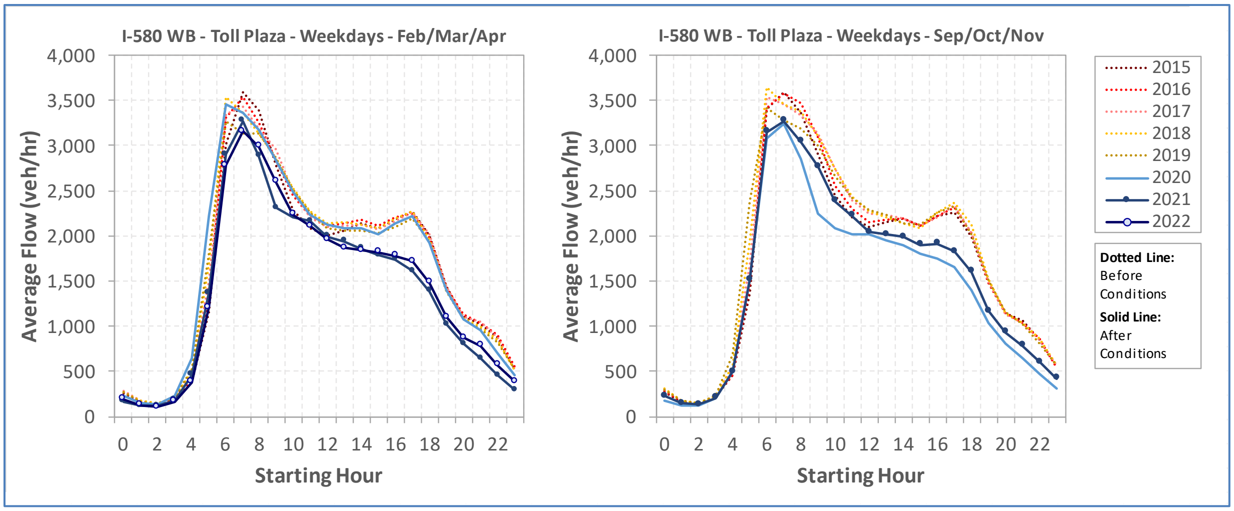

Figure 8-10: Daily Traffic Flow Profile – Bridge WB – Weekdays, 2015-2021

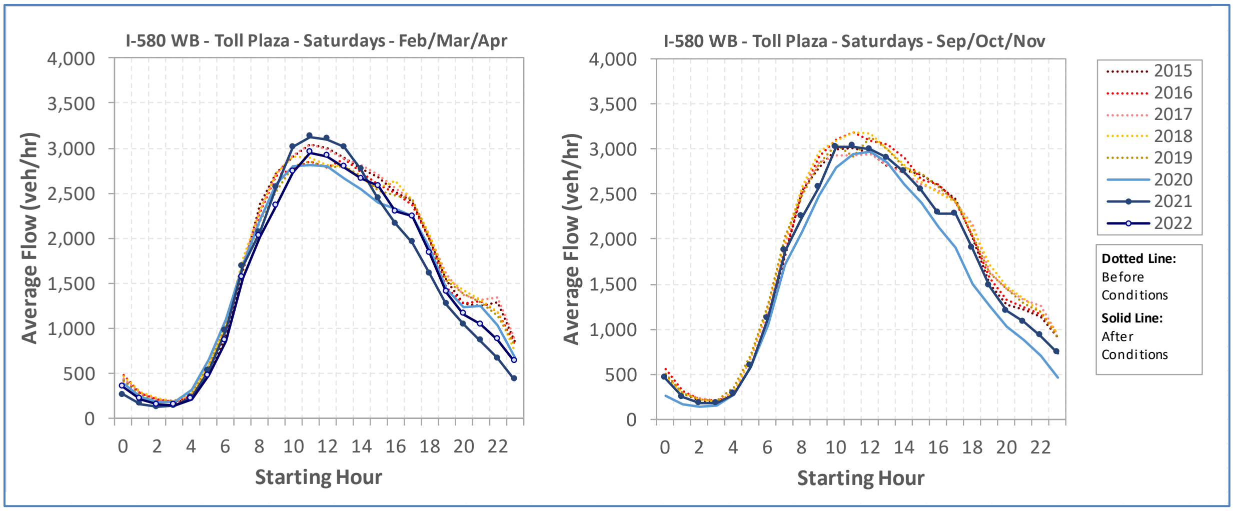

Figure 8-11: Daily Traffic Flow Profile – Bridge WB – Saturdays, 2015-2021

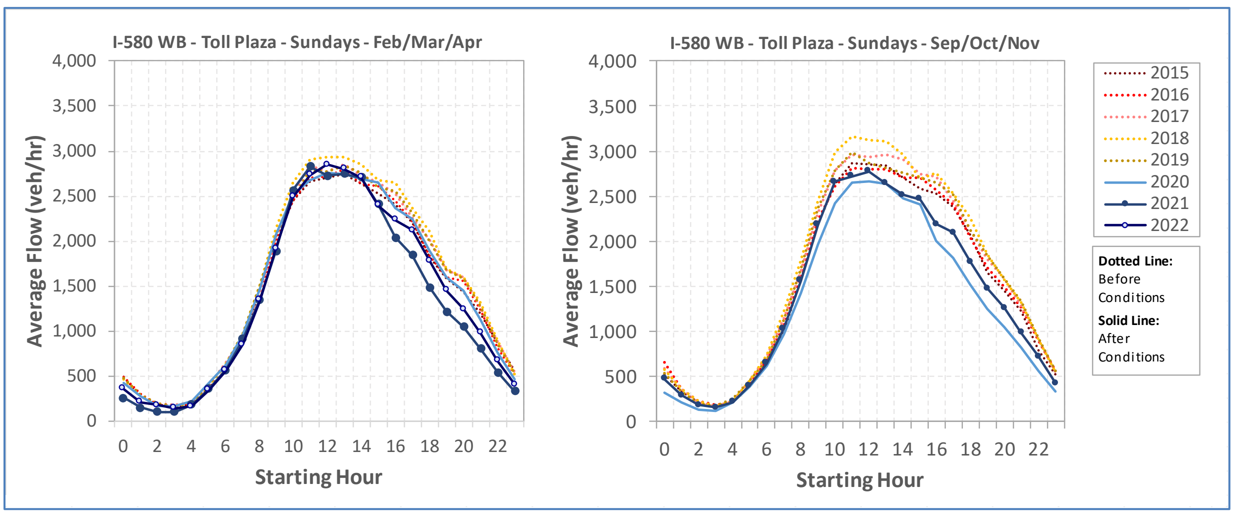

Figure 8-12: Daily Traffic Flow Profile – Bridge WB – Sundays, 2015-2021

8.2. IMPACTS ON EASTBOUND BRIDGE TRAFFIC

This section evaluates the impacts on traffic of the conversion of the eastbound lower deck shoulder lane into a part-time traffic lane. This evaluation covers the following elements:

- Eastbound freeway congestion before the modification
- Observed traffic on the shoulder lane when open
- Motorist compliance with the shoulder lane open/close periods
- Impacts of the new lane on the bridge carrying capacity
- Impacts on I-580 East traffic conditions between the US-101/I-580 interchange and the bridge
- Impacts on US-101 North travel times between Sir Francis Drake Boulevard and the I-580 interchange
- Impacts on Marin County arterials parallel to I-580 East, such as Sir Francis Drake Boulevard, Francisco Boulevard, and Andersen Drive
- Impacts on I-580 East ramp traffic at Bellam Boulevard and Main Street

8.2.1. INITIAL CONDITIONS

Figure 8-13 to Figure 8-15 illustrate the typical extent of the afternoon congestion before the shoulder lane opening on I-580 East in Marin County, the section of US-101 North south of the I-580 interchange, and the section of US-101 South north of the I-580 interchange. Data represents average observed speeds between mid-September and mid-November 2017, the last fall before the modification.

At that time, congestion along I-580 East was primarily caused by the number of traffic lanes reducing from three to two near the entrance of the bridge. As illustrated, congestion on I-580 East generally extended up to the US-101 interchange on weekdays, Saturdays, and Sundays. Weekday traffic on the

Figure 8-13: Extent of Congestion on I-580 East in Marin County before Bridge Modifications

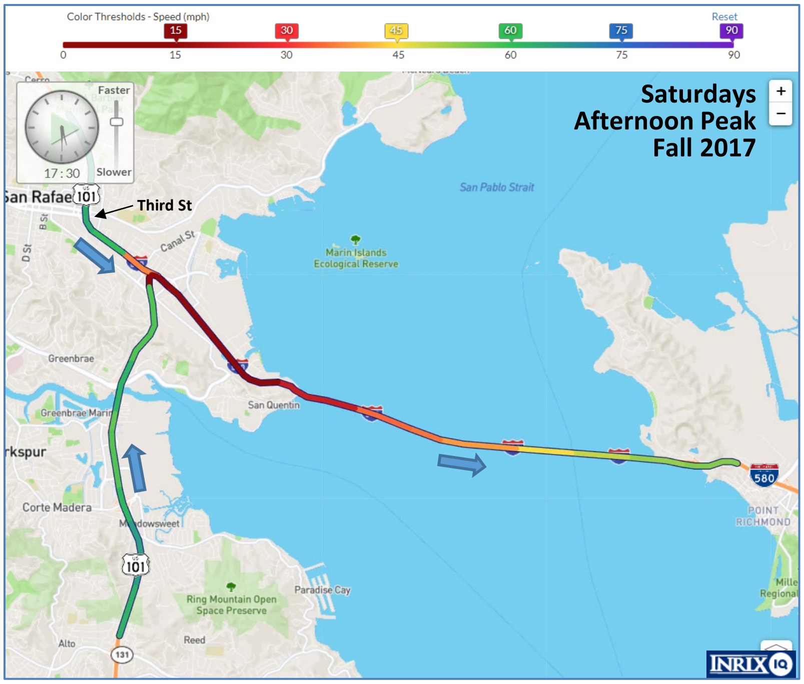

Figure 8-14: Extent of Congestion on I-580 East in Marin County before Bridge Modifications

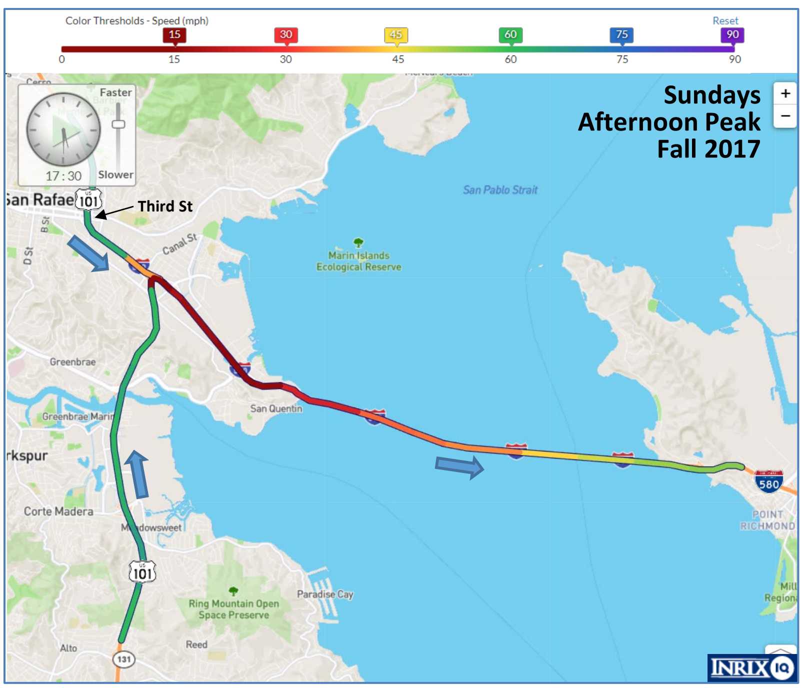

Figure 8-15: Extent of Congestion on I-580 East in Marin County before Bridge Modifications

US-101 North between Sir Francis Drake Boulevard and the I-580 interchange also appeared affected. While part of the US-101 congestion could be attributed to the I-580 East congestion, another part could also be explained by traffic frictions between the I-580 and Third Street interchanges caused by the merging of the US-101 North and I-580 West traffic. Congestion on Saturdays and Sundays also typically extended up to the US-101 interchange but did not appear to affect traffic along US-101 North.

8.2.2. SHOULDER LANE USE

Figure 8-16 illustrates the average flow rates on the shoulder lane between February and April 2021. More recent data are not used, as data for late 2021 and early 2022 are heavily affected by lane closures associated with bridge maintenance activities. As can be seen, vehicles typically start to use the lane at 2:00 PM, when it opens, and stop using it around 7:00 PM, when it officially closes. Weekday traffic typically peaked around 5:30 PM at a rate of about 1050 vehicles/hour, on Saturdays between 4:30 PM and 6:30 PM at a rate around 650 vehicles/hour, and Sundays around 5:00 PM at a rate around 600 vehicles/hour.

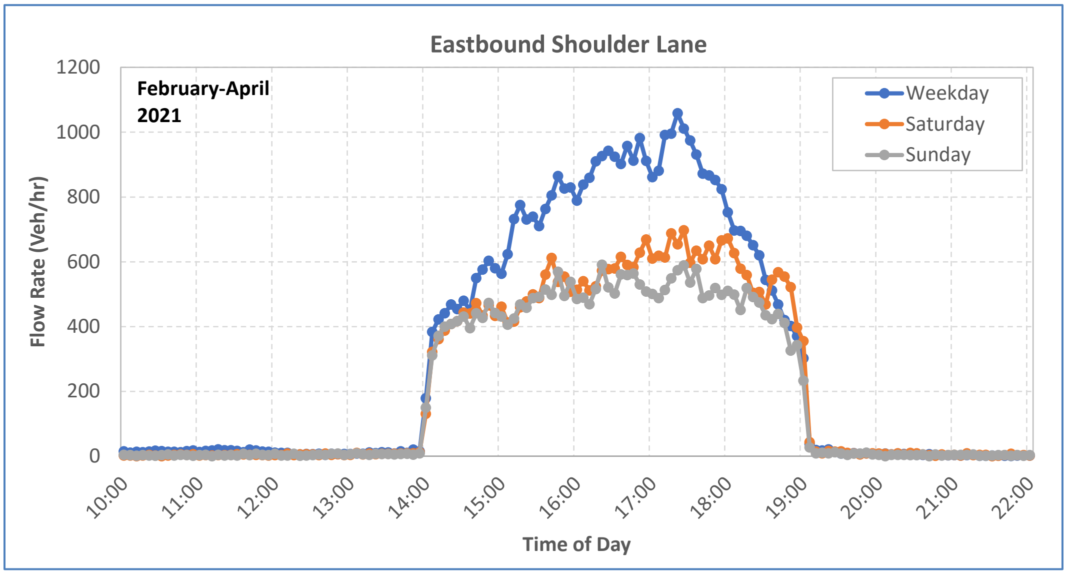

Figure 8-16: Lower Deck Shoulder Lane - Flow Rate

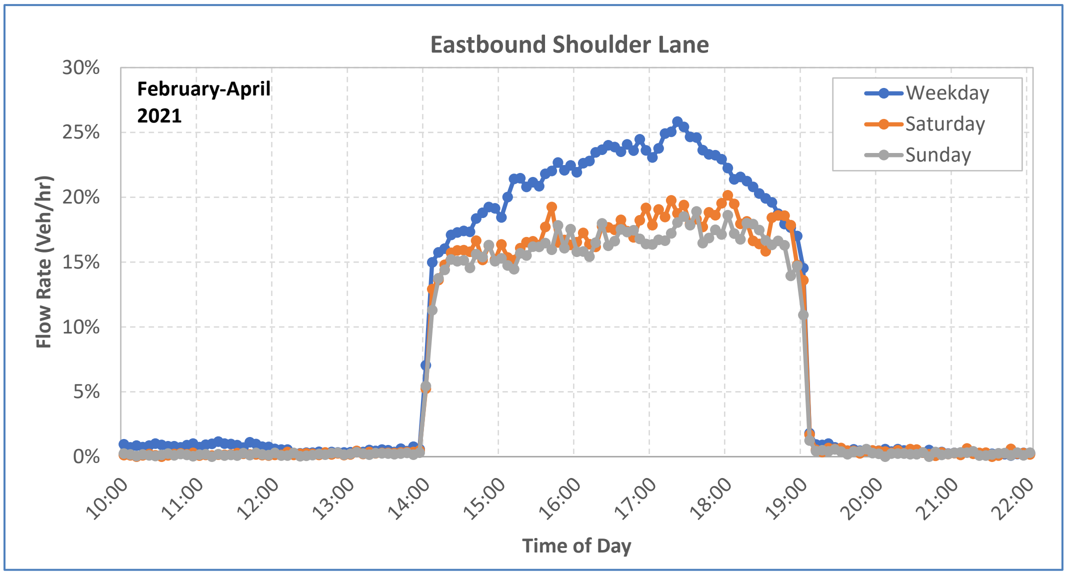

Figure 8-17: Lower Deck Shoulder Lane - Percent of Total Eastbound Flow

Figure 8-17 provides another view of the data Figure 8-16 by illustrating the percentage of vehicles on the lower deck using the shoulder lane. At its opening, about 15% of vehicles are on it. On weekdays, the proportion of traffic on the lane rose to about 25% between 5 PM and 6 PM before dropping again to 15% before its closure. On weekends, less than 20% of traffic is seen on the lane. If traffic were distributed equally among all eastbound lanes, we should instead have about 33% of traffic on each lane. The fact that utilization never roses above 25% indicates that motorists generally prefer to drive on the two regular lanes. This might be due to habits. The marking of the shoulder lane with a solid lane may also inadvertently entice motorists to stay on the two left lanes.

8.2.3. SHOULDER LANE COMPLIANCE

Based on the data in Figure 8-16, there appears to be relatively high compliance with the open/close periods of the shoulder lane. Relatively few vehicles are seen on the shoulder before 2 PM and after 7 PM when the two regular bridge traffic lanes are not affected by closures. On average, less than one vehicle per hour is observed using the shoulder at night, and between 5 and 16 vehicles per hour during other portions of the day when it is formally closed. These observations translate into a 99.6% compliance rate before 2 PM and after 7 PM on weekdays and Saturdays, and a 99.7% compliance rate on Sundays.

Some of the observed shoulder lane traffic outside its open period might be attributed to maintenance vehicles, tow trucks, and police vehicles. However, CHP officers have indicated observing vehicles using the lane to pass other vehicles. There is also a suspicion that some motorists may not understand the significance of the green arrow/yellow X/red X displayed on top of each lane, resulting in some motorists not realizing that the shoulder lane may be closed at some times.

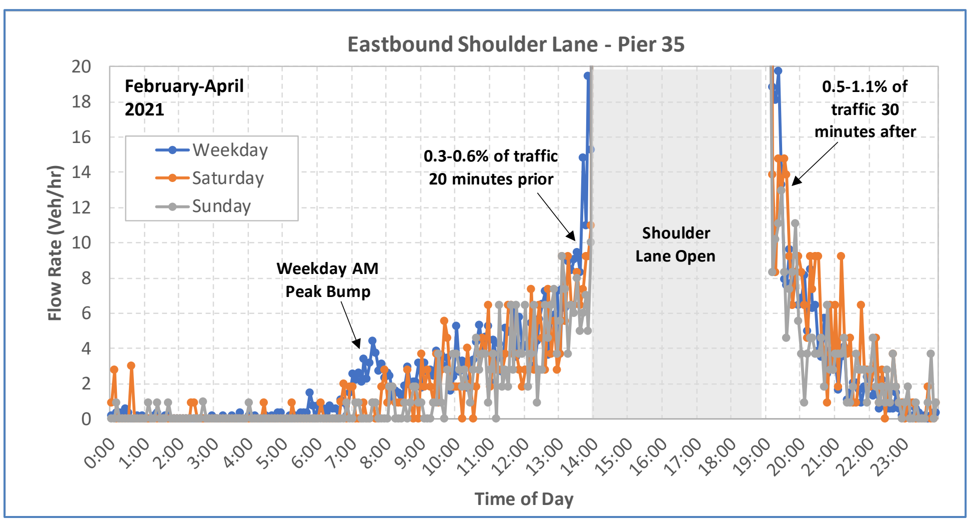

Figure 8-18: Lower Deck Shoulder Lane – Flow Rate When Closed

Figure 8-18 indicates that the periods of highest non-compliance are usually right before the shoulder lane opens and after it closes, typically 20 minutes before its opening and up to 30 minutes following its closure. A short peak in shoulder lane usage is also observed during the weekday morning AM peak period. On weekdays, shoulder traffic in the 20 minutes before its opening typically represents 0.6% of the total observed traffic. On Saturdays and Sundays, non-compliant traffic represents 0.4% and 0.3% of the 20-minute traffic respectively. For the 30 minutes following the closing of the shoulder, non-compliant traffic typically represents 1.1% of weekday traffic and 0.5% of Saturday and Sunday traffic.

Non-compliance use of the shoulder outside its opening period is believed to have a minimal impact on traffic operations, largely due to its relatively small share of the overall traffic and because some of the observed traffic might be legitimate use by maintenance, police, or other vehicles. However, the use of the lane by non-authorized users may carry increased safety risks, as motorists traveling on the right lane may be surprised by vehicles traveling on the shoulder.

8.2.4. IMPACT ON LOWER DECK CAPACITY

Figure 8-19 illustrates peak eastbound hourly flows on the bridge near its entrance on weekdays, Saturdays, and Sundays between February 2018, when the bridge sensors were activated, and mid-June 2022. As expected, the data appears to indicate that the opening of the shoulder lane has increased peak flows across the bridge. From February to mid-April 2018, between 3,300 and 3,570 vehicles/hour were observed crossing the bridge during the afternoon peak. Since the opening of the shoulder lane, peak flows have mainly ranged between 3,750 and 4,500 vehicles/hour, depending on the observation day, representing a 13-26% capacity increase.

Figure 8-20 presents an additional look at the capacity increase discussed above by comparing eastbound flows measured in May 2016 at the toll plaza to flows captured at the same location in March 2022. Similar to the previous figure, an increase in peak afternoon flow rate from 3,500-3,600 vehicles/hour to around 4,500 vehicles/hour can be observed. The figure also indicates a potential reduction in the duration of the afternoon peak period associated with the elimination of congestion on the Marin side of the bridge. This is illustrated by the earlier drop in traffic after 6 PM. While some of this drop may be due to lower traffic demand due to the Covid-19 pandemic, a portion may be due to fewer vehicles being held back on the Marin side of the bridge. Similar to other analyses, morning and evening flow reductions are primarily due to Covid-related effects.

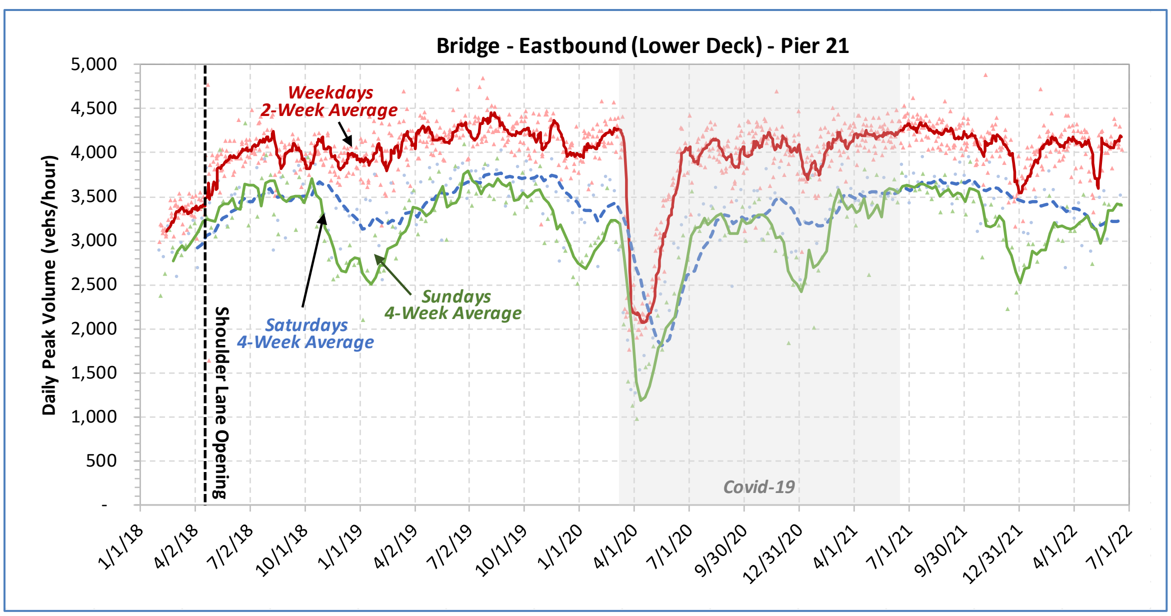

Figure 8-19: Average Peak Traffic Flow at Entrance of Bridge – Eastbound, 2018-2022

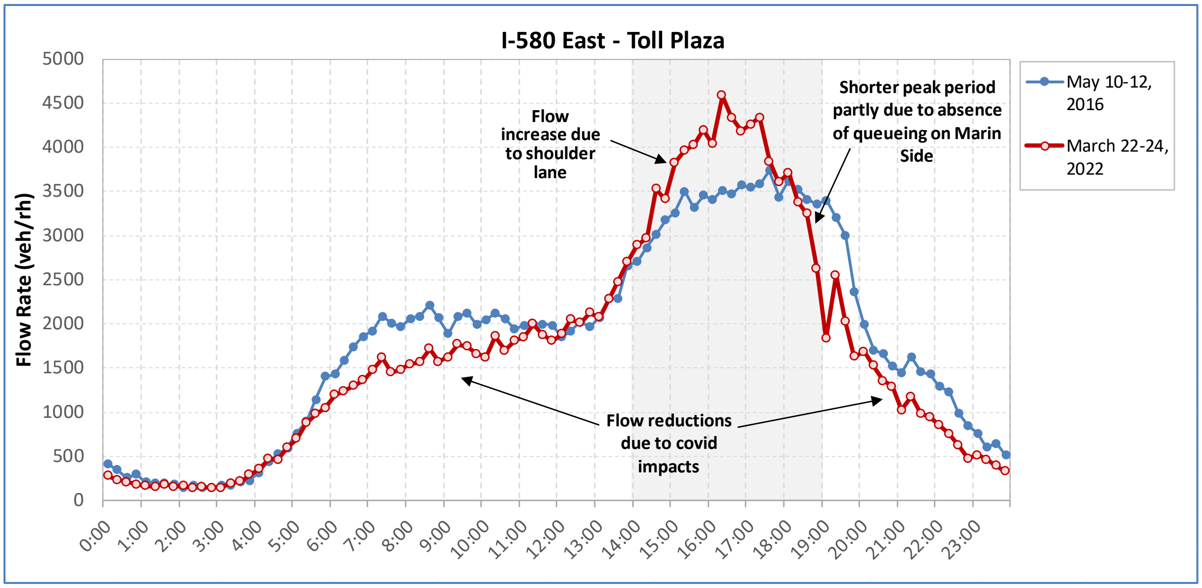

Figure 8-20: Observed Peak Traffic Flow at Toll Plaza – Eastbound, 2016 and 2022

An additional assessment can be made using data from freeway sensors just downstream of the Canal Boulevard off-ramp (PeMS station #400639) that has been continuously recorded since February 2015. While these sensors do not capture traffic that would have exited at the Castro Street and Richmond Parkway off-ramps, any significant increase in traffic crossing the bridge would normally translate into higher flows at this location. The peak flows measured there are shown in Figure 8-21. Before the opening, average peak weekday flows hovered around 2,425 vehicles/hour. After the opening, peak flows of around 2,825 vehicles/hour have been observed. This is a 16% increase that is in line with the data in Figure 8-19. While higher flows in the 3,250 vehicle/hour range appeared to have occurred immediately following the opening, motorists adjusting their travel time in response to the absence of congestion on the bridge approach may have resulted in the current lower peak flows.

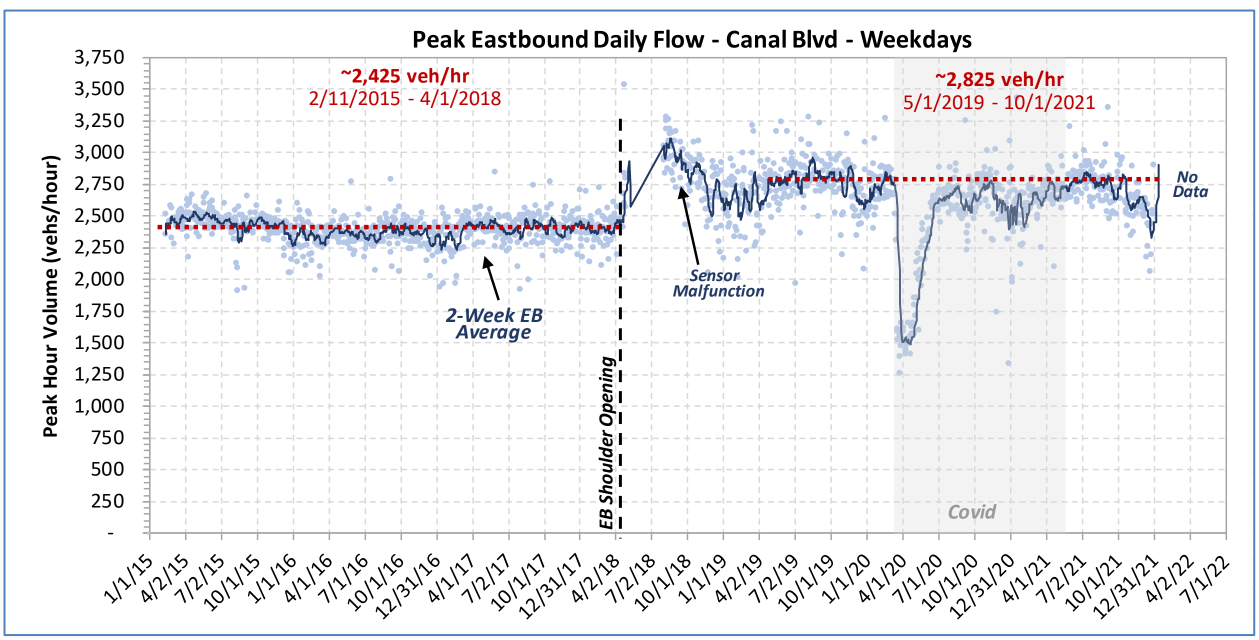

Figure 8-21: Average Peak Traffic Flow on I-580 East near Canal Boulevard, 2015-2021

Data collected from PeMS further suggests that peak hour flows on Saturdays and Sundays near Canal Boulevard have similarly increased by 15-16% following the shoulder lane opening. Prior average daily peak flows ranged from 2,250 and 2,750 vehicles/hour, while peak flows now range between 2,750 and 3,200 vehicles/hour.

The observed increases are a direct result of the added capacity provided by the third traffic lane. Before the modifications, the two existing lanes did not provide sufficient capacity to accommodate peak eastbound traffic on weekdays and weekends. This caused traffic to back up along I-580 East up to the US-101 interchange, as was illustrated earlier in Figure 8-13 to Figure 8-15. With the added capacity, the bridge is now able to better handle the peak traffic, thus explaining the current absence of congestion on the I-580 East bridge approach.

Another key observation is that the increase in maximum flow does not correspond to the full capacity of a new traffic lane. In the initial two-lane setup, an average peak flow of 3,500 vehicles/hour would translate into 1,750 vehicles/hour/lane. With three lanes of traffic, a peak flow of 4,500 vehicles/hour translates instead into an average flow of 1,500 vehicles/hour/lane. This apparent reduction in lane capacity is explained by vehicles not fully utilizing all the available lanes. As was shown in Figure 8-17, less than 25% of the weekday traffic and 20% of the weekend traffic uses the shoulder lane. If traffic were equally distributed along all lanes, each lane would instead carry 33% of the total traffic. A typical distribution is 40% on the left lane, 36-40% on the middle lane, and 20-25% on the shoulder lane. Since the shoulder lane is not fully utilized, this translates into some unused capacity.

8.2.5. TRAVEL CONDITIONS ON EASTBOUND APPROACH AND BRIDGE

The opening of the eastbound shoulder lane to traffic during the afternoon peak has significantly reduced congestion on the Marin County approach to the bridge. This change can be observed in Figure 8-22 to Figure 8-24, which illustrates the average observed speeds on I-580 East from the US-101 interchange to the toll plaza on weekdays, Saturdays, and Sundays from mid-September to mid-November for each year between 2015 and 2021. Before the April 2018 modification, speeds typically dropped below 15 mph from approximately 3:00 to 7:30 PM from the US-101 to about 0.5 miles onto the bridge. After the opening, speeds have remained at or above 50 mph in the absence of disturbances from incidents or bridge/roadway maintenance activities.

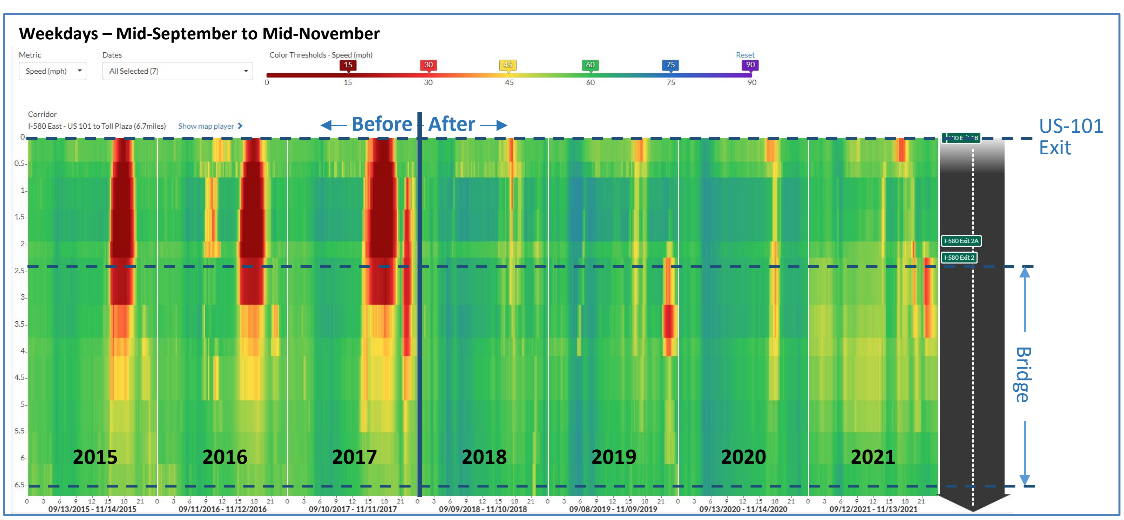

Figure 8-22: Speed Maps – I-580 East – US-101 to Toll Plaza – Weekdays, Fall 2015-2021

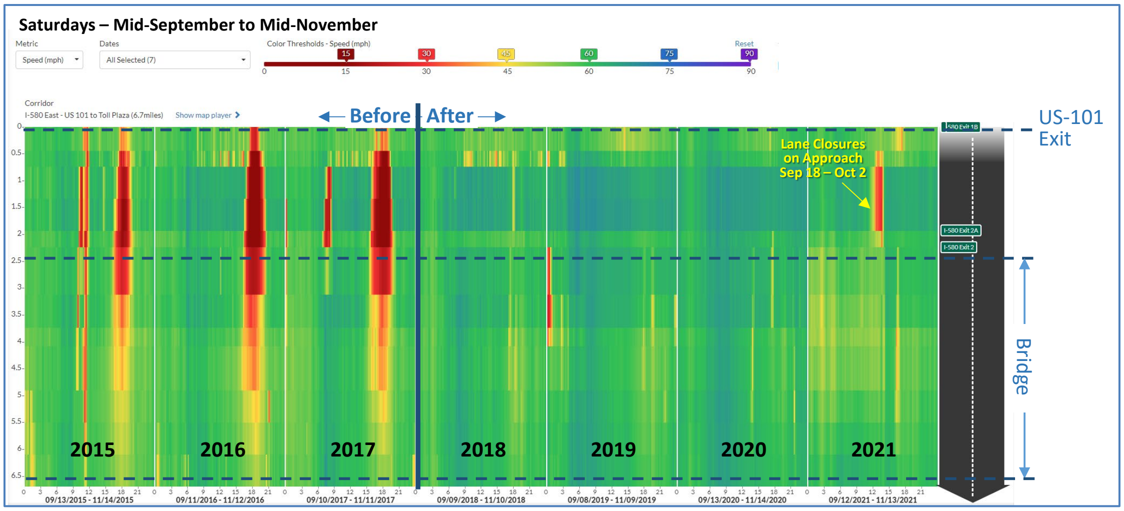

Figure 8-23: Speed Maps – I-580 East – US-101 to Toll Plaza – Saturdays, Fall 2015-2021

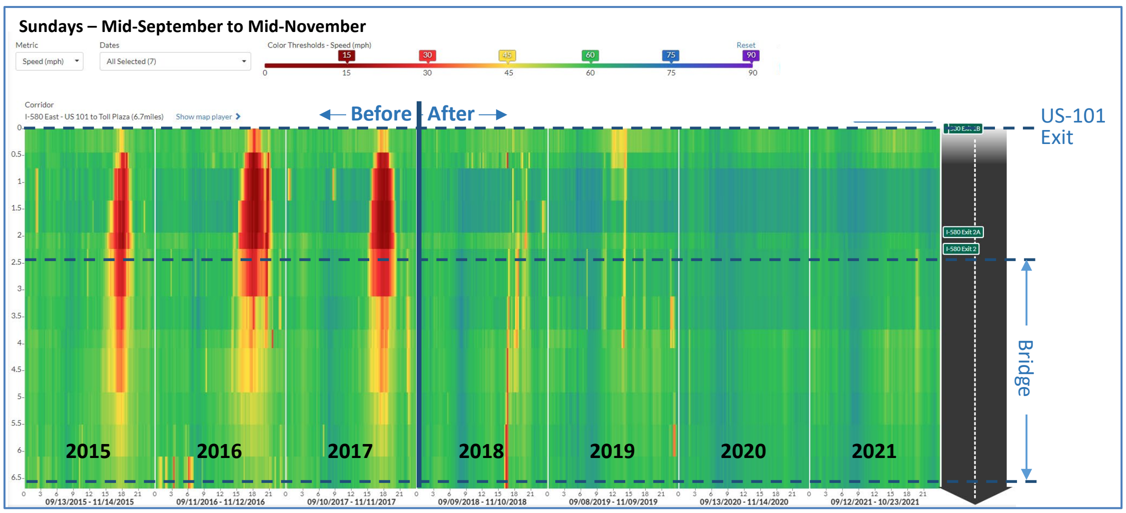

Figure 8-24: Speed Maps – I-580 East – US-101 to Toll Plaza – Sundays, Fall 2015-2021

While the 2020 data may be tainted with Covid-19 effects, this is not the case for the 2018 and 2019 data. The fact that the congestion on the approach disappears before the onset of the pandemic is proof that the improved conditions are a direct result of the bridge modifications. Figure 8-25 further enforces this point by illustrating observed speeds from four months before the modification to four months after. As can be observed, the change in traffic conditions unmistakably corresponds to the shoulder lane opening.

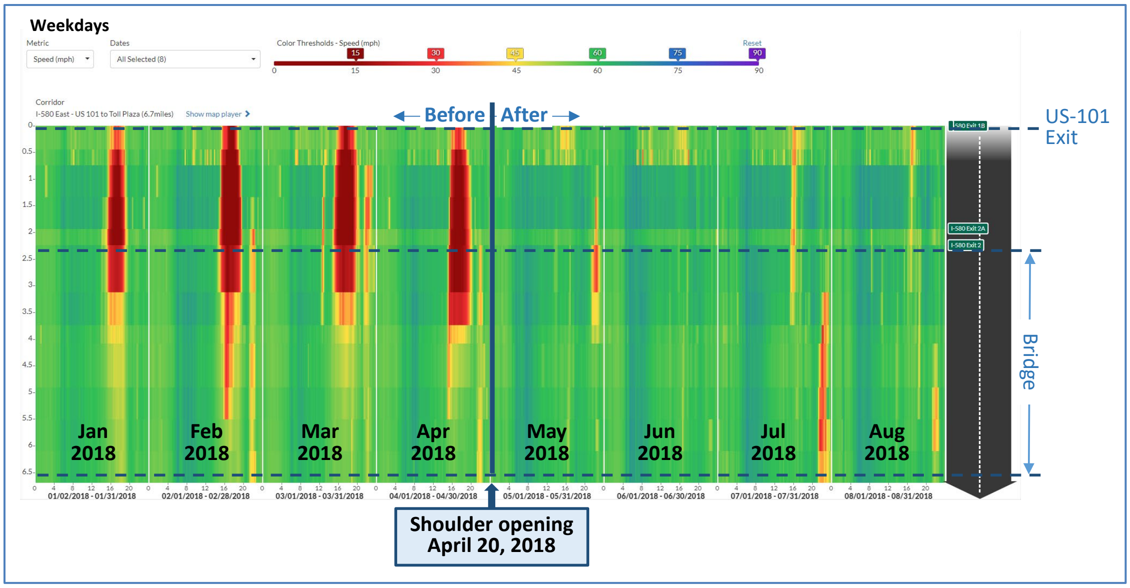

Figure 8-25: Speed Maps – I-580 East – US-101 to Toll Plaza – Weekdays, January-August 2018

Figure 8-26 to Figure 8-28 further illustrate the impacts on travel times from the US-101 interchange to the toll plaza. The travel times before the modification are shown with a dotted line and those for the after period with a solid line. Before the modification, peak weekday travel times reached 21-23 minutes. Since then, peak travel times have remained around 8-9 minutes, yielding a reduction of 13-14 minutes. On Saturdays, peak travel times have similarly reduced from 17-21 to about 7 minutes, for a reduction of 10-14 minutes. On Sundays, peak travel times have been further reduced from 13-15 to 7 minutes, for a reduction of 6-8 minutes.

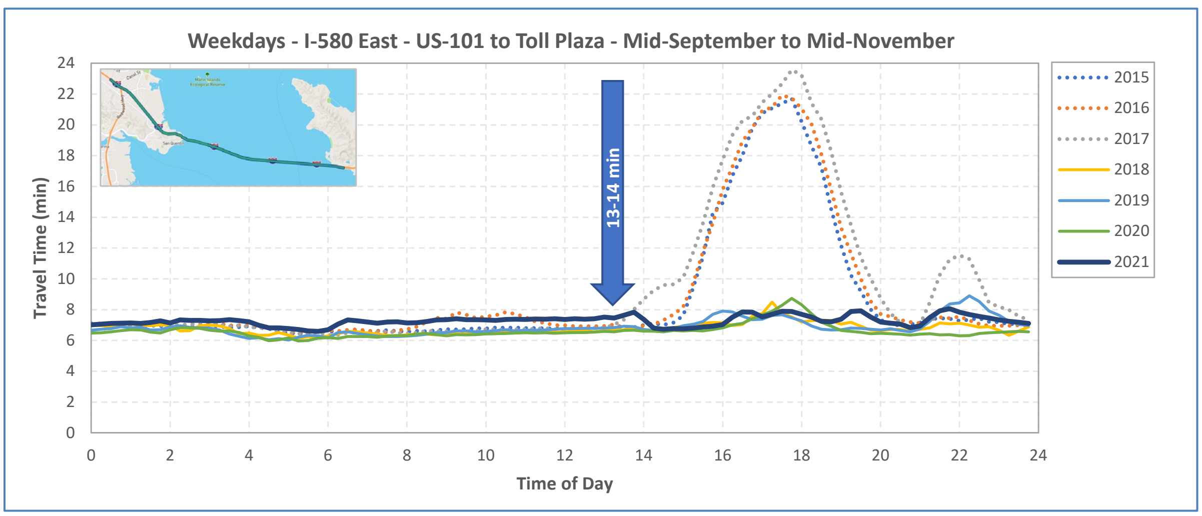

Figure 8-26: Travel Times – I-580 East – US-101 to Toll Plaza – Weekdays, Fall 2015-2021

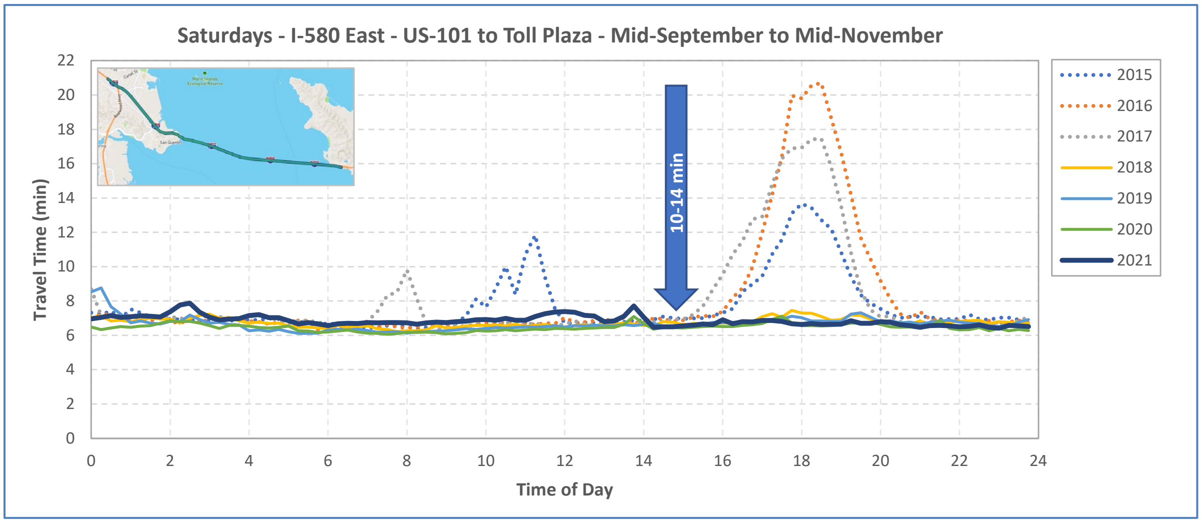

Figure 8-27: Travel Times – I-580 East – US-101 to Toll Plaza – Saturdays, Fall 2015-2021

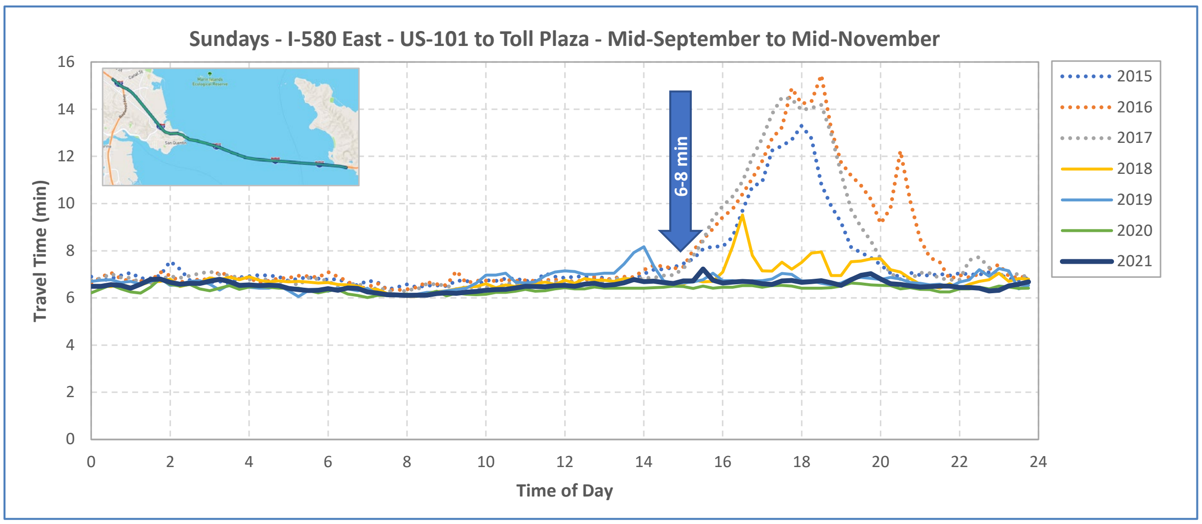

Figure 8-28: Travel Times – I-580 East – US-101 to Toll Plaza – Sundays, Fall 2015-2021

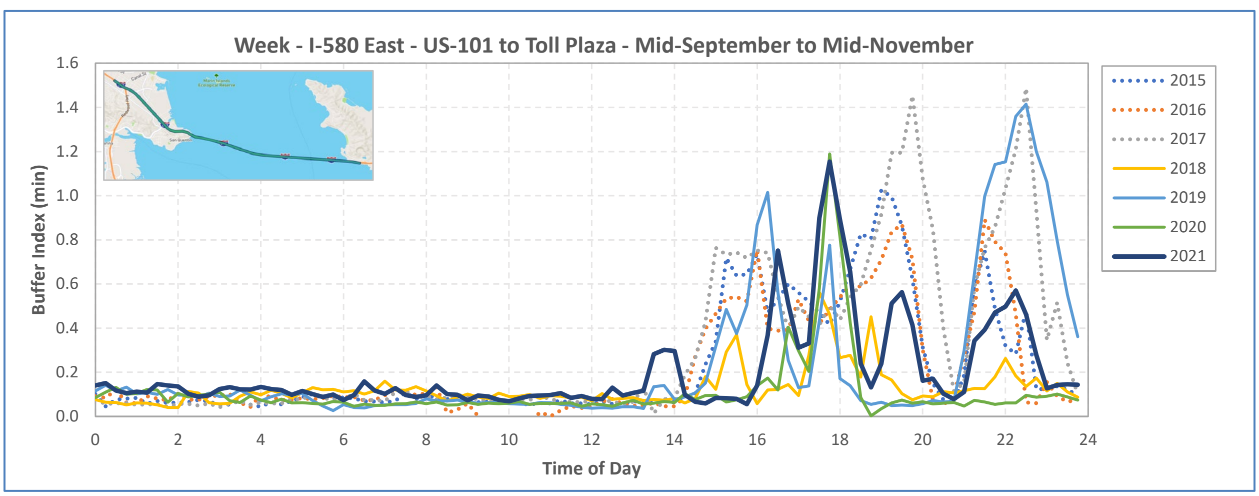

Figure 8-29: Travel Time Reliability I-580 East – US-101 to Toll Plaza – Weekdays, Fall 2015-2021

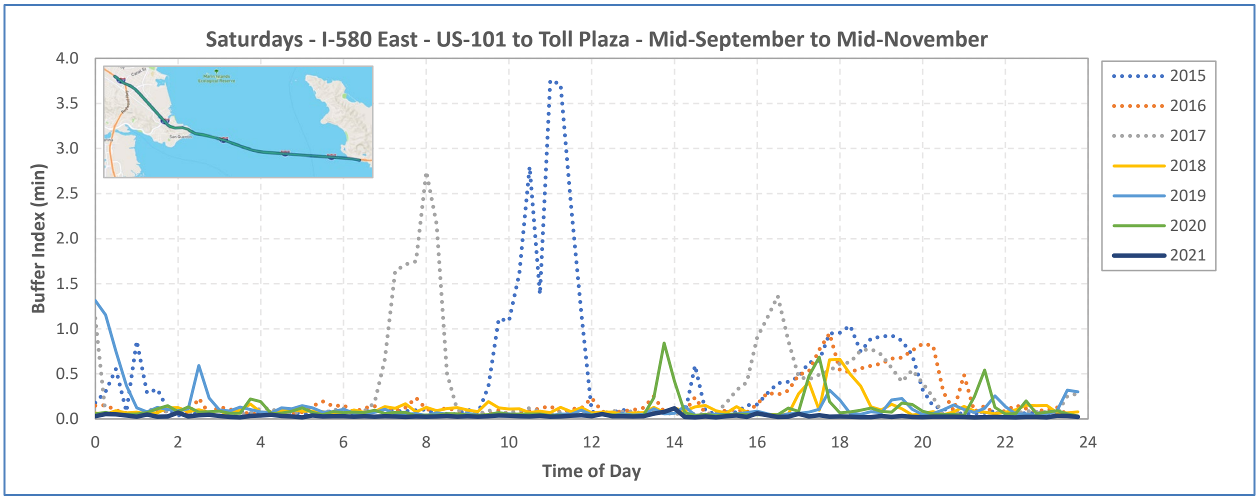

Figure 8-30: Travel Time Reliability I-580 East – US-101 to Toll Plaza – Saturdays, Fall 2015-2021

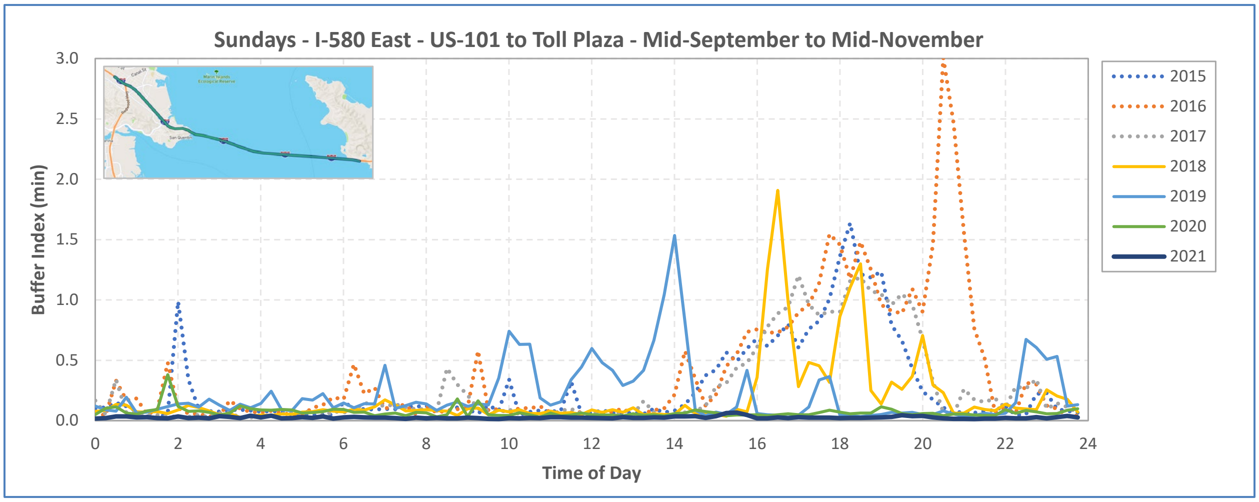

Figure 8-31: Travel Time Reliability I-580 East – US-101 to Toll Plaza – Sundays, Fall 2015-2021

Figure 8-29 to Figure 8-31 finally present the buffer time index for the weekday, Saturday, and Sunday conditions illustrated in the previous graphs. This is a measure of reliability. The index represents the additional time that travelers must add to their planned trip to arrive on time 95 percent of the time, expressed as a percentage of the average travel time. For the eastbound bridge approach, the figures indicate that the bridge modifications have significantly reduced the variability of travel times from the US-101 to the toll plaza, particularly on Saturdays and Sundays. This is mainly due to the elimination of congestion on the bridge approach during peak travel periods.

8.2.6. TRAVEL CONDITIONS ON US-101 NORTH

In addition to reducing travel times along I-580 East, the opening of the eastbound shoulder lane on the bridge may have contributed to a slight reduction in travel time along US-101 North during weekday afternoon peaks. As previously shown in Figure 8-15, the congestion generated by the lane drop at the foot of the bridge typically reached the I-580/US-101 interchange. On weekdays, this congestion then appeared to spread onto the portion of US-101 North between Sir Francis Drake Boulevard and the Francisco Boulevard/I-580 exit. However, it did not appear to significantly impact US-101 traffic on

Saturdays and Sundays. Without current congestion on I-580 East, the signals at the end of the ramp are now the only element constraining flow on the Francisco Boulevard/I-580 exit. While these signals still cause some vehicle queues to back up onto US-101 during weekdays, they do so to a much lower extent than before.

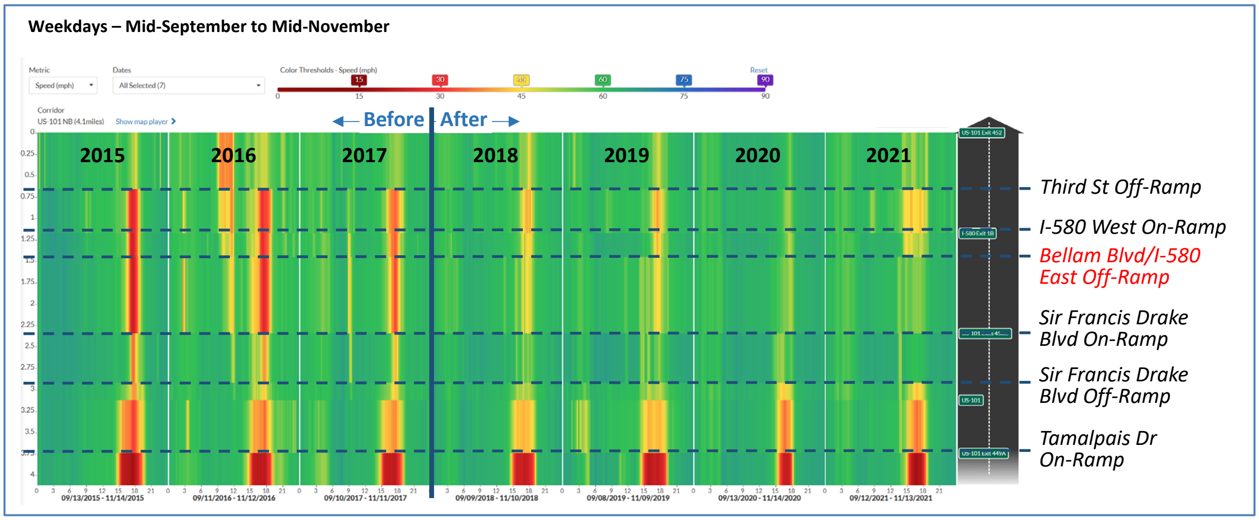

Figure 8-32: Speed Maps – US-101 North – Weekdays, Fall 2015-2021

Figure 8-32 compares the 2015 to 2021 mid-September to mid-November average speed profiles along the section of US-101 North extending from the Tamalpais interchange to the Third St interchange past the I-580 interchange. The thick vertical blue line indicates the boundary between observations made before the bridge modifications and observations made after. As can be observed, significant congestion existed on the US-101 North section between Sir Francis Drake Boulevard and I-580 before the modifications. As was noted in Section 8.2.1, this congestion could be attributed to both the I-580 East congestion and traffic frictions north of the interchange resulting from the merging of the US-101 North and I-580 West traffic streams. Following the bridge modifications, reduced congestion is observed on this section of US-101 in 2018 and 2019, before the Covid-19 pandemic, suggesting a direct potential impact from the bridge modifications. However, it can also be observed that congestion on US-101 North downstream of the off-ramp has also reduced.

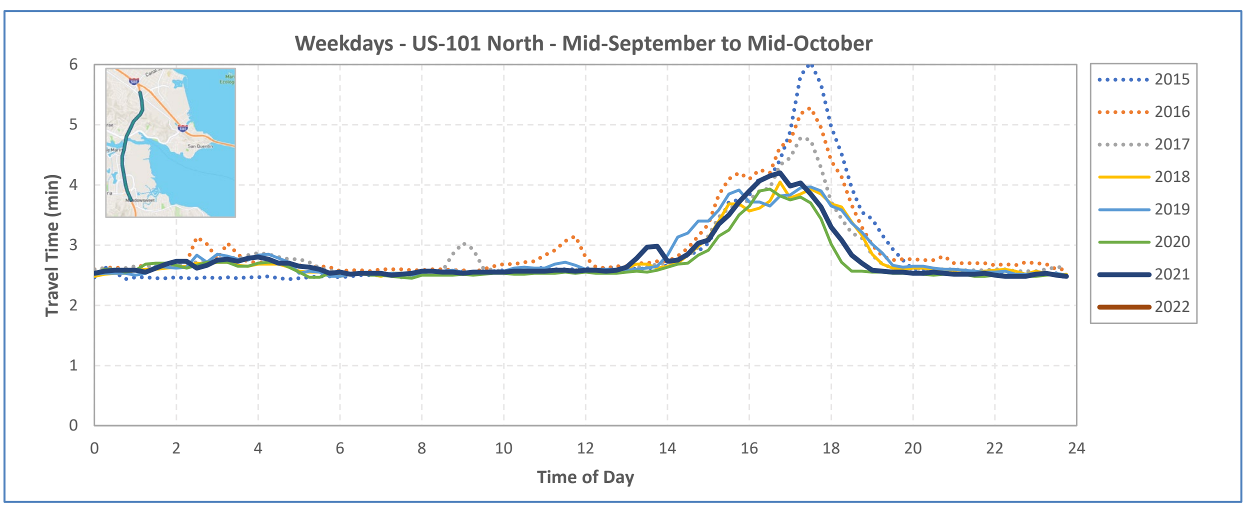

Figure 8-33: Travel Times – US-101 North – Weekdays, Fall 2015-2021

Figure 8-33 further illustrates the average travel times from mid-September to mid-November between 2015 and 2021 along the US-101 section extending from the Tamalpais Drive interchange to the Francisco Boulevard/I-580 exit, as shown in the embedded map. Before the shoulder lane opening, peak travel times on this section of US-101 ranged from 4.75 to 6 minutes. Since then, average travel times have not exceeded 4.2 minutes. This translates into an average reduction of 0.5 to 1.8 minutes. This is for all vehicles traveling on the section. Unfortunately, a more detailed characterization distinguishing travel time reductions for US-101 and I-580 bound traffic is not possible due to sensor data quality issues near the interchange with I-580, as was highlighted in Section 5.2.1.

No significant changes in travel time were observed for Saturday and Sunday over the same segment and evaluation period. This is explained by the fact that the bridge congestion did not affect the US-101 North traffic as much during the weekend before the modifications, as illustrated in the congestion maps of Figure 8-14 and Figure 8-15.

8.2.7. TRAVEL CONDITIONS ON EASTBOUND SIR FRANCIS DRAKE BOULEVARD

Figure 8-34 to Figure 8-36 illustrate eastbound speeds along Sir Francis Drake Boulevard, from the US-101 to the I-580 interchanges, over the 2015-2021 period. Similar to I-580 East, the opening of the eastbound shoulder lane has positively impacted traffic along the arterial. Before the opening, speeds below 20 mph were observed across the entire length of the arterial. While speeds below 20 mph are still currently observed on weekdays, their spatial and temporal extent is significantly reduced and primarily centered on the section west of the San Quentin Prison entrance.

Figure 8-37 to Figure 8-39 further illustrate changes in travel times along the arterial, from the US-101 to the I-580 interchanges, over the evaluation period. Travel times during the weekday afternoon peak have dropped from 11-12 minutes to around 5 minutes between fall 2017 and fall 2018. This is a 6–7-minute reduction that can be directly attributed to the improved traffic conditions that resulted from the bridge modifications. Saturday peak travel times similarly dropped from 8-10 minutes to about 3 minutes, while Sunday peak travel times dropped from 6-7 minutes to 3 minutes. These correspond to travel time reductions of 5-7 and 3-4 minutes, respectively.

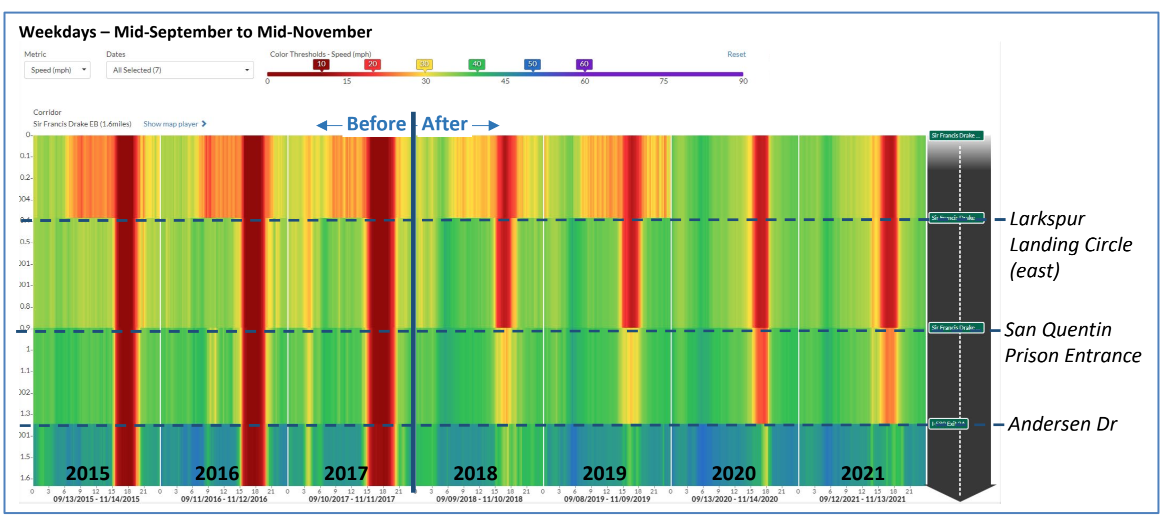

Figure 8-34: Speed Maps – Sir Francis Drake Boulevard EB – Weekdays, Fall 2015-2021

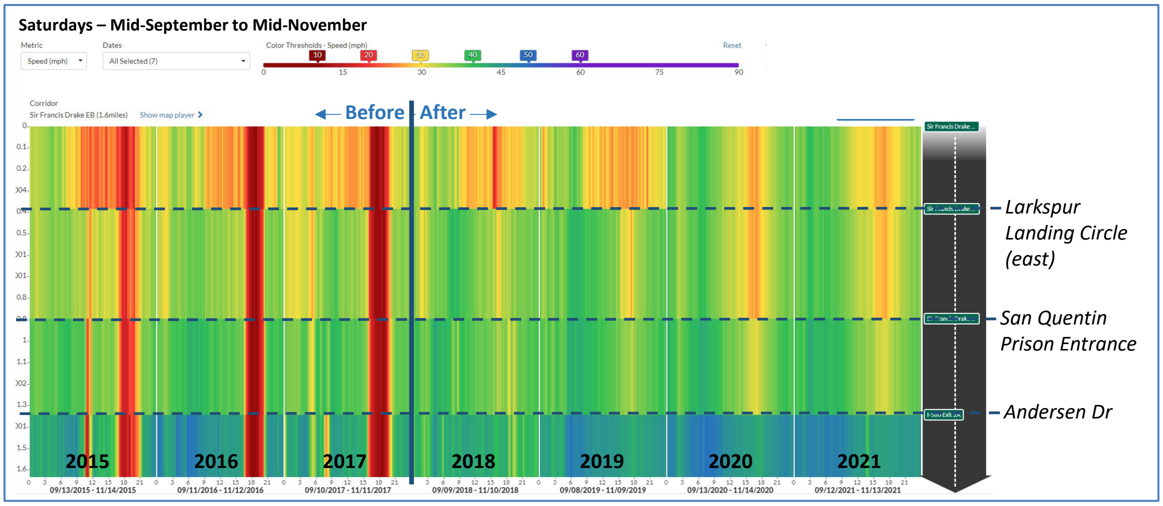

Figure 8-35: Speed Maps – Sir Francis Drake Boulevard EB – Saturdays, Fall 2015-2021

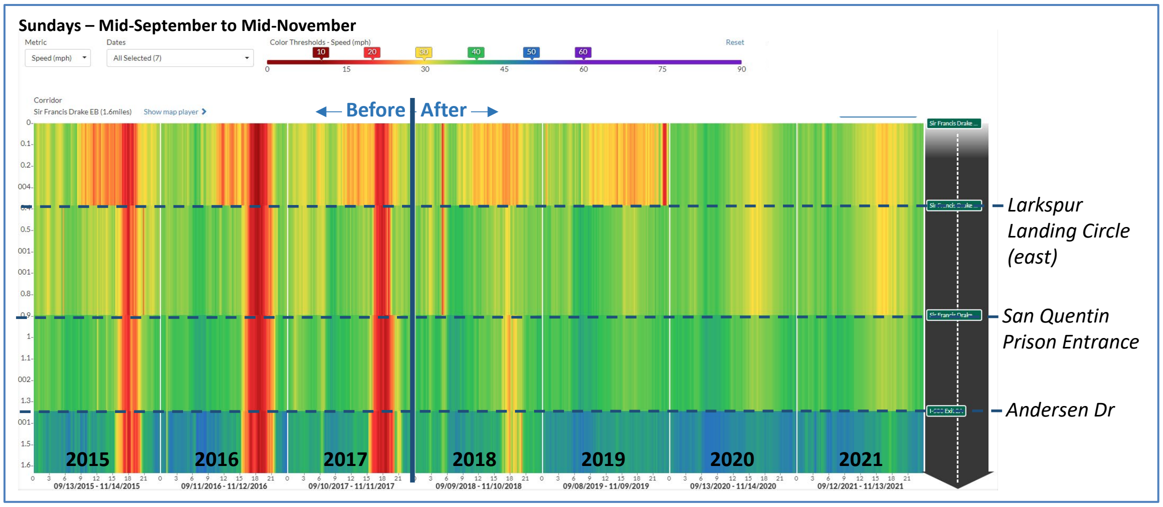

Figure 8-36: Speed Maps – Sir Francis Drake Boulevard EB – Sundays, Fall 2015-2021

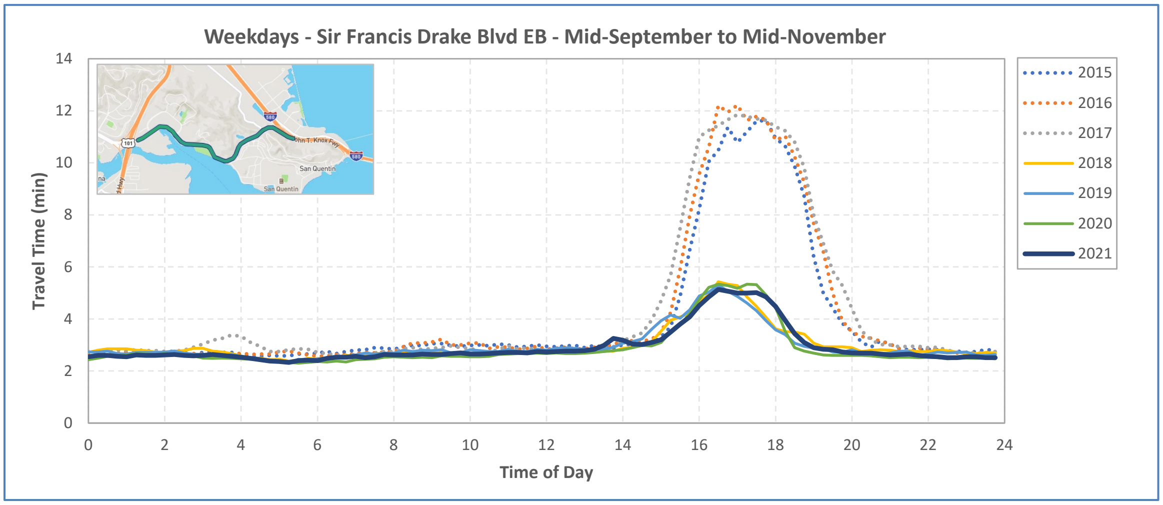

Figure 8-37: Travel Times – Sir Francis Drake Boulevard EB – Weekdays, Fall 2015-2021

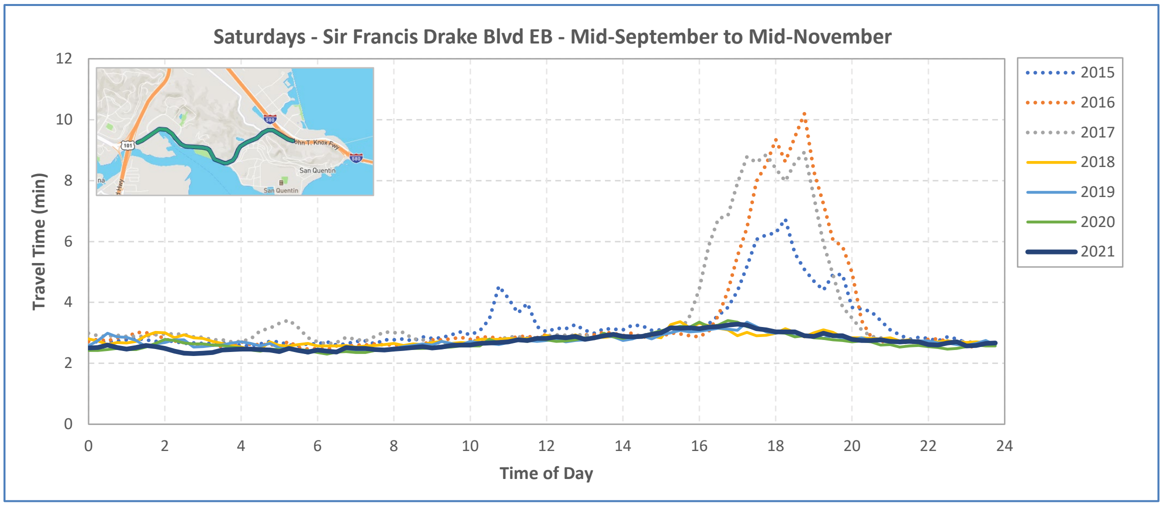

Figure 8-38: Travel Times – Sir Francis Drake Boulevard EB – Saturdays, Fall 2015-2021

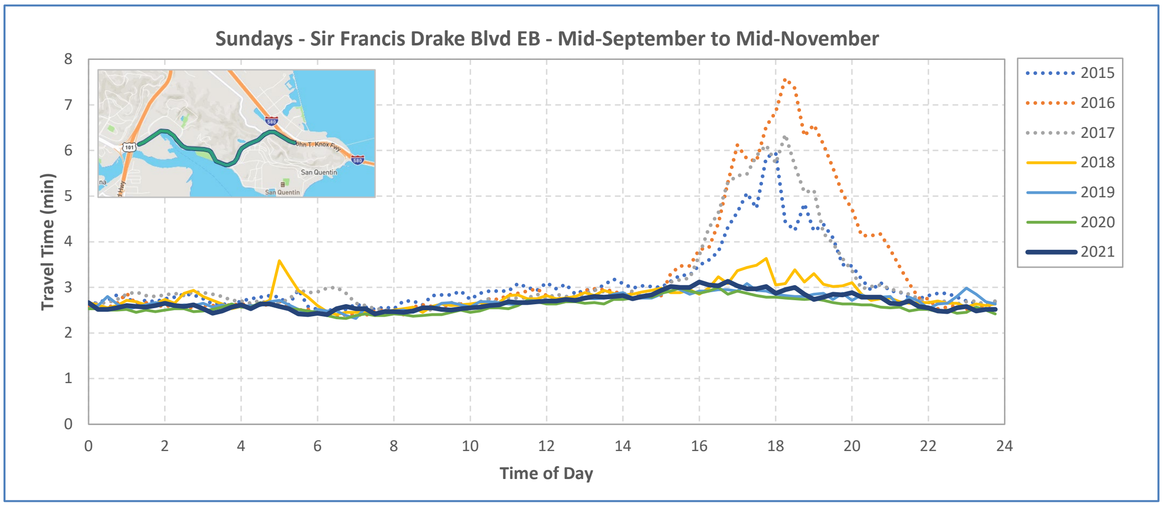

Figure 8-39: Travel Times – Sir Francis Drake Boulevard EB – Sundays, Fall 2015-2021

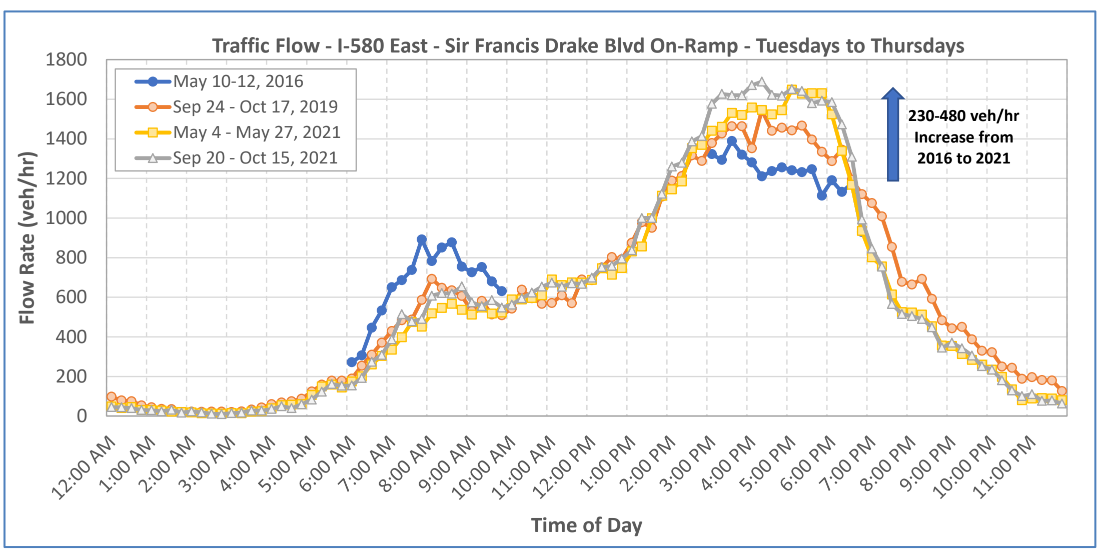

Figure 8-40: Flow on I-580 Sir Francis Drake Boulevard On-Ramp, 2016-2021

Figure 8-40 concludes by comparing weekday flow on the I-580 East on-ramp at the end of the arterial from mid-May 2016 to flows from September 2019, May 2021, and September 2021. Data from spring 2020 are not considered due to the impacts of the Covid-19 pandemic on traffic demand. Data between Spring 2016 and fall 2019 are also not presented as count data is not available.

Based on the illustrated data, the following two observations can be made regarding traffic using the arterial to access I-580 East and the Richmond-San Rafael bridge:

- Weekday afternoon peak traffic has significantly increased following the April 2020 modifications. Increases between 230 and 480 vehicles/hour in flow rate are observed between 2016 and 2021, for an average increase of 364 vehicles/hour. While this could partly be due to an increase in traffic demand, the elimination of congestion on I-580 East that used to cause backups onto Sir Francis Drake Boulevard is seen as a major contributing factor. Travel times have decreased despite the increase in traffic. Easier travel conditions along the arterial may have enticed more motorists to use it to reach I-580 East. This is supported by the data of Figure 8-41, which show a nearly 300 vehicle/hour increase in flow from the US-101 North off-ramp to the I-580 on-ramp between May 2016 and March 2022 despite reductions in flows originating from other sources.
- While AM peak on-ramp traffic has reduced since 2016, this is estimated to be likely due to changes in travel demand as there was, or is, generally no congestion affecting eastbound traffic along the arterial during the morning.

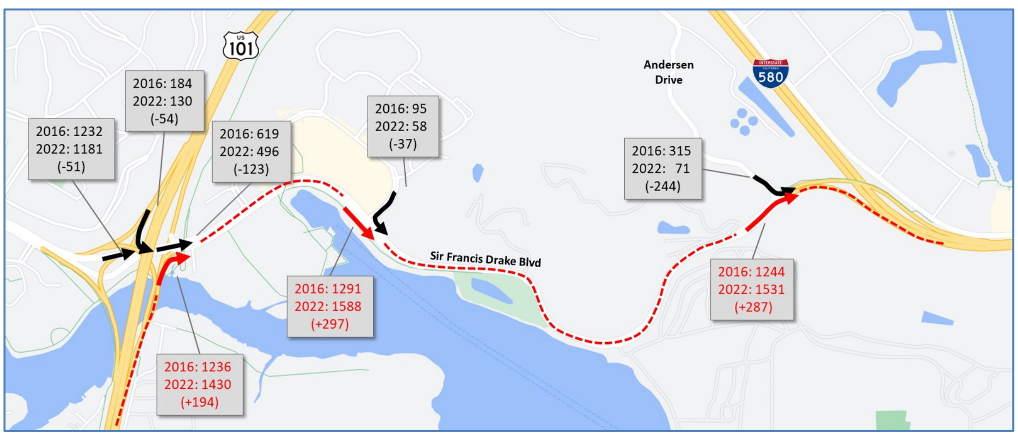

Figure 8-41: Changes in Traffic Flows along Sir Francis Drake Boulevard between 2016 and 2022

8.2.8. TRAVEL CONDITIONS ON EASTBOUND FRANCISCO BOULEVARD

Before the bridge modifications, it was hypothesized that some traffic would use Francisco Boulevard to bypass congestion along I-580 East. As shown on the left side of Figure 8-42, which illustrates counts around the Main Street interchange from May 2016, this was supported by a high volume of vehicles turning right on Main Street from Francisco Boulevard and then left onto the I-580 East on-ramp during an average weekday afternoon peak hour. Recent counts from March 2022, shown on the right side, show a significant reduction in traffic accessing I-580 East at Main Street from Francisco Boulevard. Additional evidence is provided in Figure 8-43, which shows a large drop in traffic on the Main Street on-ramp from May 2016 to fall 2019. Data between May 2016 and fall 2019 are not due to lack of availability.

While there is no direct evidence that the flow reductions described above occurred immediately after the opening of the shoulder lane in April 2018, logic suggests that this is the likely contributing factor. As the modification has eliminated congestion along I-580, motorists have had since then fewer incentives to use local arterials to shave some travel time on their eastbound trips.

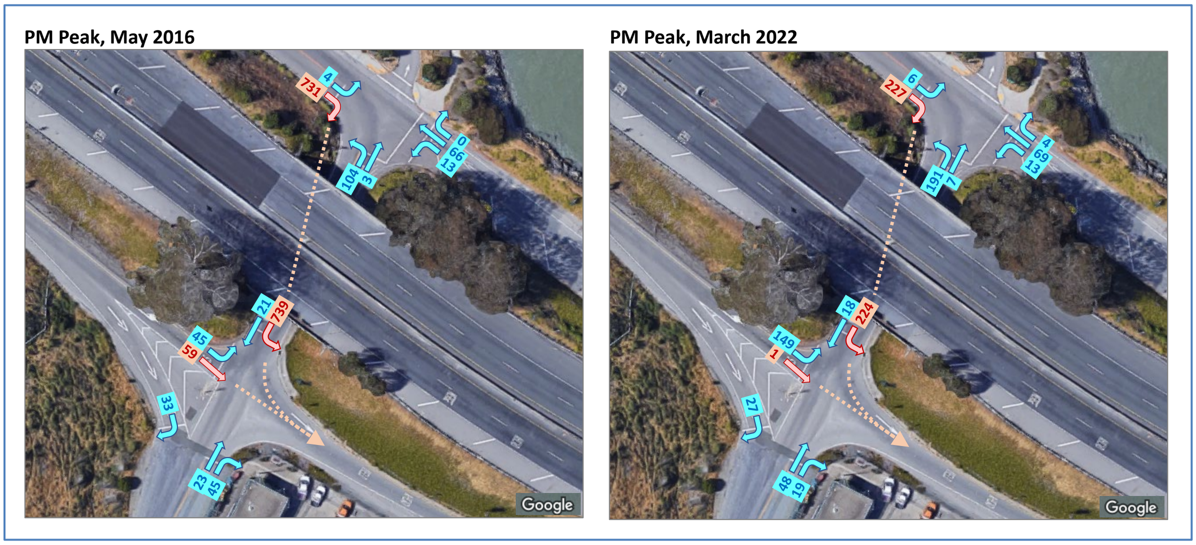

Figure 8-42: Traffic Flows at Main Street Interchange, 2016

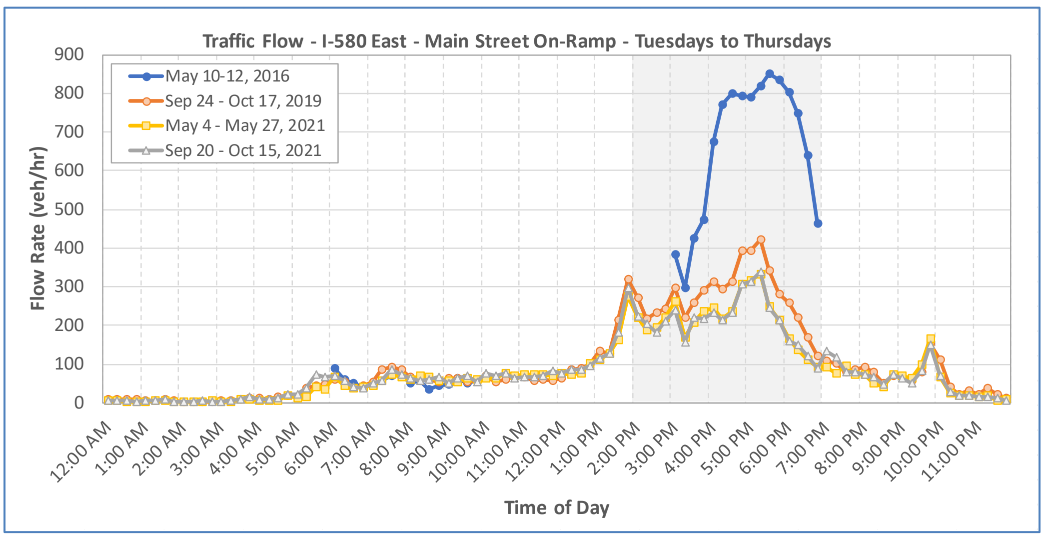

Figure 8-43: Flow on I-580 East Main Street On-Ramp, 2016-2021

Additional evidence that fewer vehicles are utilizing Francisco Boulevard to access I-580 East is obtained by comparing counts taken at various locations along the arterial, as illustrated in Figure 8-44. As can be observed, most of the reduction in traffic along Francisco Boulevard appears to originate from the intersection with Bellam Boulevard. The reduction can more particularly be traced to fewer vehicles traveling north on Bellam Boulevard and turning right onto Francisco Boulevard after having bypassed the local I-580 East on-ramp.

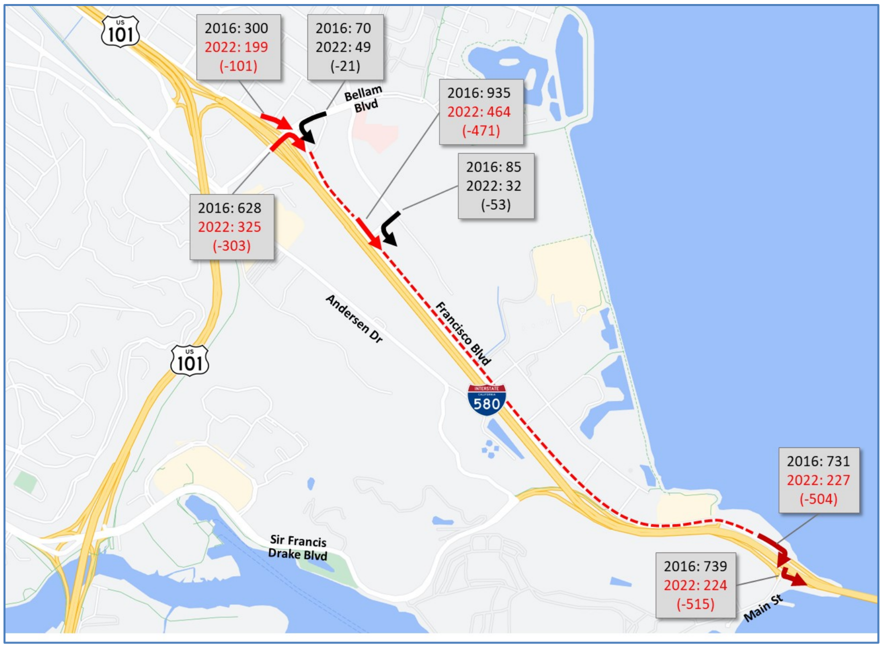

Figure 8-44: Changes in Traffic Flows along Francisco Blvd between 2016 and 2022

While an analysis of travel times along Francisco Boulevard would help confirm the above observation, such analysis could not be made as INRIX only started collecting travel times along Francisco Boulevard in 2019, after the shoulder lane opening.

8.2.9. TRAVEL CONDITIONS ON ANDERSEN DRIVE

A comparison of traffic counts from May 2016 and March 2022 indicates that a significant reduction in traffic has occurred on Andersen Drive since the shoulder lane opening. As shown in Figure 8-45, the 2016 data show an average of 315 vehicles per hour turning onto the I-580 East on-ramp from Andersen Drive, while the 2022 data only shows a flow of 71 vehicles/hour. This represents a 77% drop.

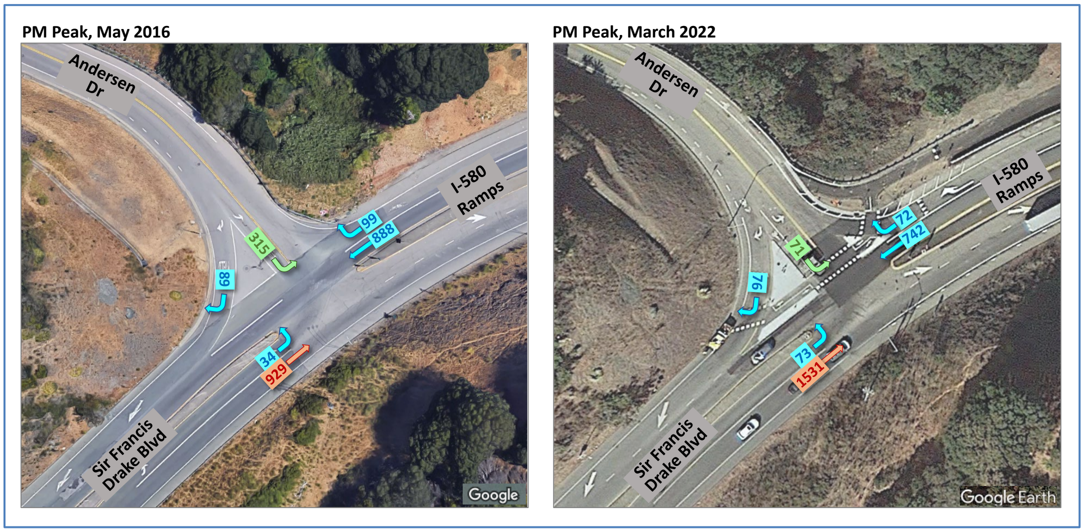

Figure 8-45: Traffic Flows at Sir Francis Drake and Andersen, 2016 and 2022

Similar to what was observed on Francisco Boulevard, it could be hypothesized that the drop results from fewer vehicles using Andersen Drive as a bypass to I-580 East. However, a review of congestion hotspots using INRIX average speed data indicates that the drop in volume may have occurred one to two years after the modifications. As shown in Figure 8-46, changes in traffic conditions along the arterial appeared to have occurred between the fall of 2019 and the fall of 2020, likely because of the Covid-19 pandemic.

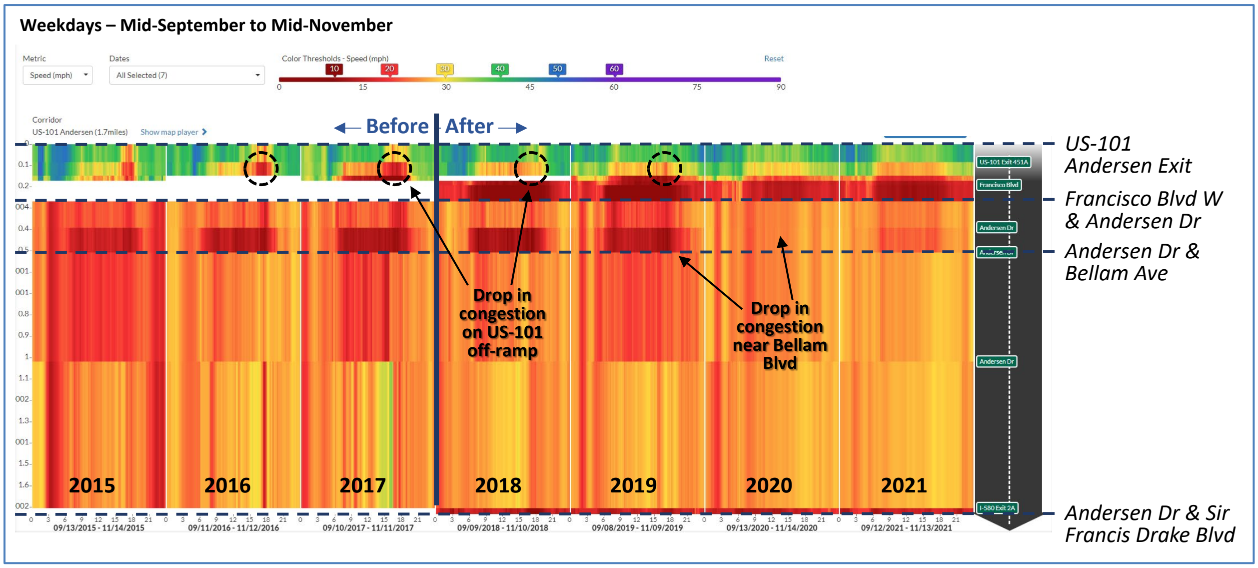

Figure 8-46: Speed Maps – Andersen Drive – Weekdays, Fall 2015-2021

However, a slight reduction in congestion could be observed on the US-101 off-ramp before and after the April 2018 bridge modifications. This change, highlighted by the black circles, could be the result of fewer vehicles taking the off-ramp due to less congestion on I-580 East. Unfortunately, there is no data to definitively prove this assertion since the traffic sensors on the Andersen Dr/Francisco Boulevard West off-ramp (PeMS 418213) did not produce reliable data before April 2020.

8.2.10. TRAVEL CONDITIONS ON I-580 EAST MAIN STREET RAMPS

As was shown in Figure 8-42, 59 vehicles/hour were observed in the May 2016 counts going straight from the Main Street off-ramp to the Main Street on-ramp during the afternoon peak. This is despite lane marking indicating the left lane as a left-turn only lane. This behavior was likely done as a way to save some travel time by bypassing a portion of the congestion along I-580 East. In the March 2022 counts, an average of only 1 vehicle/hour was observed making the same move during the afternoon peak, indicating the existence of significantly fewer travel constraints along I-580 East.

8.2.11. TRAVEL CONDITIONS ON I-580 EAST BELLAM BOULEVARD ON-RAMP

Counts data show an increase in traffic on the I-580 East Bellam Boulevard on-ramp between May 2016 and March 2022. As shown in Figure 8-47, weekday afternoon peak ramp traffic went from 282 to 464 vehicles/hour. This represents a 64% increase that occurred at the same that traffic across the intersection decreased by around 10%. This increase can be attributed to both a change in traffic demand and fewer vehicles opting to use Francisco Boulevard as a bypass to I-580, as noted in Section 8.2.8.

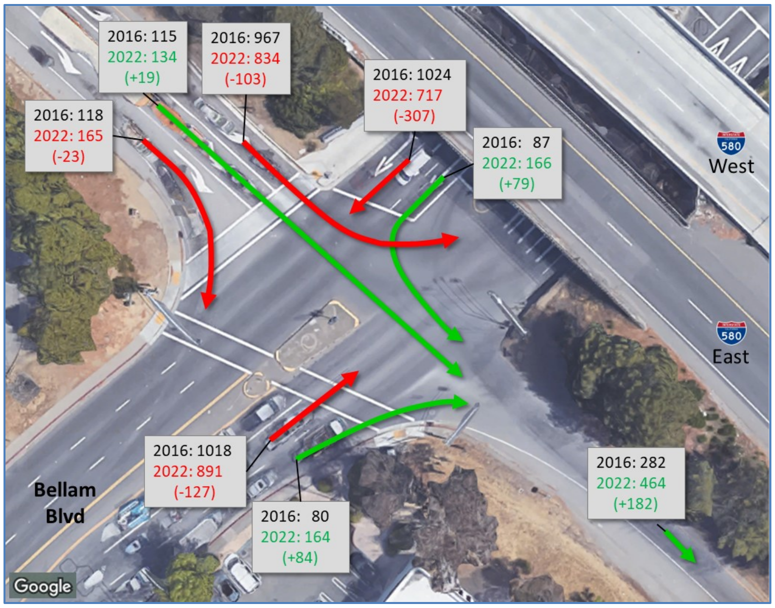

Figure 8-47: Traffic Flows at I-580 East Bellam Blvd Ramps, 2016 and 2022

8.2.12. SUMMARY OBSERVATIONS

The following are key observations from the analysis of impacts on eastbound traffic associated with the opening to traffic of the bridge lower deck shoulder lane between 2 PM and 7 PM daily:

- The availability of an extra traffic lane has increased eastbound peak hourly flow across the bridge by 13-26%, from 3,300-3,570 to 3,750-4500 vehicles/hour.
- The shoulder lane typically only carries less than 25% of the eastbound bridge traffic during weekday peak periods, and less than 20% on weekends.
- The added peak-hour capacity has eliminated congestion on the eastbound approach to the bridge. This has caused peak travel times from the US-101 interchange to the toll plaza to drop by 13-14 minutes on weekdays, 10-14 minutes on Saturdays, and 6-8 minutes on Sundays.
- Peak-hour travel times to reach the toll plaza are significantly less variable than before.
- The absence of congestion on I-580 East has likely contributed to a 1- to 2-minute reduction in average travel times on US-101 between the Sir Francis Drake and I-580 interchanges
- Weekday afternoon peak travel times along Sir Francis Drake Boulevard have dropped by up to 4 minutes, while traffic volumes have increased by over 300 vehicles/hour.
- Less traffic is using Francisco Boulevard to bypass congestion on I-580 East. While less traffic is also using Andersen Drive, it is unclear to which extent this is due to the bridge modifications.
- Fewer vehicles are using the Main Street off-ramp and on-ramp as a congestion bypass.
- Increased traffic is observed entering I-580 East at the Bellam Boulevard on-ramp, likely partly due to fewer vehicles attempting to use local arterials as bypasses to the freeway.

The following are additional observations regarding the compliance of motorists with the period during which the shoulder lane is opened to traffic:

- Motorists are generally compliant with the shoulder opening period, as relatively few vehicles are observed using the lane before 2 PM and after 7 PM.
- Non-compliant use of the shoulder lane is highest 20 minutes before its opening and up to 25 minutes following its closure.
- CHP officers have indicated observing some vehicles using the shoulder as a passing or traveling lane when a red or yellow X is shown above it. This suggests that some motorists may not fully understand the meaning of the current lane control signs.

8.3. IMPACTS ON WESTBOUND BRIDGE TRAFFIC

This section evaluates the impacts on traffic of the conversion of the westbound upper deck shoulder lane into a barrier-delimited bike/pedestrian path. The primary goals of this evaluation are to assess:

- Whether the provision of a travel path visually constrained by the path barrier is causing a capacity reduction on the bridge and/or traffic to slow down.
- whether the provision of a shorter merge area at the exit of the toll plaza is causing an increase in congestion on the westbound approach to the bridge.

Based on the above goals, the following section successively presents the following elements:

- Typical congestion profile on the bridge approach
- Impacts on upper deck capacity
- Impacts on traffic conditions on the approach to the bridge
- Impacts on traffic conditions across the bridge
- Impacts on traffic distribution across lanes on the bridge
- Impacts on local arterials on the Richmond side of the bridge
- Summary of observations

8.3.1. TYPICAL APPROACH CONGESTION PROFILES

To help with the analysis of traffic impacts associated with the bridge modifications, Figure 8-48 presents speed maps illustrating general traffic conditions on the westbound approach to the bridge in the fall of 2021. The heat map on the left illustrates average conditions on weekdays, the one in the middle on Saturdays, and the one on the left on Sundays.

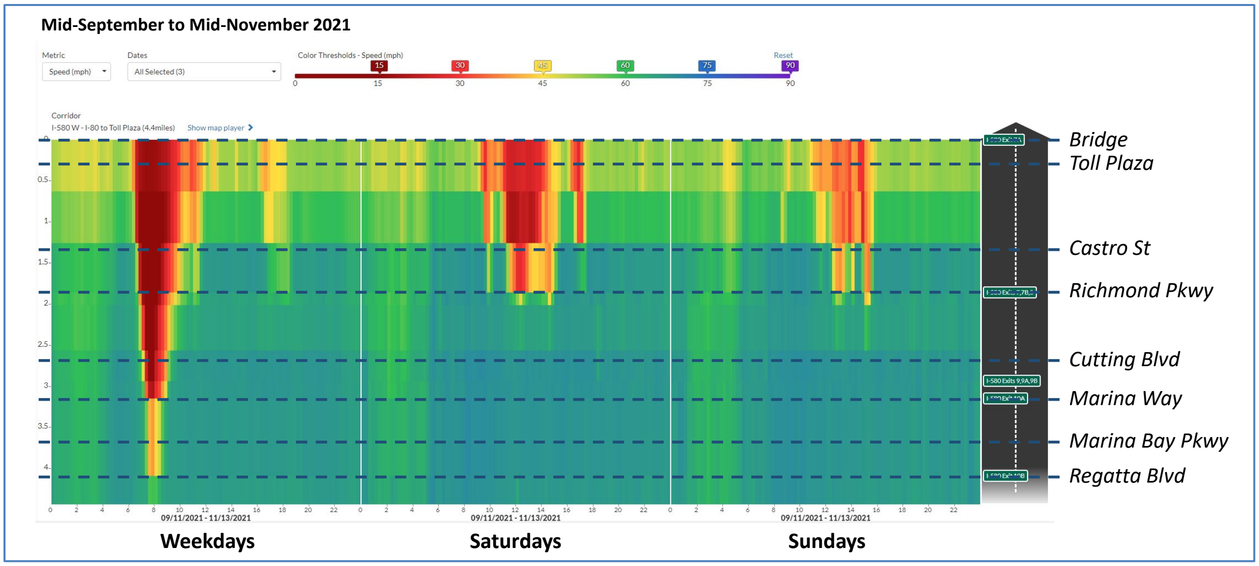

Figure 8-48: Typical Congestion Profiles on Westbound Bridge Approach, Fall 2021

Based on the illustrated data, the following observations can be made:

- During weekdays, congested conditions typically exist between 6 AM and 10 AM. Traffic speeds during this period drop to 10 mph, with peak queues occurring around 8 AM and extending 2.75 to 3.25 miles upstream of the toll plaza, to somewhere between the Marina Way and Regatta Boulevard interchanges.
- On Saturdays, congestion conditions exist between 11 AM and 2 PM. Traffic speeds during this period drop to about 20 mph, with peak queues occurring around Noon and extending 1.25 miles from the toll plaza, to around the Richmond Parkway interchange.
- On Sundays, less intense congestion occurs between 12 Noon and 3 PM. Traffic speeds during this period only drop to around 30-35 mph, with peak queues occurring around 1 PM and extending 1.00 to 1.25 miles from the toll plaza, to somewhere between the Castro Street and Richmond Parkway interchanges.

8.3.2. IMPACTS ON UPPER DECK CAPACITY

Figure 8-49 and Figure 8-50 illustrate the peak weekday and weekend hourly flows observed at the Richmond toll plaza between January 2015 and mid-June 2022. Within the figure, the dots illustrate the maximum observed flow on a given day, excluding holidays and days with abnormally low volume. Since day-to-day maximum flows are subject to significant fluctuations due to weather, incidents, variations in the proportion of trucks, and other factors, a 2-week rolling average is superimposed on the daily data to facilitate the identification of trends.

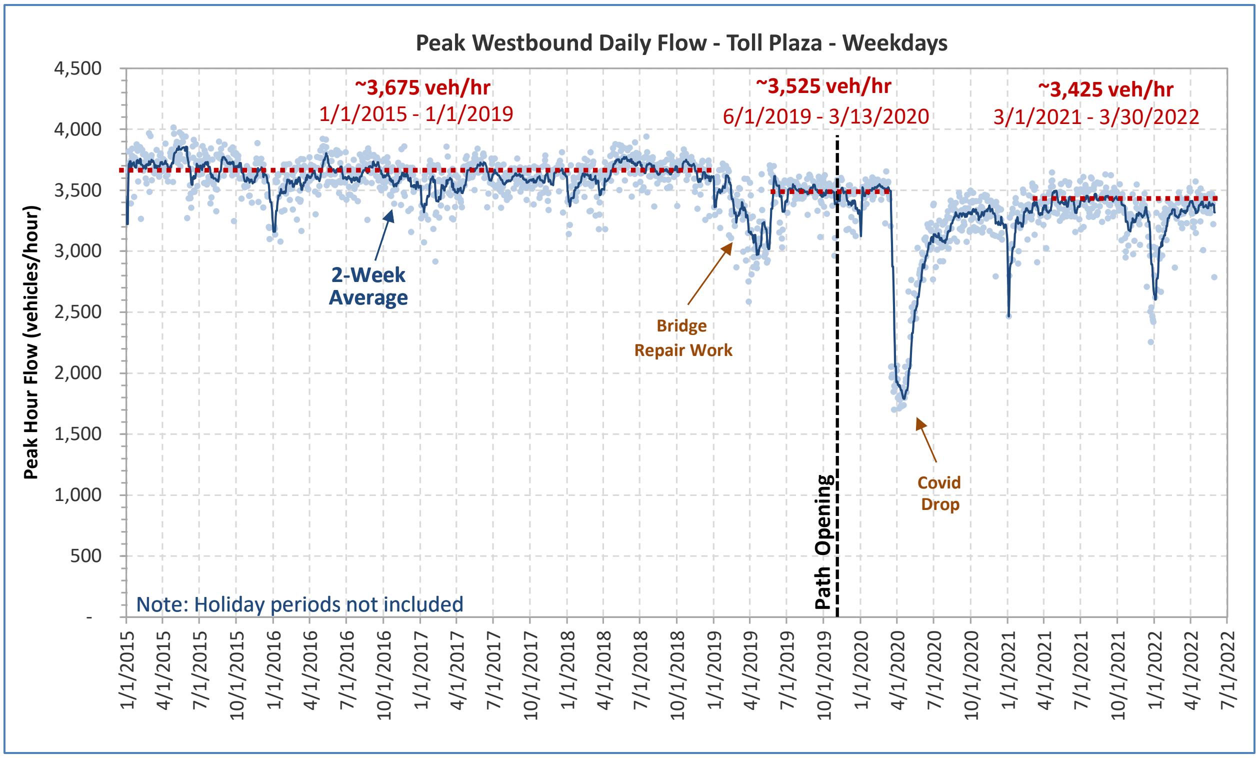

Figure 8-49: Peak Hourly Flows – I-580 West – Toll Plaza, Weekdays, 2015-2022

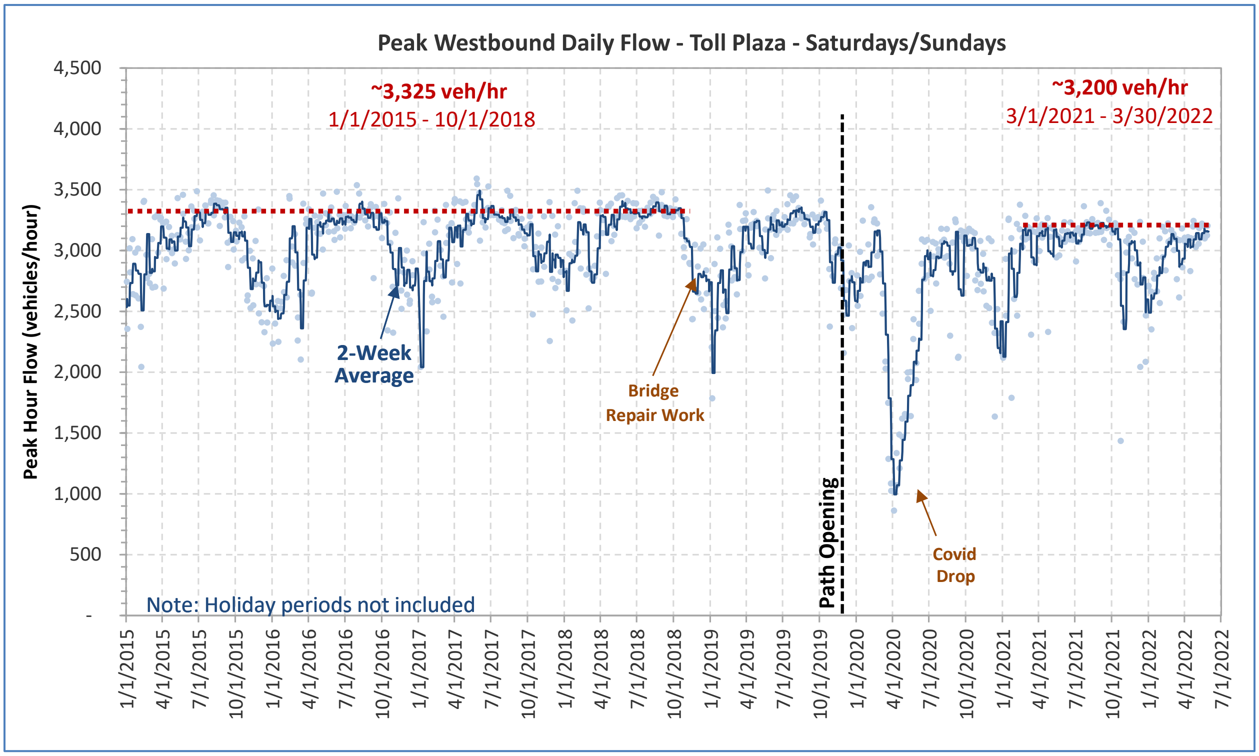

Figure 8-50: Peak Hourly Flows – I-580 West – Toll Plaza, Weekends, 2015-2022

The following observations can be made from the illustrated data:

- A weekday peak traffic capacity of approximately 3,675 vehicles/hour existed before January 2019. Average peak flows on Saturdays and Sundays were slightly lower, at 3,325 vehicles/hour, likely due to the presence of drivers with less aggressive behavior.
- Following the failure of a bridge joint on February 7, 2019, and the subsequent decision to perform emergency maintenance on the bridge, significantly lower maximum flows were observed from February to July 2019 on both weekdays and weekends. These are the results of occasional lane closures and reduced traffic speeds caused by steel plates covering joints.
- After the installation of the barrier delimiting the bike/pedestrian path, peak flows averaged 3,525 vehicles/hour on weekdays between November 2019 and February 2020. This represents a 150 vehicles/hour, or 4%, average drop over the before conditions. Weekend peak traffic flows remained too variable to provide a representative average.
- Since June 2021, following the termination of workplace Covid-19 restrictions, average peak flows across the bridge have remained around 3,425 vehicles/hour. This represents a 250 vehicles/hour, or roughly 7%, drop from the pre-modifications historical average. On Saturdays and Sundays, a similar reduction is observed, with average peak flows dropping from 3,325 to 3,200 vehicles/hours, corresponding to a roughly 4% drop.
- Over a four-hour peak period, the observed weekday decrease in capacity could translate into 1,100 vehicles that could potentially not be served by the bridge if traffic demand remains at or above capacity over the entire period. On weekends, the data further suggest that 600 vehicles may potentially not be served by the bridge if demand similarly exceeds the capacity for four hours.

While daily traffic remains lower than pre-Covid-19 levels, as shown earlier in Figure 8-1 to Figure 8-6, congestion is again observed on the approach to the toll plaza on Weekdays, Saturdays, and Sundays. This is an indication that traffic is again reaching bridge capacity during peak periods. However, since daily maximum flows have not returned to pre-Covid-19 levels, it can be inferred that the observed drops in capacity are the results of the bridge modifications, as outlined below:

- The capacity chokepoint appears to be the section downstream of the toll plaza where the number of traffic lanes reduces from seven to two. Implementation of the bikeway has reduced the length of the merge area from 900 ft to 325 ft. Forcing vehicles to merge over a shorter distance cause more friction between traffic streams and reduce the maximum number of vehicles that can go through the section in an interval.
- The barrier also creates a more visually constrained environment on the bridge, enticing vehicles to slow down. This is particularly true near the entrance of the bridge, where vehicles often change lanes. While lower speeds have historically been observed on the first half-mile of the bridge due to lane changing activities, as evidenced later in Figure 8-60, Figure 8-61, and Figure 8-62, slight additional speed reductions could further lower the maximum number of vehicles that can enter the bridge in periods of heavy traffic.

The impacts of the above factors are further compounded by the elimination of cash toll payments at the toll plaza in March 2020. This change allows more vehicles to cross the plaza on lanes that were previously not equipped with an electronic toll payment system, increasing traffic attempting to go through the merge area at the same time.

8.3.3. TRAVEL CONDITIONS ON WESTBOUND APPROACH

The following sets of figures are presented to illustrate traffic conditions on the westbound approach to the bridge:

- Figure 8-51 to Figure 8-53 present average speed contour maps along I-580 West from the I-80 interchange to the Richmond toll plaza, for weekdays, Saturdays, and Sundays, between 2015 and 2021. For each year, the speeds and travel times are the averages from mid-September to mid-November. To facilitate data analyses, the thick vertical blue line in each figure indicates which portion of the data falls before and after the path opening.
- Figure 8-54 to Figure 8-56 further present travel times over the same period and section of freeway. In this case, data from the before period are indicated by a dotted line, while the after are shown by solid lines.
- Figure 8-57 to Figure 8-59 finally present the buffer time index for the weekday, Saturday, and Sunday conditions illustrated in the previous graphs. The buffer time index is a measure of reliability. It represents the additional time that travelers must add to their planned trip to arrive on time 95 percent of the time, expressed as a percentage of the average travel time.

The following observations can be made from the illustrated data regarding the weekday traffic conditions:

- Current weekday congestion on the approach to the bridge is similar to before the modifications. In the speed maps of Figure 8-51, the congested area upstream of the toll plaza in the fall of 2021 is observed to extend between Cutting Boulevard and Marina Bay Parkway. This is like what was observed before 2019 and in prior years.
- Average peak weekday travel times from I-80 to the entrance of the bridge reached 21 minutes in the fall of 2021. As shown in Figure 8-54, this is similar to the peak of fall 2019, but still below the 23-27 travel times observed between 2015 and 2018.
- Weekday morning travel time reliability is worse in the fall of 2021 than in any previous years. This is likely due to the lack of a shoulder on the bridge's upper deck. Before the modification, some incidents could be moved out of the way onto the shoulder lane. This is no longer possible, resulting in every incident having a more significant negative impact on travel times.
- Weekday data from fall 2020 must be disregarded as the observed reductions in congestion and travel times are largely due to the drop in traffic caused by the Covid-19 pandemic. While traffic had partly rebounded by then, daily peak traffic remained below pre-Covid levels, as illustrated earlier in the daily flow profiles of Figure 8-10. This caused the congestion on the bridge approach to artificially remain subdued.

The following observations can further be made for the Saturday and Sunday conditions:

- Peak Saturday congestion appears to match what was observed before the modifications. In Figure 8-52, midday Saturday congestion in the fall of 2021 extends midpoint between Castro Street and Cutting Boulevard, like what was observed between 2015 and 2019. The similarity of traffic conditions is further highlighted by the travel time data of Figure 8-53, which show a peak average time to cross the bridge in the fall of 2021 of 9 minutes that is generally matching what was observed in previous years.

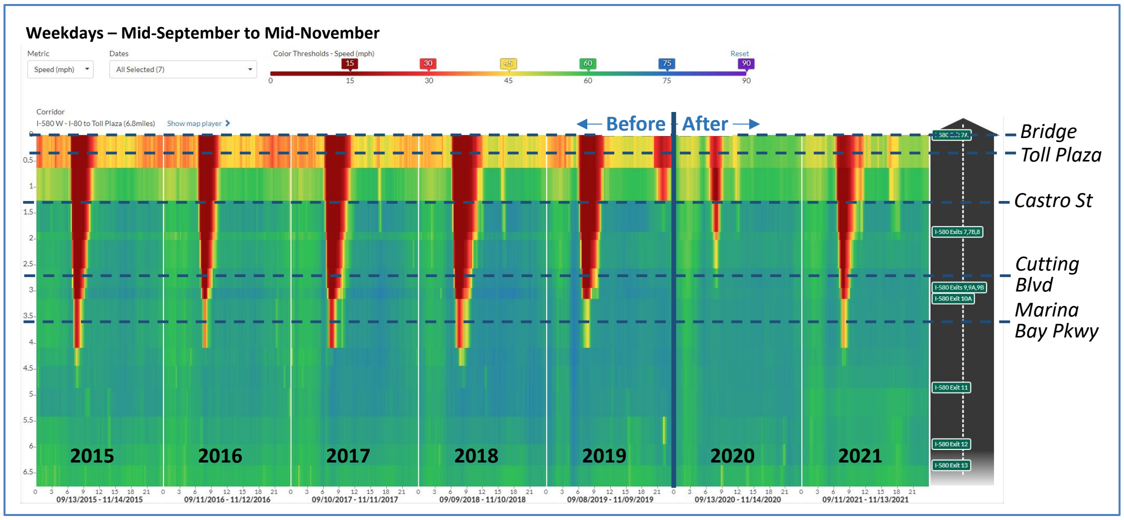

Figure 8-51: Speed Maps – I-580 West – Richmond Approach – Weekdays, Fall 2015-2021

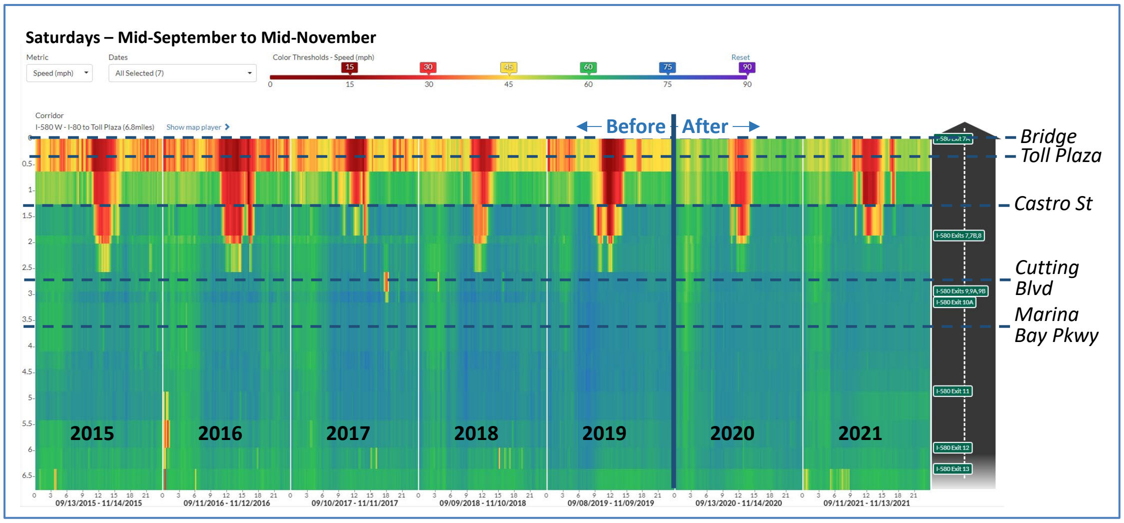

Figure 8-52: Speed Maps – I-580 West – Richmond Approach – Saturdays, Fall 2015-2021

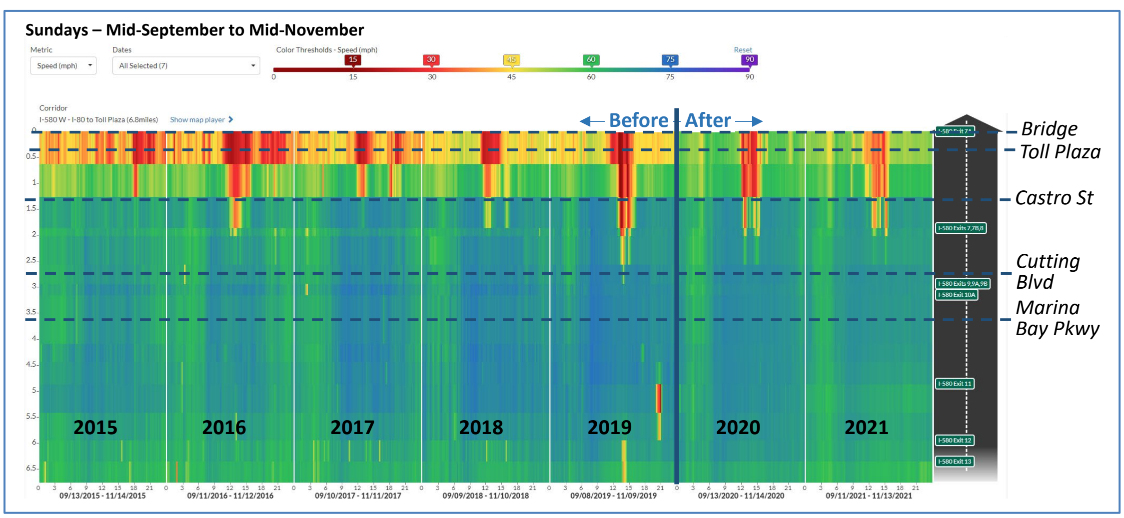

Figure 8-53: Speed Maps – I-580 West – Richmond Approach – Sundays, Fall 2015-2021

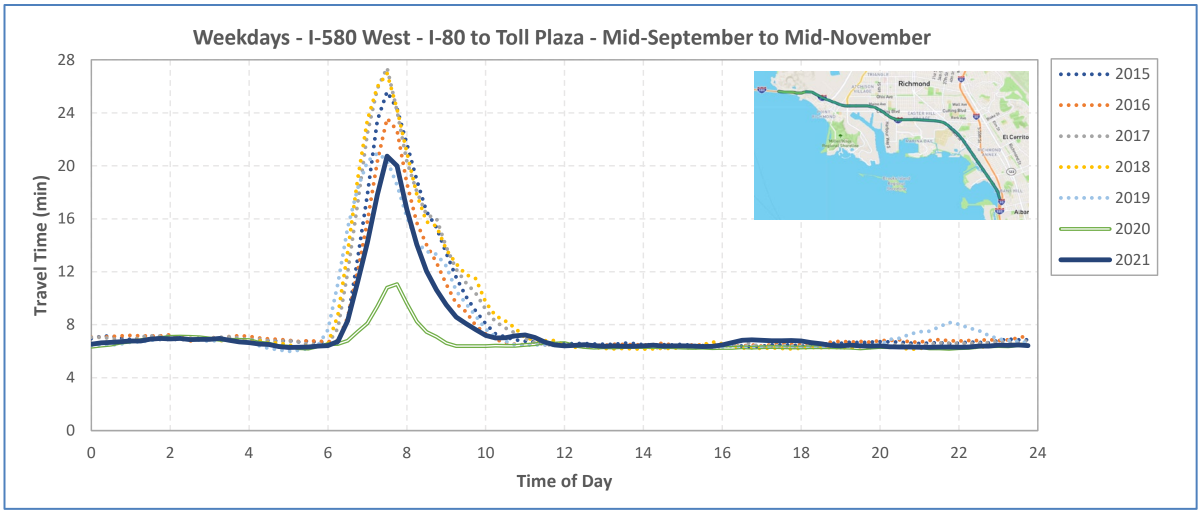

Figure 8-54: Travel Times – I-580 West – Richmond Approach – Weekdays, Fall 2015-2021

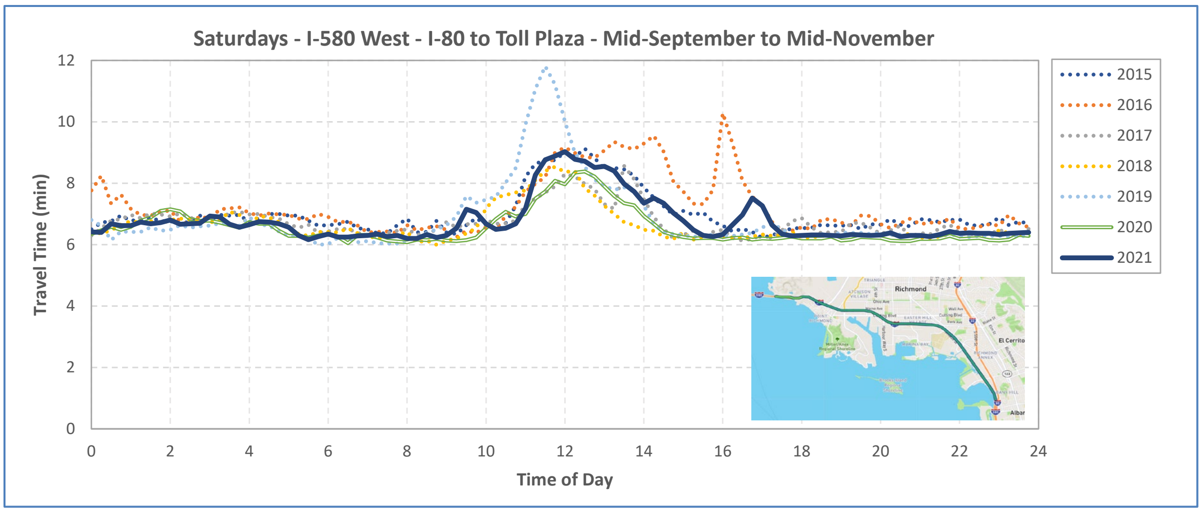

Figure 8-55: Travel Times – I-580 West – Richmond Approach – Saturdays, Fall 2015-2021

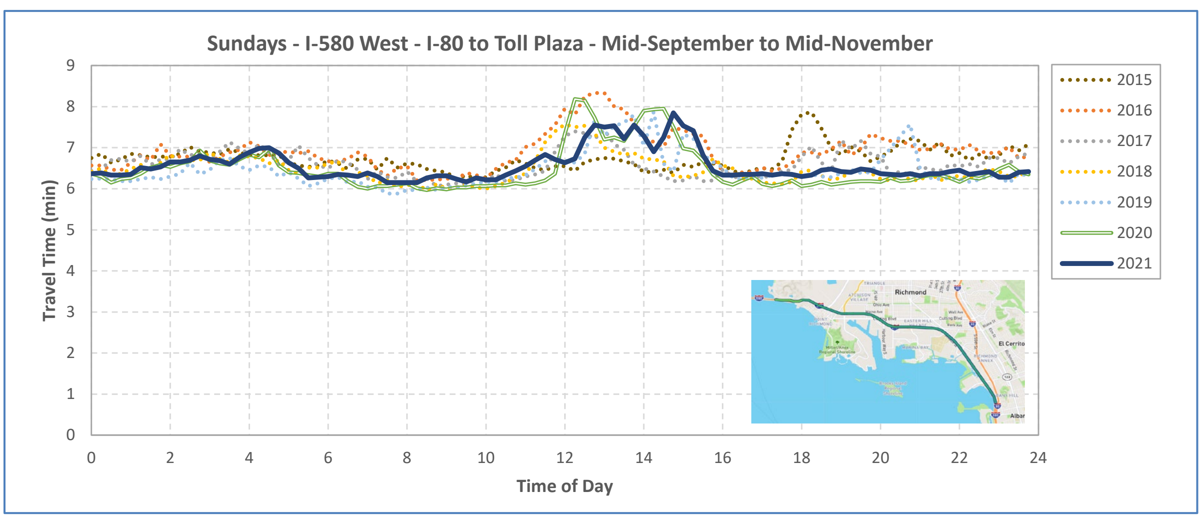

Figure 8-56: Travel Times – I-580 West – Richmond Approach – Sundays, Fall 2015-2021

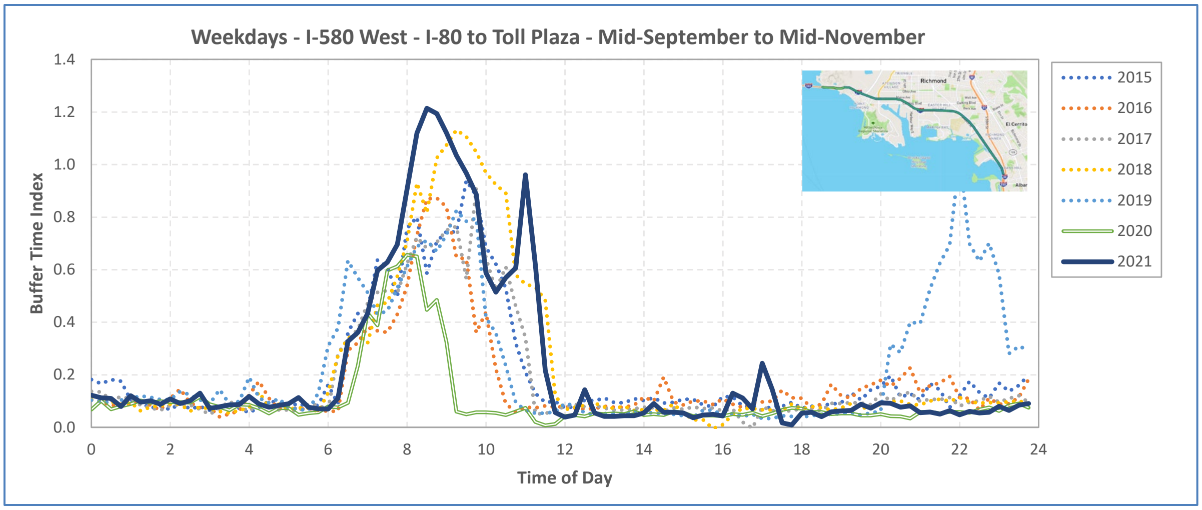

Figure 8-57: Travel Time Reliability – I-580 West – Richmond Approach – Weekdays, Fall 2015-2021

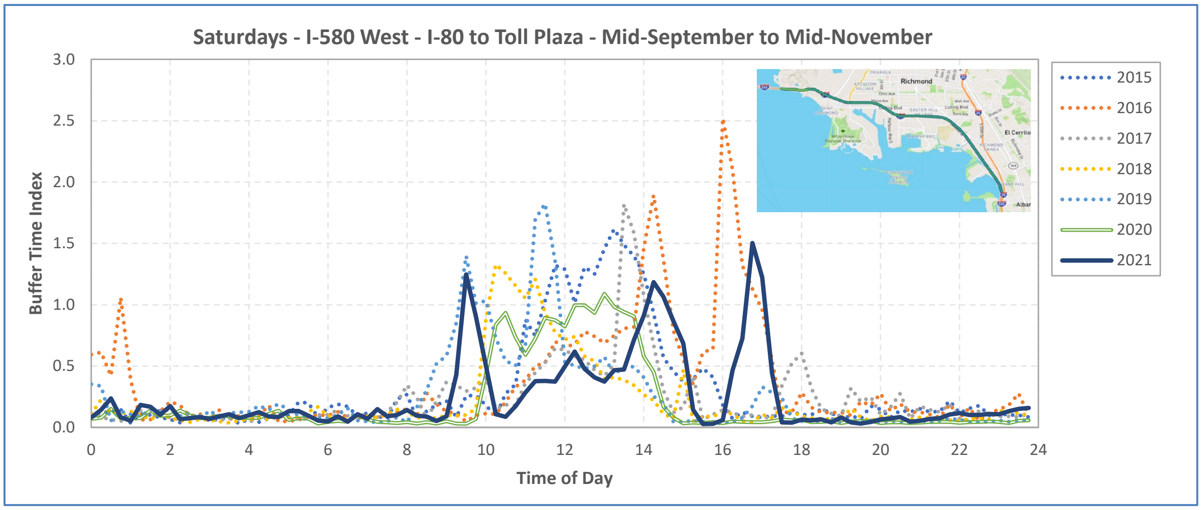

Figure 8-58: Travel Time Reliability – I-580 West – Richmond Approach – Saturdays, Fall 2015-2021

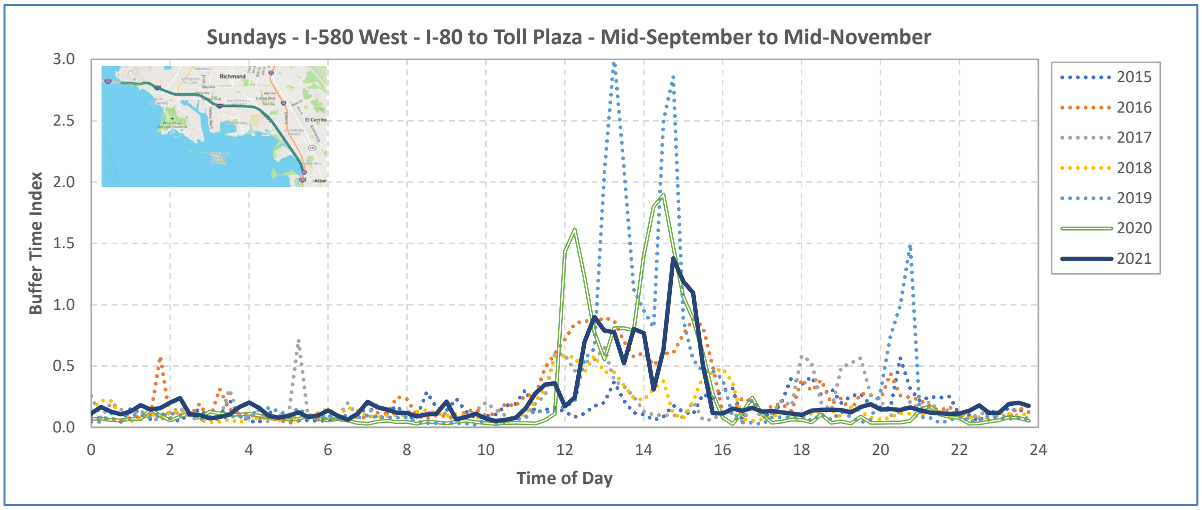

Figure 8-59: Travel Time Reliability – I-580 West – Richmond Approach – Sundays, Fall 2015-2021

- Peak Sunday congestion appears to match was what observed before the modifications. As shown in Figure 8-54, peak Sunday congestion typically extends to Castro Street before and after the modifications. As further shown in Figure 8-60, travel times to cross the bridge in the fall of 2021 generally correspond to travel times observed earlier.
- Peak travel time reliability on Saturdays and Sundays appears to be similar to what was observed before the modifications.
- A similar explanation can be provided for reductions in congestion on Saturday and Sunday in the fall of 2020. Here, while the Covid-related drop in traffic also translated into a slight reduction in travel times on Saturdays, there were no apparent impacts on Sunday. This is likely because the initial Saturday and Sunday demand did not significantly exceed the capacity of the toll plaza, resulting in the observed delays being mainly attributed to normal frictions associated with more vehicles changing lanes and merging around the toll plaza.

Based on the assessed reduction in bridge capacity outlined in Section 8.3.2, a reasonable expectation was that both the extent of congestion and travel times on the westbound approach to the bridge would have slightly increased following the upper deck modifications if traffic demand had remained the same. Based on the data in Figure 8-51 through Figure 8-56, this is not the case. Despite lower peak flows going through the toll plaza, the congestion and travel times on the approach remain similar to prior years. This can be explained by a peak traffic demand that remains slightly below the demand of prior years, particularly at the start and end of the traditional peak periods. Lower traffic demand at the beginning of the peak period may delay or constrain the growth of congestion, while lower demand at the end of the peak may facilitate a quicker return to normality.

The elimination of cash collection activities at the toll plaza may have also contributed to reducing congestion at the start and end of the peak travel periods. However, it is unlikely to have played an effect in the middle of the period. While this change allows more vehicles to go through the toll plaza in an interval, it only provides an advantage when there is no traffic backing up from the downstream merge area. As shown in Figure 8-60, Figure 8-61, and Figure 8-62 presented in the next section, congestion often exists at the entrance of the bridge during the morning peak period. This means that traffic conditions downstream of the plaza likely affect conditions at the plaza and upstream of it. Any reduction in congestion upstream of the toll plaza, while there is congestion at the foot of the bridge, is thus likely to be due to a reduction in traffic demand.

8.3.4. TRAVEL TIMES ACROSS BRIDGE

Figure 8-60 to Figure 8-62 map the average mid-September to mid-November speeds on the bridge upper deck between 2016 and 2021 for weekdays, Saturdays, and Sundays. Figure 8-63 to Figure 8-65 further present travel times across the bridge for the same period, from the toll plaza to just before the Main Street exit in Marin County. Only fall speeds are analyzed, as this is typically the period of the year with the highest traffic.

Based on the illustrated data, the following observations can be made regarding traffic conditions on the upper deck of the bridge:

- The addition of the barrier-separated path appears to have caused slight speed reductions on the bridge under heavy traffic demands. Before the modifications, reduced speeds on weekday mornings were primarily contained to the first third of the bridge, and more particularly to the

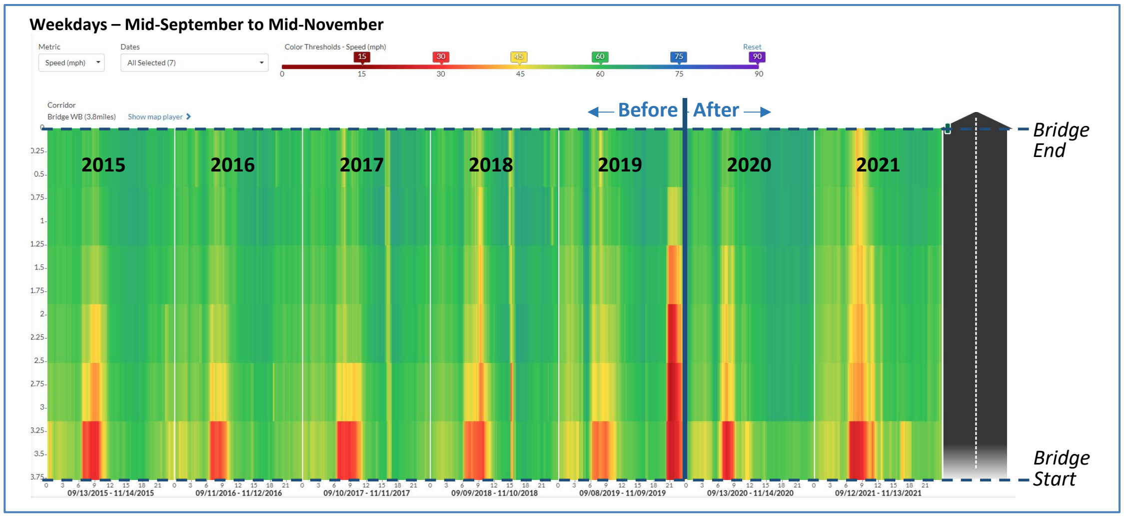

Figure 8-60: Speed Maps – I-580 West – Bridge – Weekdays, Fall 2015-2021

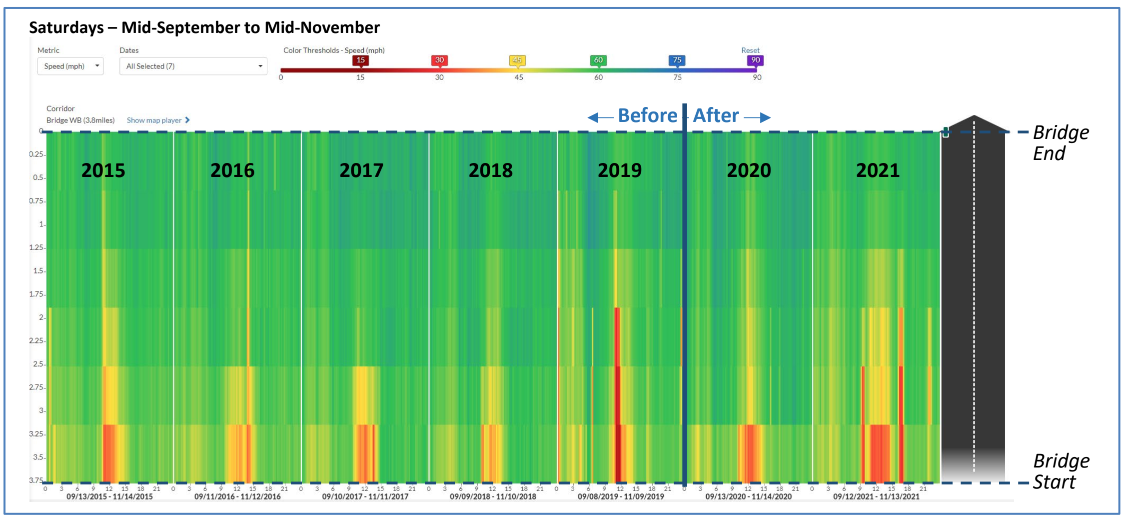

Figure 8-61: Speed Maps – I-580 West – Bridge – Saturdays, Fall 2015-2021

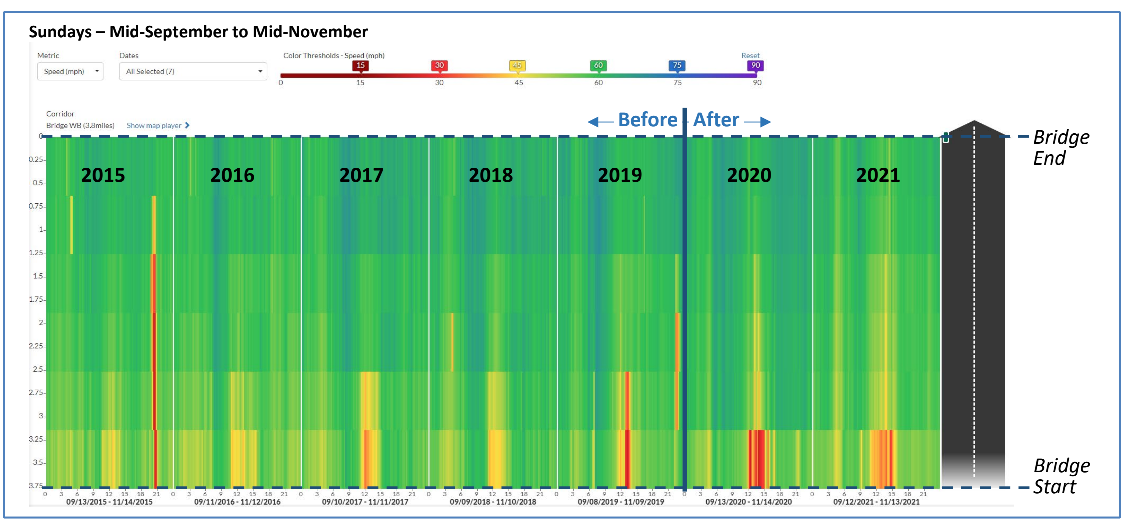

Figure 8-62: Speed Maps – I-580 West – Bridge – Sundays, Fall 2015-2021

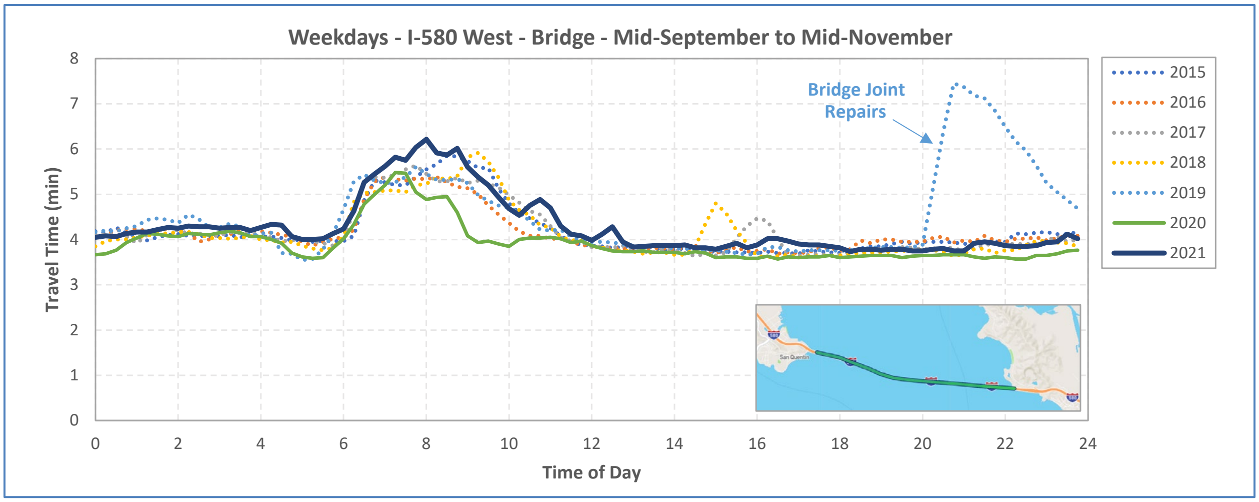

Figure 8-63: Travel Times –Bridge WB – Weekdays, Fall 2015-2021

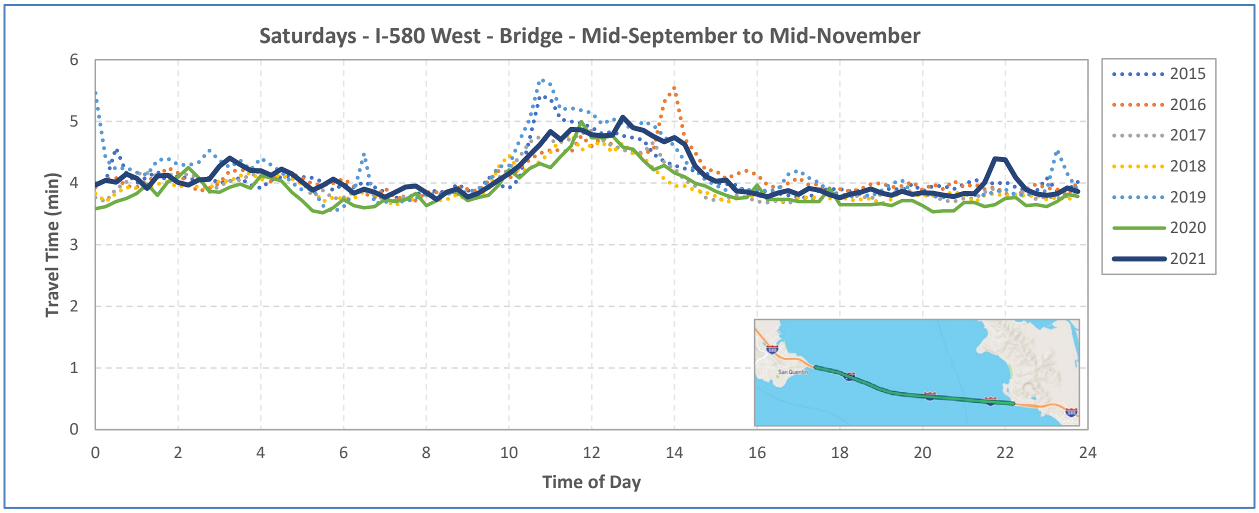

Figure 8-64: Travel Times –Bridge WB – Saturdays, Fall 2015-2021

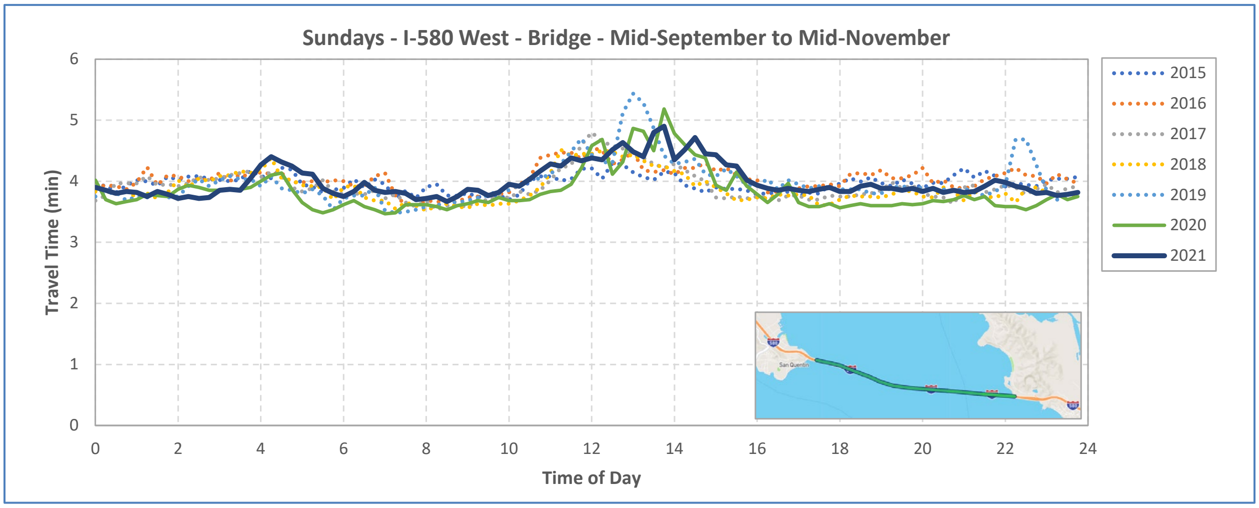

Figure 8-65: Travel Times –Bridge WB – Sundays, Fall 2015-2021

first half mile. Traffic then flowed at or above 50 mph on the remainder of the bridge. In the fall of 2021, average speeds between 40 and 50 mph (yellow and orange areas) were observed across most of the length of the bridge during weekday mornings, indicating a slight deterioration of traffic conditions under heavy traffic demand.

- Similar speed deteriorations are observed for the Saturday and Sunday afternoon peak periods, but to a lower extent due to lower traffic demands.
- The expansion of reduced speed areas did not translate into significant increases in travel times across the bridge. As shown in Figure 8-63, average peak travel times for the weekday morning peak in the fall of 2021 are less than one minute higher than the travel times that were observed before the modifications.
- As shown in Figure 8-64 and Figure 8-65, peak travel times on Saturdays and Sundays remain similar to those observed with the prior bridge configuration.

8.3.5. TRAFFIC DISTRIBUTION ACROSS LANES ON THE BRIDGE

Figure 8-66 compares the proportion of traffic using the left traffic lane on weekdays, Saturdays, and Sundays in the middle of the bridge between September/October 2018, before the modifications, and September/October 2021, after the modifications. The following observations can be made from the illustrated data:

- The changes made to the bridge have not significantly altered the distribution of traffic across the two traffic lanes between 7 AM and 7 PM on weekdays, Saturdays, or Sundays. Before the modifications, between 52% and 56% of daytime traffic used the left lane, with higher proportions observed in periods with the highest traffic. Similar proportions are observed in the fall of 2021, but 1-2% higher, suggesting a slight shift in preference towards using the left lane.
- Higher increases in left lane usage are observed before 7 AM and after 7 PM across all days. Shifts of up to 20% are observed in these cases. These shifts cannot be attributed to increases in traffic as evening, night, and morning traffic flows in the fall of 2021 were generally similar to or below those for fall 2018. The most probable cause is motorists being uncomfortable with the barrier being at the edge of the right traffic lane. Before the modifications, physical barriers were 12 feet away from the right traffic lane, at the edge of the shoulder lane, and at the edge of the left lane. After the modifications, drivers feeling uncomfortable by the closeness of the path barrier on the right might prefer to be on the left lane, where the recess in the bridge guardrail at eye level makes it visually less intimidating.

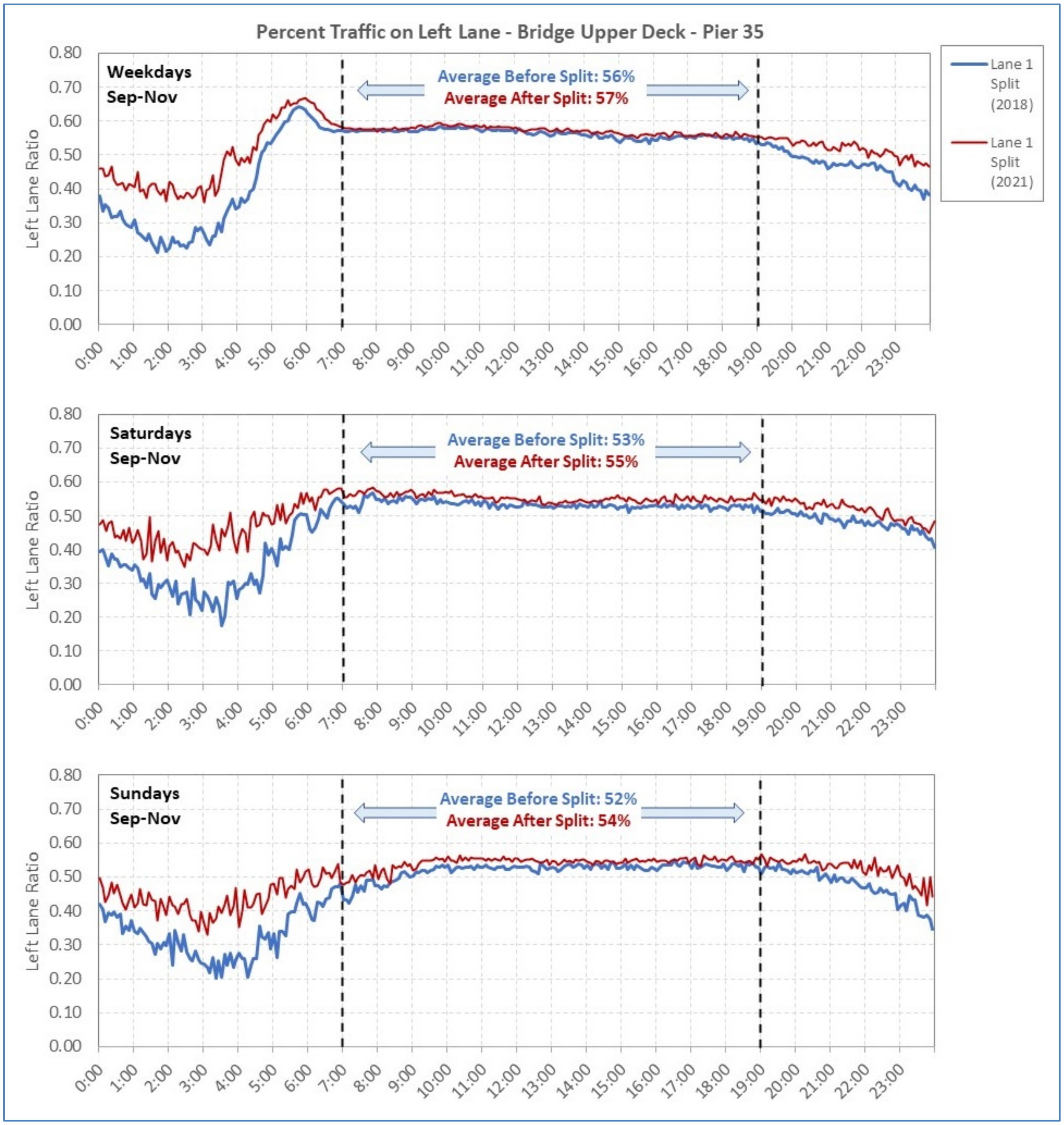

Figure 8-66: Percent of Traffic in Left Lane – Upper Deck, 2018 & 2021

8.3.6. IMPACTS ON LOCAL ARTERIALS IN RICHMOND

Figure 8-67 to Figure 8-69 illustrates observed average speeds along southbound Castro Street and Richmond Parkway/Canal Boulevard, as well as westbound Cutting Boulevard, in February/March between 2015 and 2022. As can be noted, this analysis does not reveal any negative impacts associated with the conversion of the upper deck shoulder into a barrier-delimited bike/pedestrian path during the AM peak period. Along Castro Street and Richmond Parkway/Canal Boulevard, the highest level of congestion near I-580 in the morning peak period, when traffic on I-580 is mainly traveling west, is observed in the spring of 2019, before the conversion. No significant changes are observed along Cutting Boulevard in traffic conditions between 2020 and 2017-2019.

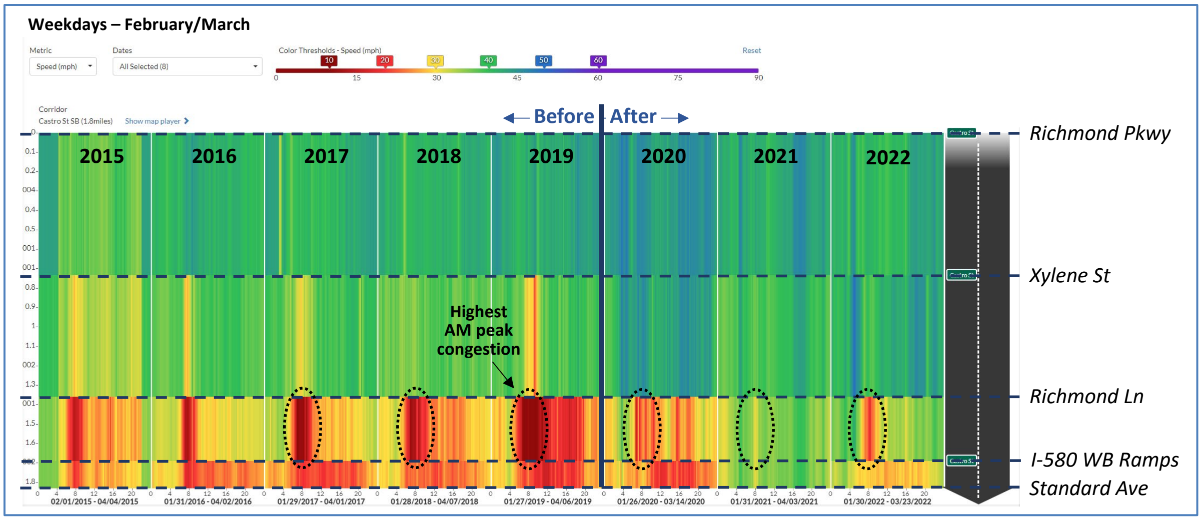

Figure 8-67: Speed Maps – Castro Street SB – Weekdays, Spring 2015-2022

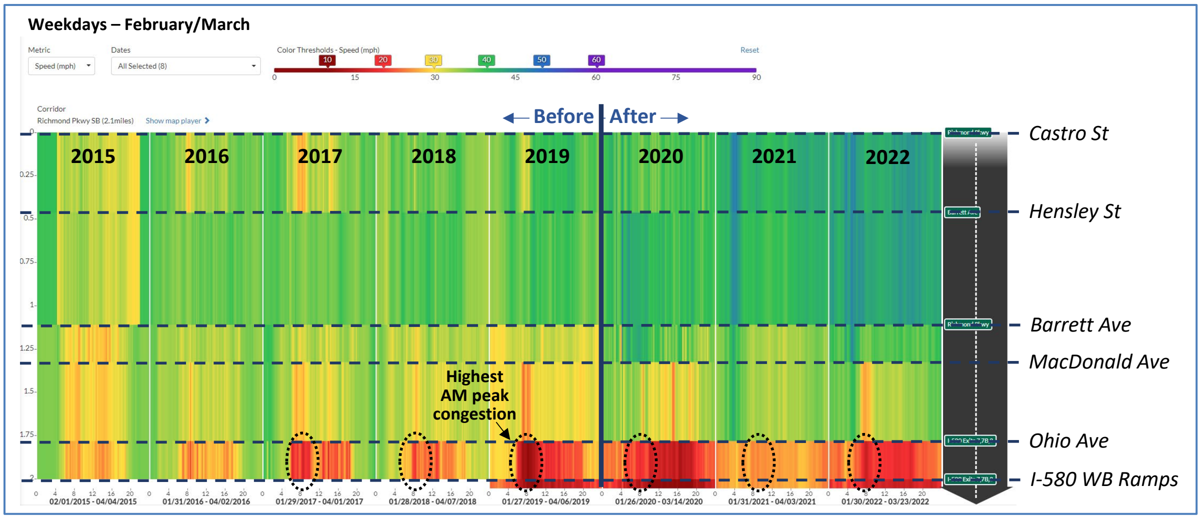

Figure 8-68: Speed Maps – Richmond Parkway SB – Weekdays, Spring 2015-2022

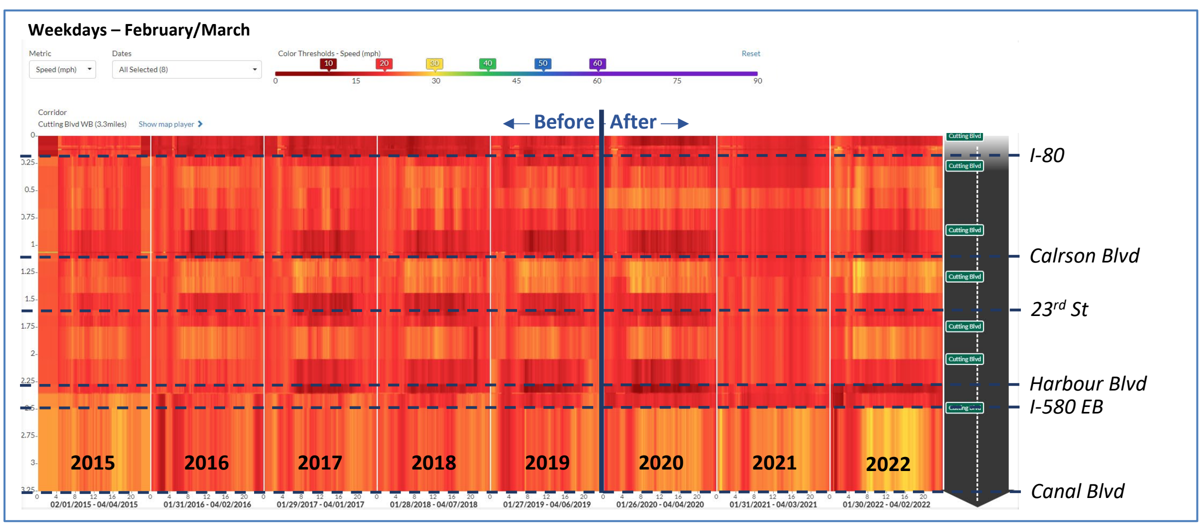

Figure 8-69: Speed Maps – Cutting Blvd WB – Weekdays, Spring 2015-2022

Along the three arterials, traffic conditions for 2021, in the after period, are heavily affected by the drop in traffic that has accompanied the Covid-19 pandemic. The observed improved conditions observed for that year should therefore be discounted. While arterial traffic has rebounded since then, observed flows remain below pre-pandemic levels. A comparison of traffic counts taken along the three arterials and I-580 West on-ramps in May 2016 and March 2022 (see section 5.2.4) indicates that AM peak arterial traffic flows in March 2022 are typically 15-20% below the May 2016 counts. This indicates that the illustrated 2022 traffic conditions are still likely affected by the Covid-19 pandemic and that definitive conclusions on arterial impacts may not be made until traffic fully recovers from the pandemic.

8.3.7. SUMMARY OBSERVATIONS

The following are the key summary observations from the analysis of the traffic impacts of the conversion of the westbound shoulder into a barrier-separated bike/pedestrian path:

- Following the modifications, average weekday peak hourly flows have dropped by 7%, and peak weekend flows by 4%. This may be due to the shorter merge area downstream of the toll plaza, as well as a roadway that appears narrower due to the barrier.
- Despite the apparent slight drop in capacity, the extent of the congestion upstream of the toll plaza during the weekday, Saturday, and Sunday peak periods remain similar to before the modifications.
- Travel times to access the bridge from I-80 remain close to historical averages on weekdays, Saturdays, and Sundays.
- Peak weekday travel times are more variable than before the modifications, likely due to the increased impacts of incidents due to the lack of a shoulder to move vehicles out of the way. Travel time reliability on weekends is like before the modifications.
- While reduced speeds are observed on more bridge sections during weekday peak periods, these reductions have only increased travel times across the bridge by less than one minute. Speed reductions observed during Saturday and Sunday midday peaks have also not caused significant changes in average travel times across the bridge.
- The installation of the path barrier appears to have caused some shift in traffic towards the left lane, particularly under low traffic volumes. Only 1-2% of traffic is observed to have shifted towards the left during high traffic periods, but up to 15% during low traffic periods.
- Available data do not indicate that the bridge modifications have had significant impacts on local arterials on the Richmond side of the bridge.

8.4. SUMMARY OBSERVATIONS

The following is a summary of key observations from the analysis of traffic impacts associated with the various bridge modifications:

- **Compliance with lower deck shoulder lane open/close periods:**
    - Motorists are generally compliant with the shoulder opening period, as relatively few vehicles are observed using the lane before 2 PM and after 7 PM.

- Non-compliant use of the shoulder lane is highest 20 minutes before its opening and up to 25 minutes following its closure.
- CHP officers have indicated observing some vehicles using the shoulder as a passing or traveling lane when a red or yellow X is shown above it. This suggests that some motorists may not fully understand the meaning of the current lane control signs.

- **Traffic impacts – Lower deck modifications:**
  - The availability of an extra traffic lane has increased the eastbound peak hourly flow across the bridge by 13-26%, from 3,300-3,570 to 3,750-4500 vehicles/hour.
  - Traffic is generally not split event across lanes. Less than 25% of traffic is observed at any given time using the shoulder lane during weekday peak periods, and less than 20% on weekends.
  - The added peak-hour capacity has eliminated congestion on the I-580 East approach to the bridge. This has caused peak travel times from the US-101 interchange to the toll plaza to drop by 13-14 minutes on weekdays, 10-14 minutes on Saturdays, and 6-8 minutes on Sundays.
  - Travel times to reach the toll plaza from the US-101 during peak periods are significantly less variable than before.
  - The absence of congestion on I-580 East has contributed to a 1- to 2-minute reduction in average travel times on US-101 North between the Sir Francis Drake Boulevard and I-580 exits.
  - Afternoon peak travel times along Sir Francis Drake Boulevard have dropped by up to 4 minutes while traffic volumes have increased by nearly 475 vehicles/hour.
  - Fewer vehicles are using local arterials as bypasses to I-580 East. The modifications have contributed to reducing traffic along Francisco Boulevard, and possibly Andersen Drive. More vehicles are also observed entering I-580 east at Bellam Boulevard, while fewer vehicles are using the Main Street ramps as a bypass.

- **Traffic Impacts – Upper deck modifications:**
  - Following the modifications, average weekday peak hourly flows have dropped by 7%, and peak weekend flows by 4%. This may be due to the shorter merge area downstream of the toll plaza, as well as a roadway that appears narrower on the bridge due to the barrier.
  - Despite the slight apparent drop in capacity, the extent of the congestion upstream of the toll plaza during the weekday, Saturday, and Sunday peak periods remain similar to before the modifications. Travel times to cross the bridge from I-80 also remain close to historical averages. This can be explained by overall traffic demands remaining slightly below before conditions, particularly at the start and end of the traditional peak periods, due to lingering Covid-related factors.
  - While reduced speeds are observed on more bridge sections during weekday peak periods, these reductions have only increased average travel times across the bridge by less than one minute. Speed reductions observed during Saturday and Sunday midday peaks have also not caused significant changes in average travel times across the bridge.

- Peak weekday travel times are more variable than before the modifications, likely due to the increased impacts of incidents due to the lack of a shoulder to move vehicles out of the way. Travel time reliability on weekends is like before the modifications.
- The path barrier appears to have caused a shift in traffic towards the left lane, particularly during low traffic periods. Only 1-2% of traffic is observed to have shifted left during high traffic periods, but up to 15% during low traffic periods.
- Available data do not indicate that the bridge modifications have had significant impacts on local arterials on the Richmond side of the bridge.

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9. BIKE/PEDESTRIAN PATH SAFETY

This section reviews reports of incidents that have occurred on the new bike/pedestrian bridge path to determine its safety for cyclists and pedestrians. The following specific elements are discussed:

- Incidents logged into the SWITRS database.
- Incidents reported on the Street Story online platform.
- Comments from a user survey
- Summary of observations.

9.1. SWITRS BICYCLE/PEDESTRIAN INCIDENT DATA

A review of bicycle and pedestrian incidents contained in the SWITRS database indicates that no incident involving cyclists or pedestrians has been logged into the database related to the new bridge path between November 2019 and December 2021.

9.2. STREET STORY REPORTS

Figure 9-1 shows a compilation of crash/near-miss incidents and safe/unsafe reports logged by travelers on the Street Story online platform between October 2018 and December 2021. The two maps indicate the following:

- No incidents or near misses were reported on the bridge.
- One hazard report was logged for the bridge path in November 2019, shortly after its opening, highlighting the need to improve access to the bridge from Marin County.

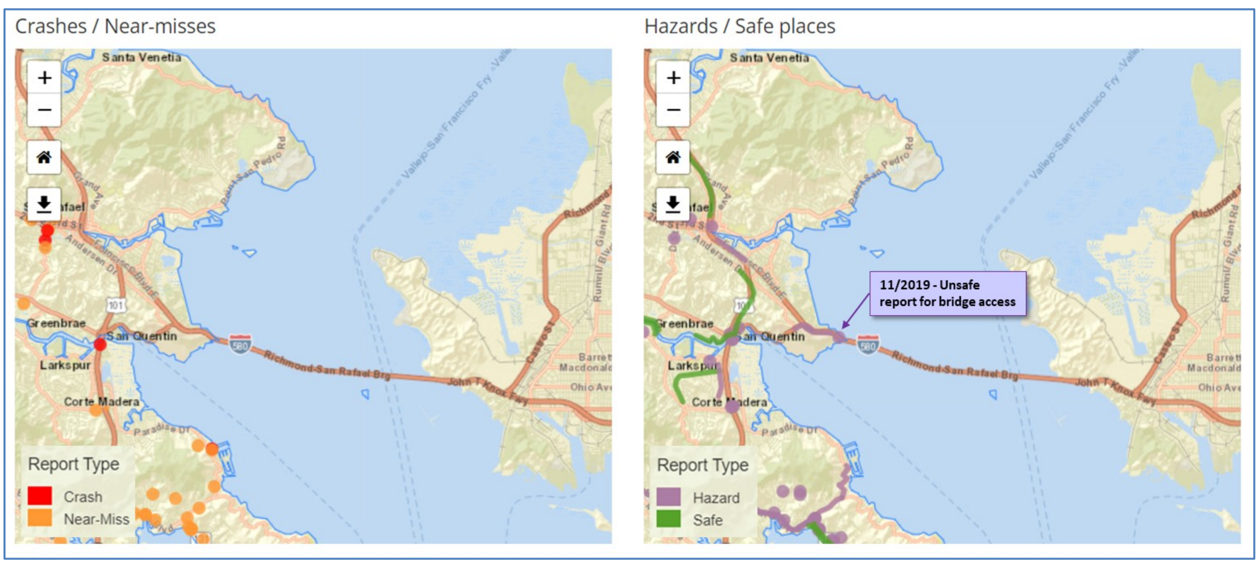

Figure 9-1: Street Story Reports for Area Surrounding Bridge

9.3. COMMENTS FROM USER SURVEY

Several respondents made safety-related comments on the bridge path during the user survey that was conducted in the summer of 2021.

Below is a summary of the key comments made regarding the bridge path:

- The bridge path needs to be swept regularly to remove glass fragments and other debris that tend to accumulate on it.
- Many were concerned about being hit by objects or incommoded by sand flung from the adjacent traffic lane and suggested that a higher barrier could help prevent such occurrences.
- A few path users commented on being blinded by lights from cars when traveling eastbound due to the low height of the barrier.
- The lane separating the two travel directions is not placed in the center of the path, resulting in a narrower eastbound lane than the westbound lane.
- Some accidents could result from cyclists traveling at high-speed sharing a narrow path with slow-moving cyclists and pedestrians.
- Noise from traffic on the adjacent lanes makes it difficult to hear other cyclists or what might be happening around.

Comments made regarding paths leading to the bridge:

- Several respondents indicated the need for improving access to the bridge, particularly on the Marin County side. Many expressed the need for fully separated bikeways going from the bridge to downtown San Rafael, as well as to Larkspur along Sir Francis Drake Boulevard.
- One rider indicated that the line of sight at the Stenmark Drive crossing might be inadequate for a safe crossing by cyclists.
- Some respondents indicated concerns that the I-580 shoulder path is only delimited by a painted line and soft bollards, as this would not stop vehicles traveling at relatively high speed to hit cyclists using the shoulder path.
- Several individuals also felt that allowing cyclists to travel along the freeway without a barrier presents a safety risk.

9.4. SUMMARY OBSERVATIONS

The following is a summary of key observations from the safety analysis of the new bridge path:

- No path-related incidents were recorded by the CHP or reported on the Street Story platform.
- While no bridge path incidents have been recorded in databases, anecdotal evidence suggests that some incidents have on rare occasions happened, such as cyclists injuring themselves after falling.
- The low height of the barrier on the bridge put riders at risk of being hit by debris flung from the adjacent traffic lanes. The low height also may cause eastbound travelers to be blinded by the

lights of passing cars and trucks in the adjacent traffic lane. While a desire has been expressed by many for a higher barrier, this may not be compatible with the barrier-moving system.

- There is a need to improve paths leading to the bridge, particularly on the Marin County side.

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10. TRAFFIC SAFETY IMPACTS

This section assesses the impacts of the bridge modifications on traffic safety along the I-580. This is accomplished by comparing the number, type, and severity of incidents before and after the bridge modifications. The following subsections respectively present:

- Identification of I-580 sections used for the safety analysis.
- Impacts of the lower deck shoulder opening on traffic safety on eastbound traffic.
- Impacts of the upper deck bicycle/pedestrian path installation on westbound traffic.
- Summary of observations.

10.1. SAFETY ANALYSIS SECTIONS

Figure 10-1 illustrates the various sections used for evaluating the safety impacts of the bridge modifications. These sections include:

- **Bridge, eastbound and westbound directions**: Sections of I-580 East and West extending from the toll plaza in Richmond to the foot of the bridge in Marin County (Contra Costa County Postmile 6.15 to Marin County Postmile 2.50).
- **Bridge westbound approach**: Section of I-580 West in Contra Costa County extending from the Harbour Way interchange to the toll plaza (Contra Costa County Postmiles 3.50 to 6.05).
- **Toll Plaza area**: Section of I-580 West around the Richmond toll plaza (Contra Costa County Postmiles 6.05 to 6.25).
- **Toll Plaza merge area**: Section of I-580 West downstream of the toll plaza where the number of traffic lanes drops from 7 to 2 (Contra Costa County Postmiles 6.25 to 6.55).
- **Bridge eastbound approach**: Section of I-580 East in Marin County from the US-101 interchange to the foot of the bridge (Marin County Postmiles 4.80 to 2.50).

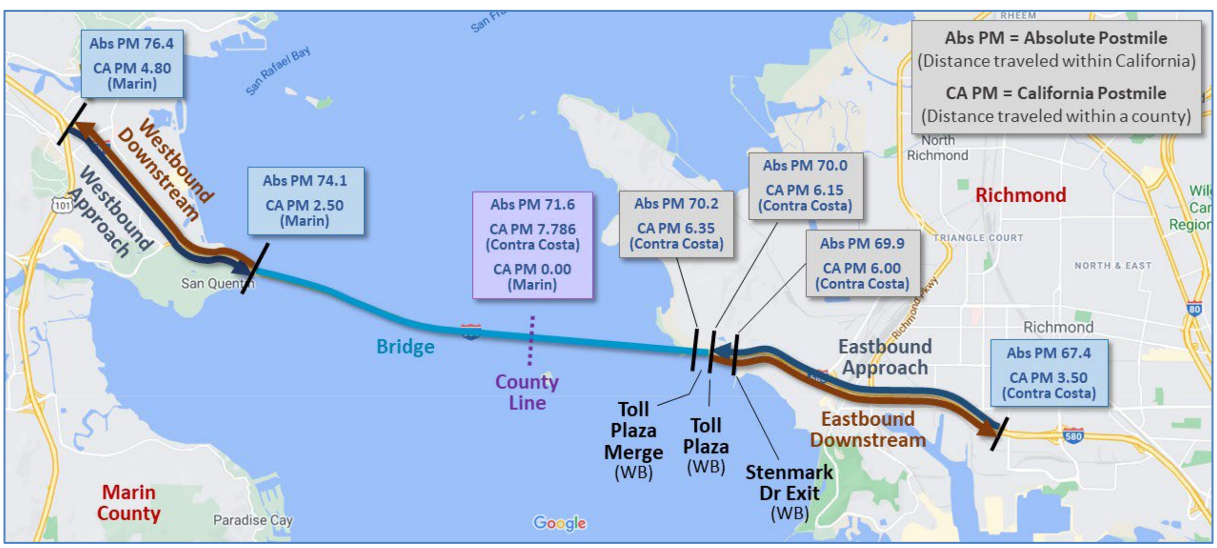

Figure 10-1: Safety Analysis Sections

- **Bridge westbound downstream section**: Section of I-580 West in Marin County from the Main Street off-ramp to the US-101 interchange (Marin County Postmiles 2.50 to 4.80).
- **Bridge eastbound downstream section**: Section of I-580 East in Contra Costa County from the toll plaza to the Harbour Way interchange in Richmond (Contra Costa County Postmiles 6.15 to 3.50).

Section limits are provided using California Postmile (also known as Relative postmiles) since incidents reported by the California Highway Patrol are typically positioned along freeways using the California Postmile system.

10.2. ESTIMATED VEHICLE MILES TRAVELED

Figure 10-2 and Figure 10-3 present the estimated vehicle miles of travel (VMT) statistics for the eastbound and westbound sections considered for the safety analysis. East figure presents the estimated VMT for the approach to the bridge, the bridge itself, and the section downstream of the bridge as defined in Figure 10-1. Within each figure, grey areas further identify the quarter during which the bridge modifications were made and the period affected by Covid-19 stay-at-home orders.

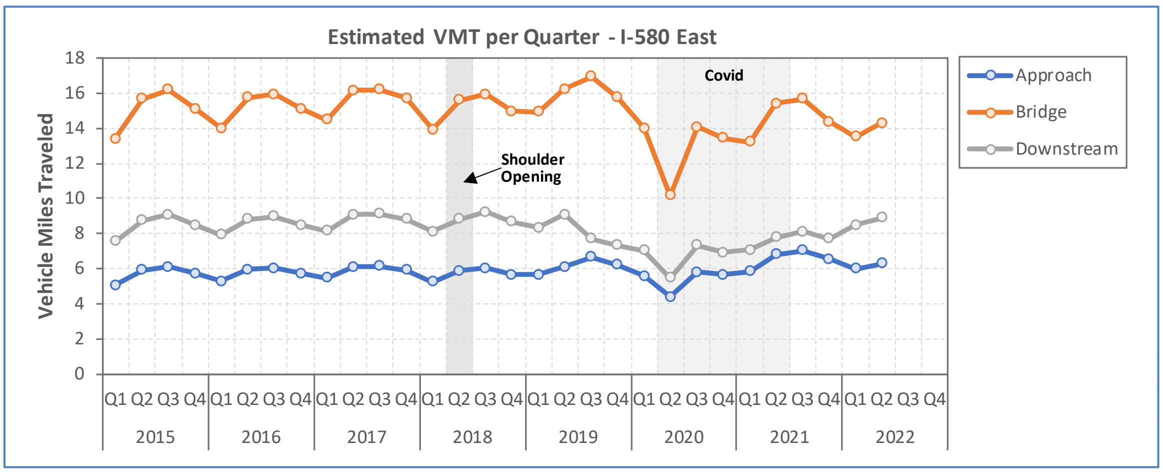

Figure 10-2: Estimated Vehicle Miles of Travel for Analysis Sections – I-580 East

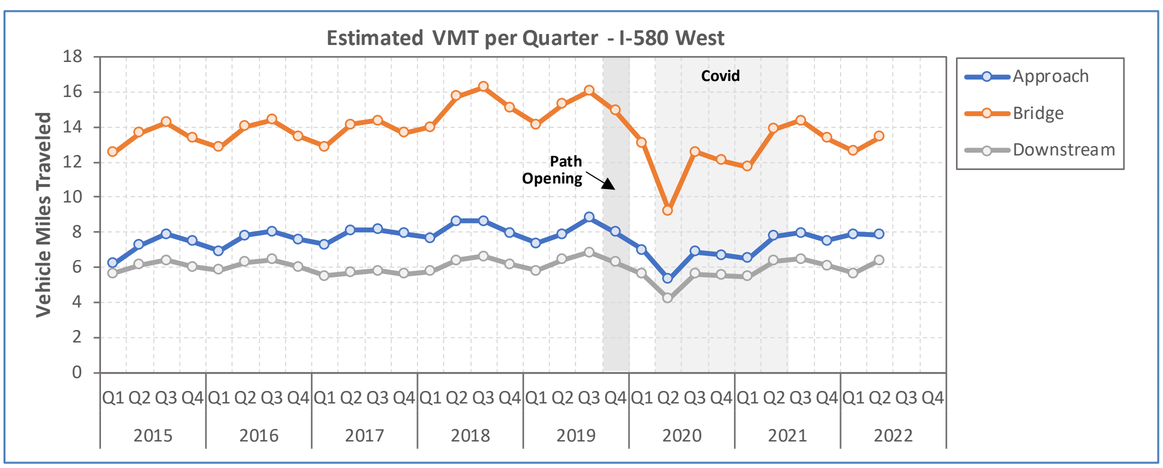

Figure 10-3: Estimated Vehicle Miles of Travel for Analysis Sections – I-580 West

For both directions, estimation of the VMT is based on data provided by PeMS. For the period between June 25, 2019, and June 2022, the statistics are mainly data directly provided by PeMS as there was adequate coverage along the corridor. Between February 2018 and June 25, 2019, data from several traffic monitoring stations on I-580 East in Marin County and Richmond had to be estimated. Statistics from the bridge were still available. Before February 2018, statistics from the bridge had to be estimated in addition to several stations on each side of the bridge as only a few stations produced count data for this period. As indicated earlier in Figure 5-1 to Figure 5-4, only the Canal Blvd stations on I-580 East and West and one station on I-580 West in Marin County were producing data, in addition to the toll plaza counts on I-580 West.

10.3. IMPACTS ON I-580 EAST SAFETY

This section presents incident statistics related to the conversion of the eastbound shoulder lane on the bridge's lower deck into a part-time traffic lane. The following analyses are presented based on data from the TASAS database from January 2016 to December 2021:

- Total number of incidents
- Categorization by incident types
- Categorization by incident severity
- Duration of incidents on the bridge
- Motorist recognition of overhead signs

10.3.1. OVERALL INCIDENT RATES ON BRIDGE AND APPROACH

Figure 10-4 illustrates the frequency of accidents, per million miles traveled, on I-580 East around the bridge for each quarter between January 2016 and December 2021 based on information contained in the TASAS database. The graph distinguishes incidents occurring on the approach to the bridge, the bridge itself, and downstream, based on the section boundaries shown earlier in Figure 10-1. The light gray area further marks the period during which the eastbound shoulder lane has been opened, while the dark gray area marks the period affected by Covid-19 stay-at-home orders.

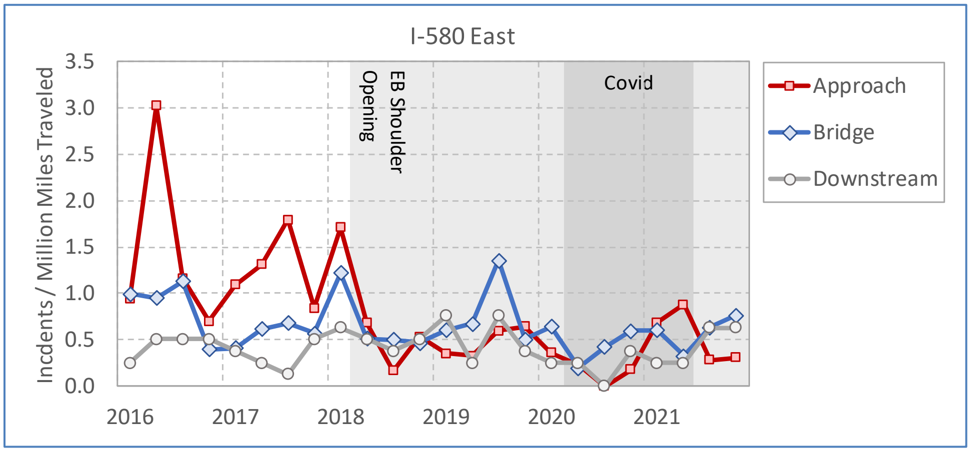

Figure 10-4: Number of Accidents by Quarter – I-580 East, 2016-2021

Ignoring any Covid-impacted data from the second quarter of 2021 to the second quarter of 2022, inclusively, the following observations can be made based on the illustrated data:

- Following the shoulder lane opening, the frequency of incidents occurring on the bridge approach has dropped from 1.40 to 0.40 per million miles traveled. This is a 72% reduction that is statistically significant at the 95% confidence level. Most of this drop coincides with the lane opening, suggesting that the modification is the primary contributing factor. The drop can largely be explained by the elimination of the congestion that used to affect traffic on the bridge approach during the weekday and weekend afternoon peak periods.
- The frequency of incidents occurring on the bridge also appears to have dropped by 10%, from 0.78 to 0.68 incidents per million miles traveled. However, this reduction is not statistically significant at the 95% confidence level based on the observed quarter-to-quarter variations in incident rates and could therefore simply be the result of stochastic variability.
- Incidents occurring downstream appears to have increased by 24%, from 0.41 to 0.51 incidents per million miles traveled. However, this change is not statistically significant at the 95% confidence level on the observed quarter-to-quarter variations in incident rates. Significant changes were not expected in this section as the only modification has been an increase in the number of lanes around the toll plaza from two to three to provide continuity in the number of lanes with downstream sections of I-580.

10.3.2. INCIDENT TYPES ON BRIDGE AND APPROACH

Figure 10-5 illustrates the frequencies at which various types of incidents have occurred on the eastbound approach to the bridge and the bridge's lower deck for each quarter between January 2016 and December 2021. Table 10-1 further presents the total numbers of documented incidents for both sections for the before and after periods, while Table 10-2 presents the average rates, on a per million miles traveled basis, at which each type of incident occurred before and after the modifications. In both tables, data from the second quarter of 2018 are ignored as some incidents within this period fall before the change and others after. Data between April 2020 and June 2021 are also ignored due to a bias towards fewer incidents associated with the drop in traffic caused by the Covid-19 stay-at-home orders.

The following specific observations can be made regarding changes in the types of incidents occurring in the eastbound traffic direction:

- For both before and after the modifications the primary types of incidents around the bridge are rear-ends, sideswipes, and vehicles hitting objects. On the approach, these three categories represent 99% of the before cases and 96% of the after cases. On the bridge, they represent 95% and 89% of the before and after incidents respectively.
- Following the shoulder opening, the rate of **rear-end collisions** per million miles traveled occurring on the approach dropped from 0.79 to 0.14 (-82%), and on the bridge from 0.50 to 0.34 (-33%). These changes reduced the overall incident rate from 0.58 to 0.28 (-51%).
- The rate of **sideswipes** occurring on the approach dropped from 0.41 to 0.16 (-60%) but increased from 0.12 to 0.15 (+22%) on the bridge, resulting in an overall drop from 0.20 to 0.15 (-23%). The increase on the bridge is likely the result of more vehicles changing lanes as a result of the availability of an additional traffic lane during peak hours.

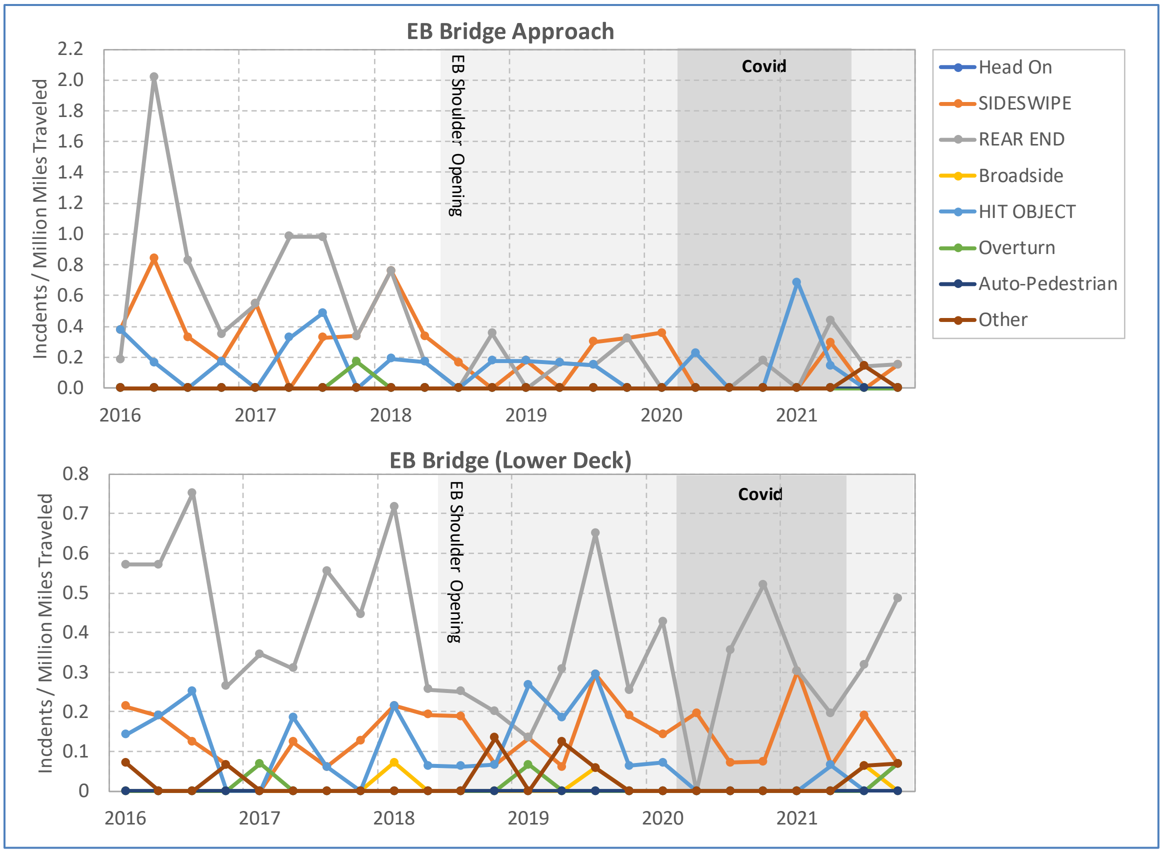

Figure 10-5: Quarter Accidents Rates by Type – I-580 East, 2016-2021

Table 10-1: Before/After Incident Types on Bridge Approach and Lower Deck – I-580 East

Incident Type	Approach		Bridge Lower Deck		Overall	
	Before	After	Before	After	Before	After
Rear-End	41 (56.2%)	8 (36.4%)	69 (65.1%)	47 (49.0%)	110 (61.5%)	55 (46.6%)
Sideswipe	21 (28.8%)	9 (40.9%)	17 (16.0%)	21 (21.9%)	38 (21.2%)	30 (25.4%)
Hit Object	10 (13.7%)	4 (18.2%)	16 (15.1%)	17 (17.7%)	26 (14.5%)	21 (17.8%)
Broadside	0 (0.0%)	0 (0.0%)	1 (0.9%)	2 (2.1%)	1 (0.6%)	2 (1.7%)
Overturn	1 (1.4%)	0 (0.0%)	1 (0.9%)	2 (2.1%)	2 (1.1%)	2 (1.7%)
Other	0 (0.0%)	1 (4.5%)	2 (1.9%)	7 (7.3%)	2 (1.1%)	8 (6.8%)
Overall	**73**	**22**	**106**	**96**	**179**	**118**

Note: Before Period: 01/2016 to 03/2018 (9 quarters)
After Period: 07/2018 to 12/2021, excluding 03/2020 to 06/2021 due to Covid-19 effects (9 quarters)

Table 10-2: Before/After Incident Rates per Million Miles Traveled by Type – I-580 East

Incident Type	Approach		Bridge		Overall	
	Before	After	Before	After	Before	After
Rear End	0.791	0.144	0.503	0.339	0.582	0.283
Sideswipe	0.405	0.162	0.124	0.151	0.201	0.154
Hit Object	0.193	0.071	0.117	0.123	0.137	0.108
Broadside	0.000	0.00	0.007	0.014	0.005	0.010
Overturn	0.019	0.00	0.007	0.014	0.011	0.010
Other	0.000	0.018	0.015	0.050	0.011	0.041
Overall	**1.408**	**0.397**	**0.772**	**0.692**	**0.946**	**0.608**

Note: Before Period: 01/2016 to 03/2018 (9 quarters)
After Period: 07/2018 to 12/2021, excluding 03/2020 to 06/2021 due to Covid-19 effects (9 quarters)

- The rate of **vehicles hitting objects** dropped from 0.19 to 0.11 (-63%) on the approach, but slightly increased from 0.117 to 0.124 (+4%) on the bridge, resulting in an overall drop from 0.14 to 0.11 (-21%) when combining both sections.
- No definitive observations can be made on the rates of other types of incidents due to their relatively low incidence. In these cases, the observed changes could simply be the results of stochastic variations.

The above results are a direct consequence of eliminating congestion on the bridge approach and increasing the number of traffic lanes on the bridge. The reduced congestion on the approach to the bridge has led to fewer stop-and-go situations and fewer lane changes. This has translated into fewer rear-end and sideswipe collisions. On the bridge, the addition of a traffic lane has led to lower traffic densities during peak traffic periods, and thus fewer risks for rear-end collisions. However, this change is also providing more opportunities for lane changes and leading to more frequent sideswipe collisions.

10.3.3. INCIDENT SEVERITY ON BRIDGE AND APPROACH

Figure 10-6 presents the rates, on a per million miles traveled basis, at which incidents of various severity have occurred on the bridge's eastbound approach and lower deck for every quarter between January 2016 and December 2021. Table 10-3 further presents the number of incidents of each type that have been documented for the before and after periods, while Table 10-4 presents the average rates at which

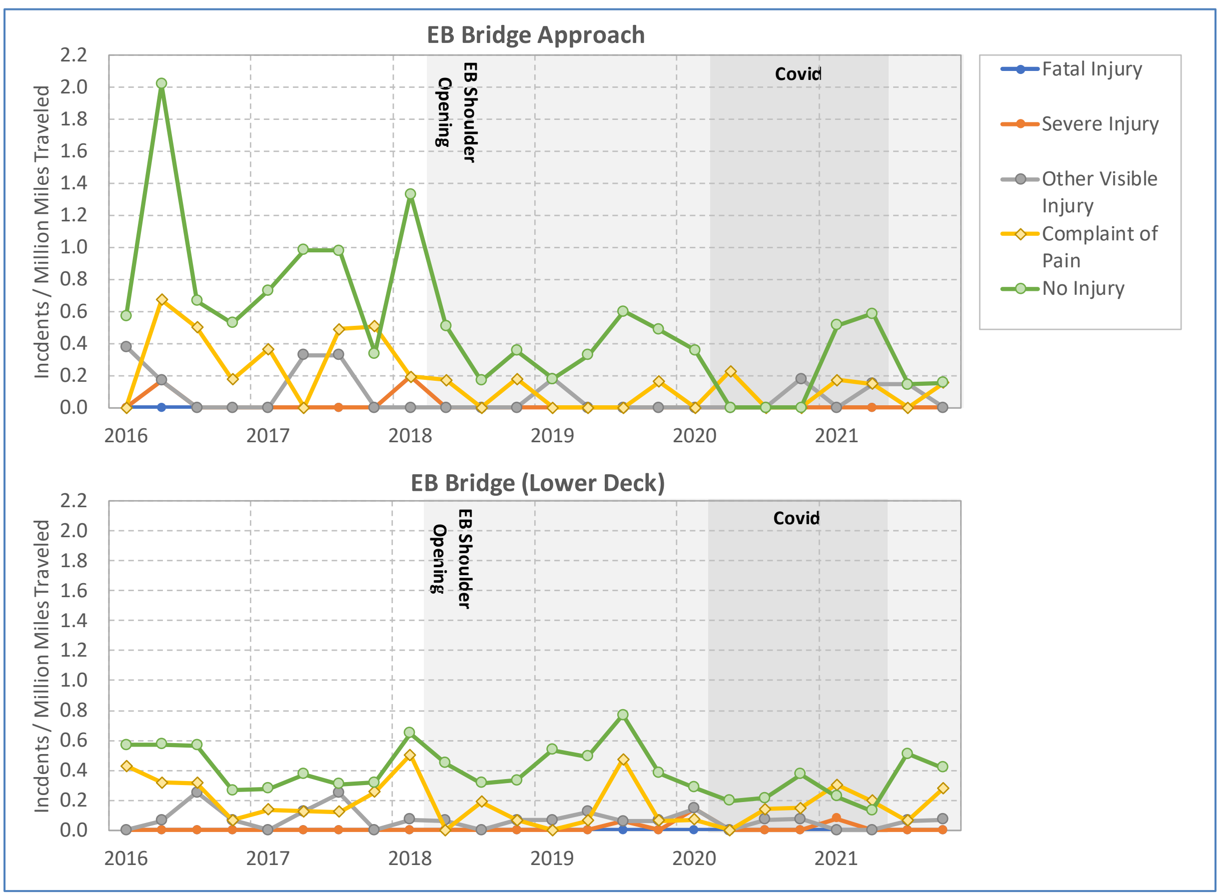

Figure 10-6: Accidents by Severity – I-580 East, 2016-2021

Table 10-3: Before/After Incidents by Severity on Bridge Approach and Lower Deck – I-580 East

Incident Type	Approach		Bridge Lower Deck		Overall	
	Before	After	Before	After	Before	After
No Injury	47 (64%)	17 (77%)	59 (56%)	63 (66%)	106 (59%)	60 (68%)
Complaint of Pain	17 (23%)	3 (14%)	34 (32%)	20 (21%)	51 (28%)	23 (19%)
Other Visible Injury	7 (10%)	2 (9%)	13 (12%)	10 (10%)	20 (11%)	12 (10%)
Severe Injury	2 (3%)	0 (0%)	0 (0%)	3 (3%)	2 (1%)	3 (3%)
Fatal Accident	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Overall	**73**	**22**	**106**	**96**	**179**	**118**

Note: Before Period: 01/2016 to 03/2018 (9 quarters)
After Period: 07/2018 to 12/2021, excluding 03/2020 to 06/2021 due to Covid-19 effects (9 quarters)

Table 10-4: Before/After Incident Rates per Million Miles Traveled by Severity – I-580 East

Incident Severity	Approach		Bridge		Overall	
	Before	After	Before	After	Before	After
No Injury	0.906	0.307	0.430	0.454	0.560	0.412
Complaint of Pain	0.328	0.054	0.248	0.144	0.270	0.118
Other Visible Injury	0.135	0.036	0.095	0.072	0.106	0.062
Severe Injury	0.039	0.000	0.000	0.022	0.011	0.015
Fatal Accident	0.000	0.000	0.000	0.000	0.000	0.000
Overall	**1.408**	**0.397**	**0.772**	**0.692**	**0.946**	**0.608**

Note: Before Period: 01/2016 to 03/2018 (9 quarters)
After Period: 07/2018 to 12/2021, excluding 03/2020 to 06/2021 due to Covid-19 effects (9 quarters)

each type of incident occurred. In both tables, data from the second quarter of 2018 are ignored as some incidents within this period fall before the change and others after. Data from April 2020 to June 2021 are also ignored due to a bias towards fewer incidents associated with the significant drop in traffic caused by the Covid-19 stay-at-home orders.

As illustrated, the dominant types of incidents occurring around the bridge both before and after the modifications are incidents without injuries and incidents with only a complaint of pain. These represent 88% of the before incidents and 89% of the after incidents. Of the 297 documented incidents, only 32 (11%) were incidents with other visible injuries and 5 (2%) incidents with severe injuries. No fatal accidents were reported during the analysis period (but one did occur in 2022).

Reflecting the overall reduction in incident rate illustrated in Figure 10-4, Table 10-4 indicates that the rates of incidence of the various types of incidents dropped on the approach to the bridge following the opening of the eastbound shoulder lane in April 2018. This is again linked to the elimination of the congestion on the approach. The data in Table 10-4 confirms the rate reductions, with a 66% reduction in the rate of incidents without injury, an 83% reduction in incidents with complaints of pain, and a 73% reduction in incidents with other visible injuries.

Matching the 10% overall reduction in incident rate mentioned earlier, small reductions in accident rates are also observed on the bridge's lower deck. The data indicate a 42% drop in the rate of incidents with a complaint of pain and a 24% drop in incidents with other visible injuries. However, the rate of incidents without injury, the dominant type, is shown to have increased by 6%, from 0.43 to 0.45. This change is at the border of statistical rejection, meaning that it may or may not be significant. While the rate of incidents with severe injury has also increased, from 0.00 to 0.02 per million miles traveled, the frequency of this type of incident remains extremely low.

Overall, the data indicate a general drop in the severity of incidents occurring on the bridge. Incidents without injury, the type with the lowest severity, represented 59% of all incidents before the modifications. Since the modifications, this incident type has represented 68% of all incidents.

10.3.4. INCIDENT DURATIONS ON BRIDGE

Figure 10-7 plots the estimated duration of crashes that have occurred on the lower deck of the bridge between 2 PM and 7 PM, from July 2016 to November 2021, based on incident logs from the CHP CAD data feed that have been processed by the Bay Area Traffic Incident Management Dashboard. This is the only dataset from which incident duration can be estimated. This is also the source of most statistics on incident durations reported by Bay Area transportation agencies.

For the analysis, only incidents that have occurred between 2 PM and 7 PM are considered since the lower deck modifications are only in effect during this period. In addition, only incidents lasting 5 minutes or more are considered as shorter incidents often have incomplete logs in the CHP CAD database.

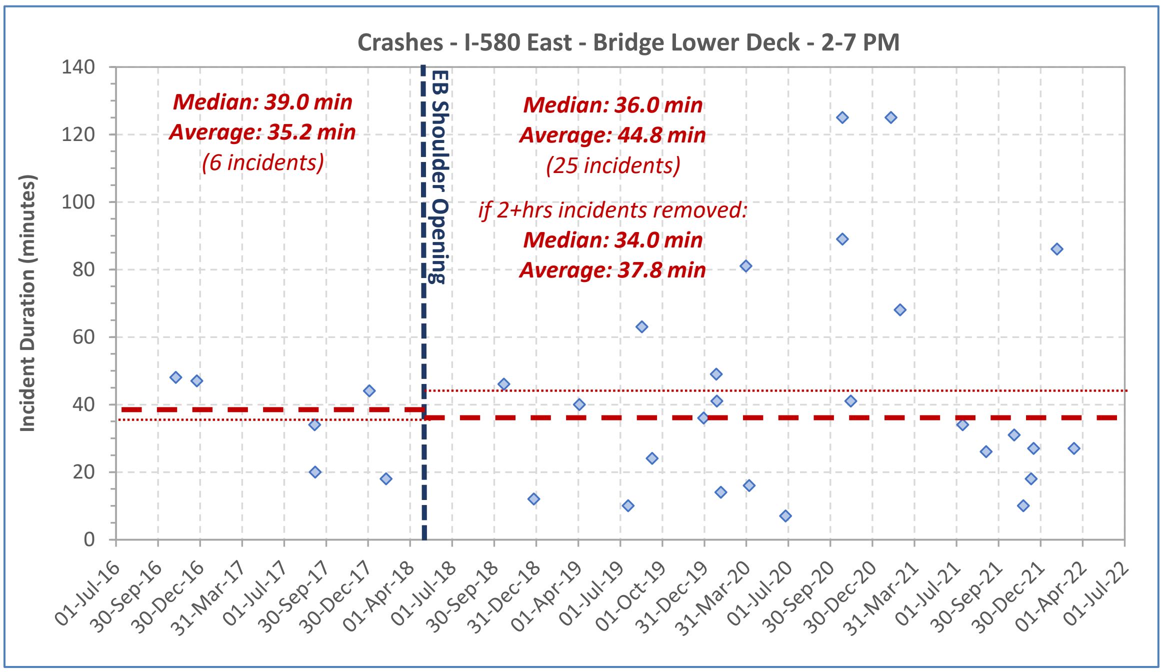

Figure 10-7: Incident Durations – Bridge Lower Deck, 2 PM to 7 PM, 2016-2022

As was indicated in Sections 5.5.4 and 5.5.5, incident durations estimated from CHP CAD logs are subject to some errors as these are simply based on when the first and last event-related messages were logged and as these messages do not always correspond to the actual start and end of an incident. While errors may exist in the reported durations, the purpose of the analysis presented here is to determine whether the bridge modifications may have had significant negative impacts on incidents. Since a single data source is used, the following analysis is thus made under the assumption that potential errors in how incident durations are estimated are consistent before and after the bridge modifications, thus allowing a rough comparative evaluation to be made of conditions before and after the changes.

The data of Figure 10-7 suggests that the average duration of incidents occurring on the bridge lower deck between 2 PM and 7 PM may have increased following the opening of the eastbound shoulder lane as the average duration is estimated to have increased from 35.2 to 44.8 minutes. However, this is contradicted by a reduction in the median duration from 39.0 to 36.0 minutes. In addition, if the two incidents lasting more than two hours are removed, there is then slightly less than a 3-minute increase in average duration.

Given the relatively wide variability of incident durations and the relatively limited number of observations, particularly before the modifications, there is a high likelihood that the observed changes might simply be due to randomness in the characteristics of incidents included in the before and after datasets. This is supported by statistical tests indicating that the before and after average durations are not statistically different at a 95% confidence level based on the low sample sizes and observed variability. As a result, no definite conclusions can be drawn from the analysis regarding the impacts of the shoulder lane opening on incident duration.

10.3.5. UNDERSTANDING OF OVERHEAD LANE SIGNS

A key concern from CHP officers regarding the overhead signage on the lower deck is that some motorists do not appear to fully understand the significance of the green arrow/yellow X/red X displayed above the lanes. This is based on the fact that officers have repeatedly seen vehicles traveling on the shoulder when a yellow or red X is displayed above, treating it as a passing lane or regular traffic lane. Such behavior may in part be promoted by the fact that motorists now generally know that the shoulder lane is used at times as a traffic lane that extends across the entire bridge. As a result, there may be a reduced perceived risk of using it when it is closed.

Unauthorized use of the shoulder creates a significant safety hazard, has unauthorized users run the risk of encountering stopped vehicles on the shoulder. This is particularly problematic for maintenance, tow trucks, and other emergency vehicles that may be stopped on the shoulder. Additional risks may also come from motorists in the adjacent regular traffic lane not expecting to be passed by a vehicle on the right.

10.4. IMPACTS ON I-580 WEST SAFETY

This section presents incident statistics related to the conversion of the westbound shoulder lane on the bridge's upper deck into a barrier-separated bike/pedestrian path. The following analyses are presented based on data from the TASAS databased between January 2016 to December 2020:

- Total number of incidents
- Categorization by incident types
- Categorization by incident severity
- Duration of incidents occurring on the bridge

10.4.1. OVERALL INCIDENT RATES ON BRIDGE AND APPROACH

Figure 10-8 illustrates the frequency of accidents, per million miles traveled, on I-580 West around the bridge for each quarter between January 2016 and December 2021 based on information contained in the TASAS database. The graph distinguishes incidents occurring on the approach to the bridge, the bridge itself, and downstream, based on the section boundaries shown earlier in Figure 10-1. The light gray area further marks the period during which the eastbound shoulder lane has been opened, while the dark gray area marks the period that has been affected by Covid-19 stay-at-home orders.

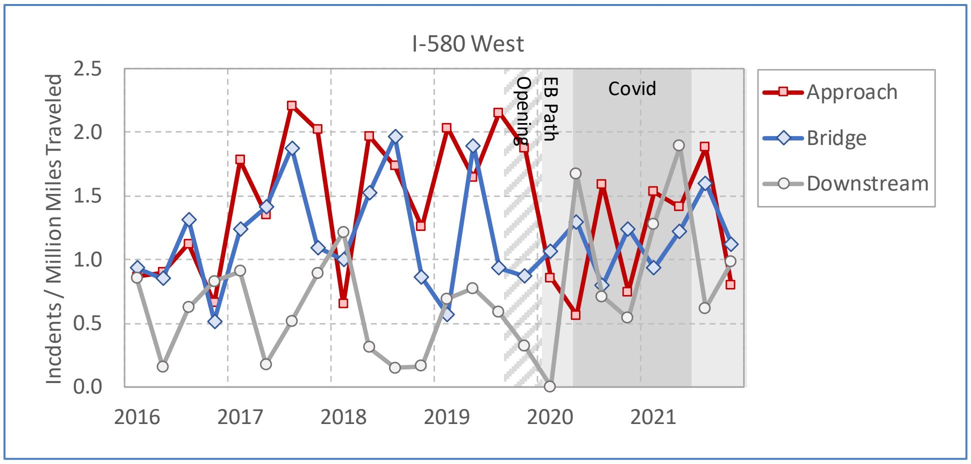

Figure 10-8: Number of Accidents by Quarter – I-580 West, 2016-2021

The following observations can be made regarding the overall rates of incidents on the approach to the bridge, the bridge itself, and the section of I-580 downstream of the bridge based on the illustrated data:

- While a large drop in the approach and downstream incident rates is observed in the first quarter of 2020, the first full quarter after the modifications, the drop falls within the past observed variability of incident rates on a quarterly basis.
- Ignoring the Covid-impacted period of April 2020 to June 2021, the overall rate of incidents on the bridge approach, expressed on a per million miles traveled basis, is observed to drop slightly from 1.51 to 1.20 (-20%) following the bridge modifications. However, the rate of incidents on the bridge increased slightly from 1.22 to 1.27 (+5%) while the rate of incidents downstream of the bridge decreased slightly from 0.58 to 0.55 (-5%).
- If the Covid-impacted period is included, the rate of incidents on the approach is calculated to have decreased further, from 1.51 to 1.18 (-21%), the rate of incidents on the bridge to have decreased from 1.22 to 1.17 (-4%) instead of increased, and the rate of incidents downstream of the bridge to have significantly increased, from 0.58 to 0.95 (+63%) instead of a slight decrease.

Based on the above elements, there is no straightforward evidence that the implementation of the bike/pedestrian path on the upper deck of the bridge has negatively impacted traffic safety on the approach of the bridge or the bridge itself. Both data analysis scenarios point to a reduction in accident rates on the approach to the bridge but provide opposite conclusions regarding what might have happened on the bridge and downstream of it. More data points would be needed to make stronger assessments.

10.4.2. INCIDENT TYPES ON BRIDGE AND APPROACH

Table 10-7 further presents the total numbers of documented incidents for both sections for the before and after periods, while Table 10-8 presents the average rates, on a per million miles traveled basis, at which each type of incident occurred before and after the modifications. In both tables, data from the last quarter of 2019 are ignored as some incidents within this period fall before the change and others after. Data from April 2020 to June 2021 are also ignored in the first set of after statistics (After A) due to the potential effects of the Covid-19 pandemic but are included for reference in the second set of after data (After B).

The following specific observations can be made regarding changes in the types of incidents occurring in the westbound traffic direction:

- For both before and after the modifications the primary types of incidents around the bridge are rear-ends, sideswipes and vehicles hitting objects. On the approach, these three categories represent 95% of the before cases and 96-97% of the after cases depending on the after period considered. On the bridge, they represent 97% of the before cases and 97-100% of the after cases.

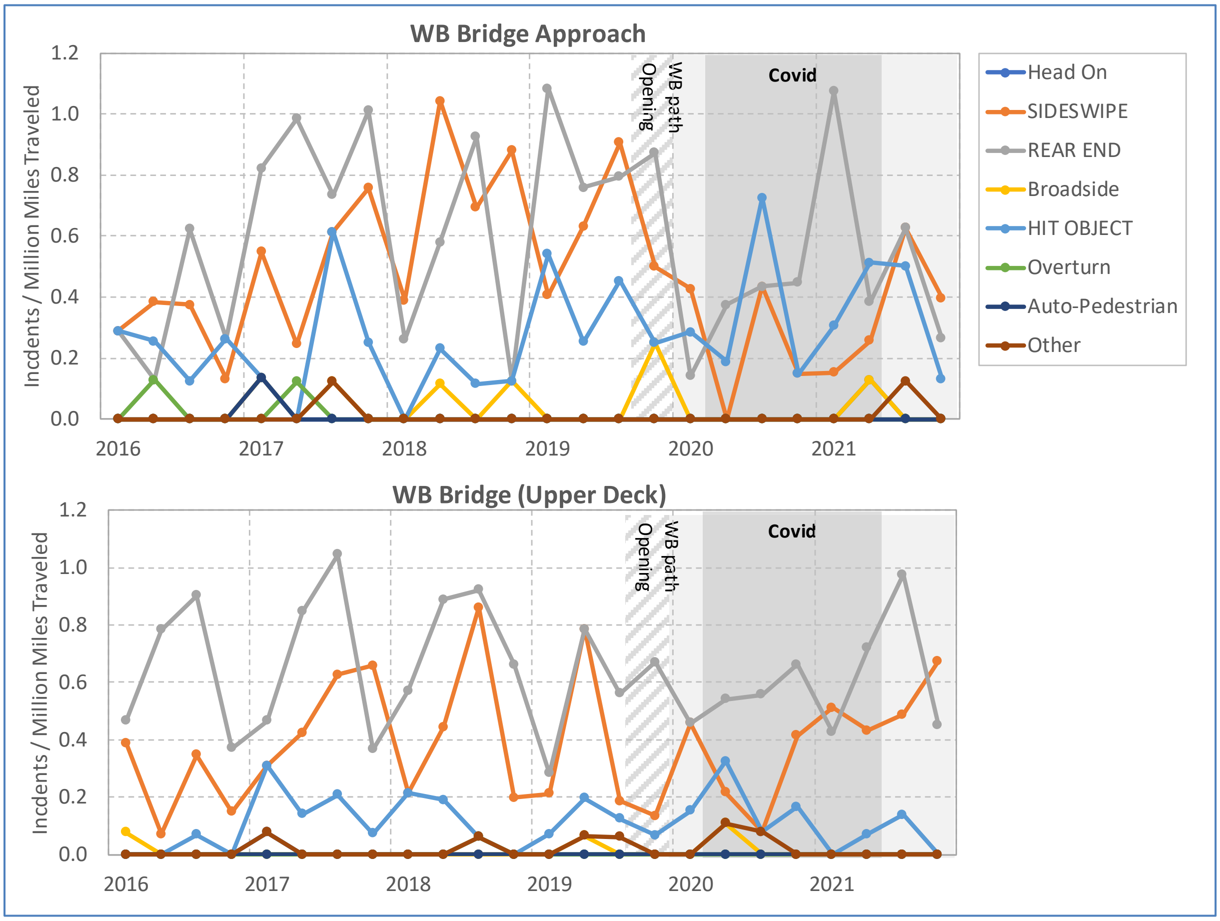

Figure 10-9: Accidents by Type – I-580 West, 2016-2021

Table 10-5: Before/After Incident Types on Bridge Approach and Upper Deck – I-580 West

Incident Type	Approach			Bridge Upper Deck			Overall		
	Before	After A[1]	After B[2]	Before	After A[1]	After B[2]	Before	After A[1]	After B[2]
Rear End	75 (41.9%)	8 (29.6%)	*26 (39.4%)*	145 (55.1%)	26 (50.0%)	*61 (52.1%)*	220 (49.8%)	34 (43.0%)	*87 (47.5%)*
Sideswipe	67 (37.4%)	11 (40.7%)	*18 (27.3%)*	86 (32.7%)	22 (42.3%)	*42 (35.9%)*	153 (34.6%)	33 (41.8%)	*60 (32.8%)*
Hit Object	29 (16.2%)	7 (25.9%)	*7 (30.3%)*	24 (9.1%)	4 (7.7%)	*11 (9.4%)*	53 (12.0%)	11 (13.9%)	*31 (16.9%)*
Broadside	4 (2.2%)	0 (0.0%)	*1 (1.5%)*	2 (0.8%)	0 (0.0%)	*1 (0.9%)*	6 (1.4%)	0 (0.0%)	*2 (1.1%)*
Overturn	2 (1.1%)	0 (0.0%)	*0 (0.0%)*	1 (0.4%)	0 (0.0%)	*0 (0.0%)*	3 (0.7%)	0 (0.0%)	*0 (0.0%)*
Other	2 (1.1%)	1 (3.7%)	*1 (1.5%)*	5 (1.9%)	0 (0.0%)	*2 (1.7%)*	7 (1.6%)	1 (1.3%)	*3 (1.6%)*
Overall	**179**	**27**	***66***	**263**	**52**	***117***	**442**	**79**	***183***

Note: Before Period: 01/2016 to 09/2019 (15 quarters)
After Period A: 01/2020 to 12/2021, excluding 03/2020 to 06/2021 due to Covid-19 effects (3 quarters)
After Period B: 01/2020 to 12/2021 (8 quarters)

Table 10-6: Before/After Incident Rates per Million Miles Traveled by Type – I-580 West

Incident Type	Approach			Bridge			Overall		
	Before	After A[1]	After B[2]	Before	After A[1]	After B[2]	Before	After A[1]	After B[2]
Rear End	0.631	0.355	*0.466*	0.670	0.637	*0.608*	0.656	0.537	*0.557*
Sideswipe	0.564	0.489	*0.323*	0.397	0.539	*0.419*	0.456	0.521	*0.384*
Hit Object	0.244	0.311	*0.359*	0.111	0.098	*0.110*	0.158	0.174	*0.199*
Broadside	0.034	0.000	*0.018*	0.009	0.000	*0.010*	0.018	0.000	*0.013*
Overturn	0.017	0.000	*0.000*	0.005	0.000	*0.000*	0.009	0.000	*0.000*
Auto-Pedestrian	0.008	0.000	*0.000*	0.00	0.000	*0.000*	0.003	0.000	*0.000*
Other	0.008	0.044	*0.018*	0.023	0.000	*0.020*	0.018	0.016	*0.019*
Overall	**1.506**	**1.199**	***1.184***	**1.215**	**1.274**	***1.166***	**1.318**	**1.247**	***1.172***

Note: Before Period: 01/2016 to 09/2019 (15 quarters)
After Period A: 01/2020 to 12/2021, excluding 03/2020 to 06/2021 due to Covid-19 effects (3 quarters)
After Period B: 01/2020 to 12/2021 (8 quarters)

- When ignoring the Covid-influenced interval in the after period (*After A*), the rate of **rear-end collisions** per million miles traveled occurring on the approach dropped from 0.63 to 0.36 (-44%), and on the bridge from 0.67 to 0.64 (-5%), following the installation of the path. These changes reduced the overall incident rate from 0.66 to 0.54 (-18%). When including the Covid-affected interval (*After B*), a 26% rate reduction is calculated for the approach and a 5% increase for the bridge, yielding a 15% overall reduction.
- When ignoring the Covid-influenced interval in the after period (*After A*), the rate of **sideswipes** dropped from 0.56 to 0.49 (-13%) on the approach but increased from 0.40 to 0.54 (+36%) on the bridge, yielding an overall increase from 0.52 to 0.38 (+14%). When including the Covid-affected interval (*After B*), the rate of sideswipes dropped to 0.32 (-43%) on the approach and 0.42 (+5%) on the bridge, producing instead an overall rate of 0.38 (-16%). The increase in sideswipe rates on the bridge calculated with the Covid-exempt period might be due to more vehicles switching lanes to the left to move away from the path barrier, as documented in Section 8.3.5. However, as suggested by the negative rates obtained by including the Covid-impacted interval, the observed increase can also be due to the relatively low number of incidents considered relative to the observed quarter-to-quarter variability of the rate.
- When ignoring the Covid-influenced interval in the after period (*After A*), the rate of **vehicles hitting objects** increased from 0.24 to 0.31 (+27%) on the approach but decreased from 0.11 to 0.10 (-12%) on the bridge, resulting in an overall increase from 0.16 to 0.17 (+10%). When including the Covid-affected interval (*After B*), the rate of vehicles hitting objects on the approach increases instead to 0.36 (+47%) and remains at 0.11 (no change) on the bridge, producing an overall rate increase to 0.20 (+26%).
- No definitive observations can be made on the rates of other types of incidents due to their relatively low incidence. In these cases, the observed increases and decreases could simply be the results of stochastic variations.

A key takeaway from the above analysis is that the installation of the bike/pedestrian path on the upper deck of the bridge does not appear to have caused vehicles to hit the new barrier as the rate of vehicles hitting objects has slightly decreased, whether the Covid-impacted interval is considered or not. The rate of rear-ends has also decreased. However, the rate of sideswipes has increased. This can be explained by the shorter merge at the entrance of the bridge causing more aggressive lane changes and a slightly higher proportion of traffic opting to travel on the left lane, resulting in more lane changes at the entrance of the bridge. Another contributing factor suggested by the slight increase in sideswipes and the very small increase in vehicles hitting fixed object might be the current inability of vehicles on the right lane to move away from vehicles encroaching on the lane. Before the path installation, this could be done by moving into the shoulder lane. Following the path installation, encroachments may then results in more frequent sideswipes if motorists try to avoid hitting the barrier. Upstream of the toll plaza, incident rates have for their part generally reduced, except for vehicles hitting objects.

However, caution in reaching definitive conclusions must still be exercised until data from more quarters are gathered to allow a before/after comparison with minimal Covid-19-related impacts. The inclusion of data for at least another year, or four quarters, should be sufficient in this case.

10.4.3. INCIDENT SEVERITY ON BRIDGE AND APPROACH

Table 10-8 presents the rates, on a per million miles traveled basis, at which incidents of various severity have occurred before on the bridge's westbound approach and upper deck for every quarter between January 2016 and December 2021. Table 10-7 further presents the number of incidents of each type that have been documented for the before and after periods, while Table 10-8 presents the average rates at which each type of incident occurred. In both tables, data from the last quarter of 2019 are ignored as some incidents within this period fall before the change and others after. Data from April 2020 to June 2021 are also ignored in the first set of after statistics (After A) due to the potential effects of the Covid-19 pandemic but are included for reference in the second set of after data (After B).

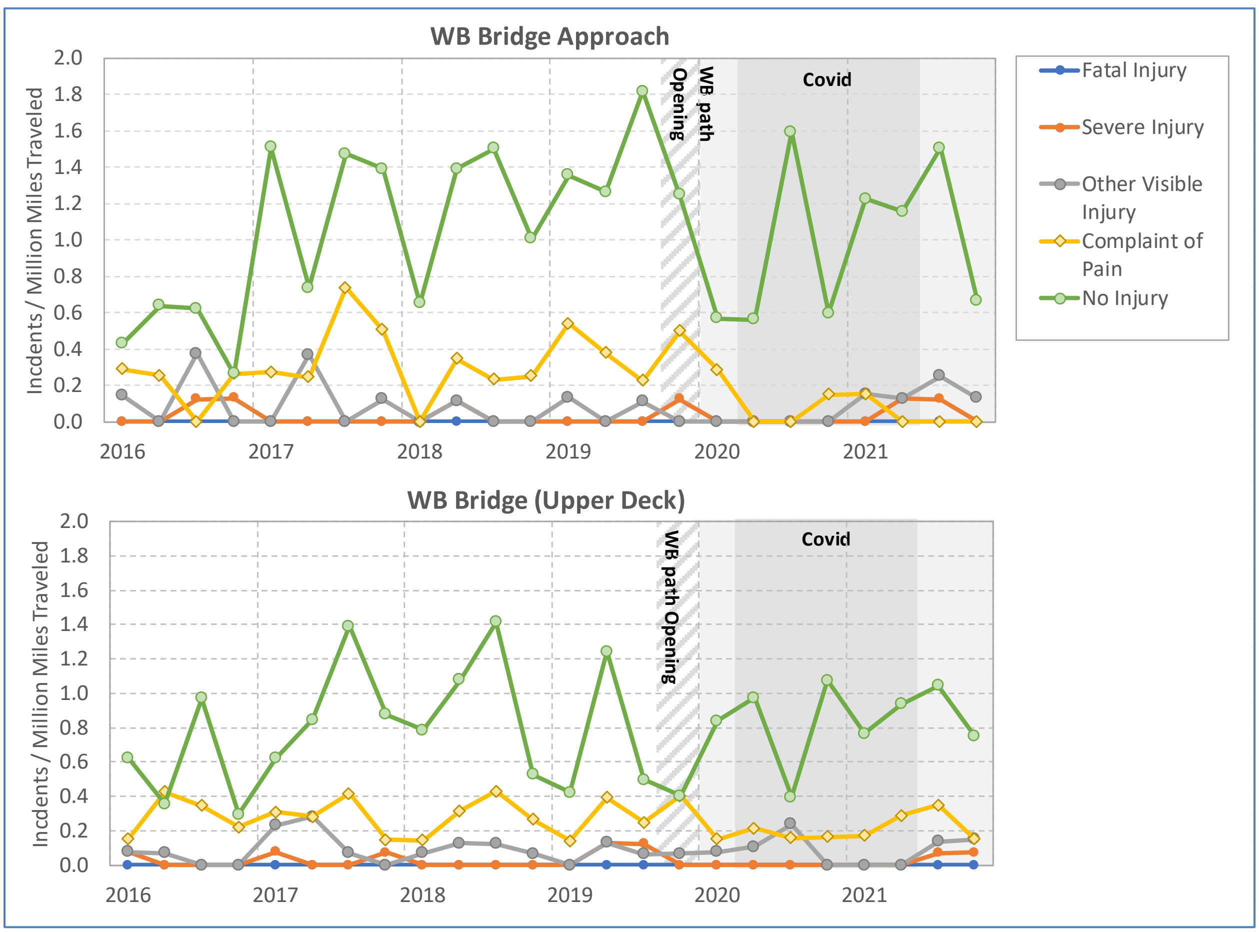

Figure 10-10: Accidents by Severity – I-580 West, 2016-2021

Table 10-7: Before/After Incidents by Severity on Bridge Approach and Upper Deck – I-580 West

Incident Type	Approach			Bridge Upper Deck			Overall		
	Before	After A[1]	After B[2]	Before	After A[1]	After B[2]	Before	After A[1]	After B[2]
No Injury	129 (72%)	21 (78%)	*56 (84%)*	175 (67%)	36 (69%)	*85 (73%)*	304 (69%)	57 (72%)	*141 (77%)*
Complaint of Pain	36 (20%)	2 (7%)	*4 (6%)*	62 (24%)	9 (17%)	*21 (18%)*	98 (22%)	11 (14%)	*25 (14%)*
Other Visible Injury	11 (6%)	3 (11%)	*5 (7%)*	19 (7%)	5 (10%)	*9 (8%)*	30 (7%)	8 (10%)	*14 (8%)*
Severe Injury	3 (2%)	1 (4%)	*2 (3%)*	7 (3%)	2 (4%)	*2 (2%)*	10 (2%)	3 (4%)	*4 (2%)*
Fatal	0 (0%)	0 (0%)	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*
Overall	**179**	**27**	***66***	**263**	**52**	***117***	**442**	**79**	***184***

Note: Before Period: 01/2016 to 09/2019 (15 quarters)
After Period A: 01/2020 to 12/2021, excluding 03/2020 to 06/2021 due to Covid-19 effects (3 quarters)
After Period B: 01/2020 to 12/2021 (8 quarters)

Table 10-8: Before/After Incident Rates per Million Miles Traveled by Severity – I-580 West

Incident Severity	Approach			Bridge			Overall		
	Before	After A[1]	After B[2]	Before	After A[1]	After B[2]	Before	After A[1]	After B[2]
No Injury	1.085	0.933	*1.004*	0.808	0.882	0.847	0.907	0.900	0.903
Complaint of Pain	0.303	0.089	*0.072*	0.286	0.221	0.209	0.292	0.174	0.160
Other Visible Injury	0.093	0.133	*0.090*	0.088	0.123	0.090	0.089	0.126	0.090
Severe Injury	0.025	0.044	*0.036*	0.032	0.049	0.020	0.030	0.047	0.026
Fatal	0.000	0.000	*0.000*	0.000	0.000	0.000	0.000	0.000	0.000
Overall	**1.506**	**1.199**	***1.202***	**1.215**	**1.274**	**1.166**	**1.318**	**1.247**	**1.179**

Note: Before Period: 01/2016 to 09/2019 (15 quarters)
After Period A: 01/2020 to 12/2021, excluding 03/2020 to 06/2021 due to Covid-19 effects (3 quarters)
After Period B: 01/2020 to 12/2021 (8 quarters)

As illustrated, the dominant types of incidents occurring on the approach of the bridge or the bridge itself both before and after the modifications are incidents without injuries and incidents with a complaint of pain. These represent 91% of the before incidents and 86-90% of the after incidents depending on whether the identified Covid-impacted interval is considered or not. 10% or less of the documented collisions were incidents with other visible injuries and 4% or less were incidents with severe injuries. No fatal accidents were reported during the analysis period.

Based on the three quarters of data considered post modifications when excluding the identified Covid-impacted interval (first quarter of 2020 and third and fourth quarter of 2021), the following observations can be made from the data of Table 10-8:

- The rate of **incidents with no injury,** on a per million miles traveled basis, occurring on the approach of the bridge dropped from 1.09 to 0.93 (-14%), while the rate of incidents on the bridge increased from 0.81 to 0.89 (+9%), for an overall marginal decrease of 1%.
- The rate of **incidents with a complaint of pain** decreased from 0.30 to 0.09 (-71%) on the approach and from 0.29 to 0.22 (-23%) on the bridge, yielding an overall reduction from 0.29 to 0.17 (-41%).
- The rate of **incidents with other visible injuries** is estimated to have increased on the approach from 0.093 to 0.133 (+44%) and the bridge from 0.088 to 0.123 (+40%), for an overall increase from 0.089 to 0.126 (+41%).

The following observations can further be made if data from the Covid-impacted interval are added to the analysis:

- The rate of **incidents with no injury** occurring on the approach of the bridge only drops from 1.09 to 1.00 (-7%), while the rate of incidents on the bridge only increases from 0.81 to 0.85 (+5%), for an overall marginal decrease of less than 1%.
- The rate of **incidents with a complaint of pain** decreases further on both the approach and the bridge, from 0.30 to 0.07 (-76%) and from 0.29 to 0.21 (-27%) respectively, yielding an overall reduction from 0.29 to 0.16 (-45%).
- The rate of **incidents with other visible injuries** remains relatively unchanged with respect to the before period instead of exhibiting an increase.

The key takeaway from the above analysis is that the upper deck bridge modifications seem to have caused a significant reduction in the frequency of incidents with a complaint of pain, and have slightly increased the rate of incidents with no injury on the bridge but reduced them on the approach, and have produced no conclusive trend regarding the incidents with other visible injuries.

Similar to the analysis regarding incident types, caution must be exercised here in reaching definitive conclusions until data from more quarters are gathered to allow a before/after comparison based on a higher number of quarters with minimal Covid-19-related impacts. In this case, the consideration of only three quarters after the modification likely does not provide sufficient data to establish clear trends. The inclusion of data for at least another year, or four quarters, should be sufficient in this case.

10.4.4. INCIDENT DURATIONS ON BRIDGE

Figure 10-11 plots the estimated duration of crashes that have occurred at any time of the day on the upper deck of the bridge between July 2016 and December 2021 based on incident logs from the CHP CAD data feed that has been processed by the Bay Area Traffic Incident Management Dashboard. This is the only dataset from which incident duration can be estimated. This is also the source of most statistics on incident durations reported by Bay Area transportation agencies.

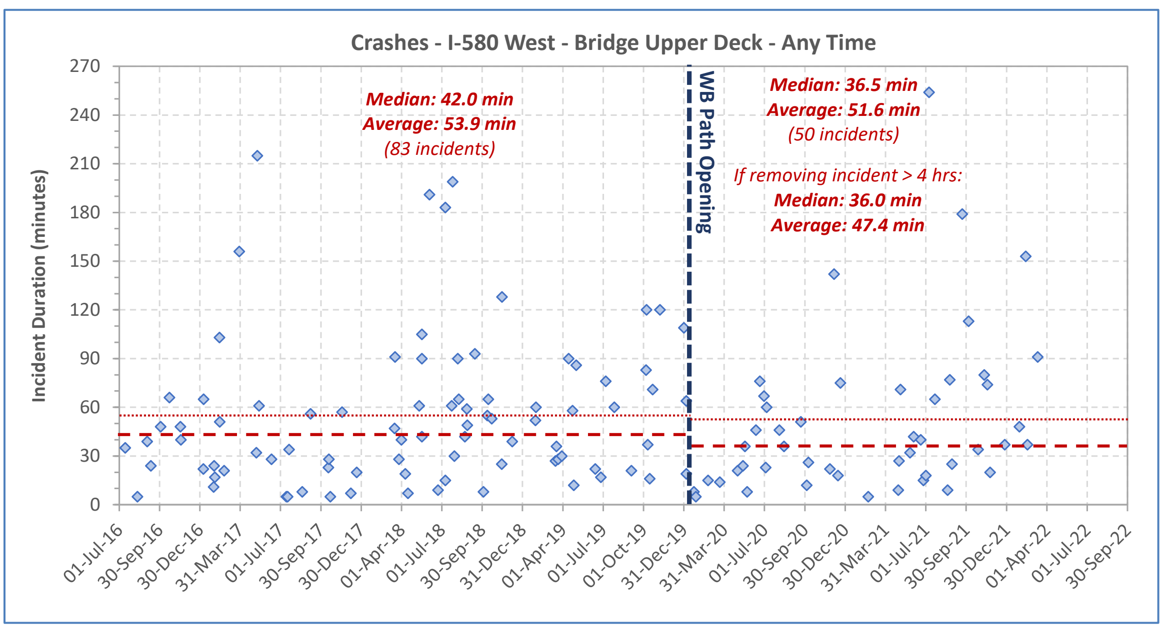

Figure 10-11: Incident Durations – Bridge Upper Deck, All Day, 2016-2022

Contrary to the lower deck analysis, all incidents that have occurred on the upper deck are considered here as the upper deck modifications affect traffic throughout the day. Like the previous analysis, only incidents lasting 5 minutes or more are considered as shorter incidents often have incomplete logs in the CHP CAD database.

As was indicated in Sections 5.5.4 and 5.5.5, incident durations estimated from CHP CAD logs are subject to some errors as these are simply based on when the first and last event-related messages were logged and as these messages do not always correspond to the actual start and end of an incident. While errors may exist in the reported durations, the purpose of the analysis presented here is to determine whether the bridge modifications may have had significant negative impacts on incidents. Since a single data source is used, the following analysis is thus made under the assumption that potential biases in how incident durations are estimated are consistent before and after the bridge modifications, thus allowing a rough comparative evaluation to be made.

The data in Figure 10-11 suggests that the average duration of incidents on the bridge's upper deck might have slightly decreased following the conversion of the westbound shoulder into a barrier-separated bike/pedestrian path, with an increase from 53.9 to 51.6 minutes. This is supported by a reduction in the median duration, from 42.0 to 36.5 minutes. In addition, if the two incidents lasting more than four hours (240 minutes) are removed, the average duration is then shown to decrease even further, from 53.9 to 47.4 minutes.

Statistical tests conducted to assess the significance of the observed changes indicate that no definitive conclusions can be made. Tests conducted at a 95% confidence level indicate that a similar variance is observed in the before and after samples and that the estimated average durations for both samples are not statistically different. This analysis thus indicates that converting the westbound shoulder lane into a barrier-delimited bike/pedestrian path does not appear to have had significant negative impacts on the duration of incidents.

10.5. SUMMARY OBSERVATIONS

Key observations from the traffic safety impacts associated with the upper and lower deck bridge modifications are as follows:

- **Lower deck modifications:**
    - The conversion of the eastbound shoulder lane into a part-time traffic lane has reduced by 72% the frequency of incidents occurring on the eastbound bridge approach. This is mainly due to the elimination of the congestion that affected traffic along I-580 East from the US-101 interchange to the entrance of the bridge. While the data also show a 10% rate reduction on the bridge, this change could simply be the result of stochastic variability.
    - On the approach, the absence of congestion on the approach to the bridge has resulted in an 82% reduction in the rate of rear-end collisions, a 60% drop in the rate of sideswipes, and a 63% reduction in the rate of vehicles hitting fixed objects.
    - On the bridge, the addition of a traffic lane has led to lower peak traffic densities and a 33% reduction in the rate of rear-end collisions. However, this change is also providing

more opportunities for lane changes, which has translated into a 22% increase in the rate of sideswipes and a slight increase (+4%) in vehicles hitting objects.

  - In terms of severity, the modifications have resulted in a reduction from 41% to 32% of the proportion of incidents on the bridge or its approach with severe injury, a complaint of pain, or other visible injuries.
  - Based on an analysis of CHP CAD logs, there is no evidence that the bridge modifications are producing longer crash-related incidents or changing the location where crashes tend to occur on the bridge.
  - Based on estimated incident duration data derived from the CHP CAD logs, there is no statistical evidence that the bridge modifications are increasing the time needed to clear crash events. In this case, data measuring more precisely the period during which an incident affects traffic would be required to provide a more definitive answer.
  - Motorists traveling on the lower deck may not fully understand the meaning of the green arrow/yellow X/red X signage above the lower deck traffic lanes, resulting in some opting to use the shoulder as a traffic or passing lane when it is formally closed.

- **Upper deck modifications:**
  - There is no straightforward evidence that the modifications have negatively impacted traffic safety on the approach of the bridge or the bridge. Scenarios including or excluding the April 2020 to June 2021 interval both point to a 20% reduction in accident rates upstream of the toll plaza but provide opposite conclusions regarding incidents on the bridge and downstream of it.
  - No clear impacts are observed on the types of incidents occurring around the bridge. Rear-end incidents remain dominant on the bridge before and after the modifications, at around 50-55% of all incidents. These are followed by sideswipes (33-42%) and vehicles hitting objects (8-9%). In particular, no increase is observed in the proportion of vehicles hitting a fixed object on the bridge, such as the path’s barrier.
  - In terms of incident severity, the upper deck modifications seem to have caused a 23% reduction in the frequency of incidents with a complaint of pain on the bridge and a 71% on the approach. The rate of incidents without injury has further slightly increased on the bridge (+9%) but reduced on the approach (-14%), while no conclusive trend could be identified for incidents with other visible injuries.
  - Based on an analysis of CHP CAD logs, there is no evidence that the bridge modifications are producing longer crash-related incidents or changing the location where crashes tend to occur on the bridge.
  - Based on estimated incident durations derived from the CHP CAD logs, there is no statistical evidence that the bridge modifications are increasing the time needed to clear crash events. In this case, data measuring more precisely the period during which an incident affects traffic would be required to provide a more definitive answer.
  - The analysis of additional data is recommended to more clearly established impacts associated with the modification, the current data only include three quarters with minimal Covid-19 impact. A recommendation is to include at least one additional year of data (January to December 2022).

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11. IMPACTS ON INCIDENT RESPONSES

This section assesses whether significant inconveniences to incident response crews have been introduced by the conversion of the lower deck shoulder lane into a part-time traffic lane and the conversion of the upper deck shoulder lane into a barrier-separated multi-use path. This is done by:

- Reviewing current incident response practice by CHP officers
- Assessing whether there have been significant changes in the location of bridge incidents
- Analyzing tow truck response logs
- Comparing available data on approximating incident response times before and after the modifications
- Summarizing key observed impacts

A key initial assumption was that the changes made to the bridge could increase response times due to the constraints they may impose on the movements of vehicles responding to incidents. A lack of noticeable change would therefore be viewed as a lack of significant negative impact.

11.1. LOCATION OF INCIDENTS ON BRIDGE

Figure 11-1 maps the locations of all reported upper and lower deck incidents on the bridge since January 2016. This includes 89 incidents on the upper deck, 56 before modifications and 33 after, and 41 incidents on the lower deck, 8 before modifications and 33 after.

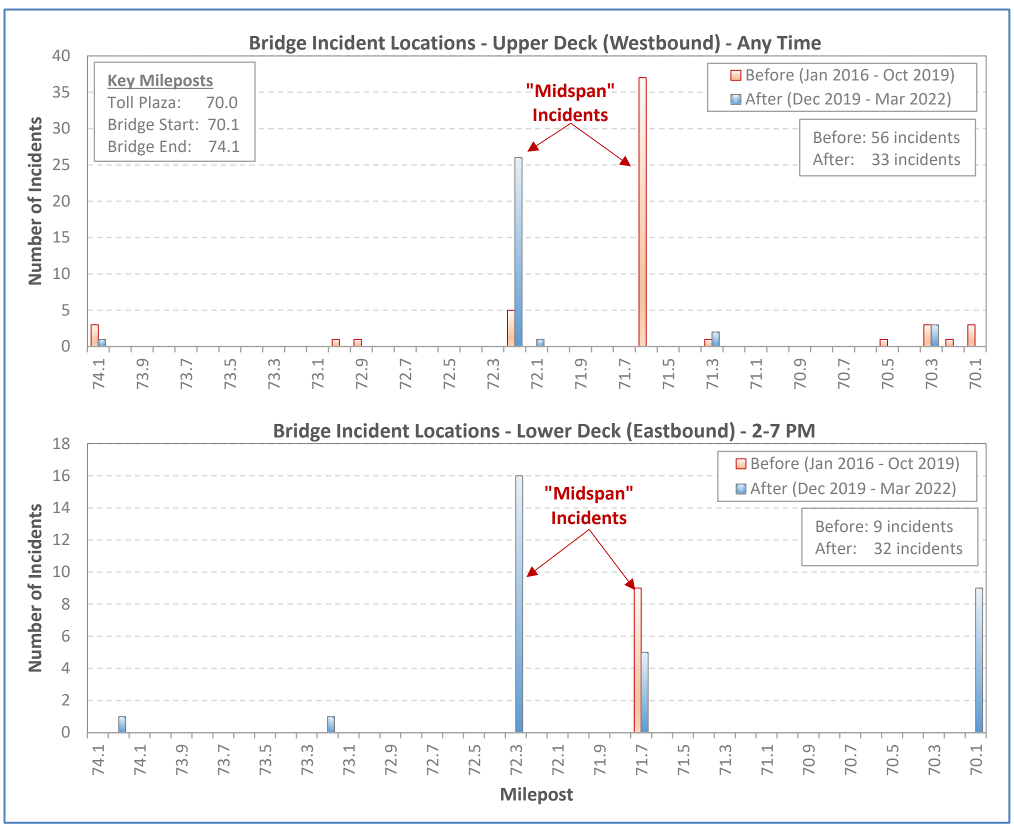

Figure 11-1: Location of Bridge Incidents – Before/After

As can be seen, most incidents are reported as having either occurred near the midspan of the bridge or the toll plaza. While there appears to be a shift in midspan location between the before and after conditions on each deck, this shift is likely the result of changes in how incident locations are reported as it would be unlikely that a similar shift happens to both decks. Milepost 71.7 appears to have generically been used to report midspan incidents up to about mid-2019, and milepost 72.3 after that.

Based on the illustrated data and the above assessment, a notable change in incident locations cannot be assumed to have occurred. This means that it can be assumed that response vehicles are roughly responding to similar incidents similarly located before and after the modifications on each deck.

11.2. CHP INCIDENT RESPONSE PRACTICE

The following summarizes current incident response practice by CHP officers for incidents occurring in traffic lanes on the Richmond-San Rafael bridge or the multi-use path.

- Response to incidents on bridge traffic lanes
  - Most incidents on the bridge are responded to by the Marin Division of the California Highway Patrol as it is often easier for them to access the bridge.
  - For incidents blocking all lanes on the upper or lower deck, CHP vehicles generally reach the incident by driving counterflow on the bridge. Vehicles to do attempt to reach a site by traveling in the normal traffic direction as it could result in units being stuck in traffic. The CHP officers that were interviewed reported that some vehicles have been stuck in the past for nearly an hour. Vehicles generally wait for all the traffic downstream of an incident to have exited the bridge before attempting to travel in a counterflow direction. Some vehicles may also travel around the bay to access the bridge from its other end. This practice is similar to what was done before the modifications.
  - For incidents that do not block all lanes, responding units generally access the location of an incident by traveling within the traffic stream. This is again similar to what was done before the modifications.
- Response to incidents on the upper deck bike/pedestrian path:
  - Responding units usually travel toward the site of an incident using the lane next to the barrier. Once the incident location is reached, officers then stopped their vehicle in the lane and jump over the barrier to assist.
  - While CHP officers could try to reach incidents using alternate transportation modes, this is not privileged as it would cause officers to lose access to the computer/communication terminals in their vehicle.
  - The need to stop vehicles on the right traffic lane is a constraint imposed by the new path.

11.3. TOW TRUCK RESPONSE TIMES

Data about tow truck response times obtained from Caltrans for incidents occurring on the bridge provided a limited view of the potential impacts of the bridge modifications on incident response times.

As shown in Table 2, analysis of the collected tow truck logs yielded an exceedingly small amount of data for both the before and after periods. The first row in the table lists the sample sizes for all incidents that have occurred around the bridge after excluding all logs for which the reported dispatch time corresponds to the scene arrival time (0-minute response time). The second row indicates the remaining sample sizes after excluding all incidents that have occurred around the toll plaza, on the eastbound or westbound approach to the bridge, and downstream of the bridge. For the eastbound direction (lower deck), only 4 incidents could be retrieved for the before period, and 7 for the after period. In this case, only incidents having occurred between 2 PM and 7 PM were considered as changes made to the shoulder lane only affect incident response during this interval. For the westbound travel direction (upper deck), only 7 before and 26 after incidents could be retrieved.

Table 11-1: Bridge Tow Truck Response Time Sample Sizes

Data Type	Eastbound Incidents 2 PM – 7 PM		Westbound Incidents Any Time	
	Before	After	Before	After
Incidents on and around the bridge with a dispatch time	15	19	39	50
Bridge incidents with dispatch time	2	9	9	26

Notes: Data coverage: January-June 2016; March 21-31, 2019; February-March 2022
Only incidents occurring on the bridge, no incident with dispatch time corresponding to arrival time

For both travel directions, the small sizes of the before and after data samples do not allow to perform robust analyses of the impacts of bridge modifications on tow truck response times. Figure X illustrates the distribution of response times for the lower and upper deck of the bridge, respectively. As can be observed, no clear trend can be established as response times for both the before and after incidents cover the same range. Due to the limited number of data points, statistical tests also indicate that there are no significant differences at the 95 percent confidence level between the before and after sampled average response times for either the lower deck or upper deck incidents. This means that any observed differences could be due to randomness.

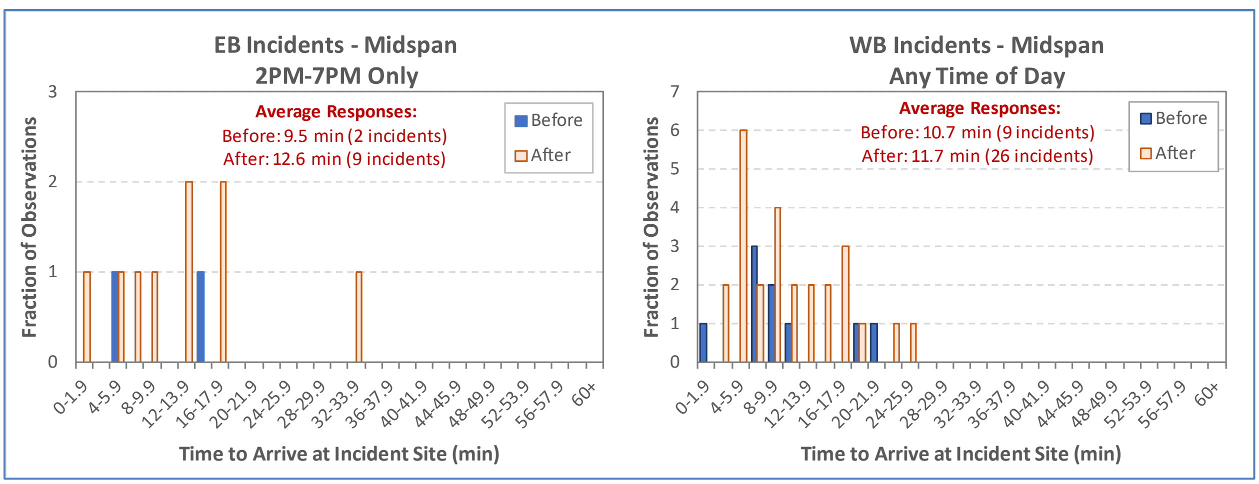

Figure 11-2: Before/After Tow Truck Response Times

The following are elements that potentially make it difficult to ensure that the evaluated before and after conditions are for responding to similar incidents, particularly with limited samples:

- Incident locations are not usually referenced precisely. While some logs mention a specific pier or call box, most logs simply indicate that a response is to a midspan incident, an incident just east of just west of the midspan, or an incident on the bridge incline. These loose references make it difficult to ensure that the before and after samples only include responses to similar incident locations.

- Response times are subject to whether a tow truck is departing from its normal waiting location or another location. Caltrans usually has tow trucks waiting for potential responses on each side of the bridge. In some cases, a service dispatch may have been issued when a truck is already on the bridge, such as while performing a routine patrol across the bridge, resulting in shorter response times. An extreme opposite example might be for a dispatch to be issued when both trucks happen to be on the same side of the bridge, thus forcing one vehicle to first go back across the bridge before being able to access the deck on which a response is needed.
- For incidents blocking all traffic lanes, a response time may be for a tow truck traveling in a counterflow on the bridge. Unfortunately, the logs do not provide information if this may have been the case.

11.4. INCIDENT RESPONSE TIMES ON LOWER DECK BASED ON CHP-CAD LOGS

Figure 11-3 illustrates estimated response times for crashes that have occurred on the lower deck of the bridge between 2 PM and 7 PM, from July 2016 to March 2021, based on CHP dispatch messages captured by PeMS and later processed by the Bay Area Traffic Incident Management Dashboard web application. Only incidents that occurred between 2 PM and 7 PM are considered as this is the only period when bridge operations have changed for this direction of travel. In addition, only incidents for which an estimated response time could be calculated are considered.

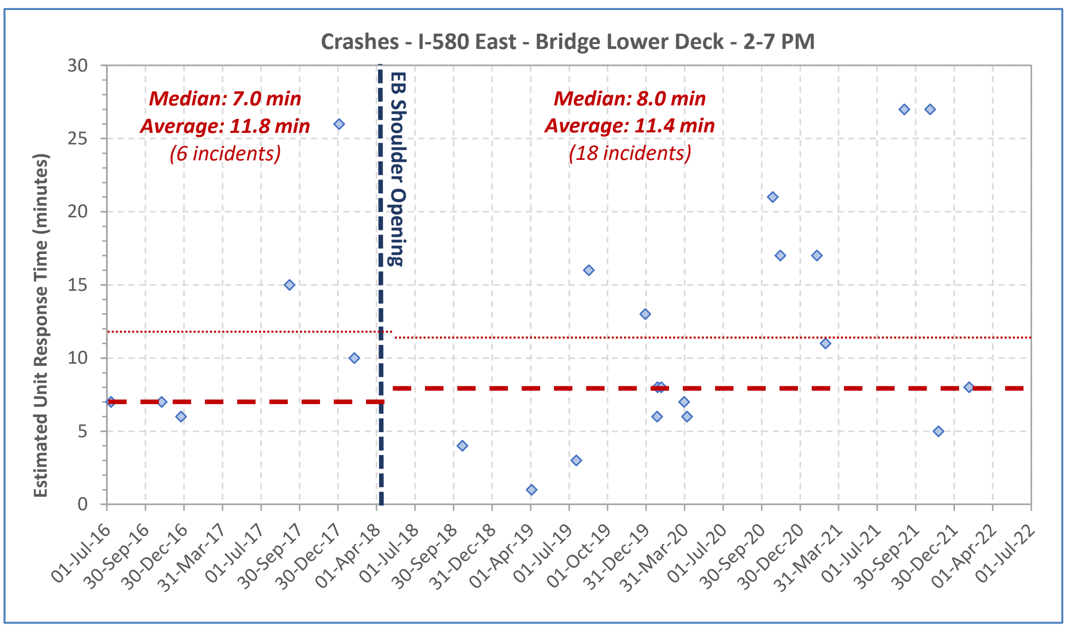

Figure 11-3: Estimated Incident Response Time – Bridge Lower Deck – 2016-2021

The reported response times are the time that elapsed between when a response vehicle has been reported in the CHP CAD system as being assigned or en route and the moment the vehicle has been logged as having arrived at the scene of an incident. These are estimates, as the dispatch logs do not always clearly indicate when a vehicle has been assigned, has departed, or has arrived. For instance, dispatch logs often record multiple vehicle assignments in succession but only specify one incident scene arrival. Many logs do not even indicate when, or whether, am assigned vehicle has arrived at an incident scene following an initial dispatch. Based on the above situations, some of the data is thus subject to interpretation.

The collected data do not indicate a notable change in response times following the conversion of the eastbound shoulder lane into a part-time traffic lane. For the six afternoon peak incidents logged before April 2018, the median response time was 8.5 minutes, while the 18 similar incidents logged after the bridge modifications have an 8.0-minute median response time. The average response time has similarly decreased from 11.8 to 11.4 minutes.

While there are slight decreases in response times, the changes are not statistically significant based on the observed variability of estimated response times across incidents. This assessment is based on standard statistical tests at the 95% confidence level. This means that the observed changes could simply be due to randomness in the characteristics of the incidents considered in the before and after conditions.

11.5. INCIDENT RESPONSE TIMES ON UPPER DECK BASED ON CHP-CAD LOGS

Figure 11-4 illustrates the estimated incident response time for crashes that have occurred on the upper deck of the bridge between July 2016 and March 2022 based on information contained in the CHP dispatch logs captured by PeMS and later processed by the Bay Area Traffic Incident Management Dashboard web application. In this case, all incidents that have occurred on a given day are included in the analysis as the shoulder lane is no longer available. Like Figure 11-3, the reported response times are only estimates based on information captured in the CHP CAD logs and may not necessarily reflect actual response times.

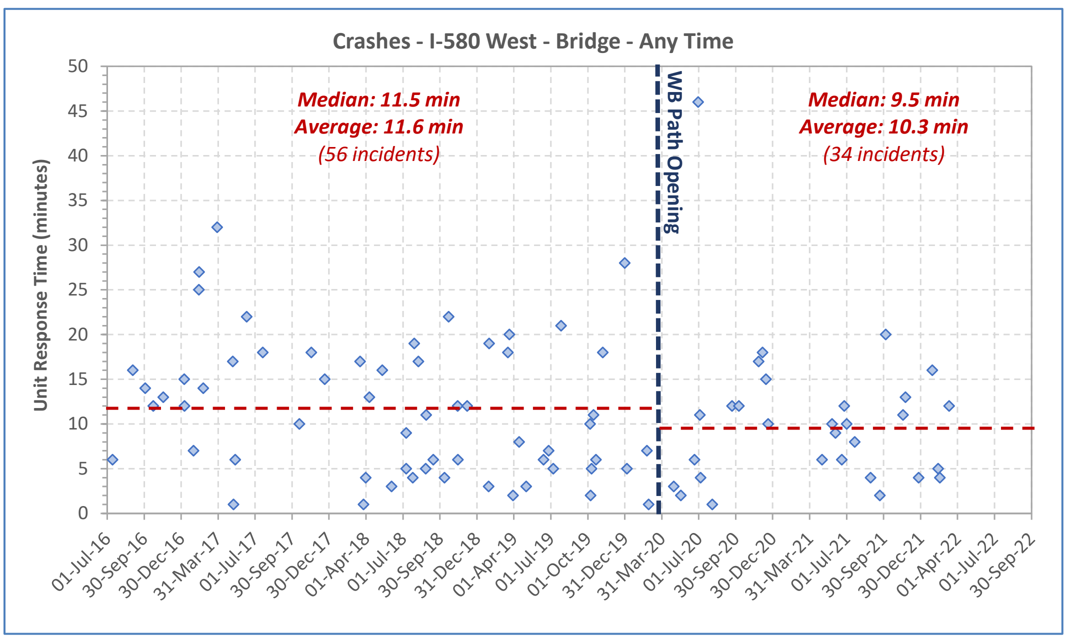

Figure 11-4: Estimated Incident Response Time – Bridge Upper Deck – 2016-2021

The starting hypothesis was that the introduction of a barrier to delimitate the bike/pedestrian path would create a significant constraint for response vehicles attempting to reach incident locations. With the elimination of the shoulder, it was thought that response vehicles might have to navigate more frequently through heavy congestion to reach an incident, thus leading to an increase in response times.

The estimated incident response times from the CHP dispatch logs suggest instead that an increase in response times has not occurred. The 56 incidents logged before the modifications have a median response time of 11.5 minutes while the 34 incidents post modifications have a median response time of 9.5 minutes. The average response time similarly drops from 11.6 to 10.3 minutes. However, similar to the lower deck analysis, statistical tests indicate that the changes are not statistically significant at the 95% confidence level. The observed differences may therefore simply be the result of randomness in the characteristics of the incidents affecting response times, such as starting location of dispatched response vehicle (Richmond or Marin side, close or far from the bridge) and ease of travel towards incident (through traffic still flowing at decent speed or low speed).

Considering all the potential influencing factors, the relatively small number of incidents that have occurred on the bridge since 2016 makes it difficult to provide any clear conclusion on whether the modifications have significantly affected incident response times. Current data suggests no significant impacts.

11.6. SUMMARY OBSERVATIONS

Key observations from the analysis of impacts on incident responses are as follows:

- There is no evidence that bridge modifications changed where incidents occur on the upper deck or lower deck.
- Retrieved tow truck dispatch logs do not provide enough observations to determine whether the bridge modifications have resulted in longer response times.
- Estimated incident response times from CHP-CAD logs also do not provide evidence that bridge modifications have caused an increase in incident response times.

12. IMPACTS ON MAINTENANCE ACTIVITIES

This section assesses whether significant inconveniences to maintenance activities have been introduced by the conversion of the lower deck shoulder lane into a part-time traffic lane and the installation of the upper deck barrier-separated multi-use path. The assessment was primarily conducted through conversations with Caltrans maintenance staff.

Summaries of key maintenance-related elements that were brought to attention by Caltrans staff are presented below for the bridge upper deck and lower deck. An overall summary concludes this section.

12.1. LOWER DECK ACTIVITIES

Key impacts on lower deck maintenance activities include the following:

- Since the lower deck shoulder lane is only open to traffic during the afternoon and maintenance activities tend to occur in the evening and at night, there has been a relatively minimal impact on operations.
- Because vehicles might be traveling on the shoulder lane when it is closed, maintenance crews must now generally always treat the lane as if it were an active lane. This means taking additional precautions to ensure that motorists are aware that stopped vehicles may be on the shoulder lane.

12.2. UPPER DECK ACTIVITIES

Key impacts on upper deck maintenance activities include the following:

- The installation of the multi-use path has eliminated the ability of maintenance crews to park vehicles on the upper without impeding traffic. Vehicles must now block a traffic lane when conducting routine or emergency maintenance work on the upper deck traffic lanes, which carries additional safety setup implications, in addition to potentially resulting in some traffic disturbances if conducted during periods of significant traffic.
- Closing of a traffic lane for path maintenance mainly occurs for routine monthly cleanings when the barrier must be moved. To minimize traffic impacts, this is typically done, with bulletins published by MTC/511 well ahead of time.
- Daytime path closures are periodically needed to conduct structure inspections as this requires moving a bucket truck along the bike path. These closures typically have no effects on vehicular traffic.
- Caltrans maintenance has a motorized cart to use on the bike path for routine maintenance. For major maintenance of the bike path, the bike path would be closed to traffic.
- The path barrier is typically realigned once a month as part of normal bridge operations. The scheduling of these activities can be observed in activity logs from the Caltrans Lane Closure System.
- Vehicles hitting the barrier can result in the barrier being moved inwards on the path. When this occurs, emergency repairs are only made if an incident causes the width of the path to be

reduced to less than 10 feet. If more than 10 feet remain available, the bridge maintenance crew generally either uses tools to manually realign the barrier or waits for the monthly machine re-alignment of the barrier to fix the issue.

- Damages to the toppers sitting on top of the barrier elements, illustrated in Figure 12-1, are usually repaired as soon as possible as this is a crucial safety element of the barrier. The toppers are added to allow the barrier to reach a legal height of 42 inches and to minimize the risk of cyclists falling over the barrier into the adjacent traffic lane. Bridge maintenance indicated that 75 toppers had to be replaced between November 2019 and March 2022, representing an average replacement rate of 2.6 toppers per month.

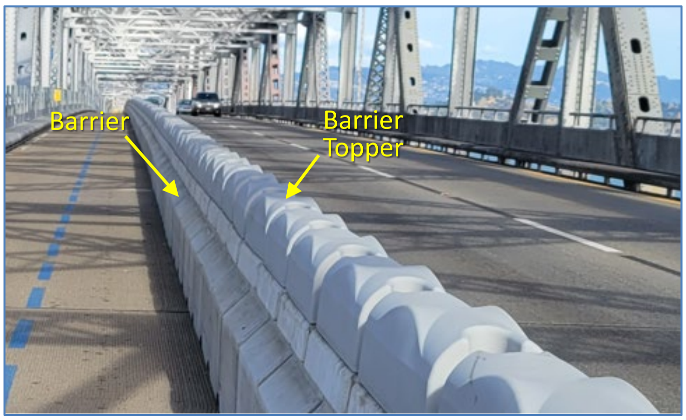

Figure 12-1: Bridge Path Barrier Toppers

12.3. SUMMARY OBSERVATIONS

The following is a summary of key observations from the analysis of impacts on maintenance activities:

- Upper deck:
    - The path barrier now forces the maintenance crew to close the right traffic lane when they need to do maintenance work on the bridge as they have no other place to park their vehicles.
    - Emergency realignment to the barrier is only conducted if an accident causes the barrier to leave less than 10 feet of width on the path. This has only occurred twice between November 2019 and April 2022. In other cases, the barrier is realigned during the monthly alignment check.

- Lower deck:
    - The primary impact of opening the eastbound shoulder to traffic during the afternoon peak is the need to always treat the shoulder as an active lane as vehicles are now more likely to be seen traveling on the shoulder when it is formally closed.

13. QUALITY OF LIFE ASSESSMENT

This section presents the results of the following two surveys that were conducted to assess impacts on quality of life:

- Before/After interviews with managers from 8 businesses located on local Marin County streets potentially used as alternate routes to the bridge, first visited in 2016 and revisited in May 2022, to obtain information about how traffic conditions around the bridge might affect their operations (see details in Section 5.9).
- An online survey of bridge path users that was conducted in the summer of 2021 to collect information on how individuals are using the path and perceiving its safety and benefits (see details in Section 5.8).

13.1. MARIN COUNTY BUSINESS SURVEY RESULTS

Results of the business survey that was conducted between April and December 2016, before the bridge modifications, were as expected. The sentiments collected primarily reflected inconveniences associated with the congestion on the eastbound bridge approach. It should however be noted that the comments collected only represent the views of managers from a relatively small number of businesses and may not, therefore, represent the sentiments of all businesses.

A summary of the key sentiments expressed by the few managers interviewed is provided below:

- Most of the interviewees indicated that congestion during the afternoon commute period typically spilled over to the local streets as commuters attempt to use alternative routes to reach the bridge. All the major alternate routes appeared to be affected, including Bellam, Francisco, Andersen, and Sir Francis Drake. The time intervals most cited for which this problem was observed were 3:00 PM to 7:00 PM or 4:00 PM to 7:00 PM, i.e., during the afternoon peak.
- Interviewees expressed that they believe that their businesses were adversely affected by the daily afternoon traffic congestion spillover.
- Due to high housing costs in Marin County, which were approaching or exceeding one million dollars in 2015, many employees of the surveyed businesses live in Richmond or on the Richmond side of the bridge and as far away as Vallejo or San Leandro. The decreasing reliability of the morning travel time, primarily due to congestion at the toll plaza merge, had resulted in an increasing proportion of employees arriving at work late.
- In certain circumstances, it could be hard to exit the businesses themselves due to traffic congestion on local streets, particularly on Francisco Boulevard or Andersen Avenue.
- Businesses that rely on trucks or delivery services (e.g., UPS) padded their schedules to accommodate the anticipated delays.
- Commute travel times in the afternoon/evening could be double those observed in the morning. Traffic has affected employee commute times.
- Only one business commented that their employees might use the new bicycle lane. Otherwise, the consensus was that their employees wouldn’t use it.

Below are the results of a similar business survey that was conducted in May 2022 to assess the potential impacts of the bridge modifications on business activities:

- Many interviewees indicated that congestion on the Richmond approach to the bridge during the morning peak period or midday Saturdays and Sundays remains a significant inconvenience. Many indicated perceiving that the congestion has never been worse, even though traffic data suggests this is not the case. A few further indicated that the lack of shoulder now amplifies the impacts of simple incidents, causing significant swings in travel times.
- For some businesses, the morning congestion on the Richmond side translates into a difficulty to hire or retain employees living on the Richmond side of the bridge. While some businesses would like to hire individuals from Marin County, it was pointed out that the high cost of housing in the counter often forces them to try to look for employees living across the bridge.
- One business indicated that while there appear to be more delays to access the bridge from Richmond in the morning this is partly compensated by shorter travel times back to Richmond in the afternoon.
- No business indicated that the congestion caused employees to frequently arrive late. Most employees appear to have built some buffer time in their morning commute to ensure arrival on time.
- No interviewee was aware of any significant impact of the Richmond approach congestion on their business activities.
- Most of the interviewees indicated that they currently do not see any issues with traveling toward Richmond at any time of the day. Afternoon traffic conditions are much better than they were. The only few negative comments were about temporary inconveniences caused by lane closures on the lower deck for bridge repairs.
- No interviewee was aware of any significant traffic currently using local arterials as a bypass to I-580.
- Several businesses along Francisco Boulevard acknowledged that fewer vehicles now use the arterial as a bypass to I-580 East.
- One business that indicated the difficulty for corporate vehicles to reach the company office from Larkspur using Sir Francis Drake Boulevard and/or Andersen Drive that existed in 2016 has completely disappeared following the lower deck modifications and the elimination of traffic backup onto Sir Francis Drake Boulevard and Andersen Drive.
- Employees from two businesses indicated that the remaining key eastbound bottleneck is the US-101 North exit to Bellam/I-580 East. Because of the traffic light at the end of the ramp, ramp queues often back up onto US-101 North, causing occasional slowdown on the right mainline lane upstream of the exit. A second bottleneck is the signals metering traffic at the Sir Francis Drake Boulevard exit.
- No one indicated being aware of employees using the bike path to commute to work. Some have indicated using it on occasion for recreational purposes.

13.2. USER SURVEY RESPONSES

This section provides a summary of responses to the user survey that was conducted in the summer of 2021. Specific elements discussed below include:

- Characterization of survey respondents
- Starting and ending points of trips made on the bridge path
- Typical use of bridge path
- Perceived safety of bridge path
- Perceived benefit of the bridge path

13.2.1. CHARACTERIZATION OF SURVEY RESPONDENTS

2,166 individuals responded to the online survey between June 16 and August 13, 2021. As indicated in Table 13-1, 1,543 of these respondents, or 73.9%, are cyclists or pedestrians who reported having used the bridge path. 623 individuals, or 28.8% of respondents, further reported having never used the bridge path. Based on the comments provided by these individuals, this group is assumed to be primarily comprised of motorists traveling across the bridge.

Table 13-1: Survey Respondents – Bridge Path Users

Bridge Path User Type	Number of Respondents	Percent
Cyclist	1,402	64.7%
Cyclist/Pedestrian	78	3.6%
Pedestrian	63	2.9%
Non-User	623	28.8%
TOTAL	2,166	100.0%

13.2.2. STARTING AND END POINTS OF TRIPS MADE ON THE BRIDGE PATH

As part of the survey, respondents were asked to indicate what were their trip starting and ending points. In this case, ending destinations were defined as locations individuals were heading to before returning home, such as a place of work, a local restaurant, or a recreational location.

Table 13-2 compiles the reported trip starting and ending points from individuals who reported using the bridge path as a cyclist or a pedestrian. These respondents were primarily individuals traveling from Richmond to Marin County. These trips represented 787, or 51.7%, of the 1522 reported trips. Only 16.8% of trips were from Marin County to the Richmond side of the bridge. 22% of trips were further reported as starting and ending on the Richmond side, while 9.5% were reported as starting and ending on the Marin side.

Table 13-2: Origin/Destination of Trips by Bridge Path Users

Trip Origin	Trip Destination		Total Origin Trips
	Richmond Side	Marin Side	
Richmond Side	335 (22.0%)	787 (51.7%)	1,122 (73.7%)
Marin County Side	255 (16.8%)	145 (9.5%)	400 (26.3%)
Total Destination Trips	590 (38.8%)	932 (61.2%)	1,522 (100.0%)

Table 13-3 further compiles the reported trips starting and ending points from individuals who did not use the bridge path. Like the path users, most of the respondents in this category were individuals traveling westward, with 361 of the 603 reported trips (59.9%) starting on the Richmond side and ending in Marin County. Only 26% of the reported trips were in the opposite direction. Only 5.8% further started and ended on the Richmond side, while 8.3% of trips started and ended in Marin County.

Table 13-3: Origin/Destination of Trips by Respondents Who Did Not Use Bridge Path

Trip Origin	Trip Destination		Total Origin Trips
	Richmond Side	Marin Side	
Richmond Side	35 (5.8%)	361 (59.9%)	396 (65.7%)
Marin County Side	157 (26.0%)	50 (8.3%)	207 (34.3%)
Total Destination Trips	192 (31.8%)	411 (68.2%)	603 (100.0%)

13.2.3. USE OF BRIDGE PATH

The following characterizes the use of the bridge path by individuals, either as a cyclist or a pedestrian:

- 1.9% of survey responses indicated using the path more than four times per week, 10.7% up to four times per week, 29.8% up to four times a month, 31.8% less than once a month, and 25.8% less than four times since its opening.
- 68.3% of respondents indicated using the path on Saturdays, 55.4% on Sundays, and 50.7% on weekdays. This is consistent with bicycle and pedestrian count data, which show significantly higher traffic on the path on weekends than on weekdays.
- 85.1% have indicated using the path for recreation (63.1%) or exercise (22.0%). Only 14.0% have used it for commuting, either to work (4.9%) or other locations (9.1%). The remaining 0.9% used it for other, non-specified, reasons.
- 83.9% indicated having completed one or more round trips on the path while cycling or walking. Of these, 90.6% reported fully crossing the bridge both ways, 6.9% turning back mid-way, and 2.5% having both fully crossed the bridge or turned back mid-way depending on the occasion.
- 3.7% reported having used a car or a bus to come back across the bridge.
- 19.2% reported having used a different route to come back to their origin point.
- Of the 63 individuals who reported having solely used the path as a pedestrian, only 23.8% completed a full round trip on the bridge. 57.1% turned around midway, 7.9% used a vehicle to cross the bridge back, and 11.1% returned to their origin using a different route.

13.2.4. SAFETY OF BRIDGE PATH

Bridge path users generally view it as safe. As shown in Table 13-4, the path received an average safety rating of 8.19 for its cyclists and pedestrians who used it, with 75.1% of them providing a rating of 8 or above. Only 4.9% of respondents gave the path a safety rating of less than 5.

Table 13-4: Bridge Path Safety Rating by User Type

User Type	Count	Rating Distribution										Average Rating
		1	2	3	4	5	6	7	8	9	10	
Cyclists	1,399	10	6	18	20	42	63	173	353	351	363	8.27
Cyclists/Pedestrians	78	4	1	1	4	1	4	10	19	14	20	7.72
Pedestrians	61	2	4	2	3	7	3	4	14	11	11	7.05
All Users	1,538	16	11	21	27	50	70	187	386	376	394	8.19

Survey respondents generally considered the ability to separate cyclists and pedestrians from the adjacent fast-moving traffic as the primary safety benefit of the path. However, the following concerns were cited more than once by various respondents:

- 46 respondents, or 3%, noted the narrow width of the path, particularly the fact that this creates problems when encountering cyclists traveling in the opposing direction or slow-moving pedestrians or cyclists. Some individuals also cited the problem caused for tricycle riders.
- While the barrier helps separate the path from the nearby fast-moving traffic, some concerns remain about the ability of the barrier to prevent trucks and cars to breach the path during an accident.
- Debris on the path flying from passing cars and trucks creates riding hazards.
- Debris flying from passing cars/trucks also creates some safety hazards

13.2.5. BENEFITS OF BRIDGE PATH

Most path users have a positive view of the new bridge path. Path users collectively assigned a rating of 8.35 to the path, with 81.5% of users giving the path a benefit rating of 8 or above. The lower ratings primarily stem from environmental factors associated with the path, such as wind, noise, and pollution from traffic, interactions with cyclists, etc.

Table 13-5: Bridge Path Benefit Rating by User Type

User Type	Count	Rating Distribution										Average Rating
		1	2	3	4	5	6	7	8	9	10	
Cyclists	1,393	40	15	20	15	39	22	83	208	193	758	8.67
Cyclists/Pedestrians	78	7	3	0	0	2	0	5	7	11	43	8.24
Pedestrians	60	14	3	6	1	3	2	4	5	4	18	5.88
Non-Users	616	392	47	25	19	20	9	13	18	8	65	2.84

Most non-path users view the new path negatively. The 616 non-users who provided a benefit rating collectively assigned a rating of 2.84 to the path, with 63.6% of them assigning a rating of 1 to it, the lowest possible. Based on the written comments provided, 156 (25%) of these respondents appear to be motorists who explicitly state that they would like the path removed for one or more of the following reasons:

- The removal of the westbound shoulder now prevents vehicles to pull out of traffic in an emergency. This results in more severe congestion when incidents occur on the bridge.
- The shoulder lane should better be used to relieve traffic congestion, as is done in the eastbound direction.
- The bike lane appears to be significantly underused.

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14. SUMMARY

This section presents a summary of the key findings from the study related to the modifications performed on the lower and upper decks of the bridge.

14.1. IMPACTS OF SHOULDER LANE MODIFICATIONS ON BRIDGE LOWER DECK

- **Compliance of traffic with lower bridge shoulder lane open/close periods**
    - On average, 99.6% of traffic observed on the bridge before 2 PM and after 7 PM is compliant with the shoulder closure.
    - Non-compliant use of the shoulder lane is highest 20 minutes before its opening and up to 30 minutes following its closure. Non-compliant use in the 20 minutes to opening varies between 0.3% and 0.6% of traffic, depending on the day of the week, while non-compliance 30 minutes after closing varies between 0.5% and 1.1%.
    - Motorists traveling on the lower deck may not fully understand the meaning of the green arrow/yellow X/red X signage above the lower deck traffic lanes, resulting in some opting to use the shoulder as a traffic or passing lane when it is formally closed.
- **Traffic impacts on I-580 East and US-101 North**
    - The availability of an extra traffic lane during peak hours has increased the hourly flow across the bridge by 13-25%, from a range of 3,300-3,600 vehicles/hour before the modification to a range of 3,750-4,500 vehicles/hour after.
    - Less than 25% of traffic is observed at any given time using the shoulder lane during weekday peak periods, and less than 20% on weekends.
    - The added peak-hour capacity has eliminated congestion on the I-580 East approach to the bridge in Marin County. This has caused peak travel times from the US-101 to the toll plaza to drop by 13-14 minutes on weekdays, 10-14 minutes on Saturdays, and 6-8 minutes on Sundays.
    - Peak-hour travel times from the US-101 to the toll plaza are significantly less variables.
    - Traffic improvements along I-580 East may have partly contributed to the observed 1-2 minutes reduction in average peak weekday travel times on US-101 North between the Sir Francis Drake Boulevard and I-580 interchanges since 2017.
    - Fewer vehicles are using the Main Street off-ramp and on-ramp as a congestion bypass. Illegal use of the ramps during the afternoon peak has dropped from an average of 56 vehicles/hour in May 2016 to 1 vehicle/hour in March 2022.
- **Traffic impacts on local arterials in Marin County**
    - Compared to 2016, weekday afternoon peak travel times along Sir Francis Drake Boulevard have dropped by up to 4 minutes, while traffic volumes have increased by over 300 vehicles/hour.

  - Fewer vehicles are using local arterials as a bypass to I-580 to save time while traveling towards the bridge in the afternoon. Peak traffic on Francisco Boulevard has for instance dropped from 730 to 227 vehicles/hour between May 2016 and March 2022.

- **Impacts on traffic safety along I-580 East:**
  - The opening of the eastbound shoulder lane has reduced by 72% the frequency of incidents occurring on the eastbound approach to the bridge. This includes significant reductions in rear-end collisions, sideswipes, and vehicle hitting objects. This is due to the elimination of the heavy congestion that used to affect traffic along I-580 East from the US-101 interchange to the entrance of the bridge.
  - On the approach, the absence of congestion on the approach to the bridge has resulted in an 82% reduction in the rate of rear-end collisions, a 60% drop in the rate of sideswipes, and a 63% reduction in the rate of vehicles hitting fixed objects.
  - On the bridge, the addition of a traffic lane has led to lower peak traffic densities and a 33% reduction in the rate of rear-end collisions. However, this change is also providing more opportunities for lane changes, which has translated into a 22% increase in the rate of sideswipes and a slight increase (+4%) in vehicles hitting objects.
  - In terms of severity, the modifications have resulted in a reduction from 41% to 32% of the proportion of incidents on the bridge or its approach with severe injury, a complaint of pain, or other visible injuries.
  - Based on an analysis of CHP CAD logs, there is no evidence that the bridge modifications are producing longer crash-related incidents or changing the location where crashes tend to occur on the bridge.
  - Based on estimated incident duration data derived from the CHP CAD logs, there is no statistical evidence that the bridge modifications are increasing the time needed to clear crash events. In this case, data measuring more precisely the period during which an incident affects traffic would be required to provide a more definitive answer.

- **Key impacts on incident response times:**
  - Retrieved tow truck dispatch logs do not provide enough observations to determine whether the bridge modifications have resulted in longer response times.
  - Estimated incident response times from CHP-CAD logs also do not provide evidence that bridge modifications have caused an increase in incident response times.

- **Key impacts on maintenance activities:**
  - Because vehicles are occasionally seen using the lower deck shoulder when closed, maintenance crews must always treat it as an active lane to ensure their safety.

14.2. IMPACTS OF NEW PATH ON BRIDGE UPPER DECK

- **Utilization of new bridge path by cyclists:**
  - Since January 2021, between 100 and 300 cyclists have been traveling in each direction on the upper deck path on Saturdays or Sundays, with an average of 190 cyclists/direction/day. Saturday traffic is usually the highest.
  - On weekdays, bicycle traffic has ranged between 50 and 75 cyclists in each direction, with an average of 68 cyclists/direction/day.
  - Weekend bicycle traffic follows an annual cycle, with the lowest demand during winter and the highest during summer months. Weekday traffic is relatively constant, with only minor seasonal variations.
  - Path users mainly travel westbound in the morning and eastbound in the afternoon. On weekends, peak westbound traffic is between 10 AM and 11 AM, and eastbound traffic is between 1 PM and 2 PM. On weekdays, peak westbound traffic is also between 10 AM and 11 AM, but peak eastbound traffic is later, between 3 PM and 4 PM, with notable traffic between 12 Noon and 3 PM.
  - 1.9% of surveyed path users in 2021 indicated using the path more than four times per week, 10.7% up to four times per week, 29.8% up to four times a month, 31.8% less than once a month, and 25.8% less than four times since its opening.
  - 85.1% of path users have indicated using the path for recreation (63.1%) or exercise (22.0%). Only 14.0% have used it for commuting, either to work (4.9%) or other locations (9.1%). The remaining 0.9% used it for other, non-specified, reasons.
  - 83.9% of path users indicated having completed one or more round trips on the path while cycling or walking. Of these, 90.6% reported fully crossing the bridge both ways, 6.9% turning back mid-way, and 2.5% having both fully crossed the bridge or turned back mid-way depending on the occasion.
  - Between 2015 and 2019, Golden Gate Transit buses typically carried between 465 and 829 bicycles per month across the bridge, depending on the season. Between April 2020 and December 2021, the number of bicycles carried over dropped 40-50% to a 227-466 range. However, between January and May 2022, monthly counts have increased significantly, to a 337-533 range, or 11-17 bicycles per day.
  - It is still unclear what part of the drop in bicycles carried over by Golden Gate Transit can be linked to the opening of the path and what part might be a byproduct of the pandemic.

- **Utilization of new bridge path by pedestrians:**
  - Pedestrian traffic on the bridge is relatively low. Average weekday eastbound traffic is only 11 pedestrians/day while westbound traffic is around 8 pedestrians/day. Weekend eastbound and westbound traffic reach 24 and 14 pedestrians/day respectively.
  - The estimated pedestrian use is likely underestimated as the counts are based on a single sensor located on the Richmond side of the bridge. This sensor would not have captured individuals accessing the path from the vista point in Marin County and turning back before having fully crossed the bridge.

- The 4-mile length of the bridge likely explains the low pedestrian demand, and why less than 24% of pedestrians indicated completing a full round trip on the bridge and 57% turned around midway.
- Fishermen have been observed using the path to access locations from where to cast fishing lines, either on the shore or the path itself. Such individuals are more often seen on the Marin County side, where they use the vista parking lot as a staging area.

- **Impacts onI-580 West traffic:**
  - Average weekday peak-hour flows across the bridge have dropped by 7% following the addition of the path, from a range of 3,500-3,850 vehicles/hour to a range of 3,250-3,600 vehicles/hour depending on the day considered. Weekend peak-hour flows have similarly dropped by 4%, from a range of 3,200-3,500 vehicles/hour to a range of 3,100-3,300 vehicles per hour.
  - The significantly shorter merge downstream of the toll plaza (325 ft instead of 850 ft) and the perceived narrowness of the roadway on the bridge causing some vehicles to slow down and others to move to the left lane may explain the maximum flow reductions across the bridge. These negative impacts may have partly been compensated by the elimination of the toll cash collection.
  - Despite the slight capacity reduction, the extent of the congestion upstream of the toll plaza and average peak travel times from I-80 to the end of the bridge on weekdays, Saturdays, and Sundays have remained similar to the before conditions. This can be explained by traffic demands remaining slightly below before conditions, particularly at the start and end of the peak periods, due to lingering Covid-related factors.
  - Before the modifications, upper deck traffic generally flowed on weekday mornings at or above 50 mph following the first mile of the bridge. In the fall of 2021, speeds between 40 and 50 mph were typically observed across the bridge, resulting in a slight increase in travel time of less than one minute. Some slight speed reductions were also observed on Saturdays and Sundays, but with negligible impacts on travel times.
  - Peak weekday travel times on the bridge's approach are now more variable, i.e., less reliable, than before the path installation, mainly due to the barrier now preventing disabled vehicles to pull out of a traffic lane. The reliability of peak weekend travel times remains similar to before.
  - The closeness of the path's barrier to the right traffic lane appears to have caused 1-2% of peak-hour traffic to shift to the left lane, and up to 20% of the evening and night traffic to do the same. This has resulted in an average 57%/43% split across the left and right lanes during weekday peaks, and a 55%/45% split during weekend peaks.
  - Many of the traffic impacts described above may still be affected by lingering reductions in traffic caused by an increase in the proportion of individuals working from home following the Covid-19 pandemic.

- **Impacts on local arterials in Richmond**
  - Available data do not indicate that the bridge modifications have had significant impacts on local arterials on the Richmond side of the bridge.

- **Safety of new bridge paths for cyclists and pedestrians:**
    - No incidents involving bicyclists or pedestrians were recorded by the CHP or reported on the Street Story platform during the evaluation period. However, anecdotal evidence suggests that some incidents have occurred.
    - Users generally have a positive view of the safety offered by the paths. The 1538 individuals who assessed the bridge path during the survey of summer 2021 gave an overall rating of 8.19 out of 10.
    - Several path users indicated that the low height of the barrier put them at risk of being hit by debris flung from the adjacent traffic lanes. Several also indicated that they could be blinded at night by vehicle lights when traveling toward Richmond. However, while a desire may exist to have a higher barrier, fulfilling such a request would be incompatible with the current barrier moving system.
    - A need exists to improve paths leading to the bridge, particularly in Marin County, notably the crossings at the intersection between Sir Francis Drake Boulevard and Andersen Drive, providing better separation for the I-580 shoulder path, and providing additional separated paths along Sir Francis Drake Boulevard and Francisco Boulevard.
    - Only 3.0% of bridge path users commented on its narrowness in the user survey.

- **Impacts on traffic safety on I-580 West:**
    - There is no straightforward evidence that the modifications have negatively impacted traffic safety on the approach of the bridge or the bridge itself despite the creation of a constrained roadway and a shorter merge downstream of the toll plaza. Scenarios including or excluding the April 2020 to June 2021 interval both point to a 20% reduction in accident rates upstream of the toll plaza but provide opposite conclusions regarding incidents on the bridge and downstream of it.
    - No clear impacts are observed on the types of incidents occurring around the bridge. Rear-end incidents remain dominant on the bridge before and after the modifications, at around 50-55% of all incidents. These are followed by sideswipes (33-42%) and vehicles hitting objects (8-9%). In particular, no increase is observed in the proportion of vehicles hitting a fixed object on the bridge, such as the path's barrier.
    - In terms of incident severity, the upper deck modifications seem to have caused a 23% reduction in the frequency of incidents with a complaint of pain on the bridge and a 71% on the approach. The rate of incidents without injury has further slightly increased on the bridge (+9%) but reduced on the approach (-14%), while no conclusive trend could be identified for incidents with other visible injuries.
    - Based on an analysis of CHP CAD logs, there is no evidence that the bridge modifications are producing longer crash-related incidents or changing the location where crashes tend to occur on the bridge.
    - The analysis of additional data is recommended to more clearly established impacts associated with the modification, the current data only include three quarters with minimal Covid-19 impact. A recommendation is to include at least one additional year of data (January to December 2022).

- **Key impacts on upper deck incident response times:**
  - Retrieved tow truck dispatch logs do not provide enough observations to determine whether the bridge modifications have resulted in longer response times.
  - Estimated incident response times from CHP-CAD logs also do not provide evidence that bridge modifications have caused an increase in incident response times.
- **Key impacts on upper deck maintenance activities:**
  - On the upper deck, the barrier now forces the maintenance crew to close the right traffic lanes when they need to do maintenance on the bridge.
  - Emergency realignment to the barrier is only conducted if an accident causes the barrier to leave less than 10 feet of width on the path. This has only occurred twice between November 2019 and April 2022. In other cases, the maintenance crew either try use tools to manually realign the barrier or wait for the monthly machine re-alignment of the barrier to fix the issue.

14.3. OTHER IMPACT ASSESSMENTS

- **Anecdotal impacts on businesses in Marin County**
  - According to 8 surveyed businesses in March 2022, morning congestion on the Richmond side of the bridge continues to affect the ability of businesses in Marin County to hire and retain staff from the East Bay. This is a problem that pre-existed the upper bridge modifications. However, travel time reductions to access Richmond from the Marin side during the afternoon peak following the lower deck improvements may have helped reduce the impacts of the morning commute.
  - For one business, less traffic using local streets to bypass I-580 East in the afternoon is significantly easing fleet movements around San Rafael and Larkspur.
  - None of the few surveyed business managers were aware of employees using the new bridge bike path for commute purposes.

APPENDIX A. USER SURVEY RESPONSES

Below is a summary of the responses that were provided to the online user survey that ran over 8 weeks from June 16 to August 13 in 2021. Summaries are provided for the four following categories of questions:

- Richmond-San Rafael bridge path
- Trip origin and destination
- Source of survey awareness

A.1 – RICHMOND-SAN RAFAEL BRIDGE PATH QUESTIONS

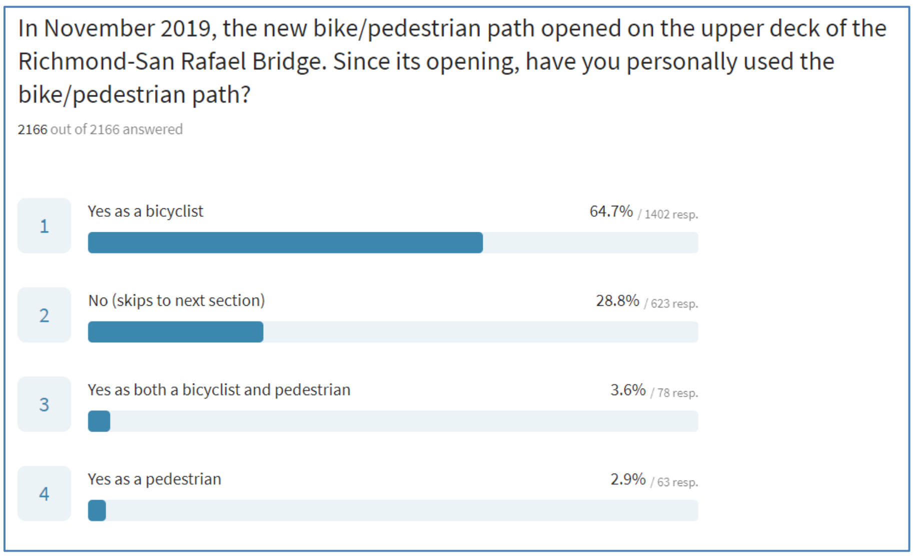

Figure A-1: User Survey – User Type

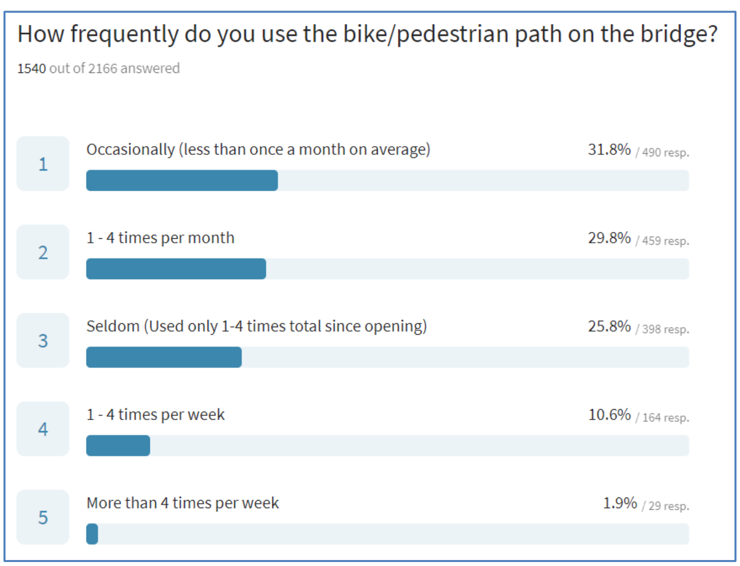

Figure A-2: User Survey – Frequency of Use

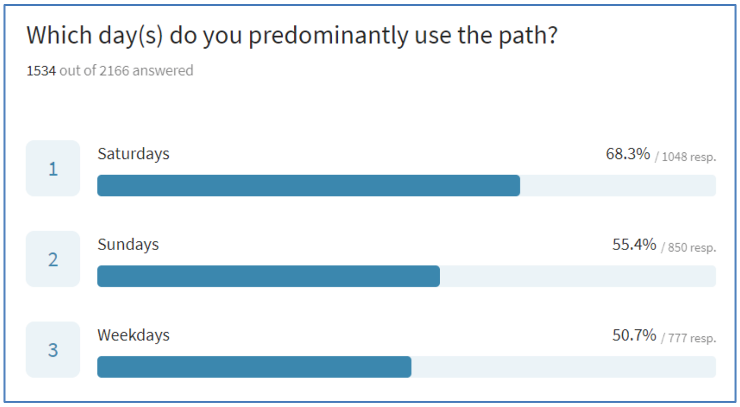

Figure A-3: User Survey – Day of Use

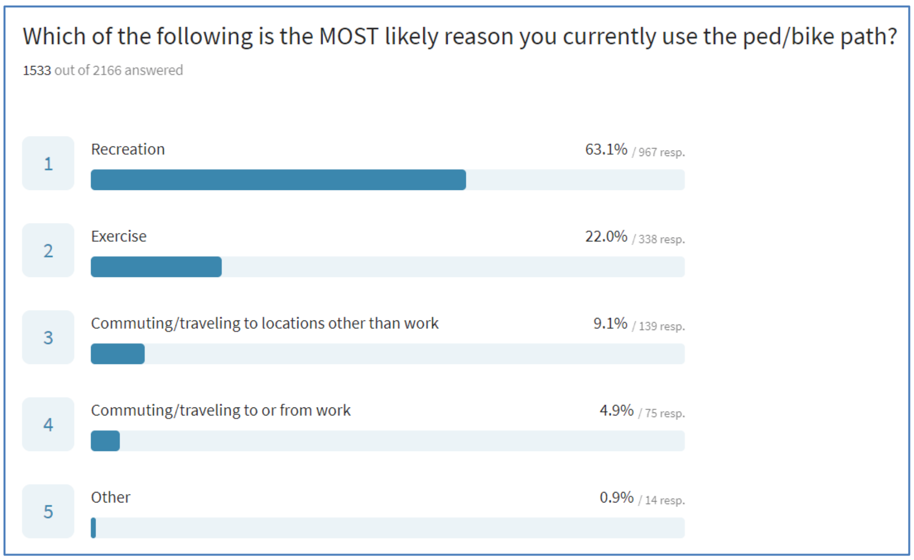

Figure A-4: User Survey – Reason of Use

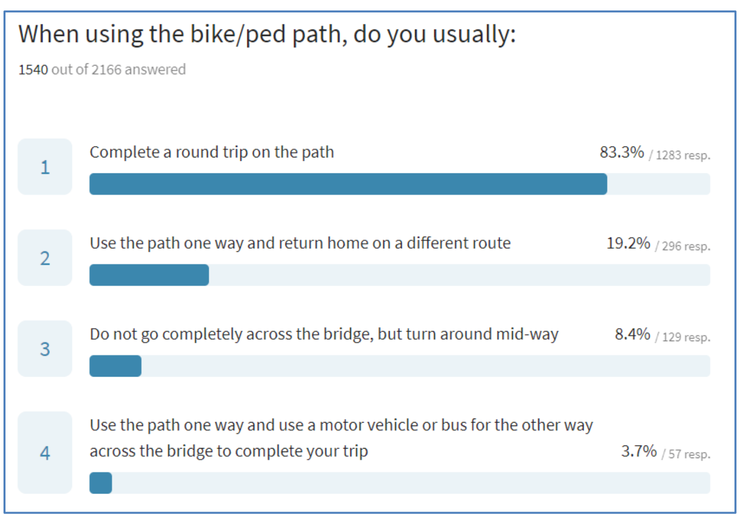

Figure A-5: User Survey – One Way or Round Trips

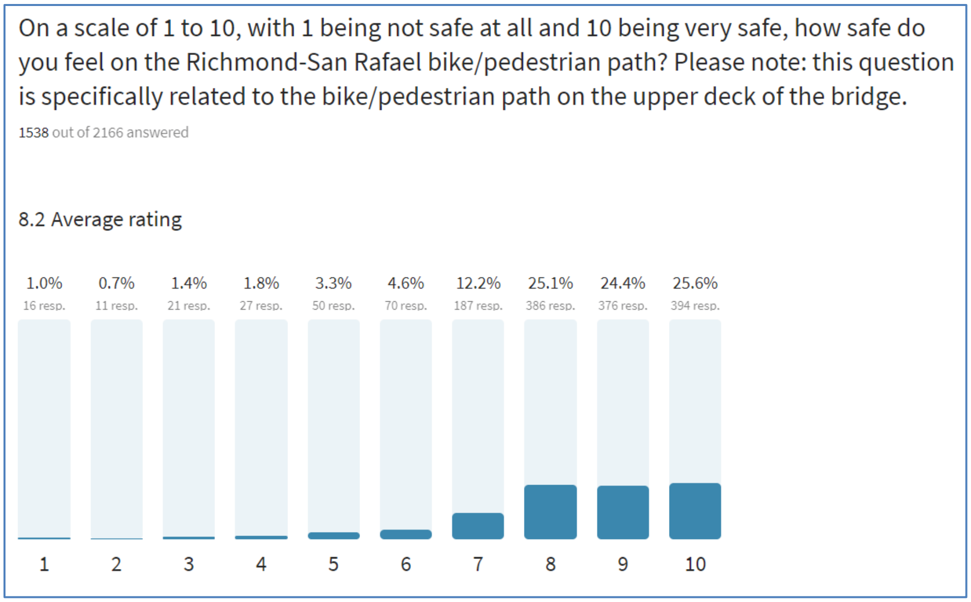

Figure A-6: User Survey – Perceived Safety

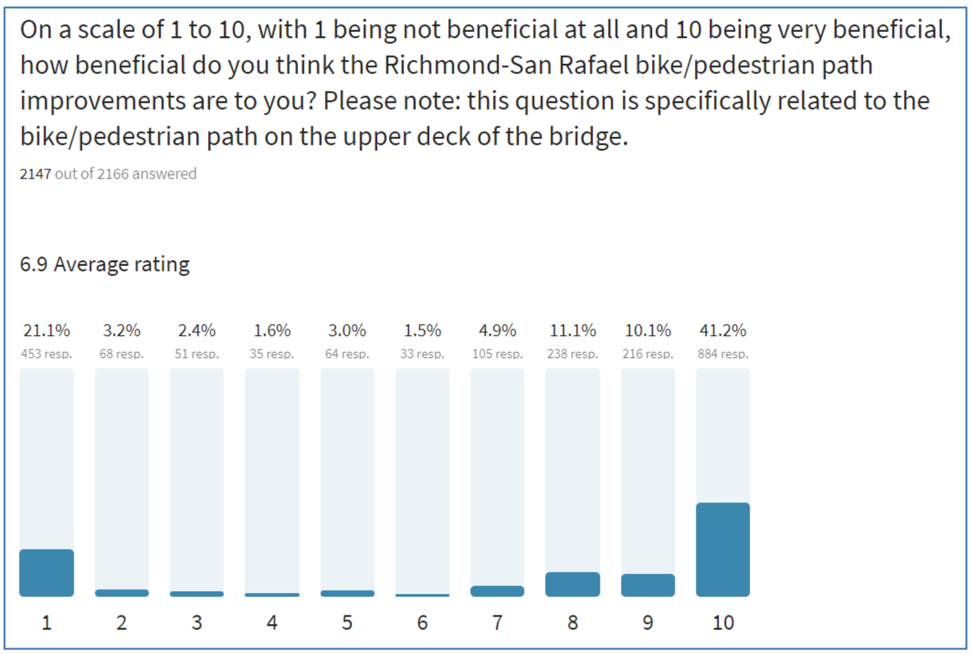

Figure A-7: User Survey – Perceived Benefits

A.2 – TRIP ORIGIN-DESTINATION QUESTIONS

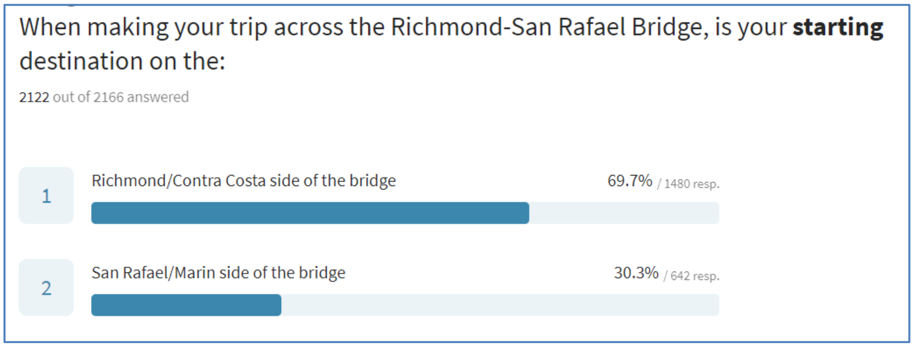

Figure A-8: User Survey – Trip Origin

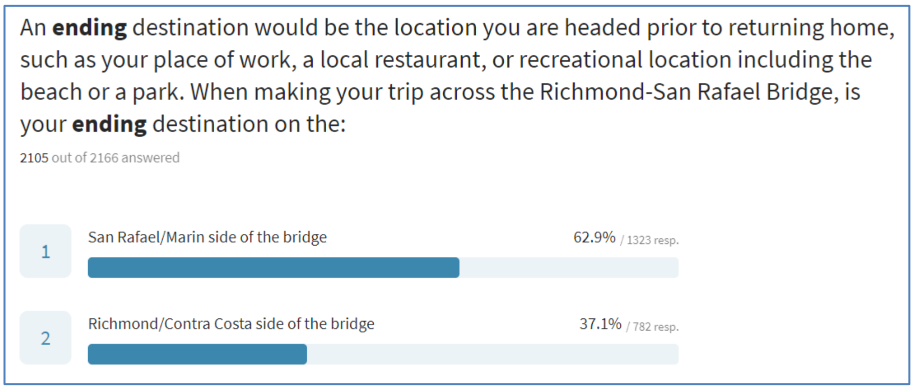

Figure A-9: User Survey – Trip Destination

A.3 – SOURCE OF SURVEY AWARENESS

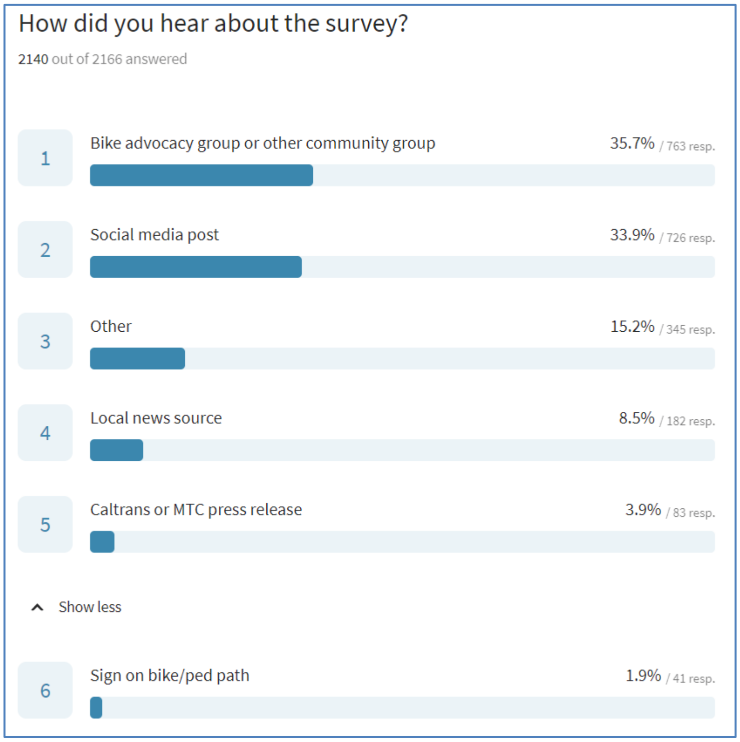

Figure A-10: User Survey – Survey Awareness