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San Francisco Bay Area US-101 Existing Conditions, ITS Assets, and Active Transportation and Demand Management Assessment

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CALIFORNIA PARTNERS FOR ADVANCED TRANSIT AND HIGHWAYS

DISCLAIMER STATEMENT

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EXECUTIVE SUMMARY

Introduction

The 58.5-mile long Highway 101 corridor from the Bay Bridge to the SR 85/US-101 interchange in South San Jose accommodates just over 2.6 million trips on an average weekday. Travel delays on the US-101 corridor over the 2012-2016 five-year period increased by more than 91% (an average delay increase of over 18% per year). Given that California's economy recently grew to become the sixth largest in the world, this waste of time stuck in traffic ranks among the most consequential economic inefficiencies in the world; workers in this region produce about 15 percent of California's annual gross domestic product (GDP), 53 percent of its patents and almost 75 percent of the state's venture capital investment.

The extensive economic strength in this corridor drives demand for travel and provides the essential context for the existing conditions and assets described in this report. This demand has overwhelmed much of the available capacity and is expected to do so in the future as well. Therefore, effective Active Transportation and Demand Management (ATDM) strategies must not only address the inefficient use of current capacity and expand capacity where possible, but also address the excess demand in the short term in ways that ensure the mobility gains achieved through these strategies (e.g., delay reductions, travel time reliability improvements) are not lost through induced demand. In short, this allocation will require strategies that will distribute trip making to alternative routes, off-peak periods, and to higher occupancy modes, or even address the more fundamental need for making some trips in the first place. This report concludes with an exploration of ATDM strategies, and provides information on current conditions, operations, built environment, roadway assets, and travel behavior along the corridor.

Objectives and Methodology

The existing conditions and assets described in this report establish context for understanding both the underlying travel demand characteristics and the constraints for corridor capacity expansion (e.g., physical constraints, political constraints). This understanding will be crucial to properly framing the conversation with corridor stakeholders during subsequent outreach and engagement aspects of this project.

In contrast to several other existing corridor initiatives, studies, and projects, this current assessment provides a holistic, and comprehensive assessment of all travel options across a wide range of performance categories for the US 101 corridor, while also establishing a foundation for specific strategies and operational improvements that may most effectively address the current congestion and safety issues on the corridor.

The contents of this report are organized into the major topic areas shown in Table ES-1.

Table ES-1: Organization and Contents of this Report

Chapter	Content	Methodology
2	Traffic Conditions	The US-101 study corridor's travel demand, observed travel-times and levels of congestion are summarized for recent years. The growth in travel demand and the associated increase in travel-times, levels of congestion and travel-time reliability metrics are evaluated and mapped. The corridor's major recurrent bottlenecks are identified and mapped with resulting impacts on congestion evaluated. The causal factors associated with the recurrent congestion patterns and the corridor's underlying causes of congestion are evaluated.

Chapter	Content	Methodology
3	Crash Analysis	High-level crash data from PeMS were aggregated and analyzed for the full length of US 101 as part of a spatial analysis, for the period between January 2010 and November 2016. Detailed crash records were analyzed using SWITRS data for crash metadata analysis, for the period between January 2013 and June 2015.
4	Crash Concentration Diagnosis and Validation	This chapter presents a diagnosis of the causal factors associated with the incident patterns and concentrations observed on the corridor, based on detailed crash data spatial analysis and detailed data investigations (e.g., SWITRS data). It then validates the findings using independent sources to verify the preliminary major causes of and contributing factors to crash concentrations identified.
5	Transit Service and Ridership Assessment	All major transit service providers are described in this chapter with respect to their service offerings and associated ridership in the vicinity of El Camino Real or US 101 between San Jose and San Francisco. The most recent data that were readily available for this assessment were used in each case.
6	ITS Corridor Assets and Inventory	ITS infrastructure along the US 101 freeway corridor is described in this chapter with respect to locations and operational and configuration data when readily available. Other assets that may be used to support or facilitate the use of alternative modes of transport are described as well, as part of the Transportation Demand Management assets discussion.
7	Related Projects	Any major transportation improvement projects on El Camino Real or US 101 between San Jose and San Francisco are described in this chapter. Only projects that have not yet been completed are described in this chapter, as the impacts of any completed projects are instead captured by the existing conditions assessments provided in the preceding chapters.
8	Potential Mitigation Strategies	This chapter presents delay and crash cost estimates associated with the most significant corridor bottlenecks and incident concentrations, and explores several common traffic management strategies in a preliminary evaluation of potentially relevant solutions to address these safety and mobility issues. As part of this high-level corridor-oriented presentation of applicable ATM, TDM, and ICM strategies, the chapter provides an overview of the contexts for which each strategy may be most impactful, along with a summary of outcomes in delay and crash reductions associated with past deployments of each strategy.
9	Recommendations and Next Steps	This chapter provides a summary of findings and concludes with a list of recommendations for next steps including the need for more detailed analysis, the need for stakeholder engagement, and the need to develop corridor Concept of Operations.
Appendices	Technical Appendices	The appendices present additional data and supporting information for the corridor crash analysis, the diagnosis of contributing crash factors, transit service and ridership, ITS assets along the corridor, and current and near-term future related projects on the corridor.

Summary of Findings

The following key findings are distilled from the detailed assessment of existing conditions, assets, projects, and potential strategies for the US 101 corridor.

- **Trip Volumes.** On a typical weekday, the corridor (including freeways, arterials, private shuttles, BART and other transit) carries approximately 1,740,000 Single Occupant Vehicle (SOV) trips, 705,000 High Occupancy Vehicle (HOV) person trips, 22,000 private shuttle trips, 36,000 BART trips, 32,000 bus trips (of which 2% are Express Bus trips), 39,000 Caltrain trips, and 36,000 light rail trips, for a total of 2,610,000 trips. For more details, refer to Chapter 2.
- **Weekday Trends.** The US-101 corridor's non-holiday weekday (daily) traffic volumes have increased by about 10% over the past five years (an average increase of 2% per year). The associated vehicular delays on the US-101 corridor over the same five-year period increased by more than 91% (an average delay increase of over 18% per year). For more details, refer to Chapter 2.
- **Weekend Trends.** The US-101 corridor's Saturday (daily) volumes have increased by over 15% over the past five years (an average increase of over 3% per year). The associated vehicular delays on the US-101 corridor over the same five-year period increased by more than 172% (an average delay increase of over 34% per year). For more details, refer to Chapter 2.
- **Major Corridor Bottlenecks.** The most significant bottlenecks on the corridor occur at I-80 in the northbound direction and I-880 in the southbound direction. Of the top 10 bottlenecks in each direction of US 101, the leading causal factor identified is merging traffic from entrances (at 60% of locations), followed by weaving sections (at 30% of locations). For more details, refer to Chapter 2.
- **Detailed Delay Trends.** Based on a regression analysis of delays on the corridor, the ratio of delays caused by recurrent bottlenecks to delays caused by incidents was roughly 4 to 1. This ratio varied substantially across the corridor, with outcomes as high as 10 to 1 in San Francisco County and as low as 3.4 to 1 in Santa Clara County. For more details, refer to Chapter 2.
- **Crash Occurrence.** Incident occurrence directly correlates with congestion. When controlling for volume, incident rates rise by as much as 300% between the midday period and the PM peak. When congestion is addressed fewer incidents are expected to occur, including fewer secondary incidents as well. For more details, refer to Chapter 3.
- **Crash Types.** Predominant incident types are rear-end (2018 annually) and side swipes (710 annually). Rear-ending is associated with stop and go conditions and smoothing traffic can significantly reduce the occurrence of this type of incident; variable speed limits and other Active Traffic Management strategies can have a significant impact on the occurrence of rear-end crashes. Side swipes are primarily caused by lane changing which in turn can be caused by slower traffic ahead, or by excessive merging and weaving of traffic. Undesired merging effects can be successfully managed by implementing ramp metering at freeway entrances. For more details, refer to Chapter 3.
- **Major Crash Concentrations.** The most significant concentration of incidents on the corridor occur at Potrero Hill in the northbound direction and approaching I-280 (near San Francisco) in the southbound direction. Of the crash concentration location in each direction of US 101 with rates exceeding 40 per year, 81% of them are correlated with known recurring bottlenecks on the corridor. For more details, refer to Chapter 4.
- **Transit Service and Ridership.** The major transit service providers on the corridor are SamTrans with 12,191 passengers a day on the corridor, Santa Clara Valley Transportation Authority with 19,790 bus passengers and 35,693 rail passengers a day on the corridor, BART with 35,959 alightings per day within

the corridor, and Caltrain with 39,420 passengers per day. Private shuttles account for another 22,000 trips along the corridor, with the majority of these trips occurring between San Francisco and San Jose. For more details, refer to Chapter 5.

- **Traffic Management Assets.** Intelligent Transportation Systems (ITS) infrastructure in the corridor includes: 389 loop detectors, 43% of which are not operating properly; 59 CCTV cameras with an additional 39 expected to be deployed in the near future; 4.5 miles of fiber connectivity; freeway service patrol; 144 ramp meters; and 23 dynamic message signs in advance of key interchanges. For more details, refer to Chapter 6.
- **Demand Management Assets.** These include: mobile apps for carpool matching, transit guidance, and bicycle routing; two Park-and-Ride lots; and eight major projects along the corridor that will enhance transit service, pedestrian accessibility, and bicycle facilities. For more details, refer to Chapter 6.
- **Current Corridor Projects.** Several improvement projects and mobility programs are already being undertaken by individual jurisdictions along this corridor, but these are generally focused on specific portions of the corridor only, rather than considering the full length between San Jose and San Francisco. For more details, refer to Chapter 7.
- **Coordination.** Corridor management policies and strategies are often discontinuous at major jurisdictional boundaries, as evidenced by the current and planned limits of managed lanes, the locations of different ramp metering policies implemented, the time-of-day availability of freeway service patrol, and the availability and distribution of various other existing corridor assets and programs. For more details, refer to Chapters 6 and 7.
- **Costs of Bottlenecks.** The preliminary total delay costs associated with the top ten bottlenecks in each direction of US 101 are $85 million annually, while the total costs associated with the top ten crash concentrations along the corridor are approximately $166 million annually, for an overall cost of $251 million per year. The bottleneck at I-80 and associated congestion upstream in the northbound direction of US 101 accounts for $43 million of this annually, while the bottleneck at I-880 in the southbound direction accounts for another $22 million annually. For more details, refer to Chapter 8.
- **Potential Traffic Management Strategies.** Of 19 potentially relevant active traffic management (ATM), travel demand management (TDM), and integrated corridor management (ICM) strategies for US 101 discussed in this report, the ones with the greatest bottleneck mitigation potential based on a preliminary analysis are: hard shoulder running, dynamic junction control, and enhanced incident management. In addition to these, the strategies with the greatest crash mitigation potential based on documented past outcomes are: adaptive ramp metering, queue warning systems, and speed harmonization (or variable speed limits). As recommended in Chapter 9 of this report more detailed analysis will be required to identify the most appropriate mitigation strategies for different parts of the corridor. For more details, refer to Chapter 8.

Conclusions and Recommendations

Active, integrated and coordinated traffic management strategies are needed to extract more congestion relief from new and existing capacity in the US 101 corridor and ensure these short term gains are not overwhelmed by induced demand. These are grouped under two types of strategies: Intelligent Transportation Systems (ITS) such as Active Traffic Management (ATM) and Integrated Corridor Management (ICM); and, Demand Management.

- Many of the most effective ITS strategies applicable to a highly congested corridor such as the US 101 may be grouped under ATM and ICM. ATM/ICM holds both near and long term promise for reducing congestion on our highways. In general, ATM/ICM utilizes real-time measurement of highway usage, in conjunction with decision support systems and communication technologies, to manage elements that control traffic flow. The operational objectives are often to increase peak throughput, mitigate conditions that lead to breakdown, to improve safety, and to recover from incidents more rapidly – when they do occur. ATM/ICM tactics including variable speed limits, hard-shoulder running and coordinated and adaptive ramp-metering have been implemented successfully throughout the world.
- **Transportation Demand Management** (TDM) strategies may also be deployed to reduce congestion. These could include alternate work schedules, bus-only lanes, dynamic HOV or managed lanes and dynamic congestion pricing (Express Lanes) as well as other tactics.

Three types of next steps are recommended, including:

- **More Detailed Analysis** to develop an effective and integrated combination of mitigation strategies. The analysis will help decision-makers identify technical and implementation gaps, evaluate different mitigation strategies, and invest in the combination of strategies that would most minimize congestion and produce the greatest benefits. Comprehensive analysis and modeling would increase the likelihood of success and help lower the risk associated with implementation.
- **Stakeholder Engagement** to help build awareness, create partnerships and facilitate the adoption of ATM/ICM and TDM strategies on the US-101 corridor through a series of stakeholder meetings and outreach activities. This can be accomplished by assembling and convening an expert panel of stakeholders that consists of representatives from regional and corridor entities.
- Development of a **Concept of Operations** to define a prioritized set of strategies for deployment on the US-101 corridor. The strategies will primarily consist of ATM/ICM and TDM solutions that can be deployed in the next 3 to 5 years such as coordinated ramp metering, dynamic lane management (HOV, HOT, transit-only), dynamic speed limits, advanced traveler information systems, incident management, interface with arterial management system, dynamic shoulder lanes (hard shoulder running), queue warning, transit signal priority, HOV ramp metering bypass lanes, dynamic ridesharing and shared mobility, and other transit-focused strategies and incentives.

CHAPTER 1: INTRODUCTION

1.1 Background and Project Motivation

San Francisco, with the second highest urban density among major metropolitan areas, ranks third in traffic congestion and requires 34.4% more time than the average per trip across comparable major urban areas. Its neighbor, San Jose, was ranked sixth, requiring 32.2% more time than the average per trip. The US-101 corridor connects San Jose to San Francisco, and is subject to frequent, recurrent, and severe congestion particularly during commute hours. In 2014, the Metropolitan Transportation Commission (MTC) released a study about congestion on Bay area roadways, which examined the impact of economic recovery by comparing 2014 post-recession data to 2010 mid-recession data.[1] Over that four-year period, the Bay Area was ranked as the second-most congested metropolitan area in the US (Los Angeles was first). Figure 1-1 displays the US-101 Corridor Assessment's limits of study in the context of the San Francisco region.

Figure 1-1: US 101 Corridor Assessment in San Francisco, San Mateo and Santa Clara Counties

[1] http://www.vitalsigns.mtc.ca.gov.

The congestion along the 101 Corridor, however, is expected to have more significant economic consequences than these high-level rankings and accompanying MTC findings suggest, given the types of activities that occur along this corridor with respect to the commercial, technology, and production centers that are located in the vicinity. Traffic congestion reduces the scope of the potential labor pool for any employer, but the effects of congestion on US 101 may be especially disruptive given the need for highly skilled workers to fill many of the technology-focused positions at firms in this particular area and the inherent challenges with attracting such highly-qualified candidates from a limited labor catchment area.

1.2 Project Goals and Objectives

This effort focused on producing an assessment of current traffic and crash conditions, identifying existing transportation management assets, and then identifying promising transportation management strategies that might be applied to the US-101 corridor. The study team assembled information about the existing physical characteristics and the existing operational conditions of the US 101 corridor as it related to the implementation of the proposed ATM/ICM/TDM mitigation strategies. Every effort was made to leverage existing data sources such as PeMS and other agency-owned databases, as well as relevant traffic studies of the US-101 corridor. Given the short timeframe for this project, the data gathered were collected, assessed and presented at a high-level.

The following listing was used as guidelines for the types of information to be collected:

- Location of major employment centers, their characteristics, and that of other traffic generators (such as event venues, educational institutions and medical centers);
- Characteristics of incidents logged by California Highway Patrol on US-101 – between San Francisco and San Jose;
- Characteristics of Incidents to which Caltrans' Traffic Management Team must respond;
- Planned improvements for the corridor (e.g. additional HOV lanes or Express lanes);
- Traffic volumes, speeds and occupancies on US-101 by time of day;
- Freeway and ramp lane configuration diagrams, sensing infrastructure, communications channels, controllers;
- Entry ramp storage assessment including meter presence, design flow, number of lanes, and existing storage, detection, controller type and its connectivity;
- Transit service and ridership on US-101 and adjacent corridors (e.g., Caltrain, commuter bus service, etc.);
- Travel times and travel time reliability;
- Mapping of high crash locations; and,
- Assessment of current traffic management assets on US-101 including Advanced Traffic Management Systems (ATMS), vehicle detection, Dynamic Message Signs (DMS), Closed-Circuit Television (CCTV), ramp meters (including current algorithms), communications capabilities, and existing ATM/ICM/TDM programs in the corridor.

This report contains graphic aids and a technical summary of the characteristics of the corridor.

1.3 Organization of the Report

This document provides the reader with a tractable, approachable high-level characterization of the corridor, with the content organized into the following major topic areas:

1. Corridor overview and project background;
2. Traffic conditions assessment;
3. Crash analysis;
4. Diagnosis of crash concentrations and associated causes;
5. Transit service and ridership assessment;
6. Corridor ITS assets inventory;
7. Related projects overview;
8. Potential strategies to address current corridor deficiencies regarding congestion and safety; and,
9. Recommendations and next steps.

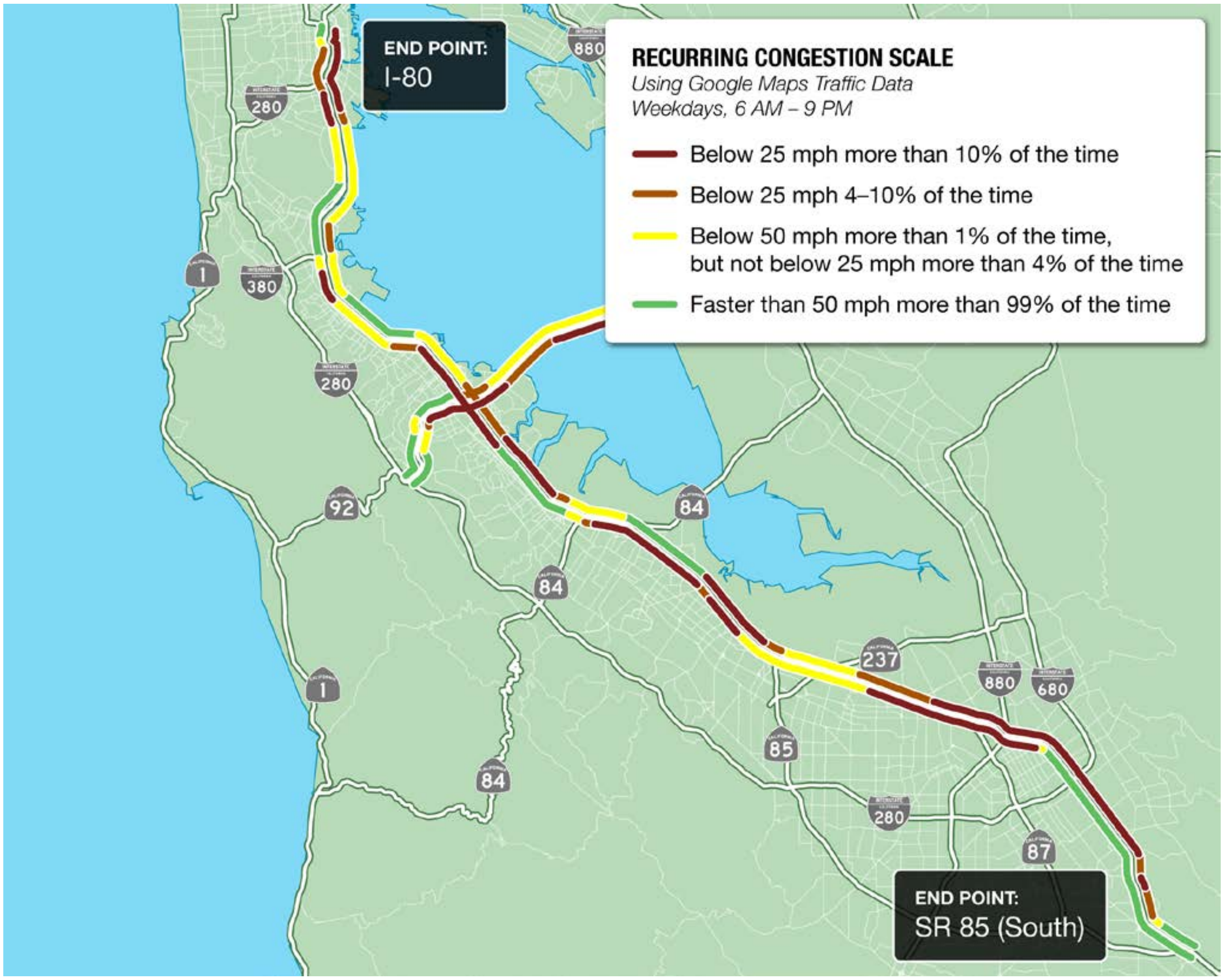
Technical appendices are included at the end of this report to provide the reader with additional details and data about the above topic areas.

CHAPTER 2: TRAFFIC CONDITIONS

2.1 US 101 Corridor Conditions Overview

The geographic extents for this analysis are shown in Figure 2-1, along with an overlay of typical traffic conditions on the corridor based on Google Maps historical data. These conditions are based on typical traffic conditions on the corridor as reported by Google separately for each weekday, in one-hour increments between 6 AM and 9 PM.

Figure 2-1: US 101 Corridor in San Francisco, San Mateo and Santa Clara Counties



2.2 Data Sources for the US-101 Traffic Evaluation

Caltrans PeMS and INRIX websites were fundamental data sources for the traffic demand and congestion evaluation efforts. The PeMS and INRIX websites provided the underlying data to quantify the corridor's vehicular travel times, speeds, vehicle miles of travel (VMT), vehicle hours of travel (VHT), along with the vehicular delay and travel-time reliability performance metrics. Additional published Caltrans traffic data were obtained from the Caltrans Division of Traffic Operations website. Collision and freeway incident data were obtained from the Transportation Injury Mapping System (TIMS) website and from the Caltrans PeMS website.

Caltrans PeMS: PeMS collects data in real-time from over 39,000 individual detectors spanning the freeway system across all major metropolitan areas of the state of California. PeMS is also an Archived Data User Service (ADUS) that provides over ten years of data for historical analysis. It integrates a wide variety of information from Caltrans and other local agency systems including:

- Traffic Detectors
- Incidents
- Lane Closures
- Toll Tags
- Census Traffic Counts
- Vehicle Classification
- Weight-In-Motion
- Roadway Inventory

The Caltrans PeMS website was used to provide stationary point traffic volumes, average traffic speeds and traffic delay data for the US-101 mainline facility. The Caltrans PeMS website also collects and makes available Caltrans Traffic Accident and Surveillance Analysis System (TASAS) data for users with a Caltrans account, and CHP-reported freeway incident data.

INRIX Analytics: The INRIX website provides historical and real-time traffic information, travel times and travel time information to public agencies, businesses and individuals. To do this, INRIX collects trillions of bytes of information about roadway speeds from nearly 100 million anonymous mobile phones, trucks, delivery vans, and other fleet vehicles equipped with GPS locator devices. The data are processed in real-time, creating traffic speed information for major freeways, highways and arterials across North America, as well as much of Europe, South America, and Africa. INRIX "Analytics" and INRIX "User Delay Cost Analysis" modules were used to provide traffic delay (congestion) and corridor travel time measures for preselected segments of the US 101 freeway and El Camino Real Avenue (arterial) corridors.

Transportation Injury Mapping System (TIMS): The TIMS website was developed by researchers at the Safe Transportation Research and Education Center (SafeTREC) at the University of California, Berkeley to provide data and mapping analysis tools and information for traffic safety related research, policy and planning. SafeTREC began assessing the usage of the California Statewide Integrated Traffic Records System (SWITRS) by state and local agencies in 2003 on a project funded by the California Office of Traffic Safety (OTS). Grants from OTS allowed SafeTREC to develop a geocoding methodology and apply it to SWITRS data statewide. In order to distribute the geocoded SWITRS data, a web-based data query and download application was developed with the ability to display pin maps in Google Maps. A second application was designed to provide a more map-centric experience with other types of data layers and spatial analysis capabilities typically seen in a Geographic Information System (GIS). The TIMS concept was subsequently formed to give these applications a common foundation and provide a framework for continued development in the future.

2.3 Traffic Demands on US-101

Demand data in the form of 5-minute vehicle count (speed and detector occupancy) data and VMT data were downloaded from the Caltrans PeMS database for the Vehicle Detector Stations (VDS) along the three county US-101 study corridor. Additionally, published and previously unpublished Caltrans count data were obtained for comparative purposes and to provide vehicle classification and vehicle occupancy information.

Freeway mainline volumes along with the observed traffic and congestion patterns are presented in the following tables and figures.

Caltrans published the statewide annual average daily traffic (AADT) values for year 2015 on their Traffic Operations website. From the published 2015 AADT volumes, year 2016 average weekday (daily) traffic volumes were estimated. The 2015 AADT and 2016 weekday ADT values for US-101 study segments in San Francisco County are listed in Table 2-1; Table 2-2 contains the daily traffic volumes for San Mateo County segments; and Table 2-3 lists the same for the Santa Clara County segments.

Table 2-1: San Francisco County AADT and Weekday Daily Volumes on US-101

Cnty	Rte	Post Mile	Description	2015 Caltrans AADT	2016 Weekday ADT*
SF	101	4.241	San Francisco, Jct. Rte. 80	226,000	237,000
SF	101	4.100	San Francisco, Vermont Street Connection	234,000	246,000
SF	101	2.920	San Francisco, Army Street	**239,000**	**251,000**
SF	101	1.976	San Francisco, Jct. Rte. 280	227,000	239,000
SF	101	1.108	San Francisco, Paul Avenue Connection	219,000	230,000
SF	101	0.000	San Francisco/San Mateo County Line	202,000	212,000

Source: Caltrans (http://www.dot.ca.gov/trafficops/census/) "2015AADT.xls".

Table 2-2: San Mateo County AADT and Weekday Daily Volumes on US 101

Cnty	Rte	Post Mile	Description	2015 Caltrans AADT	2016 Weekday ADT*
SM	101	25.700	Brisbane, Candlestick Park Connections	201,000	211,000
SM	101	23.393	South San Francisco, Old Bayshore Conn.	202,000	212,000
SM	101	22.713	South San Francisco, Oyster Point Blvd	215,000	226,000
SM	101	21.915	South San Francisco, Grand Ave Interchange	226,000	237,000
SM	101	21.691	Sb Off To Produce/Airport	246,000	258,000
SM	101	20.719	South San Francisco, Jct. Rte. 380 West	236,000	248,000
SM	101	19.120	San Francisco Airport Interchange	243,000	255,000
SM	101	17.947	Millbrae, Millbrae Avenue	249,000	262,000
SM	101	16.575	Burlingame, Broadway	251,000	264,000
SM	101	14.690	San Mateo, Peninsula Avenue Interchange	253,000	266,000
SM	101	14.330	San Mateo, Poplar/Dore Ave Connections	265,000	278,000
SM	101	13.461	San Mateo, Third Avenue	**268,000**	**282,000**
SM	101	12.690	San Mateo, Kehoe Avenue Connection	**268,000**	**282,000**
SM	101	11.895	San Mateo, Jct. Rte. 92	236,000	248,000
SM	101	11.147	San Mateo, East Hillsdale Blvd Interchange	238,000	250,000
SM	101	9.552	Belmont, Ralston Avenue Interchange	227,000	239,000
SM	101	8.401	Holly Street Interchange	226,000	237,000
SM	101	6.623	Redwood City, Whipple Avenue	214,000	225,000
SM	101	5.385	Redwood City, Jct. Rte. 84	221,000	232,000
SM	101	3.592	Menlo Park, Marsh Road Interchange	203,000	213,000
SM	101	1.869	Jct. Rte. 114	215,000	226,000
SM	101	0.890	East Palo Alto, University Avenue	222,000	233,000
SM	101	0.000	Santa Clara/San Mateo County Line	222,000	233,000

Source: Caltrans (http://www.dot.ca.gov/trafficops/census/) "2015AADT.xls".

Table 2-3: Santa Clara County AADT and Weekday Daily Volumes on US 101

Cnty	Rte	Post Mile	Description	2015 Caltrans AADT	2016 Weekday ADT*
SCL	101	52.170	Embarcadero Rd/Oregon Ave Interchange	235,000	247,000
SCL	101	50.323	Palo Alto, San Antonio Road Interchange	216,000	227,000
SCL	101	49.611	Mountain View, Rengstorff Ave Interchange	227,000	239,000
SCL	101	48.974	Mountain View, Middlefield Rd Interchange	227,000	239,000
SCL	101	48.103	Mountain View, Jct. Rte. 85 South	179,000	188,000
SCL	101	47.891	Mountain View, Moffett Blvd Interchange	183,000	192,000
SCL	101	47.014	Sunnyvale, Moffett Field Interchange	181,000	190,000
SCL	101	46.134	Sunnyvale, Jct. Rte. 237	161,000	169,000
SCL	101	45.684	Sunnyvale, Matilda Avenue Interchange	174,000	183,000
SCL	101	44.831	Sunnyvale, Fair Oaks Avenue Interchange	181,000	190,000
SCL	101	43.850	Sunnyvale, Lawrence Expressway	188,000	198,000
SCL	101	42.734	Great America Parkway	201,000	211,000
SCL	101	41.978	San Tomas Expressway Interchange	196,000	206,000
SCL	101	40.701	San Jose, De La Cruz Boulevard	201,000	211,000
SCL	101	39.925	Jct. Rte. 87, Guadalupe Parkway	154,000	162,000
SCL	101	39.285	San Jose, North First Street Interchange	138,000	145,000
SCL	101	38.800	San Jose, North Fourth Street Connections	147,000	154,000
SCL	101	38.300	San Jose, Jct. Rte. 880	192,000	202,000
SCL	101	37.726	San Jose, Oakland Road	189,000	199,000
SCL	101	36.144	San Jose, Mc Kee Road	158,000	166,000
SCL	101	35.759	San Jose, Jct. Rte. 130 East	200,000	210,000
SCL	101	34.870	San Jose, Jct. Rte. 280 West/680 North	**258,000**	**271,000**
SCL	101	33.034	San Jose, Tully Road Interchange	219,000	230,000
SCL	101	31.695	San Jose, Capitol Expressway Interchange	180,000	189,000
SCL	101	30.097	Hellyer Avenue Interchange	165,000	173,000
SCL	101	28.609	San Jose, Jct. Rte. 82 North	138,000	145,000
SCL	101	26.780	San Jose, Jct. Rte. 85, Bernal Rd	146,000	153,000

Source: Caltrans (http://www.dot.ca.gov/trafficops/census/) "2015AADT.xls".

The US-101 corridor's average weekday travel demand can regularly exceed 250,000 vehicles per day at several locations along the three county study area, with the highest demand being just north of the SR 92 junction in San Mateo County, in the vicinity of the I-280/I-680 junction in Santa Clara County, and south of the I-80 junction in San Francisco County.

Upon summarizing the travel demand in terms daily traffic volumes, the overall corridor's travel demand was measured in vehicle-miles of travel (VMT). The corridor's overall VMT trends and growth in VMT are presented next. Figure 2-2 displays the average non-holiday weekday VMT estimates by month; and Figure 2-3 displays the same for the average Saturday VMT estimates. From these monthly average daily VMT estimates it is clear that the demand for travel has increased over the three year 2014-2016 period.

Figure 2-2: US 101 (NB+SB), Average Weekday Vehicle Miles Traveled (VMT)

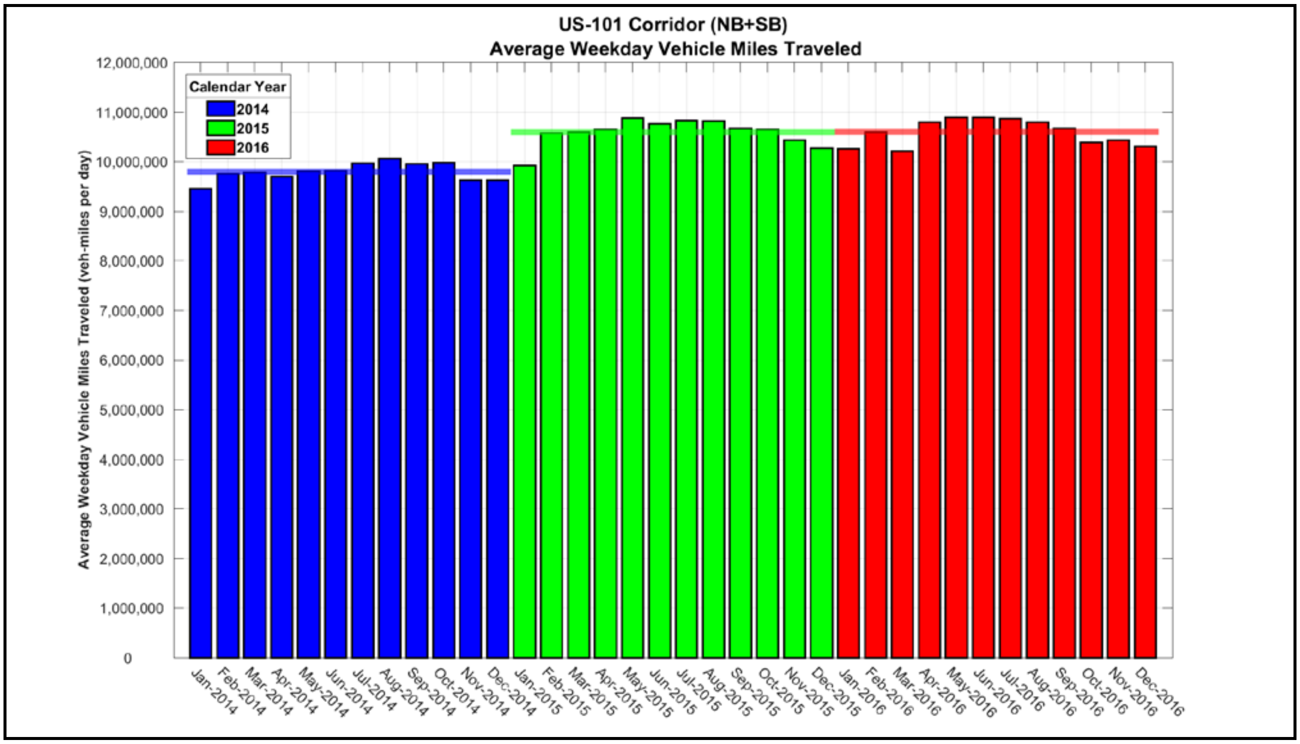
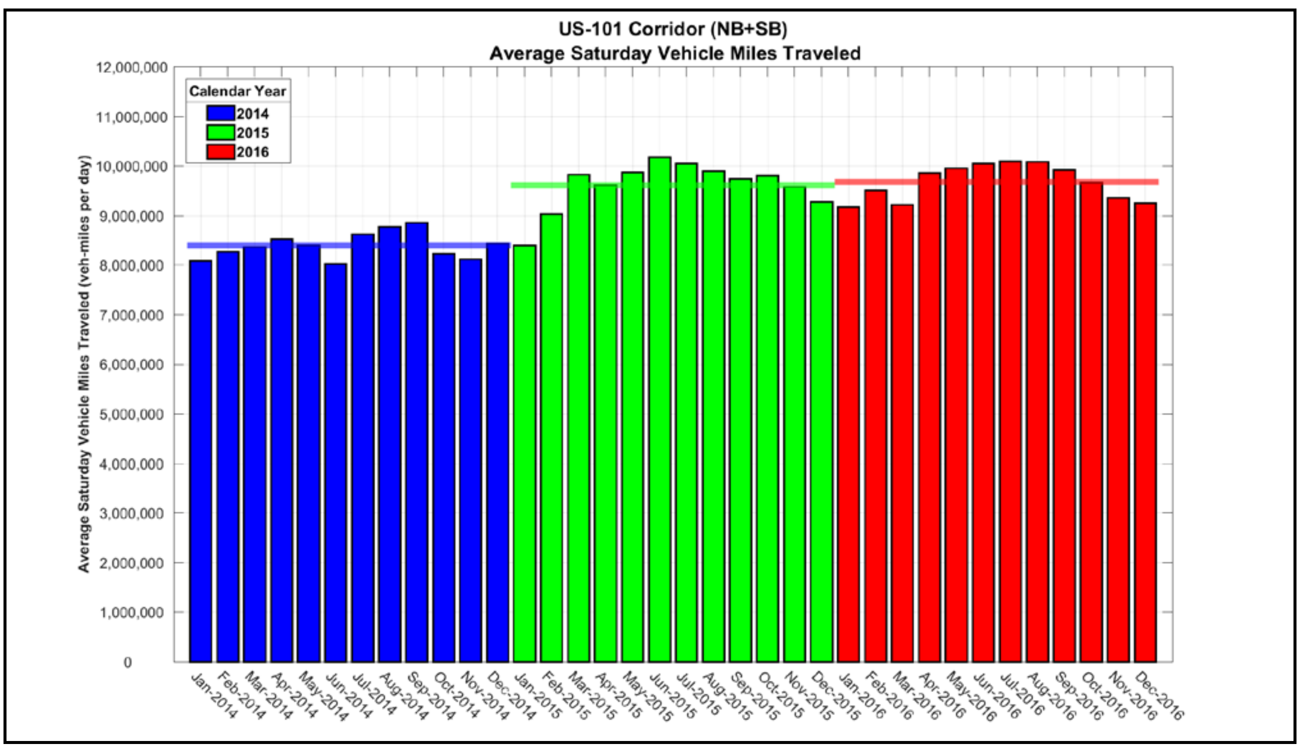


Figure 2-3: US 101 (NB+SB), Average Saturday Vehicle Miles Traveled (VMT)



2.4 Travel-Times and Vehicular Delays on the US-101 Corridor

The average time required to travel the distance of a study corridor is a commonly used metric to gauge the average levels of congestion along a freeway or major arterial corridor. The actual (measured) travel times are often compared to the minimum required travel time during uncongested times of the day. This minimum required travel time is referred to as the "free flow travel time". The delays to travel, or the time costs of congestion can be directly estimated or calculated as the difference between the actual measured travel times and the minimum required free flow travel times.

The measured or observed US-101 corridor travel times, the free flow travel times, and the associated delays (per vehicle trip) are shown in Figure 2-4 for the Northbound travel direction and in Figure 2-5 for the Southbound travel lanes. The corridor average free flow speed according to the year 2016 INRIX data was 64.8 mph, and 64.2 mph for the southbound direction. As expected, the largest delays on an average non-holiday weekday are expected during the morning and evening commute periods. Also, it becomes clear that the travel times are increasing for the commute peaks and for the midday period between the peaks when one compares the 2014 travel time trends to the 2015 and 2016 travel times.

Vehicle miles of travel (VMT) is a measure of utilization or a measure of overall demand for travel. Vehicle hours of delay (VHD) quantifies the number of vehicle hours lost to delays from traffic slow-downs and queuing. Using a congestion threshold of 45 mph, the average daily VMT and VHD was estimated for each day in year 2014, 2015 and 2016 for the US-101 study corridor. Then the VHD was tallied by month to gain insights into traffic demand and congestion seasonality trends along the corridor. The daily VMT and VHD estimates were also tallied by day-of-week to ascertain the weekday trends in VMT and VHD. Figure 2-6 through Figure 2-9 show the monthly and day-of-week VMT and VHD trends.

Table 2-4 contains a summary of the annual average growth trends in VMT and VHD for the US-101 corridor. It is common for VHD to outpace VMT growth rates for heavily congested corridors like the US-101 corridor in the San Francisco, San Mateo and Santa Clara Counties.

Although the weekend (Saturday and Sunday) traffic levels are generally lower than average weekday levels, the weekend traffic demands are growing faster than weekday demands. As such, the weekend delays (VHD) are growing faster than the weekday delays.

Figure 2-10 uses side-by-side bar charts to contrast and compare the long-term traffic volume and congestion growth trends for years 2005 through 2016. From the figure, it is very clear that the congestion's growth rates (or the changes in congestion) consistently outpace the growth or changes in the demand for travel (i.e., daily traffic volumes).

Figure 2-4: US-101 Northbound, Average Weekday Vehicular Travel-times

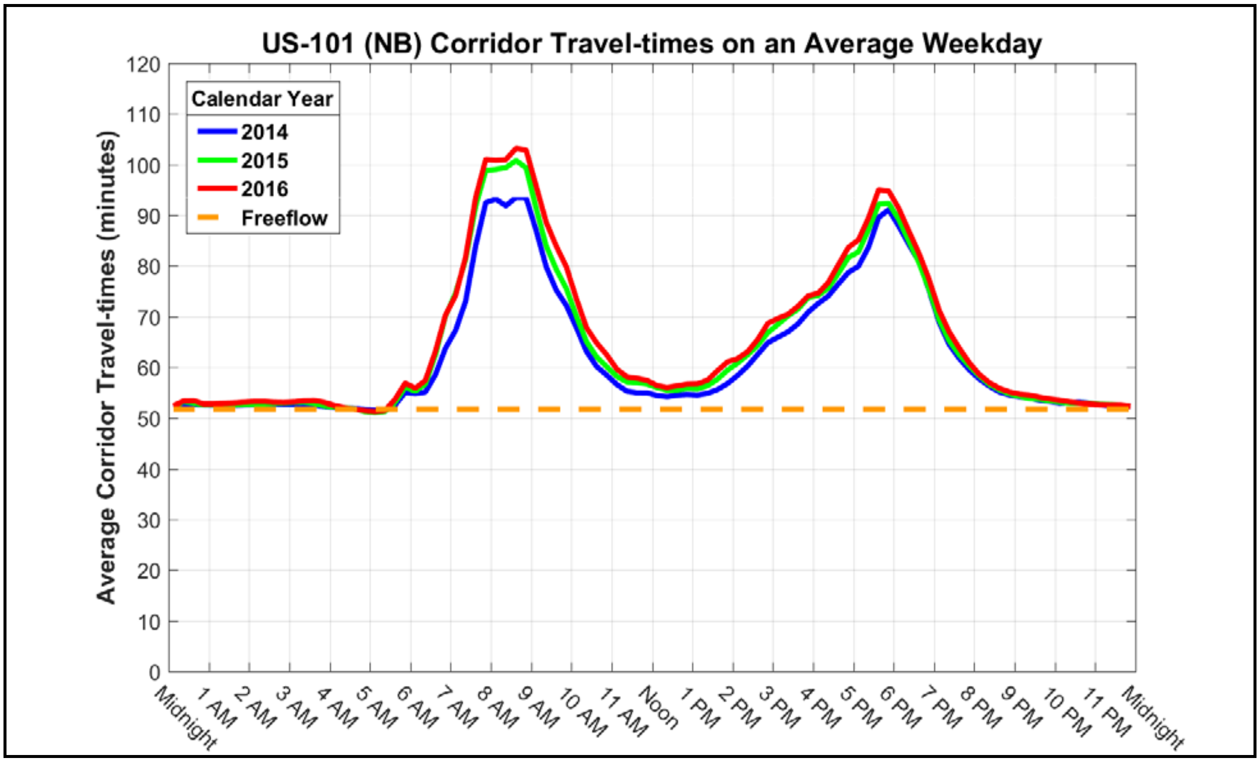


Figure 2-5: US-101 Southbound, Average Weekday Vehicular Travel-times

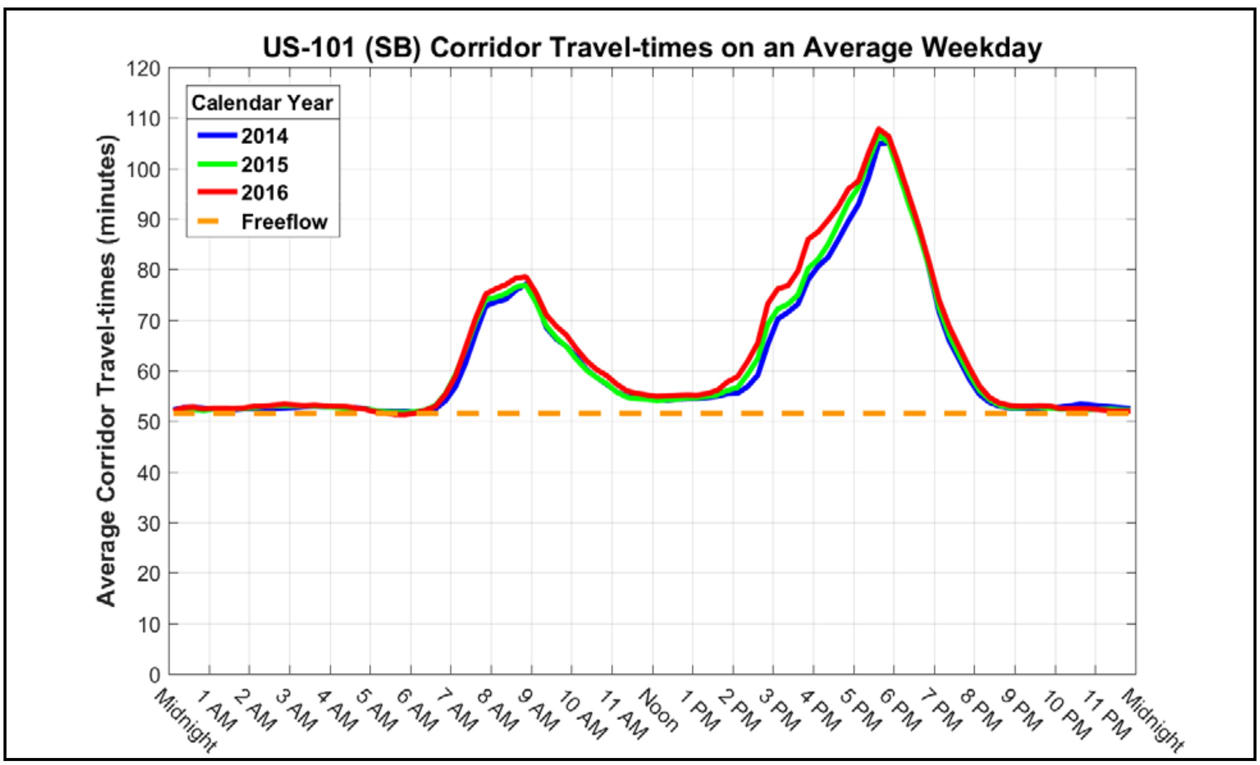


Figure 2-6: US-101 (NB+SB), Average Weekday Vehicle Hours of Delay (VHD)

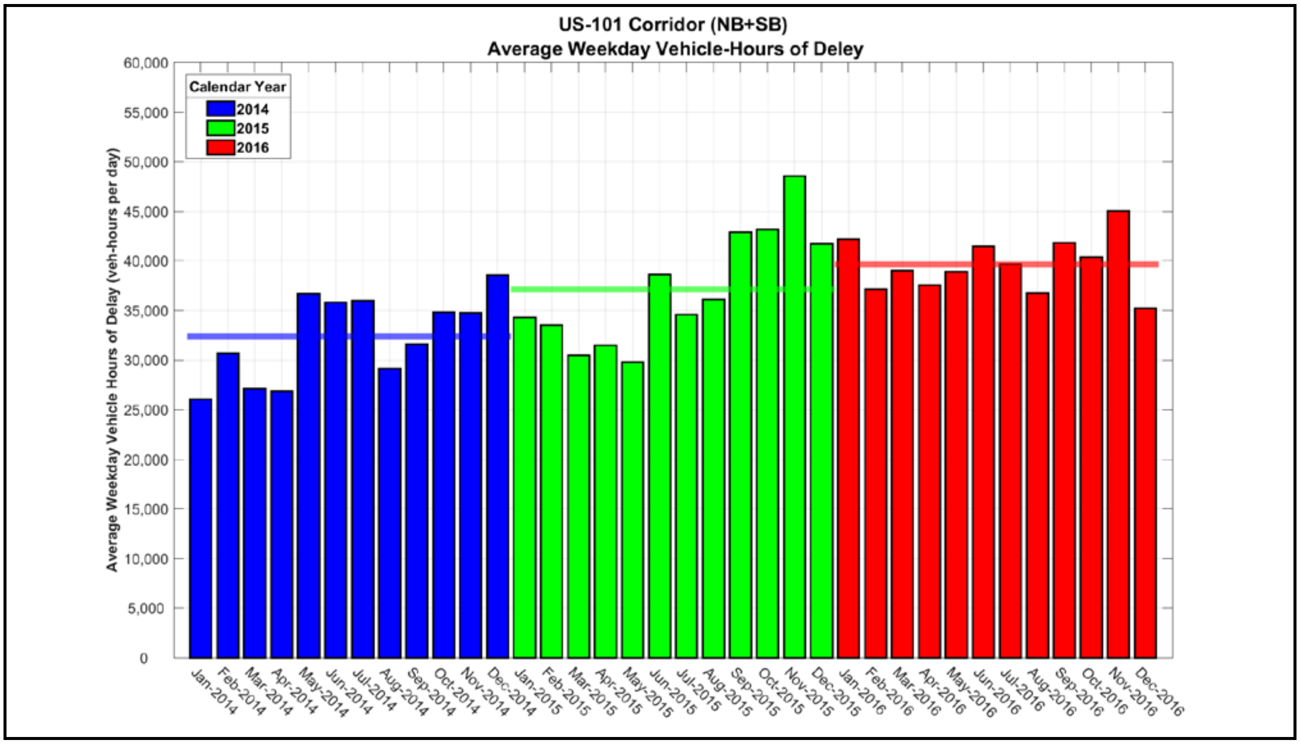


Figure 2-7: US-101 (NB+SB), Average Saturday Vehicle Hours of Delay (VHD)

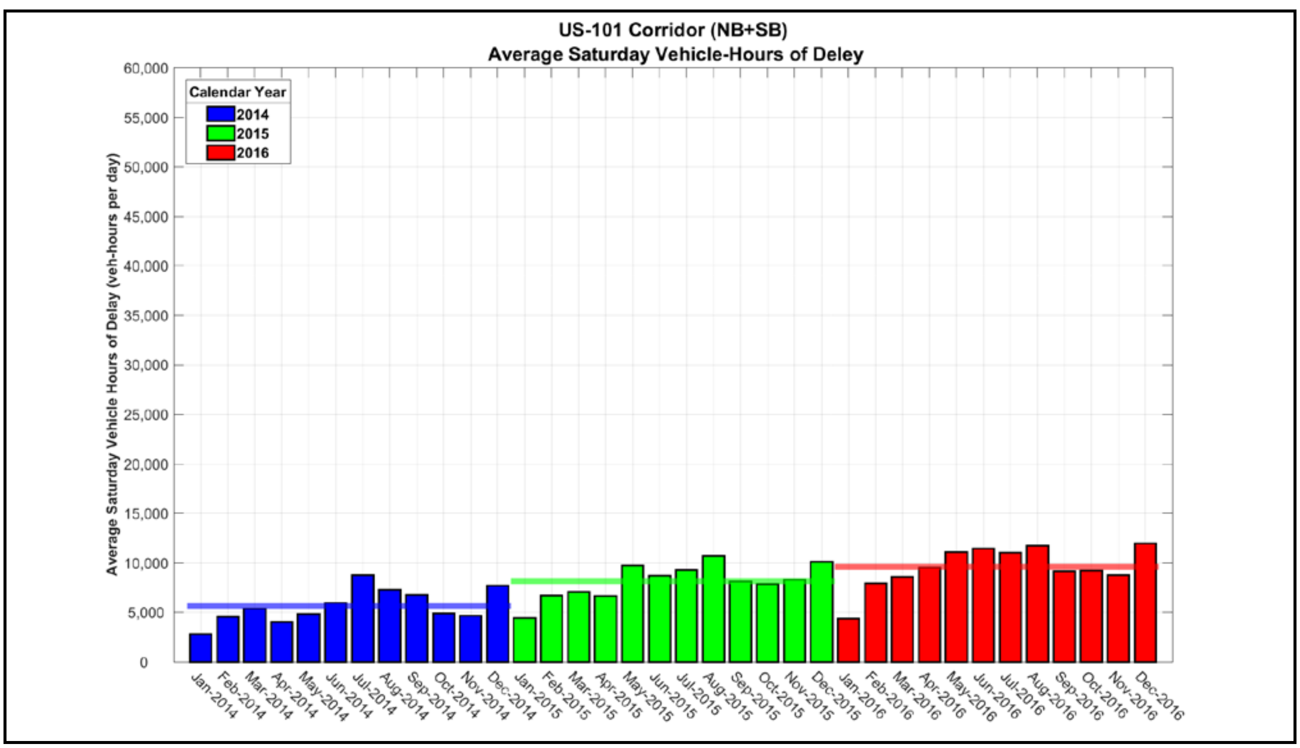


Figure 2-8: US-101 (NB+SB), Average Vehicle Miles of Travel (VMT) by Day-of-Week

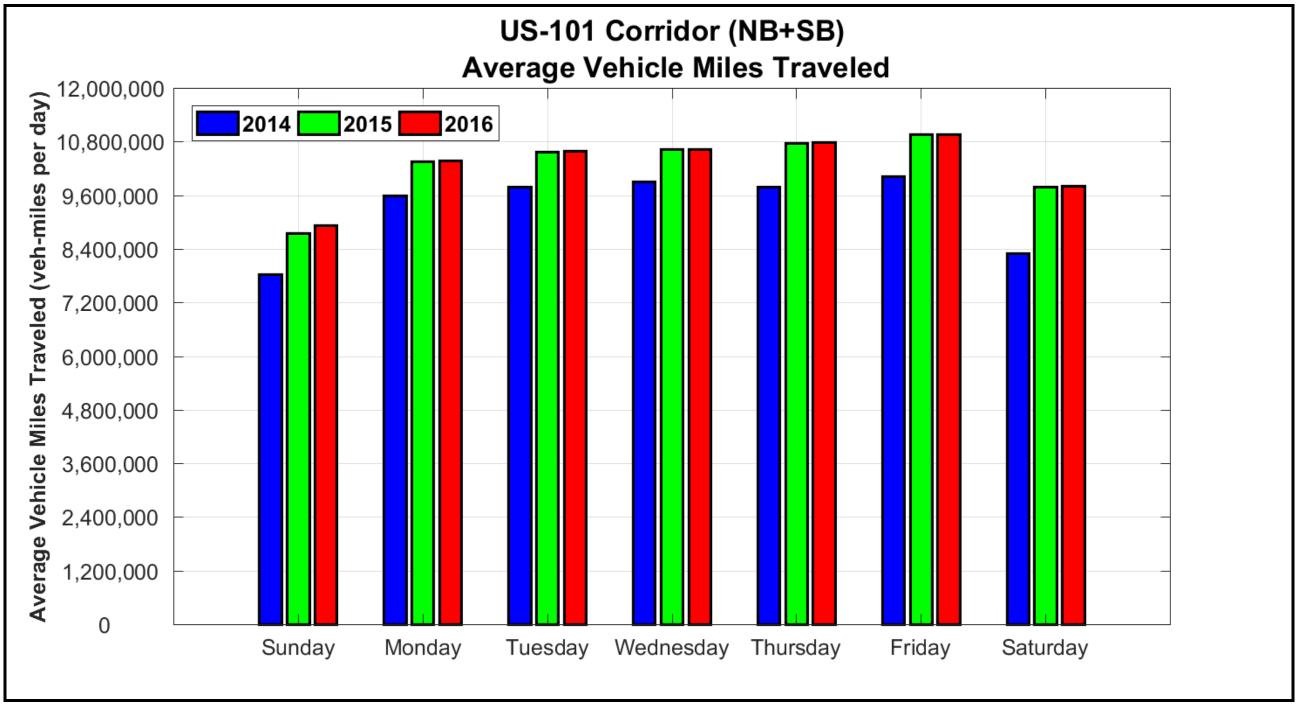


Figure 2-9: US-101 (NB+SB), Average Vehicle Hours of Delay (VHD) by Day-of-Week

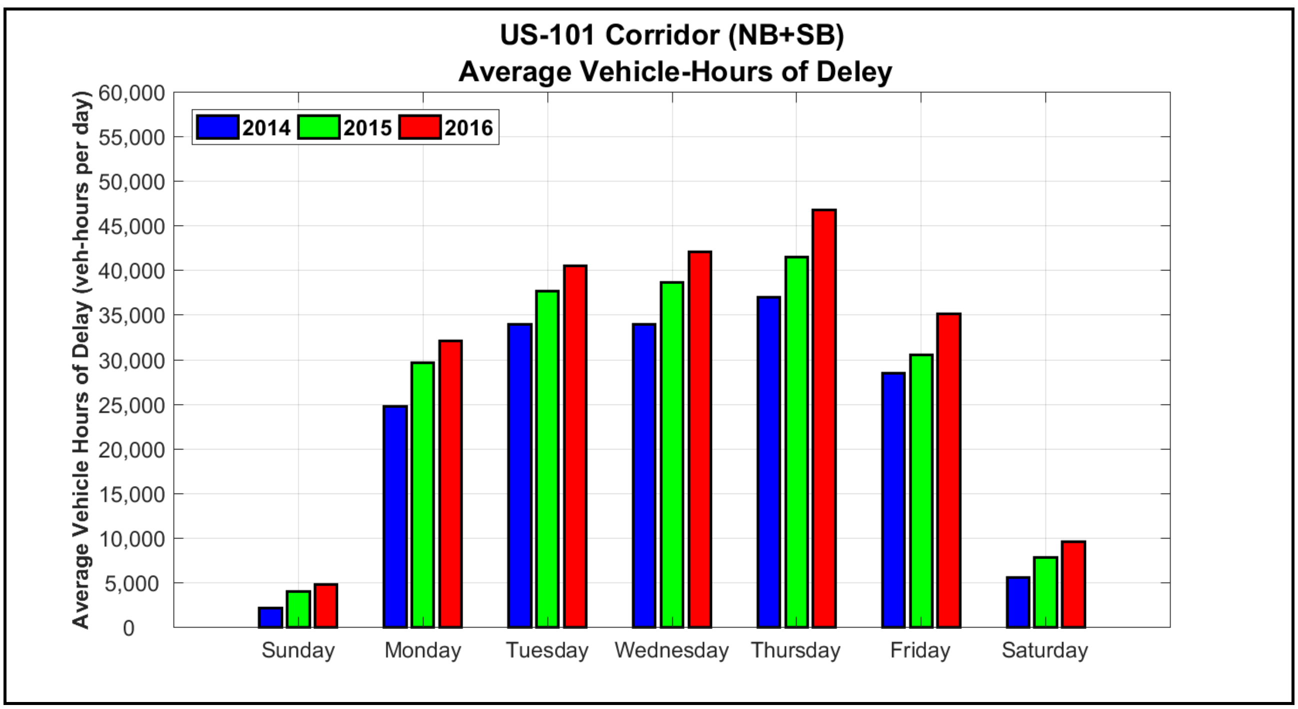
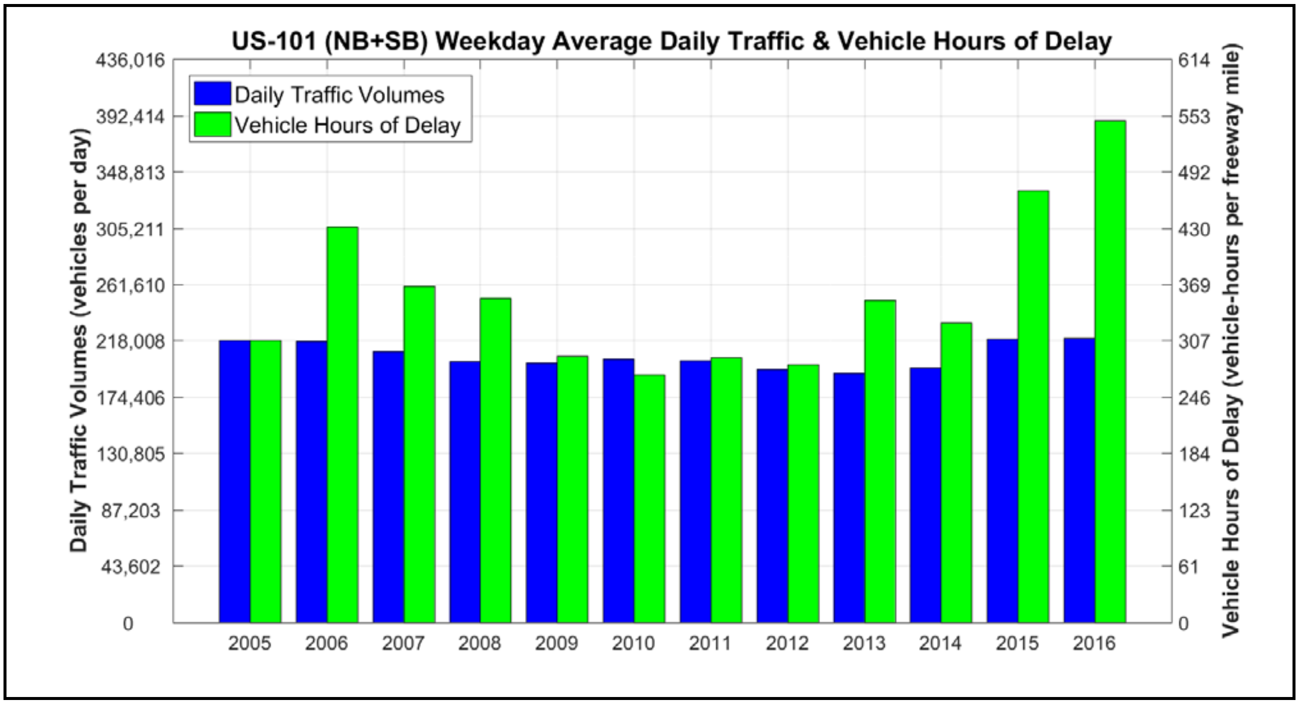


Table 2-4: Summary of (2014-2016) Traffic Growth in VMT and VHD for the US-101 Corridor

Day(s) of Week	Corridor Performance Metric	US-101 Northbound	US-101 Southbound	US-101 NB+SB
Non-holiday Weekday	VMT	2.9%	4.3%	3.5%
	VHD	10.8%	11.7%	11.5%
Saturday	VMT	6. 0%	7.4%	6.6%
	VHD	28.1%	29.4%	27.8%
Sunday	VMT	5.2%	7.0%	6.0%
	VHD	29.0%	41.8%	32.2%

Figure 2-10: US-101 Long-Term Weekday Annual Average Daily Traffic and Vehicle Hours of Delay



2.5 Traffic Congestion Patterns on the US-101 Corridor

To view the bottleneck activity and quantify queuing on US-101 throughout the three county study area, non-holiday weekday traffic congestion maps (for year 2016) were created, revealing the congestion patterns and the extent and duration of weekday queuing. Traffic congestion maps are data visualizations that are created using traffic speed data that show the congestion patterns and areas of traffic queuing along a corridor for some preselected period of time.

Figure 2-11 and Figure 2-12 each contain two paired side-by-side graphics, both using a common vertical axis. This common vertical axis is location on the US-101 freeway, or the vertical axis can be thought of as distance along the study corridor; bottom-to-top is south-to-north.

Figure 2-11: US-101 Northbound, Duration of Congestion and Average Weekday Traffic Speeds

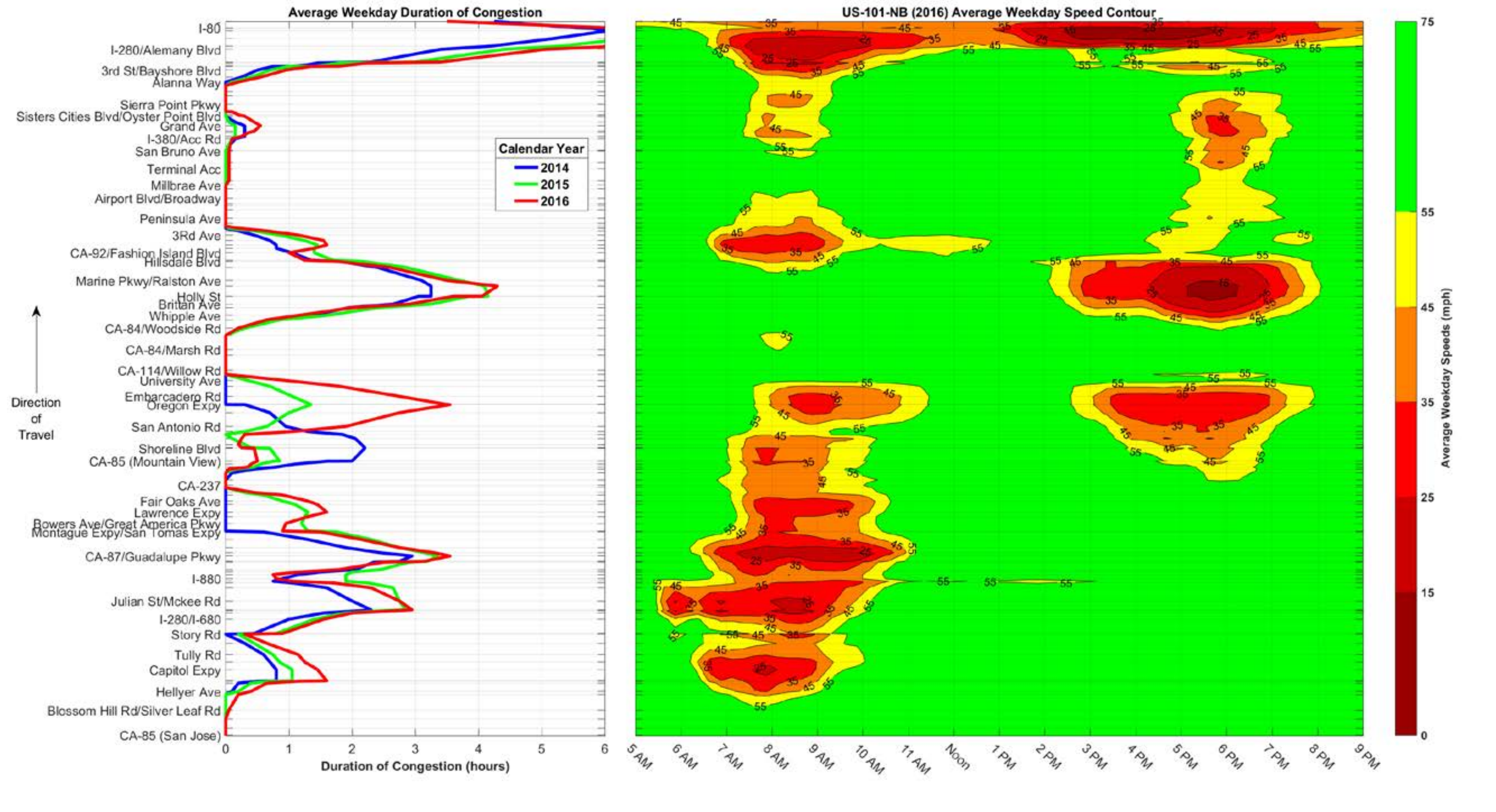
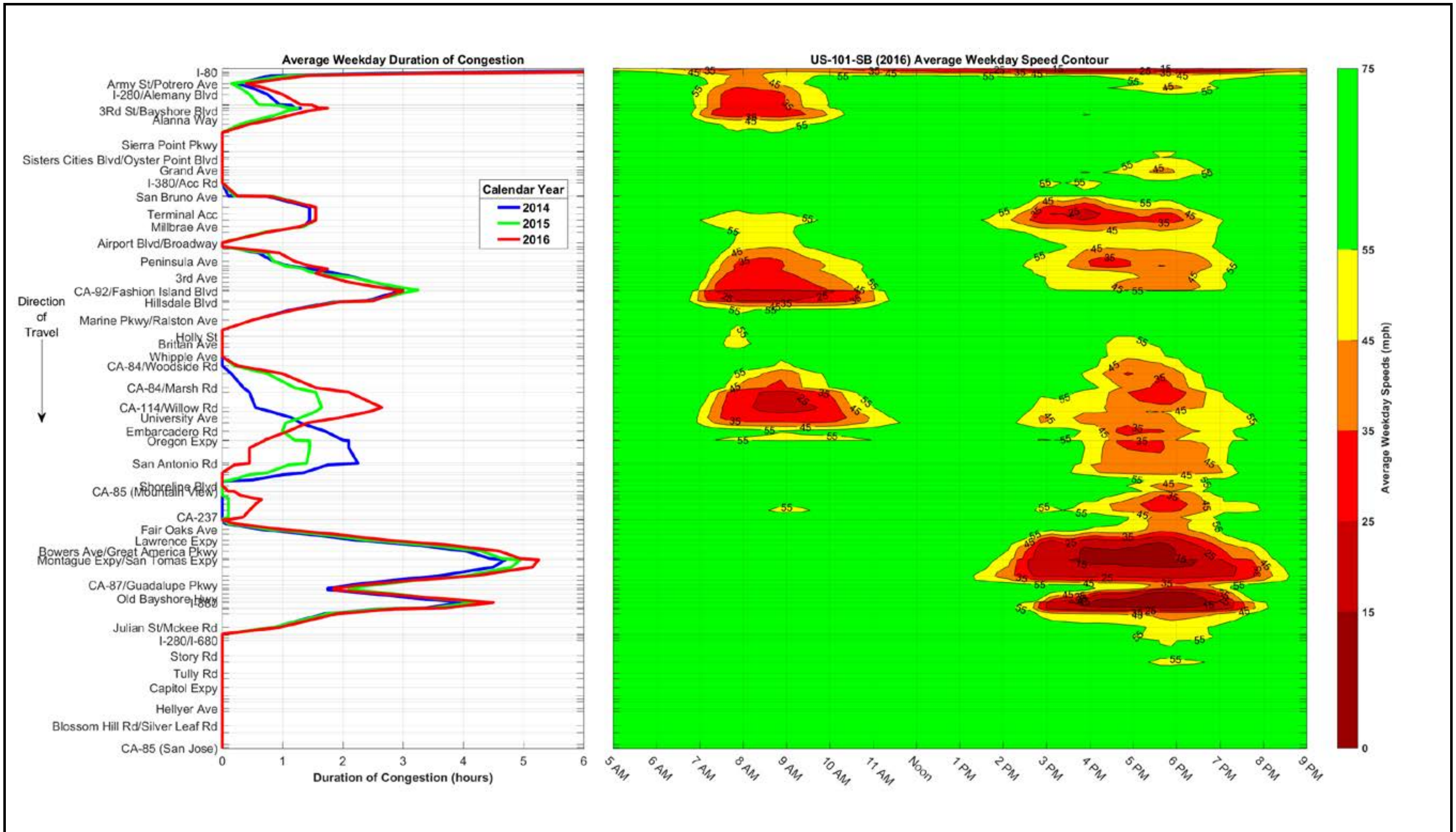


Figure 2-12: US-101 Southbound, Duration of Congestion and Average Weekday Traffic Speeds



The graphic on the left-hand-side shows the average weekday duration of congestion (in hours per day) along the US-101 corridor. The duration of congestion is the number of hours, per day, that the US-101 freeway is congested on an average non-holiday weekday. The duration of congestion for years 2014, 2015 and 2016 was computed and is displayed, showing the annual growth rates for traffic congestion along the corridor.

The graphic on the right-hand-side is the year 2016 congestion scan for the average non-holiday weekday. The horizontal axis is time-of-day. The congestion scan shows where the freeway's recurrent bottlenecks are located and the duration and extent of the traffic queuing upstream of these bottlenecks.

From the congestion scans it is clear that there are multiple bottlenecks along the corridor and that there is considerable traffic congestion (queuing) in both the AM and PM peak periods. This holds true for both the northbound and southbound directions of travel. Another trend that can be clearly identified is that congestion is spreading; the duration of congestion is growing over time. Congestion is encroaching into the midday and is no longer confined to a nicely defined AM and/or PM peak period.

The northbound direction of travel (toward downtown San Francisco) suffers the heaviest levels of traffic congestion during the morning commute period. For the southbound direction of travel, the heaviest levels of congestion are during the evening commute period. However, US-101 congestion is not confined to the peak direction of travel and traffic queuing is a common problem during both the AM and PM peak in either direction of travel.

2.6 Major Freeway Bottlenecks along the Corridor

In past decades, the morning commuter traffic congestion had been associated with the northbound direction – inbound to San Francisco's central business district. Conversely, the evening rush hour congestion was predominately associated with the southbound traffic, leaving downtown San Francisco. These generalized accounts no longer adequately describe or explain the complex traffic demand and congestion patterns along the US-101 corridor. The multiple business centers throughout the South Bay and San Jose regions create travel demand patterns and recurrent congestion patterns that can no longer be accurately portrayed with "one size fits all" explanations.

Many of the US-101 corridor's recurrent bottlenecks occur regularly in both the morning and evening peak periods. Some of the more severe bottlenecks remain active or activate during the midday on typical workdays. As important, congestion from recurrent bottleneck activity is becoming a common occurrence on holidays and/or on weekends.

With the tight spacing of ramp interchanges along the US-101 corridor, multiple recurrent (on-ramp merge) bottlenecks can be observed within relatively short 2 to 3 mile sections of the corridor. Queues from the corridor's major bottlenecks regularly extend upstream sufficiently far as to interfere with bottlenecks at adjacent upstream ramp interchanges. The observed queue lengths are growing steadily over time; likewise, the number of hours of the day where congestion is regularly observed (i.e., peak spreading) continues to grow.

Using the Caltrans PeMS websites and associated data, the US-101 bottlenecks were ranked by average annual (weekday) vehicle-hours of delay (VHD) – for this process a 45 mph congestion threshold was used. Table 2-5 lists the top 10 recurrent bottlenecks for US-101 in the northbound direction for the study corridor; and Table 2-6 lists the same for the US-101 southbound direction.

Figure 2-13 overlays the top 10 northbound bottlenecks onto the US-101 northbound congestion scan, visually relating the bottleneck's average weekday vehicle-hours delayed with the queuing upstream of these bottlenecks. Figure 2-14 geographically maps the US-101 northbound bottlenecks.

Figure 2-15 overlays the top 10 southbound bottlenecks onto the US-101 southbound congestion scan, visually relating the bottleneck's average weekday vehicle-hours delayed with the queuing upstream of these bottlenecks. Figure 2-16 geographically maps the US-101 Southbound bottlenecks.

The major causes of the corridor's major bottlenecks are typical for congested urban freeway corridors – freeway merge areas at heavily utilized on-ramps and freeway weaving segments between relatively close and heavily used on- and off-ramps. As expected, traffic queuing and congestion is regularly observed upstream of these heavily utilized on-ramps (merge bottlenecks) and weaving segments where an on-ramp is followed in relatively close downstream proximity by a heavily utilized off-ramp.

It can be seen in the provided tables and figures, the three most prominent causes of northbound vehicular delays are:

1. The four northbound lanes at "20th Street - Hospital Curve" (in San Francisco County)
2. Weaving between the Hillsdale Boulevard on-ramp and the SR 92 off-ramps (in San Mateo County)
3. Merging just downstream (i.e., north) of the Lawrence Expressway on-ramp (in Santa Clara County)

Table 2-5: Major Recurrent Bottlenecks for US-101 Northbound

Bottleneck Location (Description)	Average (Weekday) Vehicle-Hours of Delay				
	Daily	AM Peak Period (5 am to 10 am)	Midday Period (10 am to 3 pm)	PM Peak Period (3 pm to 8 pm)	Bottleneck Ranking
20th Street - Hospital Curve	2,288	812	702	774	1
Sierra Point Parkway on ramp Merge bottleneck	294	159	0	134	6
SR 92 On Ramp(s) Merge bottleneck with lane drop	197	69	62	67	9
Hillsdale Boulevard on and SR 92 off ramps Weave bottleneck	1,477	120	176	1,181	2
Ralston Avenue/Marine Parkway on ramps Merge bottleneck	1,240	0	100	1,140	3
Embarcadero Road on ramps Merge bottleneck	251	71	52	128	7
Lawrence Expwy on to Fair Oaks Ave off ramps Weave bottleneck	1,116	1,116	0	0	4
Trimble Road on ramp(s) Merge bottleneck	221	158	63	0	8
Oakland Road on ramp(s) Merge bottleneck	187	187	0	0	10
Capital Expressway on ramp(s) Merge bottleneck	465	465	0	0	5

Data Source: Caltrans PeMS (http://pems.dot.ca.gov/).
Note: Bottlenecks are listed in north-to-south order.

Table 2-6: Major Recurrent Bottlenecks for US-101 Southbound

Bottleneck Location (Description)	Average (Weekday) Vehicle-Hours of Delay				
	Daily	AM Peak Period	Midday Period	PM Peak Period	Bottleneck Ranking
3rd Street on ramp(s) Merge bottleneck	385	331	0	53	7
Airport Access Rd on & Millbrae Ave off ramps Weave bottleneck	563	85	89	390	6
Upstream of Peninsula Avenue Horizontal curve	340	53	0	286	10
SR 92 on ramp(s) Merge bottleneck	1,253	711	109	433	4
Willow Road on ramp(s) Merge bottleneck	346	0	0	346	9
University Ave on & Embarcadero Rd off ramps Weave bottleneck	2,056	1,250	348	458	2
Embarcadero Road on ramp(s) Merge bottleneck	355	0	0	355	8
Great America Pkwy on & San Tomas Expwy off Weave bottleneck	1,335	0	120	1,215	3
De La Cruz Blvd on & Guadalupe Pkwy off Weave bottleneck	620	0	266	354	5
Interstate 880 SB on ramps Merge bottleneck	2,888	0	0	2,888	1

Data Source: Caltrans PeMS (http://pems.dot.ca.gov/).
Note: Bottlenecks are listed in north-to-south order.

Figure 2-13: Relationship between Congestion Patterns and Major Bottlenecks for US 101 North

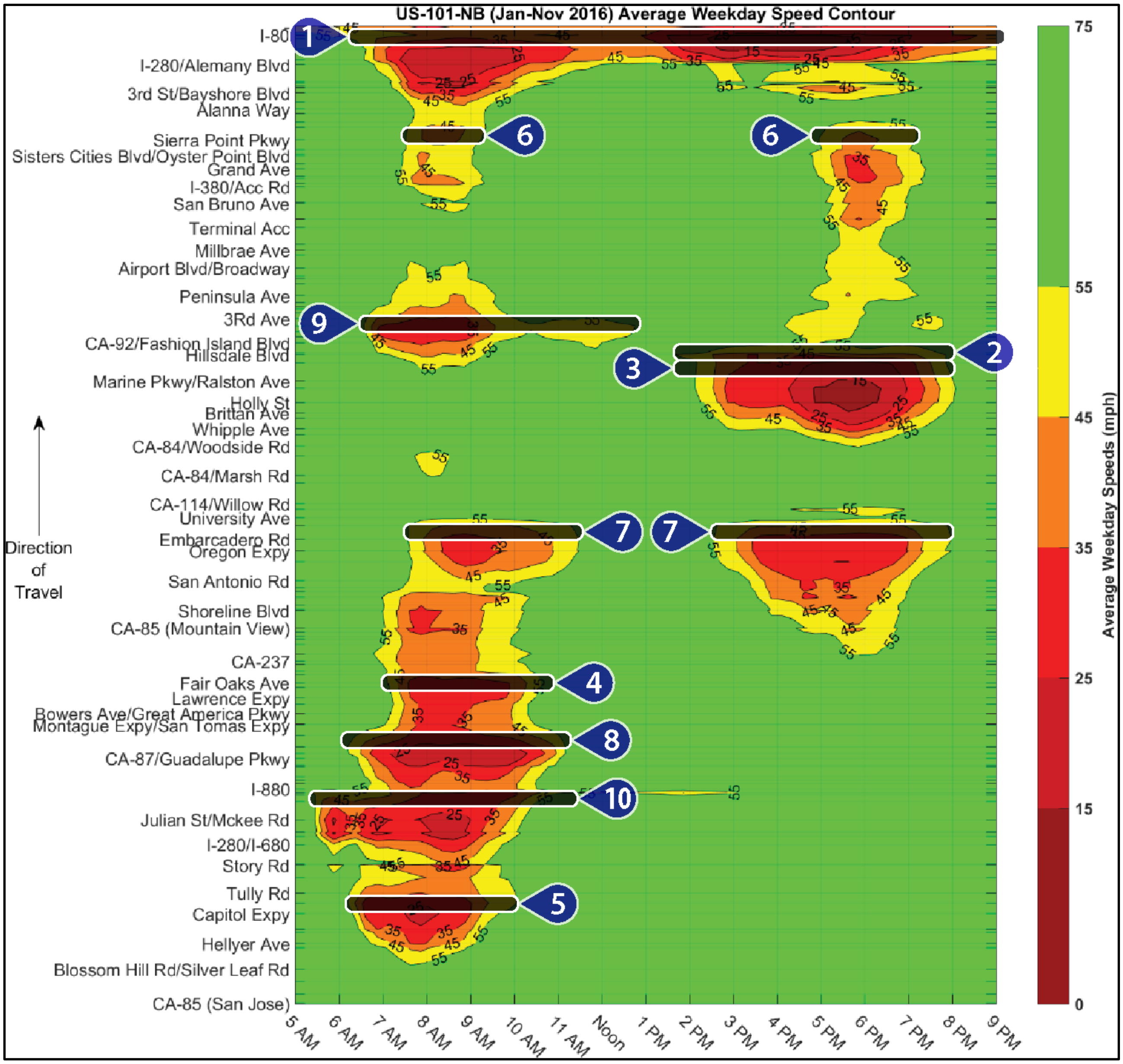
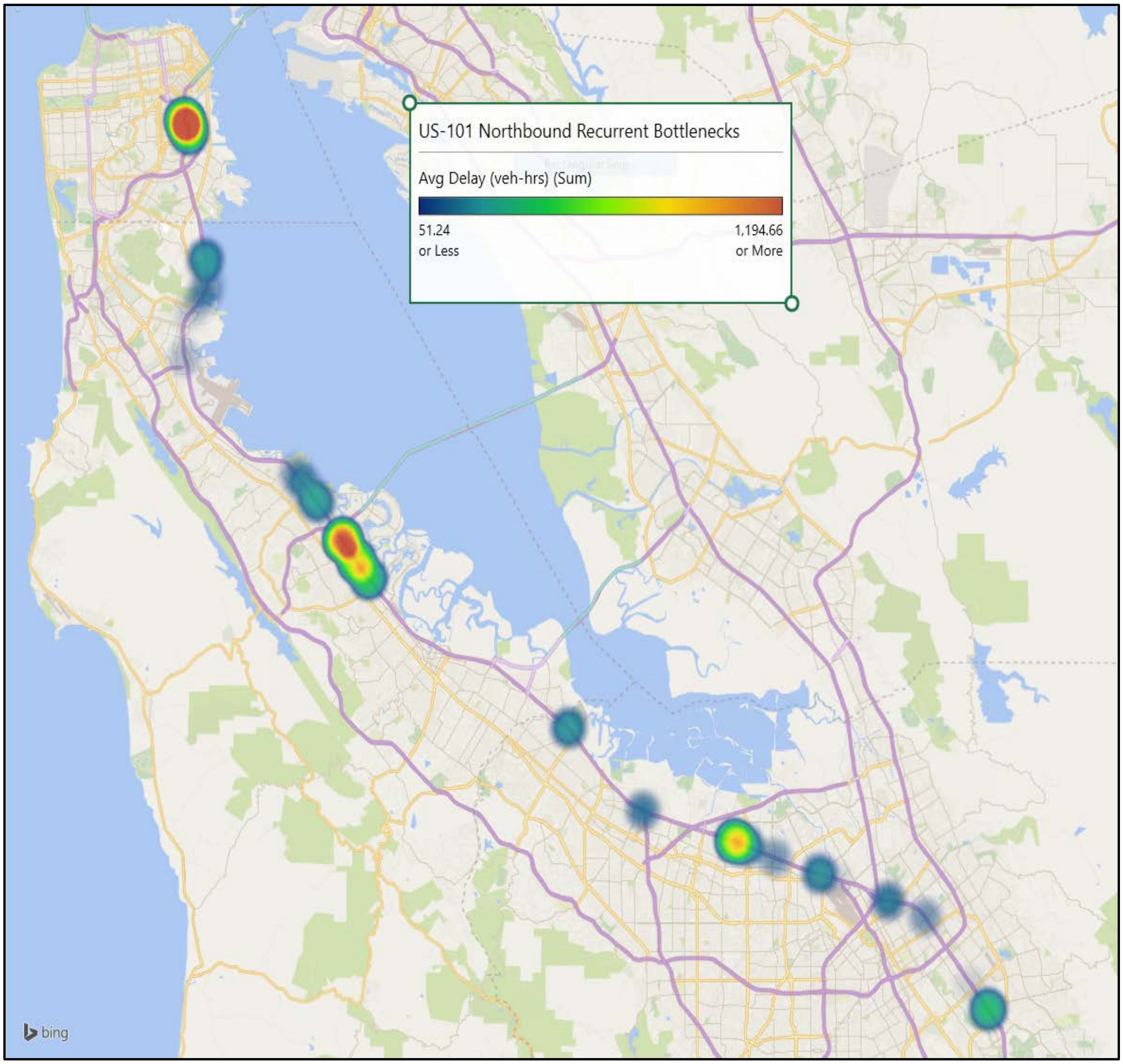


Figure 2-14: Major Recurrent Bottlenecks for US-101 Northbound



Data Source: Caltrans PeMS (http://pems.dot.ca.gov/).

Figure 2-15: Relationship between Congestion Patterns and Major Bottlenecks for US 101 South

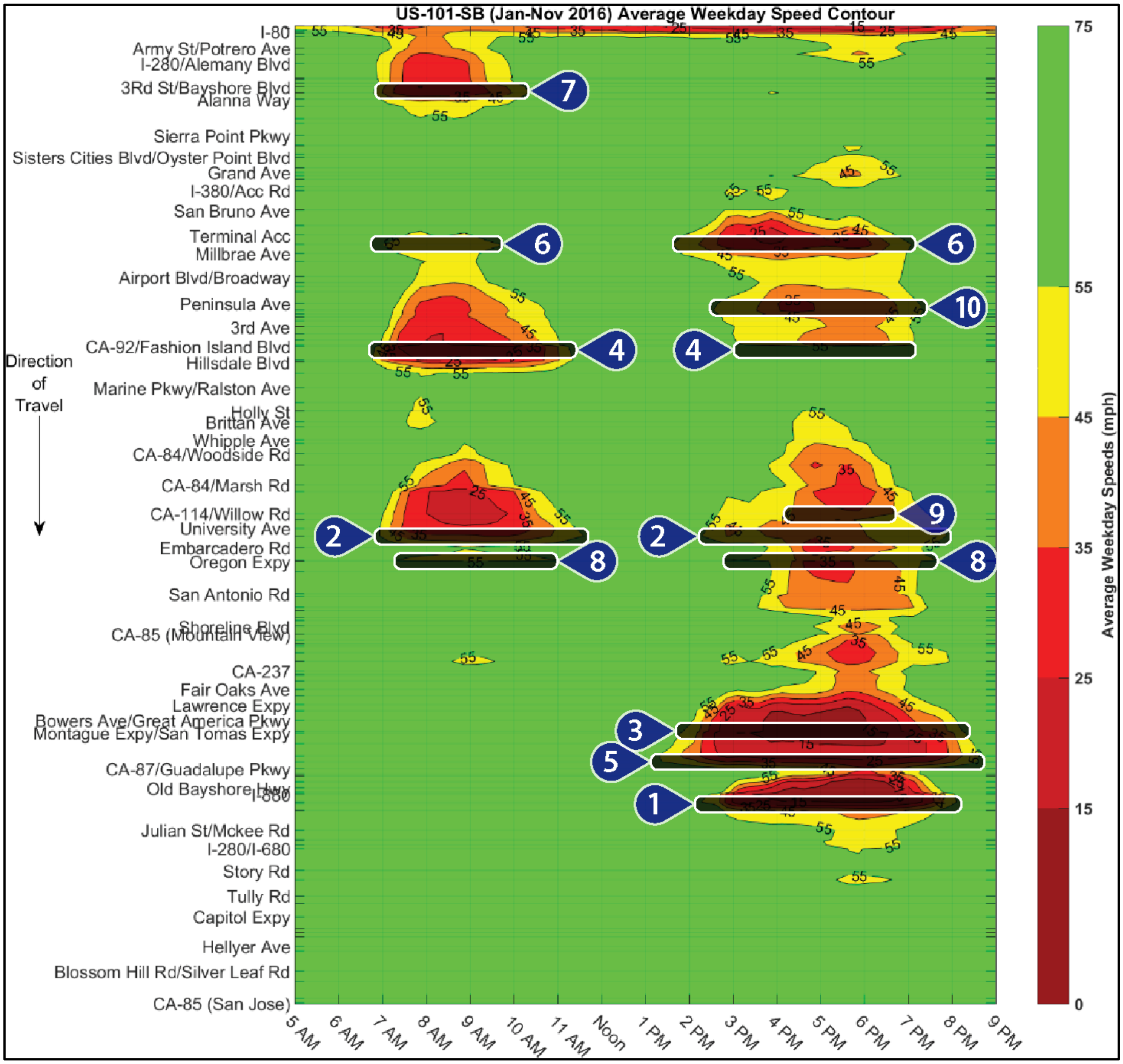
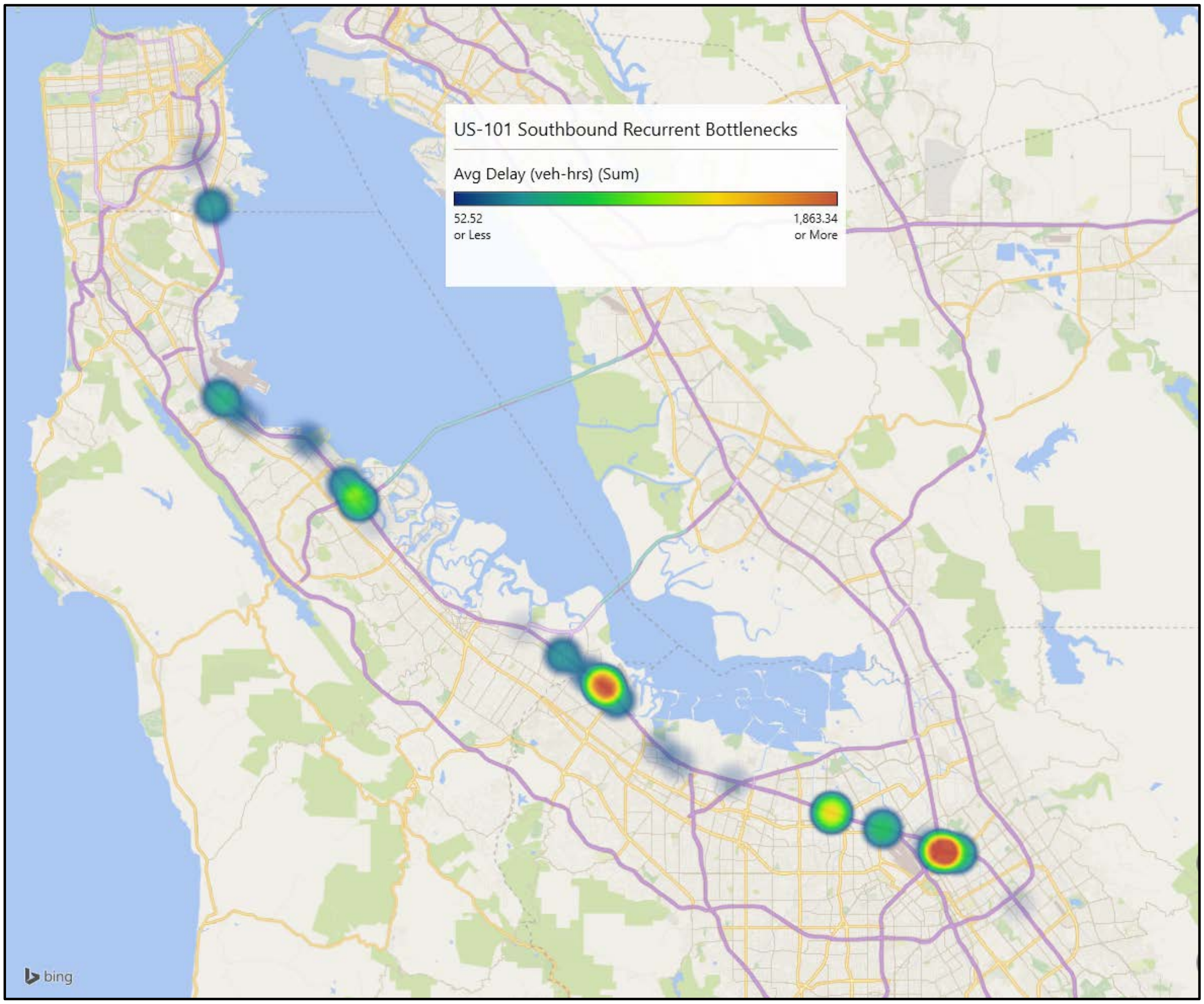


Figure 2-16: Major Recurrent Bottlenecks for US-101 Southbound



Data Source: Caltrans PeMS (http://pems.dot.ca.gov/).

Figure 2-16 displays the US-101 freeway's major recurrent bottlenecks in the southbound direction of travel. The most congestion causing recurrent bottlenecks are near the SR 92 on-ramp merge (in San Mateo County), the stretch of freeway just upstream (north) of the Oregon Expressway off-ramps (in Santa Clara County), and the Great America Parkway and I-880 merge areas (in Santa Clara County).

2.7 "Causes of Congestion" Analysis for the US-101 Corridor

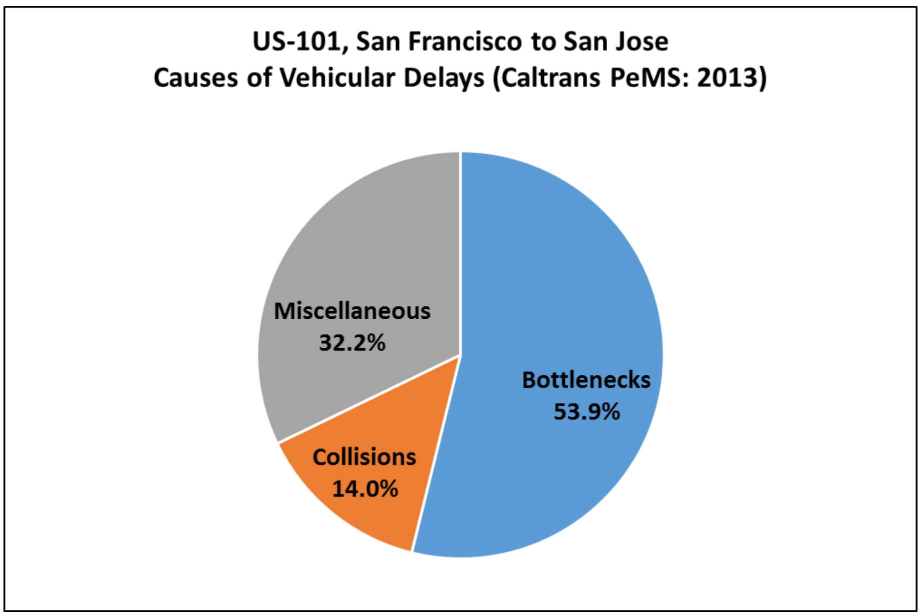
The Caltrans PeMS website facilitates the evaluation of major causes of congestion on California freeways. Using the PeMS data and tools, a "causes of congestion" evaluation was performed for US-101 in the three county study area. Table 2-7 lists the resulting causes of congestion (in percentage points of overall or total congestion). Correspondingly, Figure 2-17 displays the corridor-wide assessment as a pie chart.

Table 2-7: Major Causes of Congestion on US-101

Freeway and Direction	County	Recurrent Bottlenecks	Collisions	Miscellaneous
US-101 Northbound	San Francisco	64.6%	3.8%	31.6%
	San Mateo	51.3%	13.7%	35.0%
	Santa Clara	47.3%	20.0%	32.7%
	Total	52.6%	14.2%	33.2%
US-101 Southbound	San Francisco	33.2%	12.2%	54.6%
	San Mateo	59.8%	18.2%	22.0%
	Santa Clara	55.1%	10.9%	34.0%
	Total	55.2%	13.7%	31.1%
US-101 (NB+SB) Corridor	San Francisco	57.2%	5.8%	37.0%
	San Mateo	55.9%	16.1%	28.0%
	Santa Clara	51.5%	15.1%	33.4%
	Total	53.9%	14.0%	32.2%

Source: Caltrans PeMS (http://pems.dot.ca.gov/).

Figure 2-17: US-101, San Francisco to San Jose, Causes of Vehicular Delays



2.8 Travel-Time Reliability along the US-101 Corridor

Travel time reliability and traffic congestion are two distinct measures of mobility. Travel time reliability is a measure of day-to-day consistency or predictability of a corridor's travel time. The Buffer Index (BI) is one of the commonly used travel-time reliability metrics. FHWA describes the buffer index as representing the extra time (or time cushion) that travelers must add to their average travel time when planning trips to ensure an on-time arrival.

$$BI\ (\%) = 100\% * \frac{95th\ percentile\ travel\ time\ (minutes) - average\ travel\ time\ (minutes)}{average\ travel\ time\ (minutes)}$$

The mean (average) travel time the most commonly used statistical measure of central tendency. The 95th percentile travel time quantifies a reasonable upper bound for expected travel time along the corridor – expected travel times on a heavily congested day. A travel time Buffer Index of zero means that the 95th percentile travel time and the average travel time are the same; that is there is no variability in travel times between the average day and a heavily congested day. A BI of 50 means that the travel times on heavily congested day are 1.50 times greater than on an average day.

For the US-101 corridor, the annual average BI was estimated for each 15-minute period for the 24-hour workday (non-holiday weekday). The resulting buffer index metrics were plotted by time-of-day and are displayed in Figure 2-17 for the US-101 Northbound direction of travel, and in Figure 2-18 for the US-101 Southbound travel lanes.

The travel time reliability Buffer Index has actually improved over the past few years (2014 – 2016). At first glance this might seem to be a contradiction – travel time reliability improving while traffic congestion is getting worse. However, this is in fact commonly observed in heavily congested corridors and consistent with a more in depth understanding of traffic theory. Consider a freeway with no recurrent congestion, that is basically freely flowing at all times. On this freely flowing freeway, there are no bad days or no heavily congested days. Therefore, the measured travel times on an average day and the travel times on the 95^{th} percentile day are basically the same – and travel times are consistent and reliable. Now, consider a freeway that suffers heavy congestion every day (no days when congestion is not present). The associated congestion levels and delays will be extremely high. However, since the freeway is congested all the time, heavy congestion and long travel times are the norm. An average day is heavily congested and a bad day (i.e., the 95^{th} percentile day) is also heavily congested – there is little difference between an average day and a bad day as they are all bad. With this, the freeway's travel times are consistently bad; and the associated travel time buffer index looks reasonable. Therefore, travel time reliability metrics can actually improve as a freeway transitions from being only moderately congested to being heavily congested. This is not necessarily good news but it is consistent with freeway traffic behavior and traffic flow theory.

Additionally, the travel time buffer index was plotted in the time-space plane, producing a reliability mapping very similar to the congestion mapping seen a little earlier in this report. The reliability map and the congestion map are shown side-by-side in Figure 2-20 for the US-101 Northbound direction of travel; and in Figure 2-21 for the US-101 Southbound direction of travel.

The geographic sections and time periods of queuing identified by the yellow-orange-red contours on the right-hand-side generally correlate to the areas with reliability problems identified by the buffer index contour mappings on the figures in the left-hand-side. The overall finding is that the freeway's recurrent bottlenecks are one of the major causes of both the observed congestion problems and the freeway's reliability problems.

Figure 2-18: US-101 Northbound, Average Weekday Travel-Time Reliability (Buffer Index)

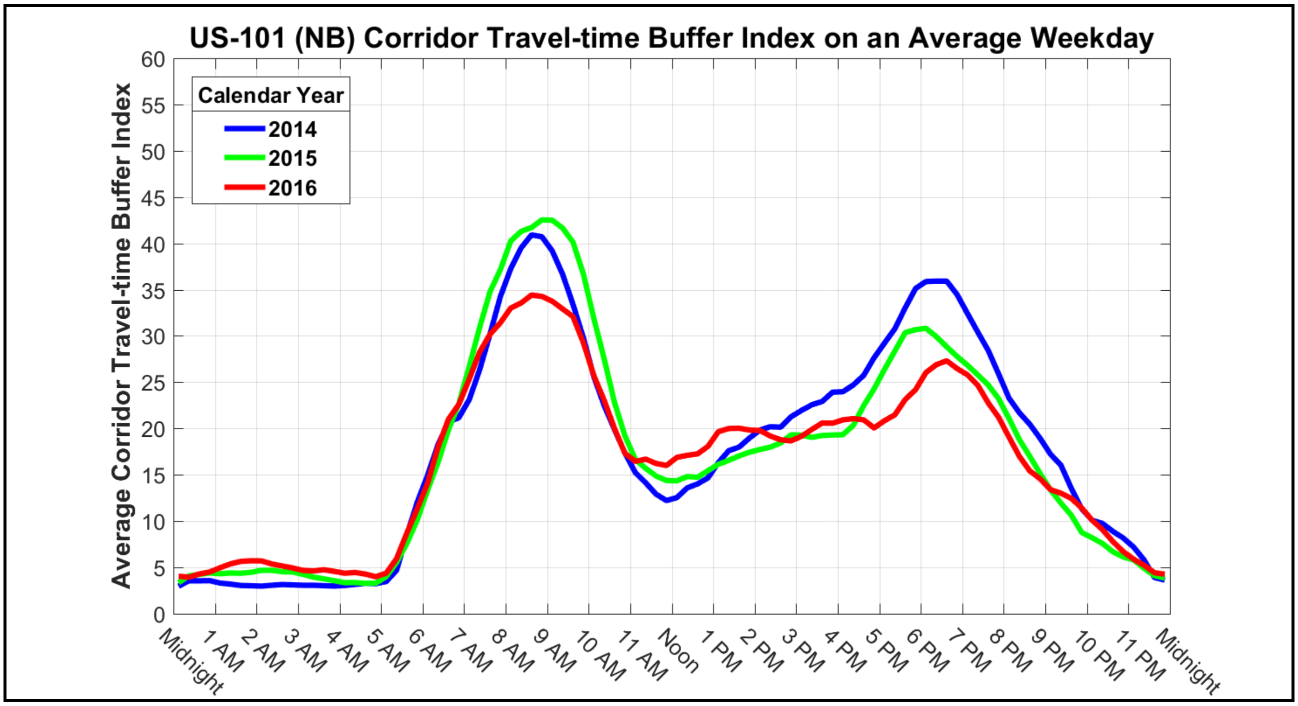


Figure 2-19: US-101 Southbound, Average Weekday Travel-Time Reliability (Buffer Index)

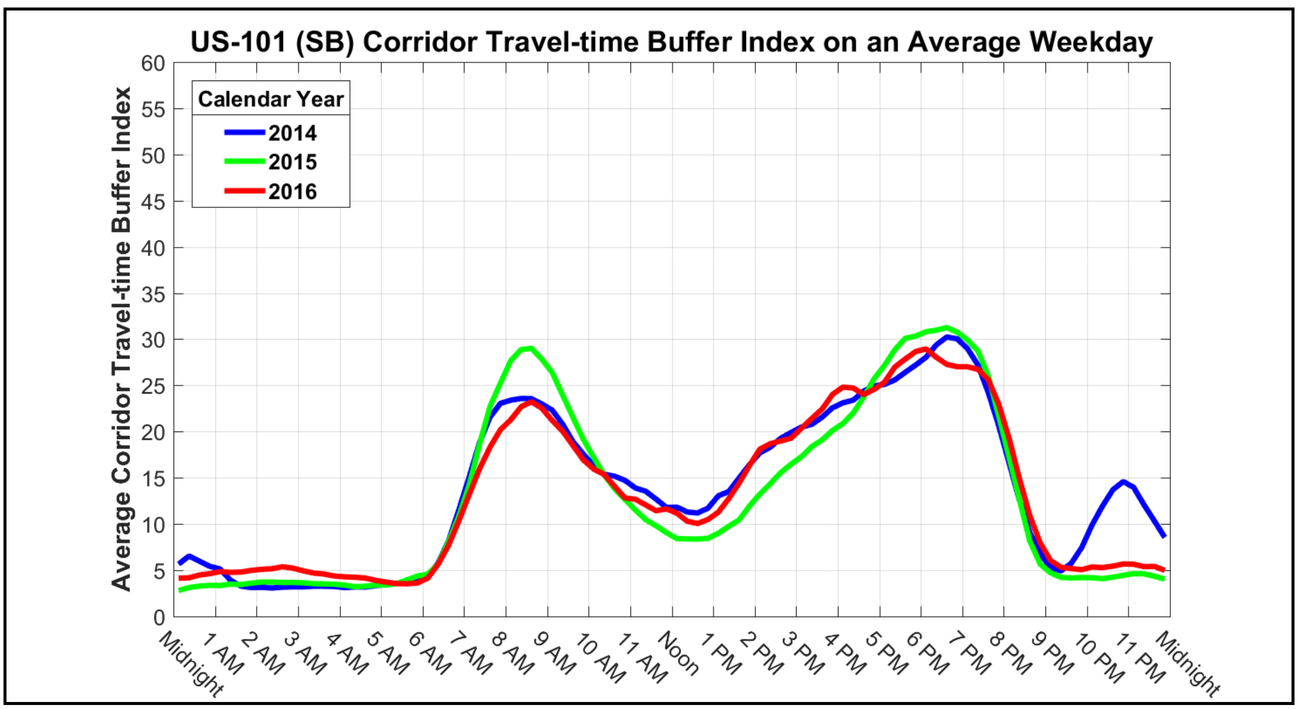


Figure 2-20: US-101 Northbound, Weekday Travel-Time Reliability and Average Traffic Speeds

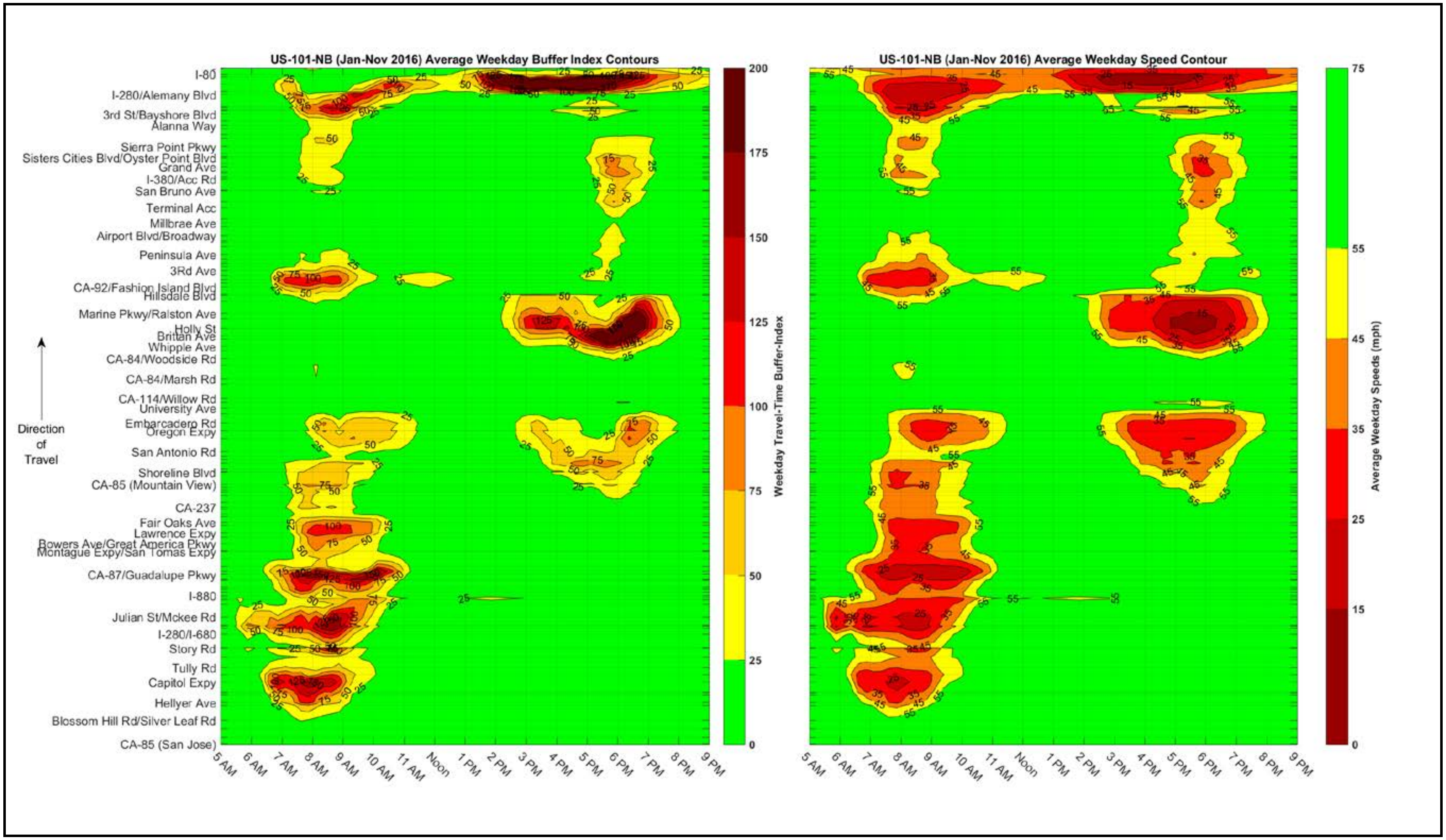
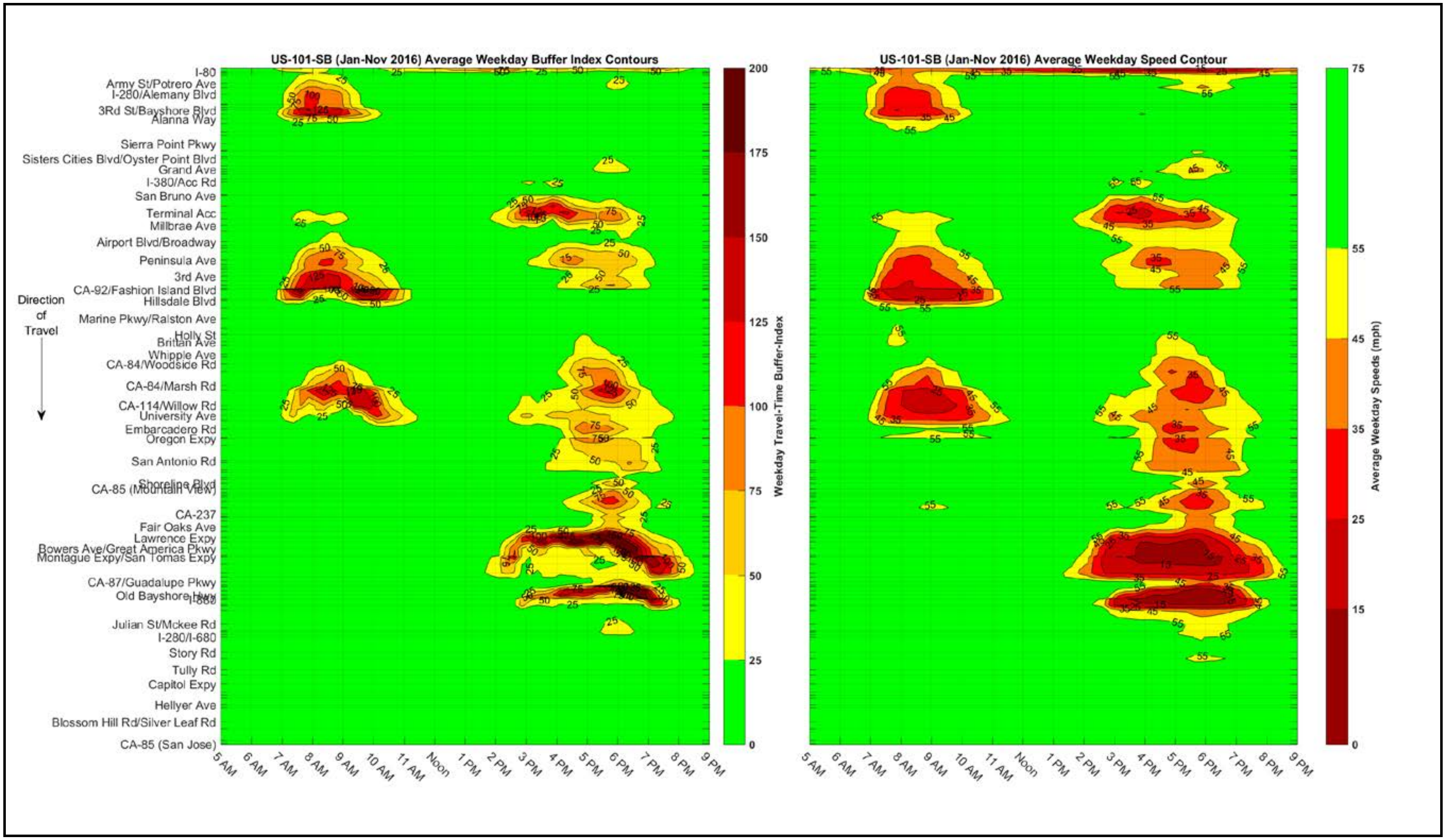


Figure 2-21: US-101 Southbound, Weekday Travel-Time Reliability and Average Traffic Speeds



CHAPTER 3: CRASH ANALYSIS

This section examines incident and/or crash frequencies and distributions on the corridor with respect to several factors, to obtain insight into the safety performance of the corridor. The specific types of analyses that have been conducted as part of this safety assessment are:

- Spatial Analysis
  - Incidents normalized by time
  - Incidents normalized by VMT
- Incident Rates and Relative Frequencies, by:
  - Day of the week
  - Time of day
  - Collision type
  - Collision severity
  - Causal factor

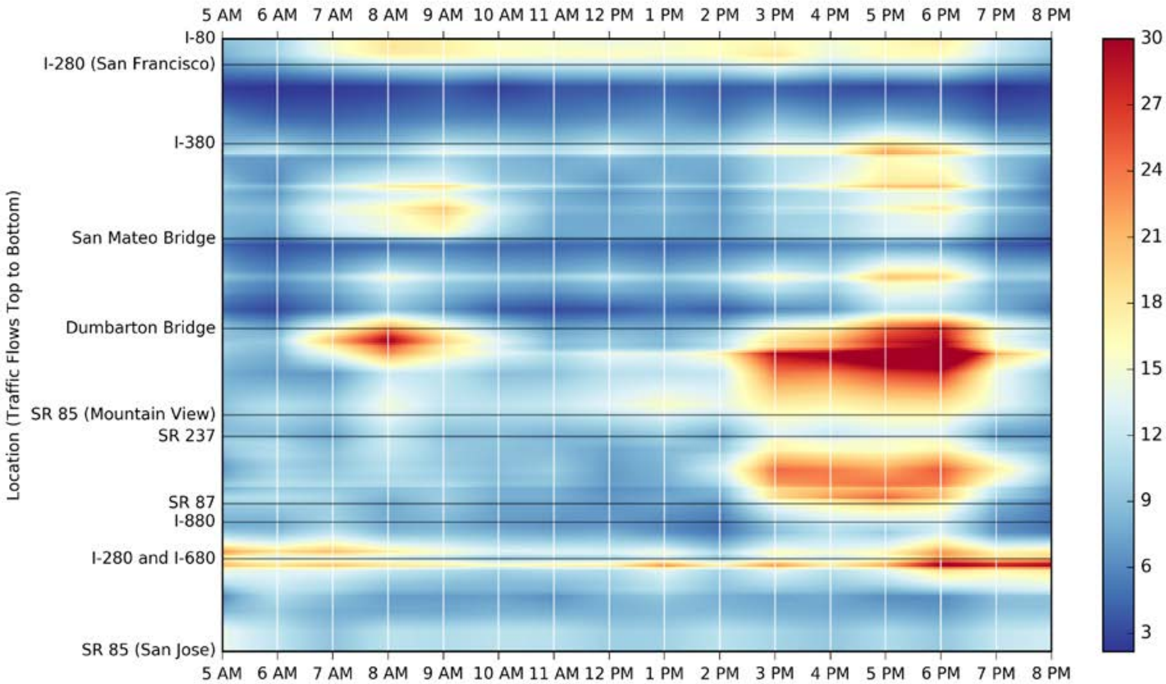
3.1 Spatial Analysis

This spatial analysis uses PeMS data to examine the spatial and temporal patterns in incident occurrence on the corridor, normalized by either volume (Figure 3-1 and Figure 3-3) or by time (Figure 3-2 and Figure 3-4). Both types of normalization have different purposes and applications. Normalizing by volume allows for a more accurate evaluation of incident risk to users on the corridor, as it shows the relative frequency of incidents for a constant number of vehicles. Alternatively, calculating incident rates per year provides insight into which segments experience the greatest number of incidents in a given amount of time, and can be used to evaluate where safety investments may be most justified based on a cost/benefit approach by enabling a quick estimation of where crashes are most likely to occur at any given time.

As shown in Figure 3-1 through Figure 3-4, clear increases in incident occurrence are observed across all locations along the corridor during the AM and PM peak periods. Note that the color scales on Figure 3-2 and Figure 3-4 are not the same, such that direct comparisons between the two must be done with caution. Instead, the color scales have been selected to make differences within each figure easier to appreciate, thereby providing the viewer with a clear presentation of crash concentrations on the corridor in time and space. If direct comparisons between the two directions of travel are desired, Figure 3-1 and Figure 3-3 may be used as they both have the same color scales.

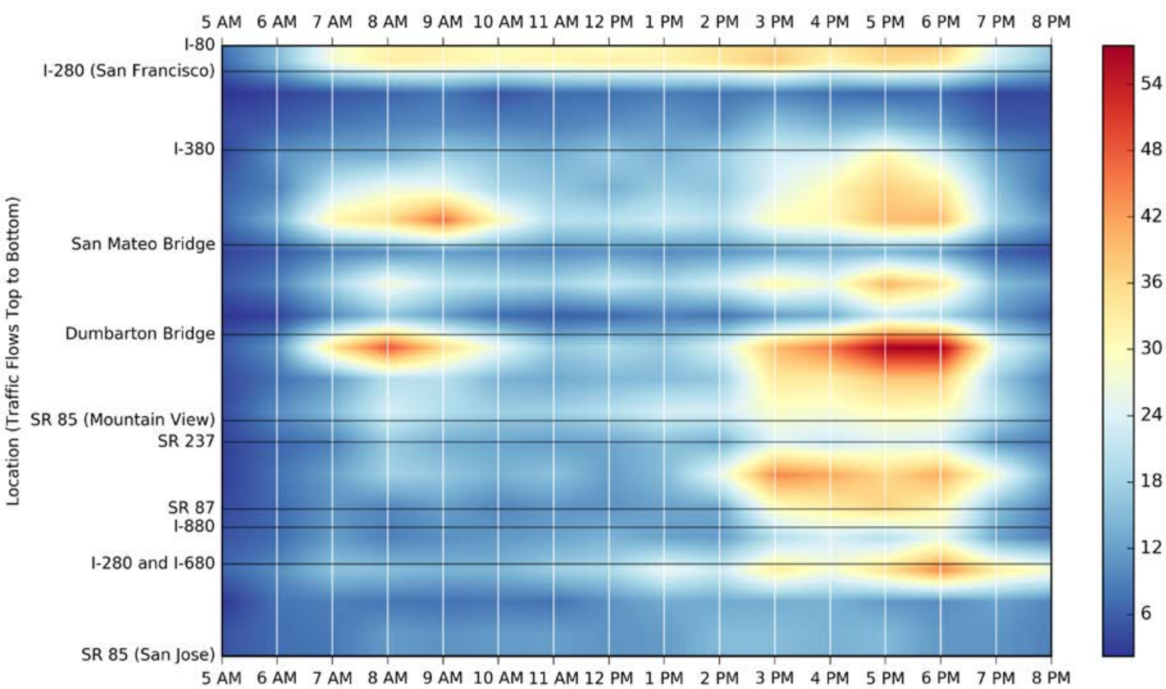
For the southbound direction of US 101 (Figure 3-1 and Figure 3-2), the greatest concentration of incidents occur in the PM Peak in the vicinity of the Dumbarton Bridge, with a less severe concentration observed between SR 237 and SR 87. Both of these areas of increased incident occurrence correspond to times and locations of frequent and severe recurrent congestion, suggesting that presence of active bottlenecks on these segments may be having a negative influence on the measured crash frequencies.

Figure 3-1: Hourly Incident Rates per Million Vehicles by Location and Time, Southbound



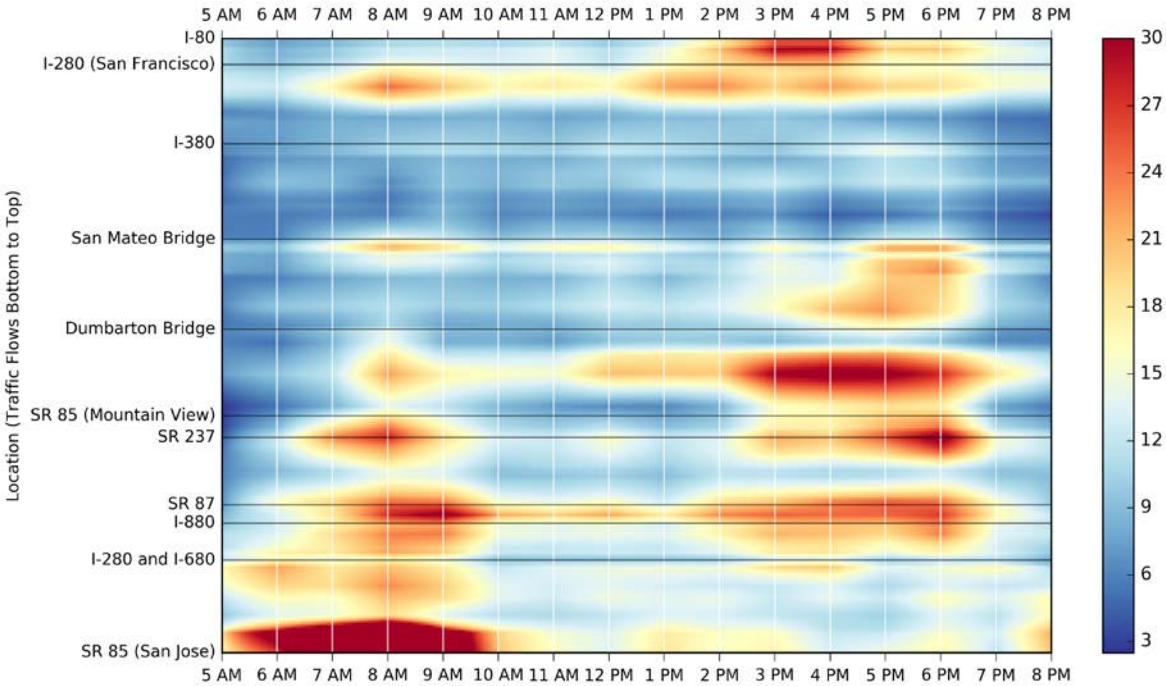
Source: Cambridge Systematics, using PeMS data, January 2010 through November 2016

Figure 3-2: Hourly Incident Rates per Year by Location and Time, Southbound



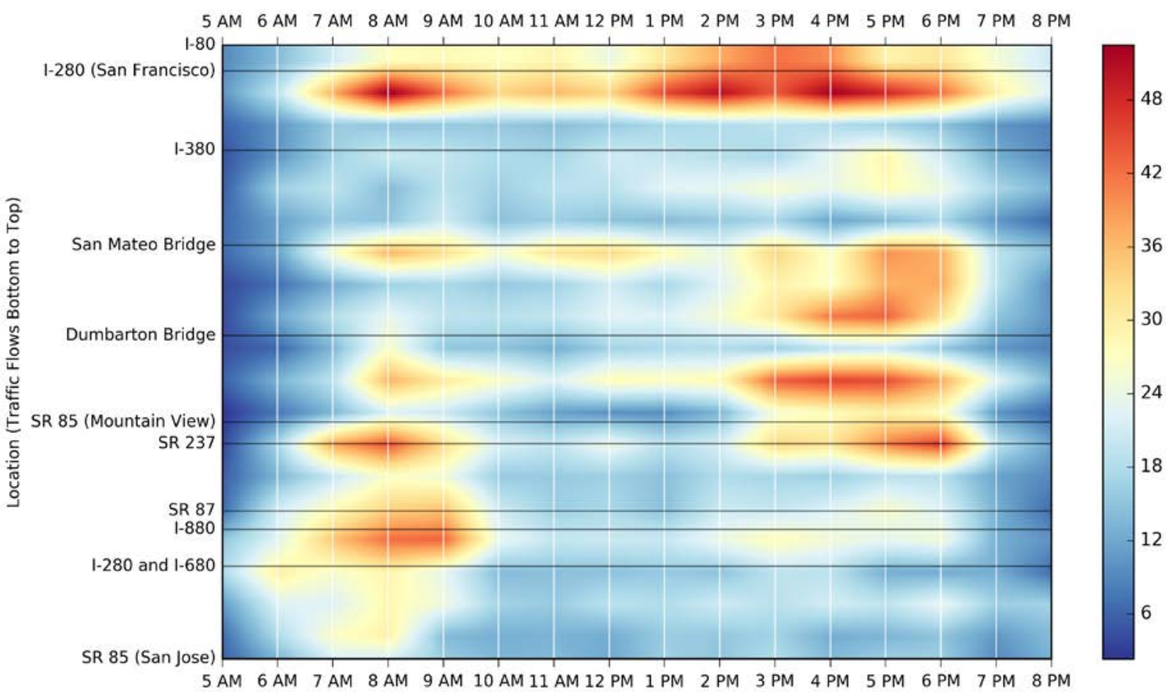
Source: Cambridge Systematics, using PeMS data, January 2010 through November 2016

Figure 3-3: Hourly Incident Rates per Million Vehicles by Location and Time, Northbound



Source: Cambridge Systematics, using PeMS data, January 2010 through November 2016

Figure 3-4: Hourly Incident Rates per Year by Location and Time, Northbound



Source: Cambridge Systematics, using PeMS data, January 2010 through November 2016

For the northbound direction of US 101 (Figure 3-3 and Figure 3-4), similar correlations are observed between locations and times of recurrent congestion and elevated incident rates. Specifically, there are high concentrations of incidents approaching the Dumbarton Bridge and the San Mateo Bridge in the PM Peak, and approaching SR 237 in the AM Peak. A notable difference between the two figures is observable near SR 85 in San Jose during the AM Peak, where the incident rates by million vehicles are relatively high. This can be attributed to the relatively low volumes measured near the SR 85 interchange, compared to sections farther downstream.

3.2 Collision Rates and Relative Frequencies

Using detailed collision record data from SWITRS between January 2013 and June 2015, deeper insights into the causes and conditions of the collisions on the corridor may be obtained. For these data, freeway direction is not directly reported for each collision, but can be inferred by cross-referencing the collision and vehicle datasets, as directions of travel are provided for each vehicle involved.

As Figure 3-5 shows, collisions show the same general peaking trends as traffic volumes and travel times on the corridor, again implying a causal relationship between the two. Furthermore, the largest peak is observed to occur during the PM Peak at approximately 5-7 PM, with a less pronounced AM Peak at approximately 8-9 AM. An examination of the data by analysis segment reveals that this same temporal pattern holds for most of the segments except for northbound US 101 between SR 85 in San Jose and SR 85 in Mountain View, where the largest peak of the day occurs during 8-9 AM. This is reasonable given that congestion on this portion of the corridor is typically most severe during the AM Peak rather than the PM Peak. Additional data regarding time-of-day collision peaks is provided in the appendix.

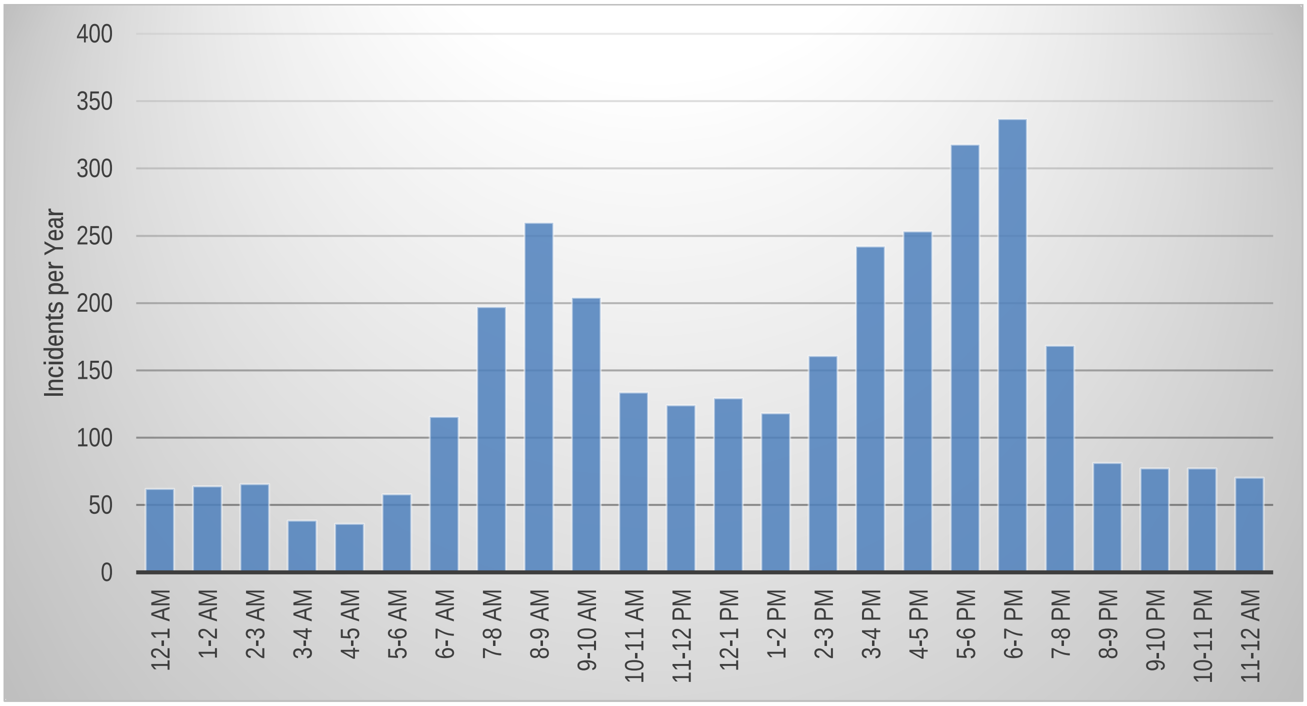
Figure 3-6 provides insight into both the distribution of collisions on the corridor by day of the week, and also how this distribution compares to the rest of the Bay Area.[2] As expected, the largest collision frequencies occur on mid-week business days, with substantially lower volumes on Saturday and the lowest volumes on Sunday. While the same trend holds for both the US 101 corridor and the Bay Area as a whole, the reduction in collisions on weekends is less pronounced for the overall Bay Area, which may suggest that commuters constitute a higher proportion of traffic on US 101 than most other roadways in the Bay Area.

With respect to weather, 85% of collsions on this corridor occur during clear conditions, while 13% occur during cloudy conditions and 2% occur during rainy conditions.

Considering the types of collisions occurring on the US 101 corridor, Figure 3-7 shows that a significant majority are rear-end type collisions, which is reasonable given that these may be expected at the upstream ends of queued traffic, and that the corridor experiences several distinct areas of recurring congestion and queuing on a regular basis. Sideswipe collisions are also common on this corridor according to Figure 3-7, which is also as expected given that these types of collisions can occur as drivers attempt to merge or change lanes. The same patterns in collision rates by collision type are also observed for each individual analysis segment.

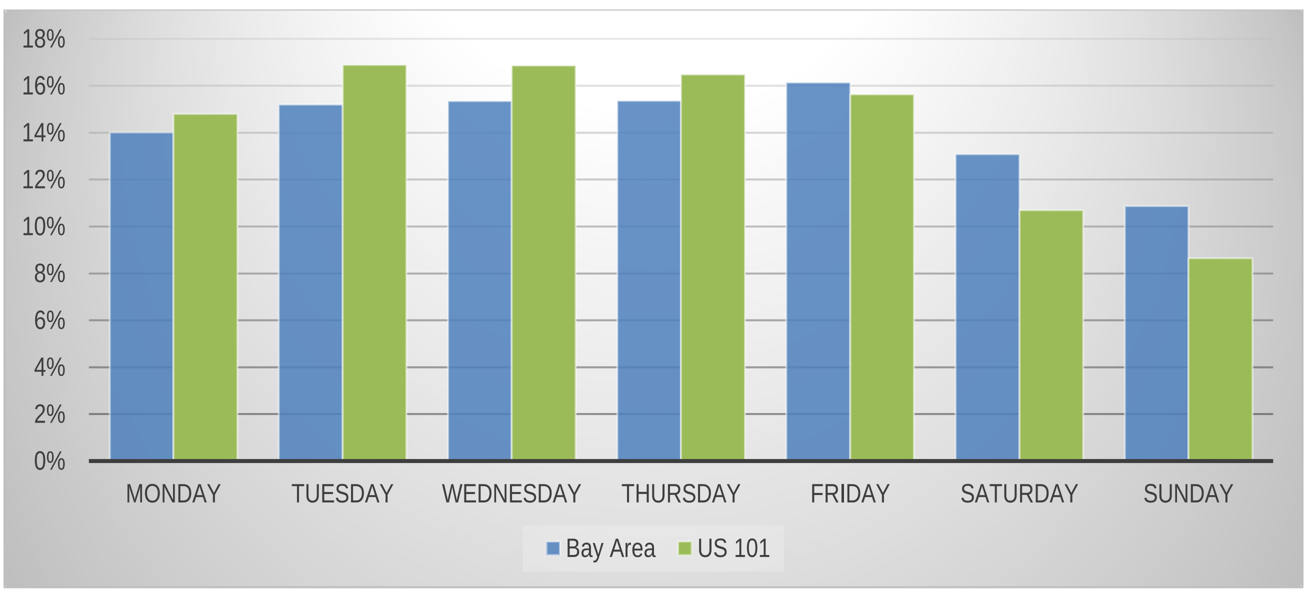
[2] It is for this latter purpose that a bar chart is used in this case, rather than a pie chart.

Figure 3-5: Annual Collision Rates by Time of Day for the Full US 101 Corridor



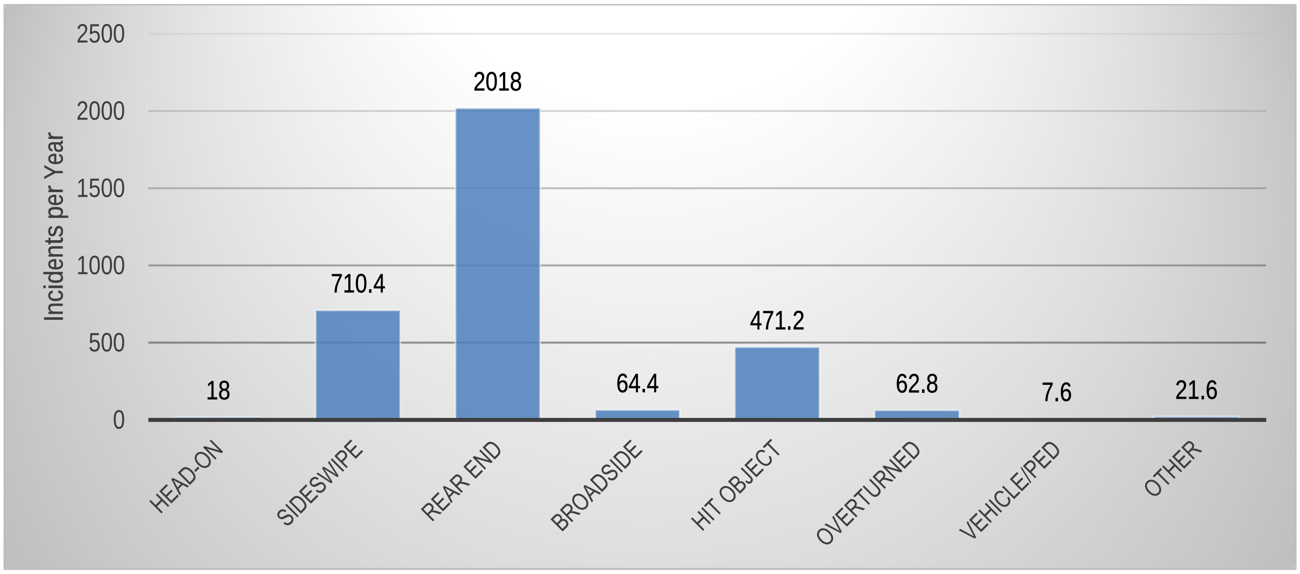
Source: Cambridge Systematics, using SWITRS Data for 2013-2015

Figure 3-6: Relative Collsion Frequency by Day of Week, for the Full US 101 Corridor and the Bay Area



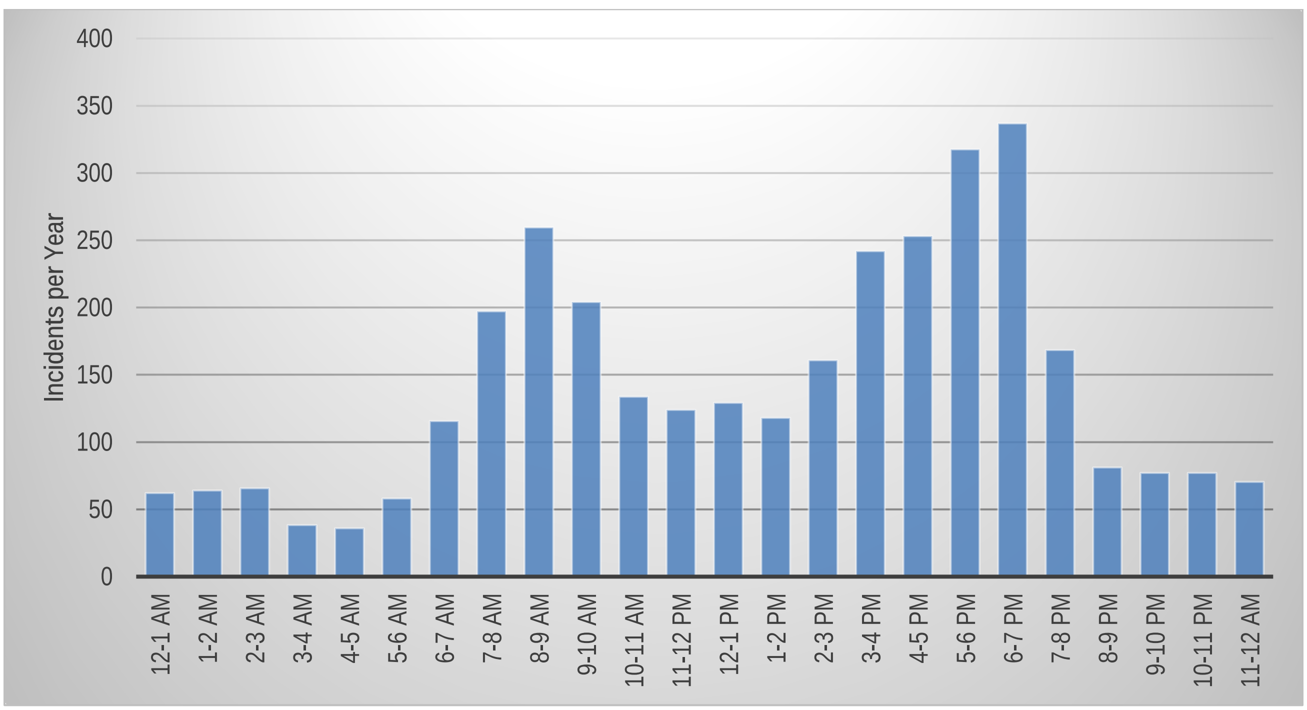
Source: Cambridge Systematics, using SWITRS Data for 2013-2015.

Figure 3-7: Annual Collision Rates by Collision Type for the Full US 101 Corridor



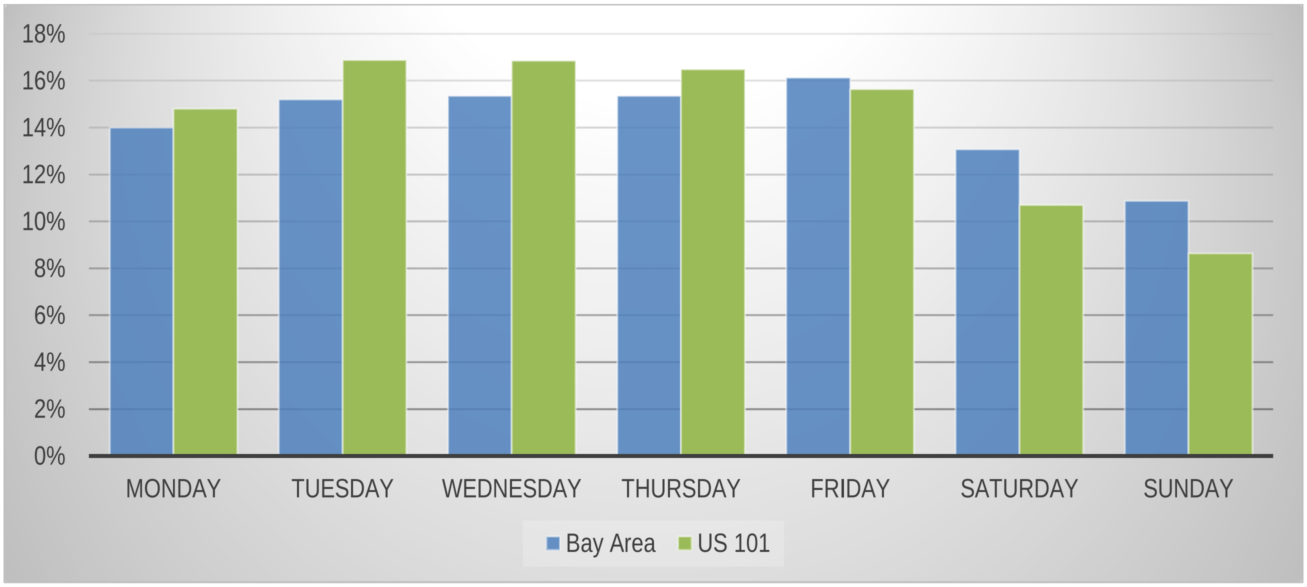
Source: Cambridge Systematics, using SWITRS Data for 2013-2015.

Figure 3-8 provides insight into the factors that contributed to the occurrence of each collision on the corridor, with unsafe speed being the leading cause by a wide margin. This aligns well with the observation in Figure 3-5: Annual Collision Rates by Time of Day for the Full US 101 Corridor



Source: Cambridge Systematics, using SWITRS Data for 2013-2015

Figure 3-6: Relative Collision Frequency by Day of Week, for the Full US 101 Corridor and the Bay Area

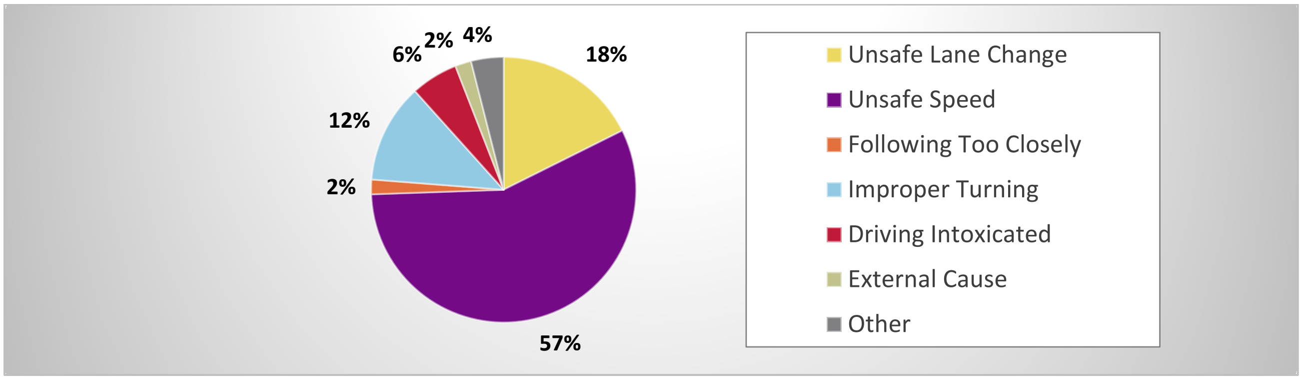


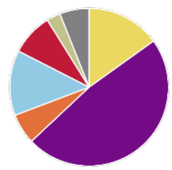
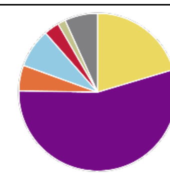
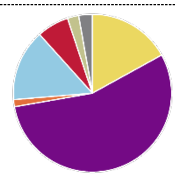
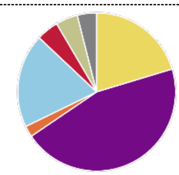
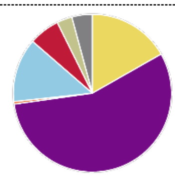
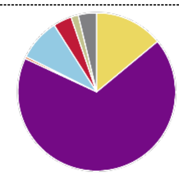
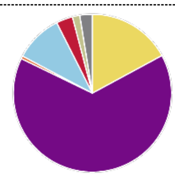
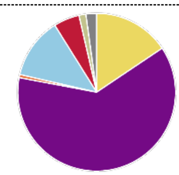
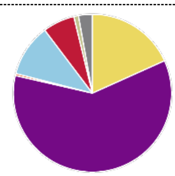
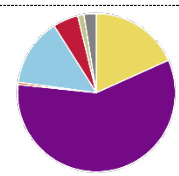
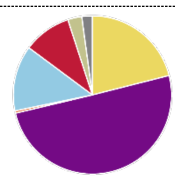
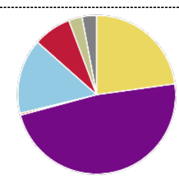
Source: Cambridge Systematics, using SWITRS Data for 2013-2015.

Figure 3-7 that most collisions on this corridor are of the rear-end type, while the second-most common causal factor in Figure 3-8 (i.e., unsafe lane change) aligns with the elevated rate of sideswipe collisions on the corridor as well. Figure 3-8 also provides results by segment, although in each case the same three leading factors are observed, and in the same ranking.

Collisions on this corridor occur at an average rate of 30.0 per mile per year. Of these, approximately 71% are property damage only, 21% include one or more complaints of pain, 7% include visible injuries, and 1% include major injuries or deaths. This same general pattern holds for all individual analysis segments as well, with slightly higher proportions of injury collisions occurring on the northern segments. A detailed data table with collision rates by severity and by segment is provided in the appendix.

Figure 3-8: Primary Collision Factors for Collisions for Full Corridor and by Segment



Southbound Segments	Causal Factors	Northbound Segments	Causal Factors
I-80 to I-380 1. Unsafe Speed (48%) 2. Unsafe Lane Change (15%) 3. Improper Turning (13%)		**I-380 to I-80** 1. Unsafe Speed (55%) 2. Unsafe Lane Change (20%) 3. Improper Turning (8%)	
I-380 to Marine Pkwy 1. Unsafe Speed (55%) 2. Unsafe Lane Change (17%) 3. Improper Turning (15%)		**3rd Av to I-380** 1. Unsafe Speed (45%) 2. Unsafe Lane Change (20%) 3. Improper Turning (19%)	
Marine Pkwy to SR 84 1. Unsafe Speed (56%) 2. Unsafe Lane Change (17%) 3. Improper Turning (13%)		**SR 84 to 3rd Av** 1. Unsafe Speed (68%) 2. Unsafe Lane Change (14%) 3. Improper Turning (9%)	
SR 84 to SR 85 (Mountain View) 1. Unsafe Speed (65%) 2. Unsafe Lane Change (17%) 3. Improper Turning (10%)		**SR 85 (Mountain View) to SR 84** 1. Unsafe Speed (62%) 2. Unsafe Lane Change (16%) 3. Improper Turning (13%)	
SR 85 (Mountain View) to I-680 1. Unsafe Speed (60%) 2. Unsafe Lane Change (18%) 3. Improper Turning (11%)		**I-680 to SR 85 (Mountain View)** 1. Unsafe Speed (58%) 2. Unsafe Lane Change (18%) 3. Improper Turning (14%)	
I-680 to SR 85 (San Jose) 1. Unsafe Speed (50%) 2. Unsafe Lane Change (21%) 3. Improper Turning (13%)		**SR 85 (San Jose) to I-680** 1. Unsafe Speed (48%) 2. Unsafe Lane Change (23%) 3. Improper Turning (15%)	

Source: Cambridge Systematics, using SWITRS 2013-2015 Data.

CHAPTER 4: CRASH CONCENTRATION DIAGNOSES AND VALIDATION

This chapter covers a diagnosis of the causal factors associated with the collision patterns and concentrations observed on the corridor using the following data sources and methods:

- **Detailed crash data spatial analysis:** A comprehensive, detailed spatial analysis of crash locations on the corridor was conducted using SWITRS data, to identify specific areas with high crash concentrations.
- **Detailed data investigations:** For locations with significant concentrations of crashes on the corridor, SWITRS data have been analyzed to inform potential causes and contributing factors for the collision concentrations with respect to trends in:
  - Time of day
  - Collision type
  - Primary collision factor
  - Violation type for the at-fault driver
  - Most recent action taken by the driver before the crash

This candidate set of causal factors for each of the significant crash concentration locations on the corridor was then validated using independent methods and data sources including the following:

- **Review of detailed PeMS CHP collision logs** to identify any additional relevant information reported to CHP regarding the crash.
- **Review of historical satellite imagery** through Google Earth and other sources to identify potential sources of high-risk traffic conditions, such as lateral queue spreading, high speed differentials between adjacent lanes, and locations with elevated lane change rates.

The remainder of this chapter is organized into the following sections:

1. Locations of crash concentrations on the corridor
2. Preliminary causal factors contributing to each area with elevated crash frequency
3. Independent validation of causal factors
4. Ranking of crash concentration locations by frequency and validated causal factors

4.1 Crash Concentrations on the Corridor

Using geocoded SWITRS data for 2013-2015 by direction for US 101, collision rates have been evaluated for all locations along the corridor between I-80 in San Francisco and SR 85 in San Jose. SWITRS datasets specify precise locations for each record (i.e., collision) using a combination of three fields: the nearest major junction, the direction from the junction to the actual collision scene (i.e., north or south of the junction), and the distance (in feet) from the junction to the specific collision location. However, although this method allows field officers to specify a collision location with high precision, the accuracy of the reported locations may vary according to how well the officer estimated the distance between the nearest junction and the collision scene. Therefore, when evaluating the relative collision rates at each location along the corridor in increments of 1/10 of a mile, a tolerance range of 0.5 miles was used in either direction to account for potential inaccuracy regarding the location data for each collision. The results of this location-based collision rate analysis are shown in Figure 4-1 and Figure 4-2, with blue annotations indicating relative rankings of each peak or “hotspot” location in decreasing order. Only those locations with an average rate of at least 40 collisions per year were selected for further examination in this chapter. Table 4-1 provides additional detail about each of these locations with high collision concentrations.

Figure 4-1. Number of Collisions Recorded for Each Location along US 101 South, for 2013-2015

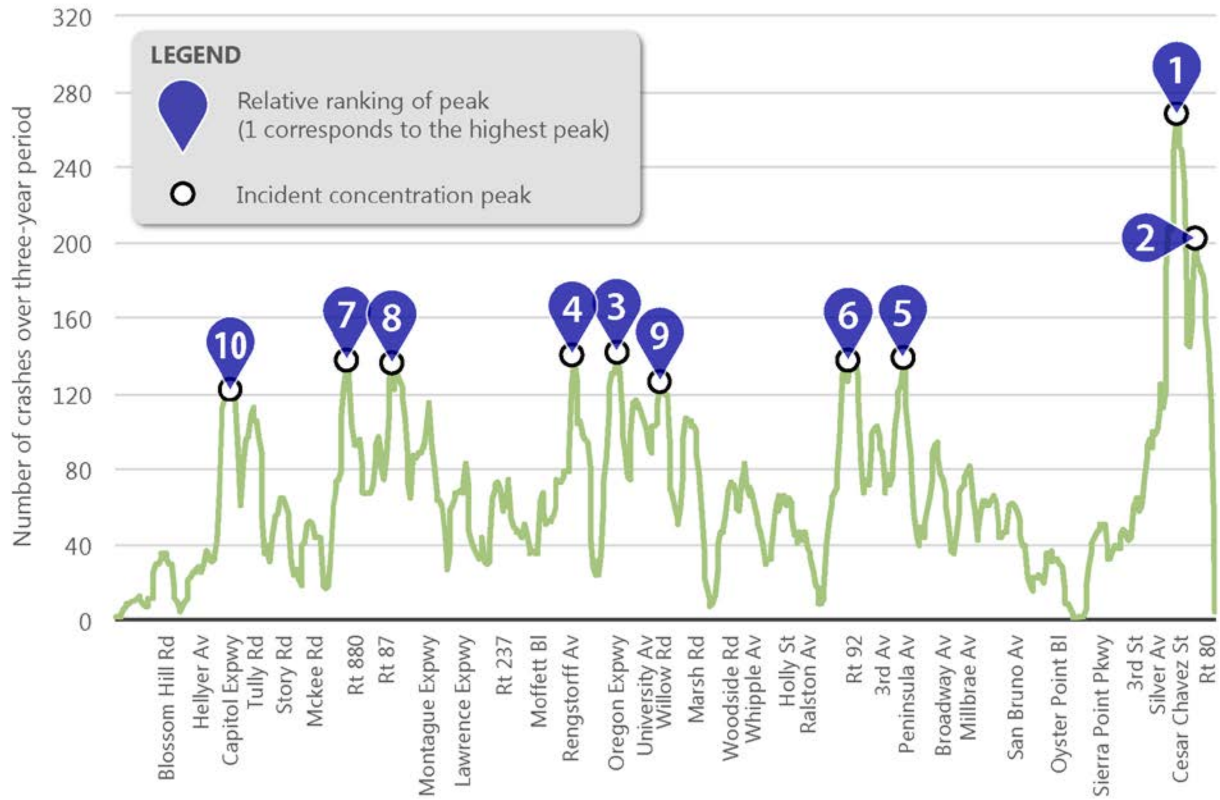


Figure 4-2. Number of Collisions Recorded for Each Location along US 101 North, for 2013-2015

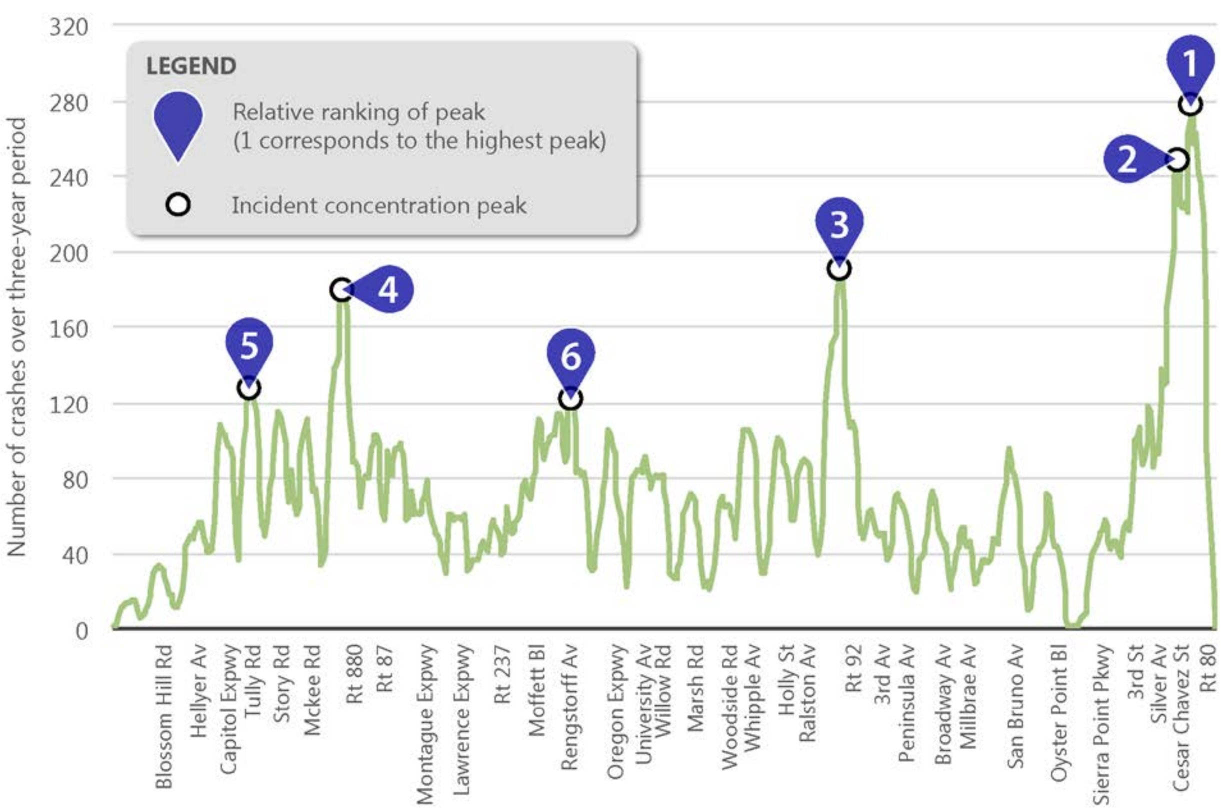


Table 4-1. Locations with Collisions Exceeding 40 per Year

SOUTHBOUND

Rank	Milepost	Approximate Location	Collisions (2013-2015)
1	431.3	North of I-280	267
2	432.3	Potrero Hill	201
3	401.9	Oregon Expy	141
4	399.6	San Antonio Rd	139
5	417	Poplar Av	138
6	414.1	Past SR 92	137
7	387.7	Past I-880	137
8	390	SR 87 Split	136
9	404.2	Willow Rd	126
10	381.5	Capitol Expwy	121

NORTHBOUND

Rank	Milepost	Approximate Location	Collisions (2013-2015)
1	432.1	Potrero Hill	277
2	431.3	Cesar Chavez St	248
3	413.7	SR 92 Exit	190
4	387.5	I-880	179
5	382.7	Tully Rd	127
6	399.6	San Antonio Rd	122

To provide additional context for each of these hotspot locations, Figure 4-3 and Figure 4-4 show each of them superimposed on speed contour plots that indicate the typical congestion patterns across the corridor by time of day and direction. Each hotspot is drawn to indicate not only its physical location on the corridor, but also the approximate time of day during which the collision rate is elevated. Specifically, the time periods shown reflect the times of day for which the relative distribution of collisions at a given location were higher than the corridor average. Supporting charts are provided in the appendix (see charts of "Collision Frequency by Time of Day" for each location). The following categorical times of day were used in Figure 4-3 and Figure 4-4: AM Peak (5–10 AM), Midday (10 AM – 3 PM), PM Peak (3–8 PM), and Night (8 PM – 5 AM).

Figure 4-3. Relationship between Congestion Patterns and Collision Hotspots for US 101 South

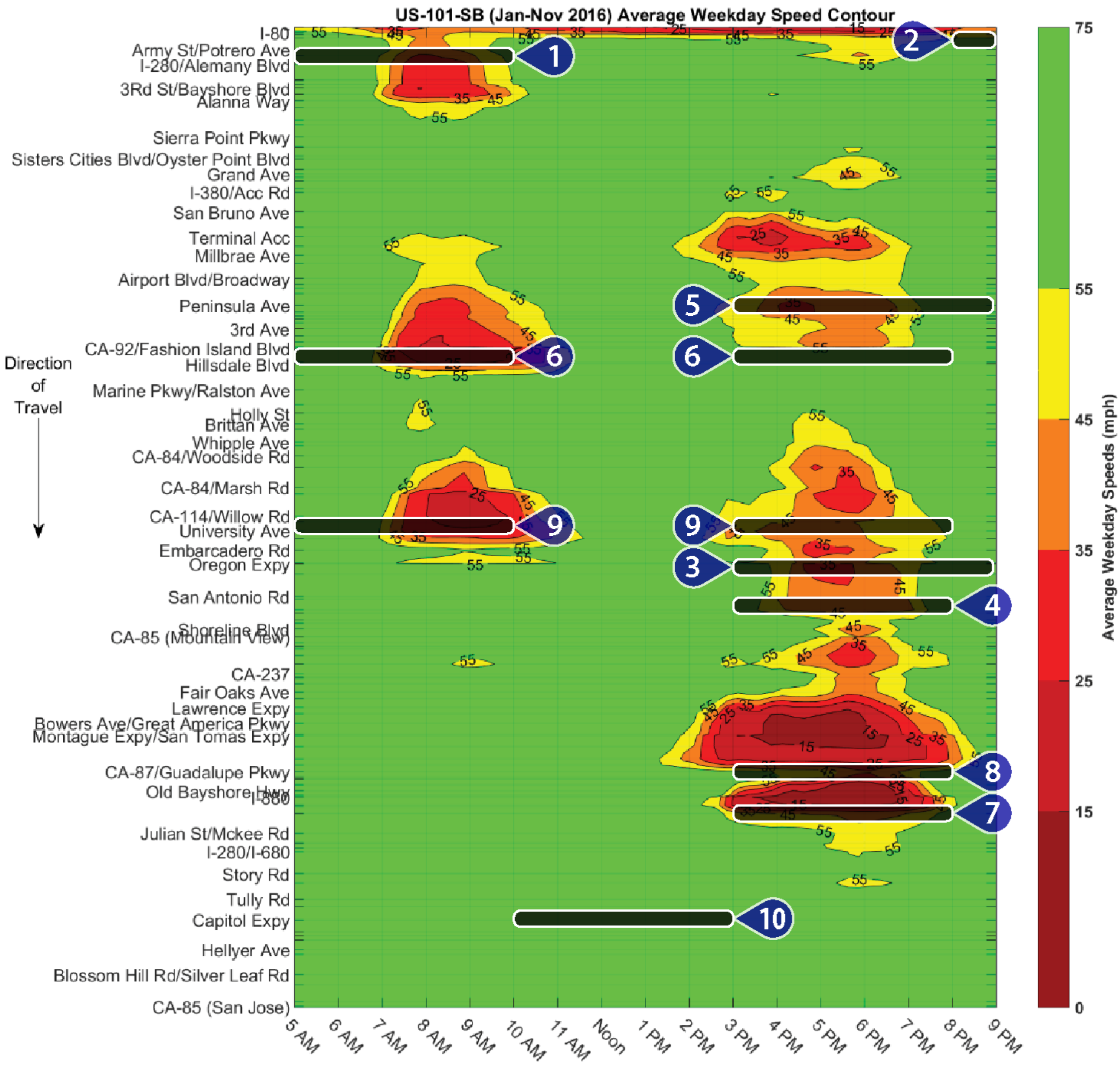
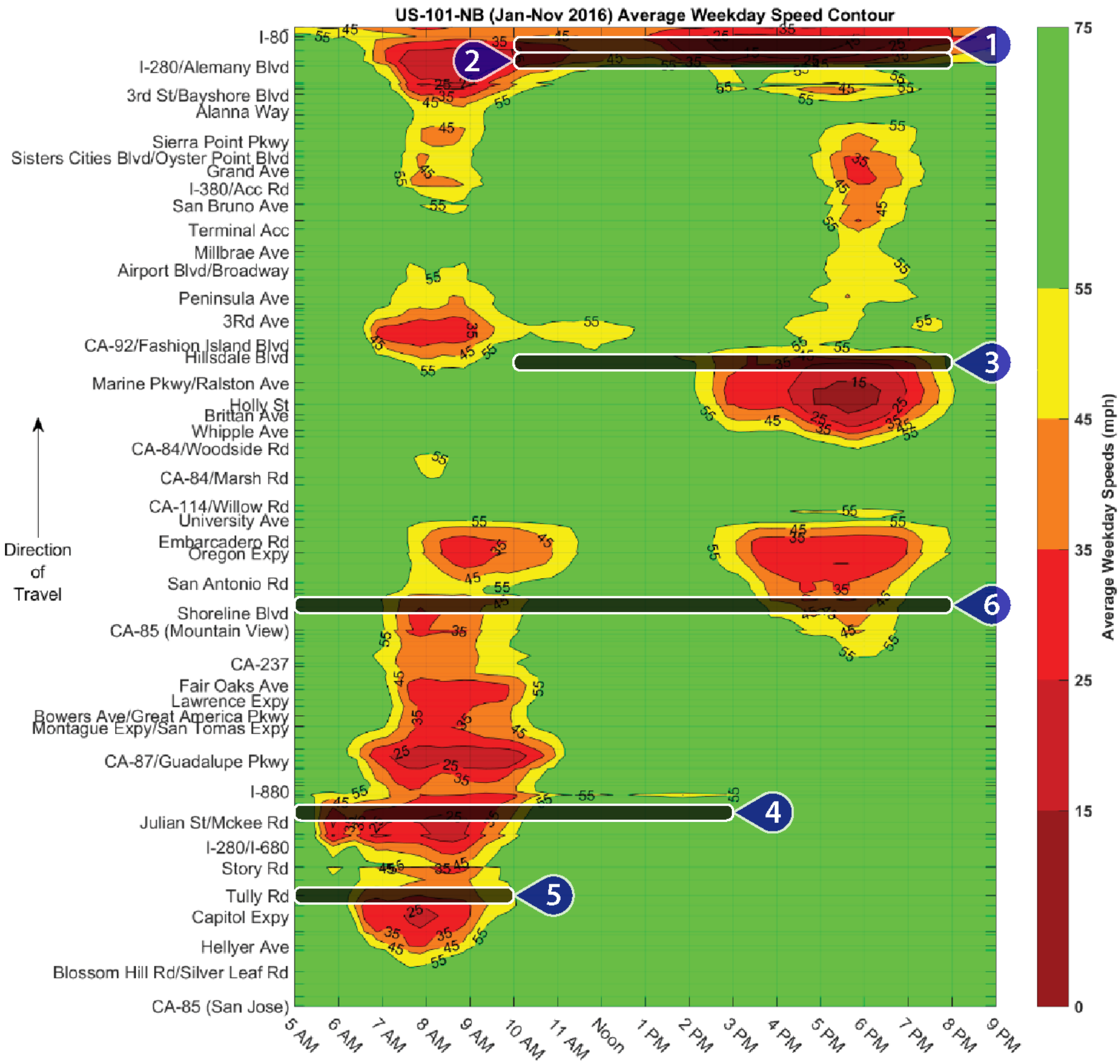


Figure 4-4. Relationship between Congestion Patterns and Collision Hotspots for US 101 North



4.2 Preliminary Causal Factors Associated with Crash Concentrations

For each of the locations shown in Table 4-1, additional information was extracted from the raw SWITRS data to investigate the potential causes contributing to the relatively high collision rates at each location. This included consideration of the following distributions for all collisions occurring at a given location:

- Time of day
- Type of collision
- Primary collision factor
- Traffic violation of the at-fault driver
- Any secondary contributing factors identified
- The at-fault driver's maneuver immediately prior to collision

These data for each location were then combined with considerations of roadway geometry and configuration in the vicinity of each hotspot, along with the typical congestion patterns for that section of roadway (i.e., Figure 4-3 and Figure 4-4), to more precisely evaluate the potential causes of elevated collision rates in each case. The results of these investigations are presented in the following subsections separately for each hotspot, with additional supporting data for each location provided in the appendix. Specifically, each of the following subsections includes a summary of the following:

- General roadway geometry and lane configuration details, presented in the form of a diagram.
- **Prevailing Congestion Patterns:** An interpretation of the recurrent congestion patterns for the location and times of day with elevated collision rates (see Figure 4-3 and Figure 4-4).
- **Ramp Occurrence:** The percent of collisions occurring on ramps rather than the freeway mainline (the average for the corridor is 13%), and a qualitative label indicating whether this is significantly higher, significantly lower, or not significantly different from the average.

The discussions for each hotspot also include consideration of the following factors if they met these criteria: (1) were significantly higher than the corridor average at a 95% significance level; (2) accounted for more than 10% of all collisions at the hotspot location; and (3) were among the top four factors in that category at the given location.

4.2.1 Southbound Hotspot 1: North of I-280

As shown in Figure 4-5 and Table 4-2, potential contributing factors to the collision rates observed at this location include following too closely, resulting in an increased frequency of rear-end collisions at the back of the recurrent congestion queue on the descent away from Potrero Hill (i.e., approaching Potrero Ave).

Figure 4-5. Roadway Configuration in the Vicinity of Southbound Hotspot #1

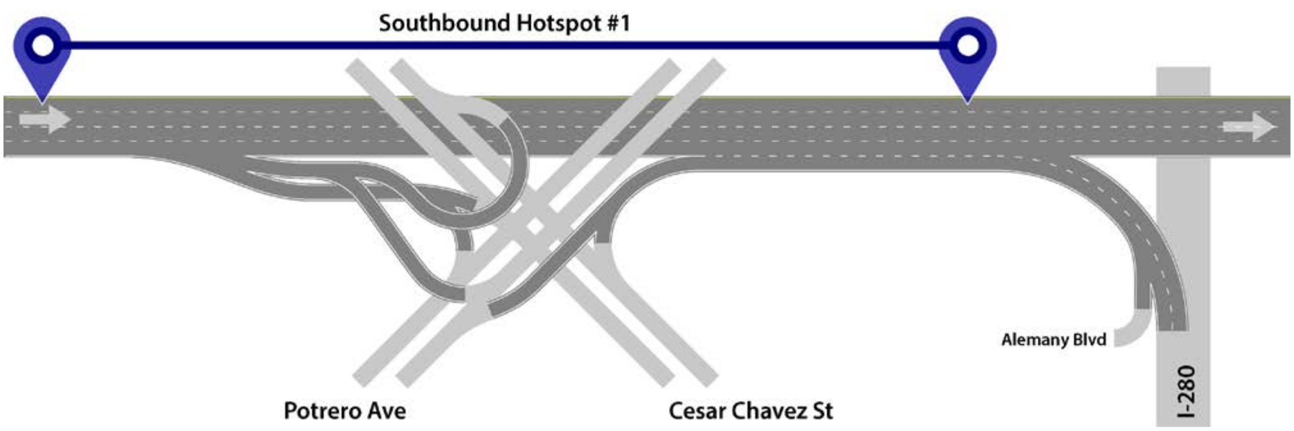


Table 4-2. Summary of Significant Crash Factors and Contextual Information for Southbound Hotspot #1

Factors	Significance
Prevailing Congestion Patterns	Back of queue: upstream end of slow traffic region
Ramp Occurrence	Significantly lower than average (7%)
Significant Collision Types	Rear-end
Significant PCFs or Violations	Following too closely
Secondary Contributing Factors	N/A
Movements Prior to Collisions	Proceeding straight

4.2.2 Southbound Hotspot 2: Potrero Hill

As shown in Figure 4-6 and Table 4-3, the only unusual factors about this segment of roadway for the periods of elevated collision frequency are the grade and curve at Potrero Hill, which are more challenging to negotiate than other segments of roadway that are straight and flat, and may explain the increased occurrence of collisions particular with respect to inhibited drivers or drivers unable to maneuver safely away from unexpected road hazards. Excessive speed and congestion were not found to be sources of elevated crash risk or frequency here.

Figure 4-6. Roadway Configuration in the Vicinity of Southbound Hotspot #2

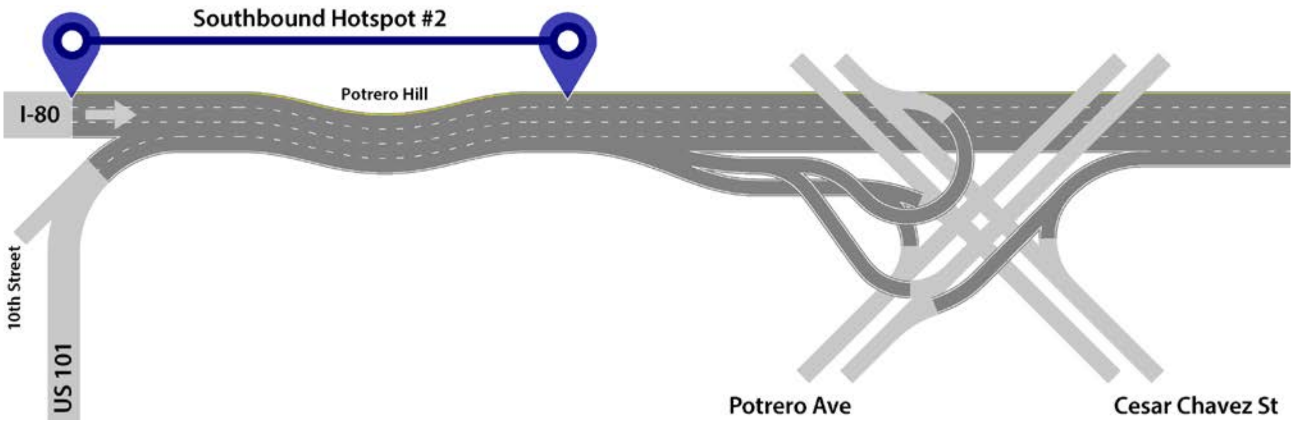


Table 4-3. Summary of Significant Crash Factors and Contextual Information for Southbound Hotspot #2

Factors	Significance
Prevailing Congestion Patterns	No significant congestion
Ramp Occurrence	Significantly lower than average (7%)
Significant Collision Types	Hit object
Significant PCFs or Violations	Driving under the influence
Secondary Contributing Factors	Traffic violation (see above)
Movements Prior to Collisions	Ran off road

4.2.3 Southbound Hotspot 3: Oregon Expwy

As shown in Figure 4-7 and Table 4-4, a leading cause of elevated crash occurrence at this location is higher-than-normal ramp collision rates. Given that this occurs during congested periods, traffic may be attempting to use the ramps to bypass mainline congestion, and this mixing of higher-speed through traffic with slower-speed exiting and merging traffic may create inherently risky environments that, when combined with the complex interchange design, may result in higher crash rates than average.

Figure 4-7. Roadway Configuration in the Vicinity of Southbound Hotspot #3

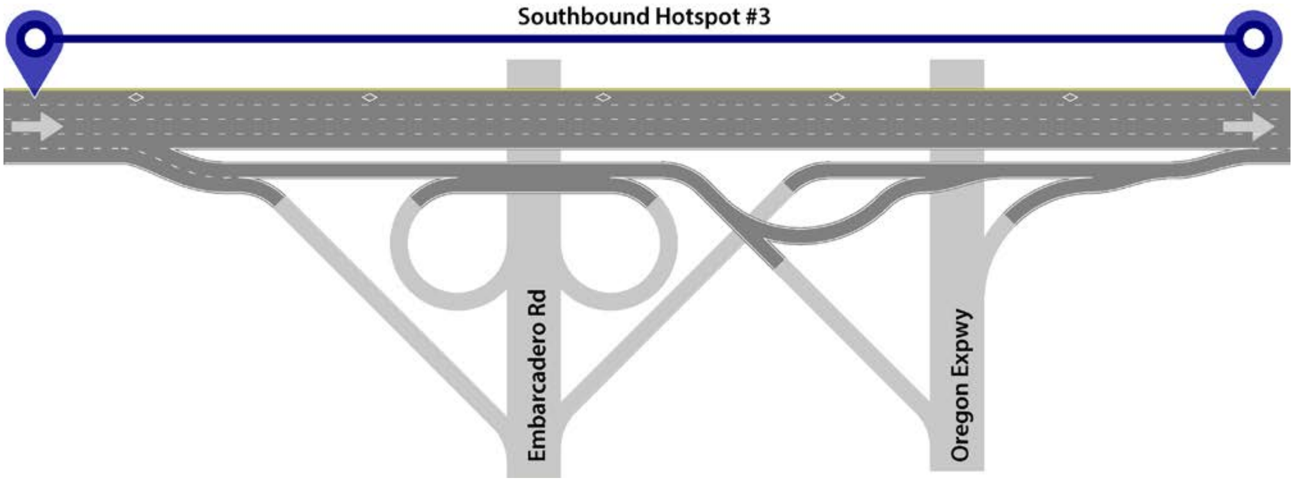


Table 4-4. Summary of Significant Crash Factors and Contextual Information for Southbound Hotspot #3

Factors	Significance
Prevailing Congestion Patterns	Mid-queue: Middle of slow traffic region
Ramp Occurrence	Significantly higher than average (28%)
Significant Collision Types	N/A
Significant PCFs or Violations	N/A
Secondary Contributing Factors	Ramp-related
Movements Prior to Collisions	N/A

4.2.4 Southbound Hotspot 4: San Antonio Rd

As shown in Figure 4-8 and Table 4-5, rear-end collisions constitute a significantly higher fraction of all crashes relative to the rest of the corridor. One potential explanation is that high entrance volumes from the entrance ramps at Rengstorff Ave, which also capture all entrance traffic from San Antonio Rd via Charleston Rd, creates intermittent slowing in the right lane only, and that this fluctuating speed differential between the right lane and other freeway lanes results in higher rates of rear-end collisions.

Figure 4-8. Roadway Configuration in the Vicinity of Southbound Hotspot #4

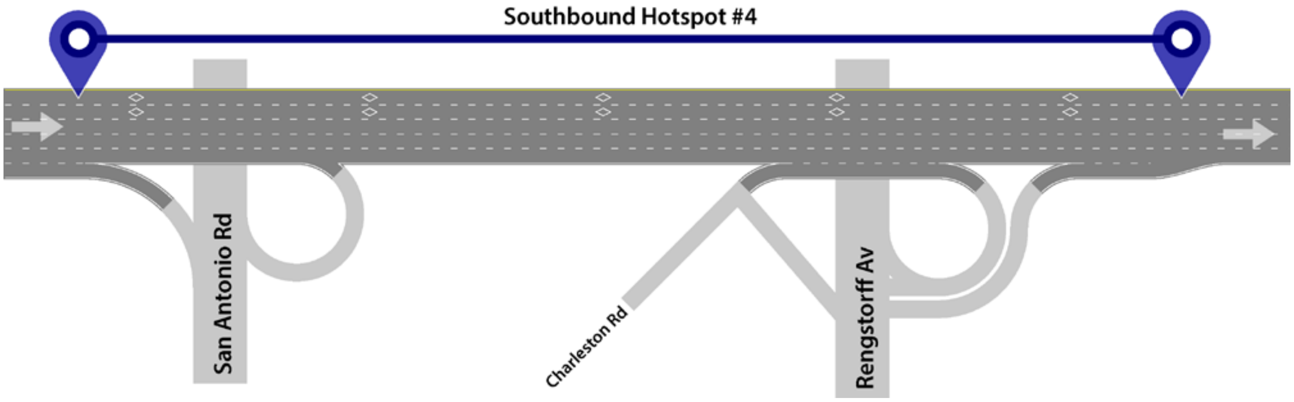


Table 4-5. Summary of Significant Crash Factors and Contextual Information for Southbound Hotspot #4

Factors	Significance
Prevailing Congestion Patterns	Bottleneck location: downstream end of slow traffic region
Ramp Occurrence	Significantly lower than average (5%)
Significant Collision Types	Rear-end
Significant PCFs or Violations	Unsafe speed
Secondary Contributing Factors	N/A
Movements Prior to Collisions	Proceeding straight

4.2.5 Southbound Hotspot 5: Poplar Av

As shown in Figure 4-9 and Table 4-6, the roadway geometry suggests that a potential cause of collisions would be the short entrance and exit ramps at Poplar Ave, though this is not supported by the SWITRS data. A potential alternate explanation is that merging behavior leading up to the lane drop at Poplar Ave creates flow disturbances that result in elevated crash occurrence at this location.

Figure 4-9. Roadway Configuration in the Vicinity of Southbound Hotspot #5

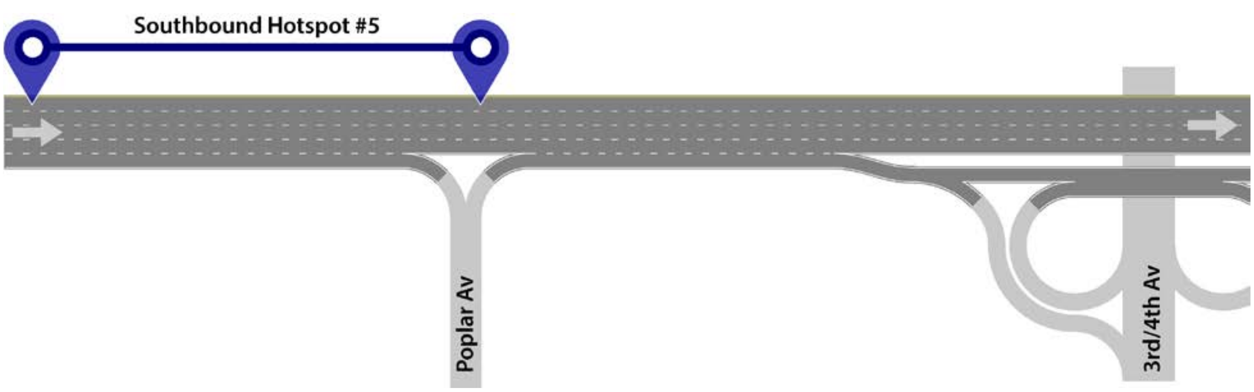


Table 4-6. Summary of Significant Crash Factors and Contextual Information for Southbound Hotspot #5

Factors	Significance
Prevailing Congestion Patterns	Partial bottleneck: downstream end of slow traffic region, at certain times.
Ramp Occurrence	Significantly lower than average (0%)
Significant Collision Types	N/A
Significant PCFs or Violations	N/A
Secondary Contributing Factors	None apparent
Movements Prior to Collisions	N/A

4.2.6 Southbound Hotspot 6: Past SR 92

As shown in Figure 4-10 and Table 4-7, a significant contributor to the crash rate here is ramp-related collisions. When also recognizing that unsafe speed is a major contributing factor to collisions, one possible conclusion is that ramp design is a contributing factor—either in a location where an unexpectedly tight turn occurs, or at a location where a turning radius is not held constant over the course of the turn (e.g., the connection to SR 92 East). Unexpected congestion on the high-volume ramp connection to SR 92 may be another contributing factor, as it would explain both the relatively high rate of ramp-related collisions and the frequent mentioning of high speed as a contributing factor.

Figure 4-10. Roadway Configuration in the Vicinity of Southbound Hotspot #6

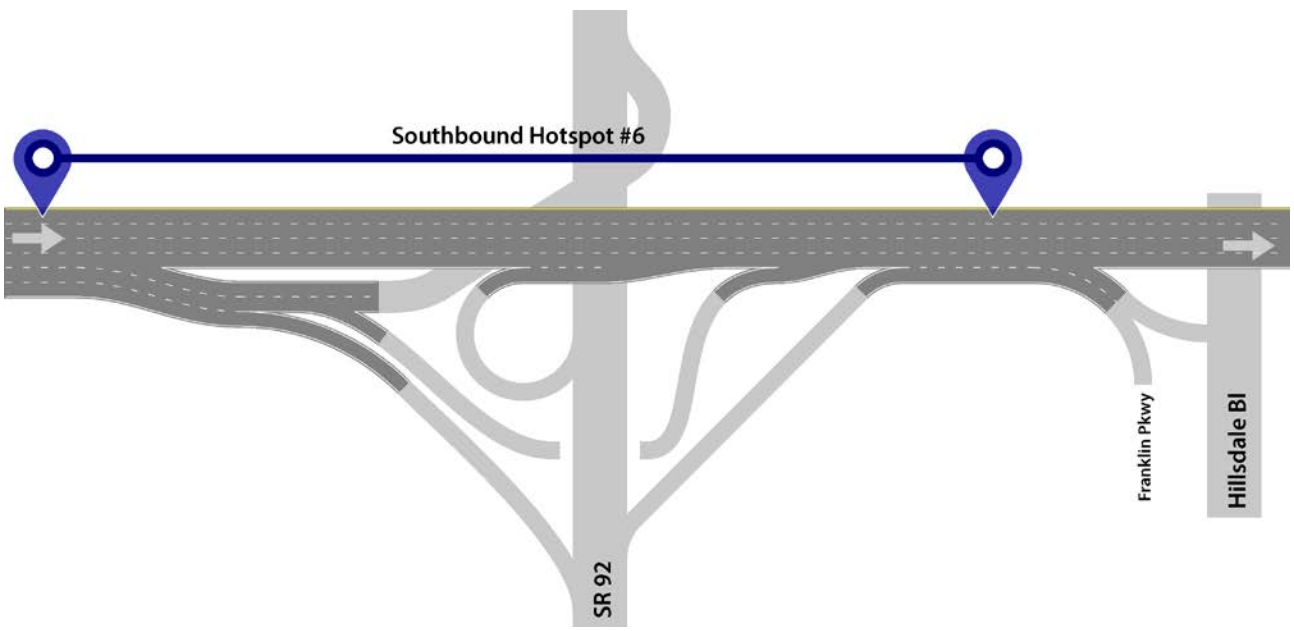


Table 4-7. Summary of Significant Crash Factors and Contextual Information for Southbound Hotspot #6

Factors	Significance
Prevailing Congestion Patterns	Bottleneck location: downstream end of slow traffic region
Ramp Occurrence	Significantly higher than average (23%)
Significant Collision Types	N/A
Significant PCFs or Violations	Unsafe speed
Secondary Contributing Factors	N/A
Movements Prior to Collisions	N/A

4.2.7 Southbound Hotspot 7: Past I-880

As shown in Figure 4-11 and Table 4-8, a major cause of elevated crash rates at this location is merging, weaving, or other lane-changing situations. The presence of a 400-foot weave section for traffic transitioning between US 101 and I-880 is a promising candidate, along with additional weaving and merging in advance of the land drop immediately after the junction with I-880 (i.e., at Oakland Rd approximately 0.2 miles after the entrance ramp from northbound I-880.

Figure 4-11. Roadway Configuration in the Vicinity of Southbound Hotspot #7

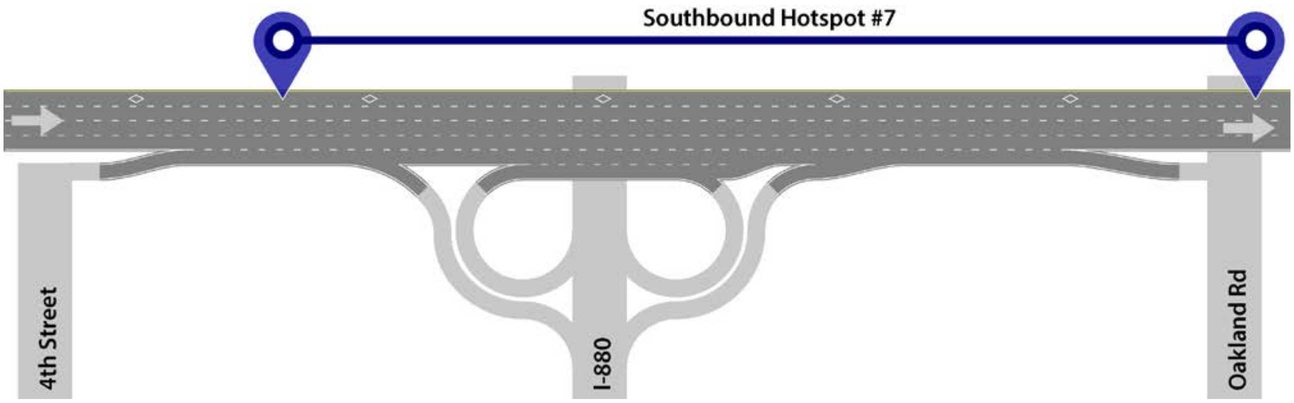


Table 4-8. Summary of Significant Crash Factors and Contextual Information for Southbound Hotspot #7

Factors	Significance
Prevailing Congestion Patterns	Bottleneck location: downstream end of slow traffic region
Ramp Occurrence	Not significantly different from the corridor average (12%)
Significant Collision Types	Sideswipe
Significant PCFs or Violations	Unsafe lane change
Secondary Contributing Factors	N/A
Movements Prior to Collisions	Changing lanes, other

4.2.8 Southbound Hotspot 8: SR 87 Split

As shown in Figure 4-12 and Table 4-9, leading contributing factors regarding the elevated crash rates at this location include stop-and-go traffic and unsafe speed. Given that this occurs at the downstream end of a congested region, the collisions may be occurring as a result of high speed differentials between congested and uncongested lanes, which could include the right lane leading up to SR 87, or the left HOV lane throughout this segment. Poorly executed or timed merges between high-speed lanes and adjacent slow-moving lanes could create the right conditions for these types of collisions.

Figure 4-12. Roadway Configuration in the Vicinity of Southbound Hotspot #8

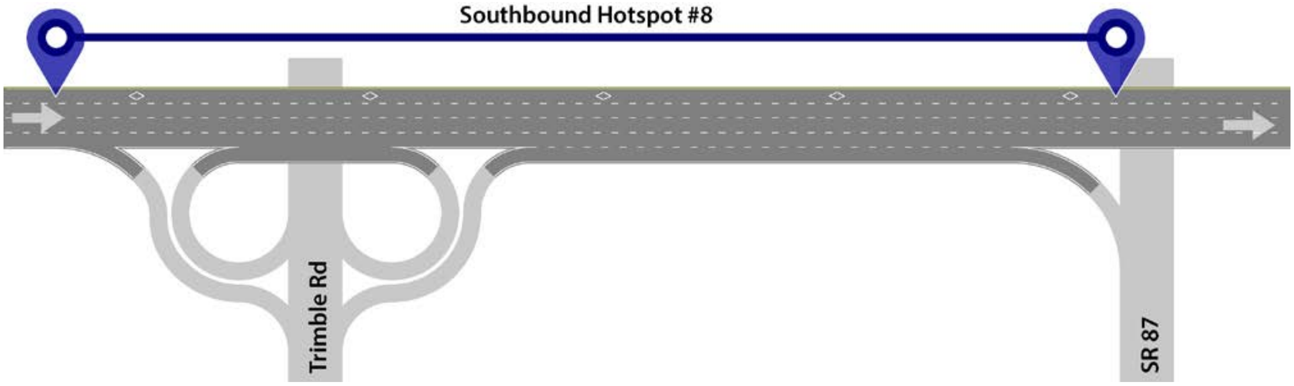


Table 4-9. Summary of Significant Crash Factors and Contextual Information for Southbound Hotspot #8

Factors	Significance
Prevailing Congestion Patterns	Bottleneck location: downstream end of slow traffic region
Ramp Occurrence	Significantly lower than average (3%)
Significant Collision Types	Rear-end
Significant PCFs or Violations	Unsafe speed
Secondary Contributing Factors	Stop-and-go traffic
Movements Prior to Collisions	Proceeding straight

4.2.9 Southbound Hotspot 9: Willow Rd

As shown in Figure 4-13 and Table 4-10, there are no particularly compelling reasons to expect higher collision rates at this location with respect to the common contributing factors, although the geometry of the junction at Willow Rd does include a short weaving section that may be a contributing factor. Otherwise, the relatively high crash rates at this location may simply be a result of the co-location with a common bottleneck, which may produce intermittent and unexpected slow-moving traffic at this location.

Figure 4-13. Roadway Configuration in the Vicinity of Southbound Hotspot #9

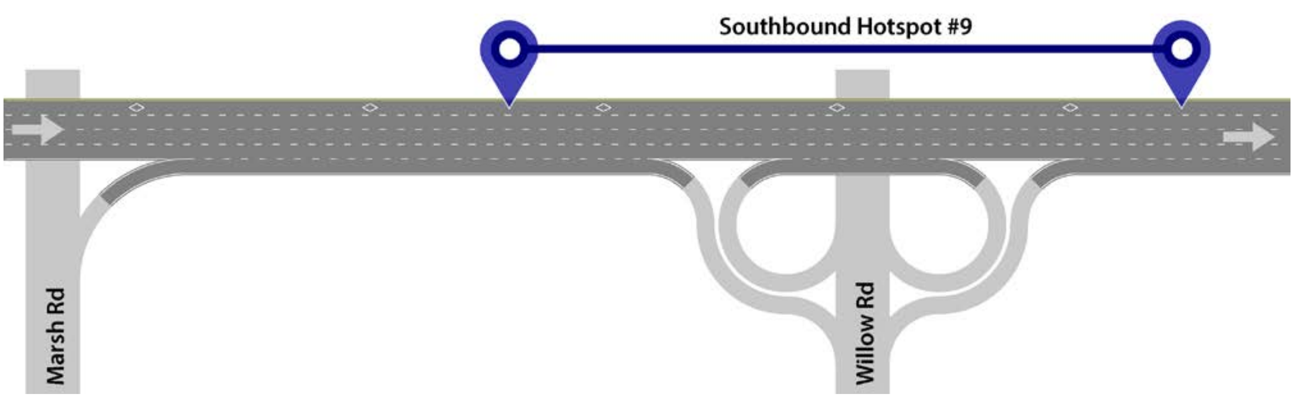


Table 4-10. Summary of Significant Crash Factors and Contextual Information for Southbound Hotspot #9

Factors	Significance
Prevailing Congestion Patterns	Bottleneck location: downstream end of slow traffic region
Ramp Occurrence	Not significantly different from the corridor average (6%)
Significant Collision Types	N/A
Significant PCFs or Violations	N/A
Secondary Contributing Factors	N/A
Movements Prior to Collisions	N/A

4.2.10 Southbound Hotspot 10: Capitol Expwy

As shown in Figure 4-14 and Table 4-11, there are no immediately apparent causes for elevated crash risk at this location, apart from an indication that one of the ramps may be a contributing factor. Review of satellite imagery reveals an anecdotal tendency for traffic to form queues in the right lane of the exit at Capitol Expwy, due to congestion on Capitol Expwy itself (heading West).

Figure 4-14. Roadway Configuration in the Vicinity of Southbound Hotspot #10

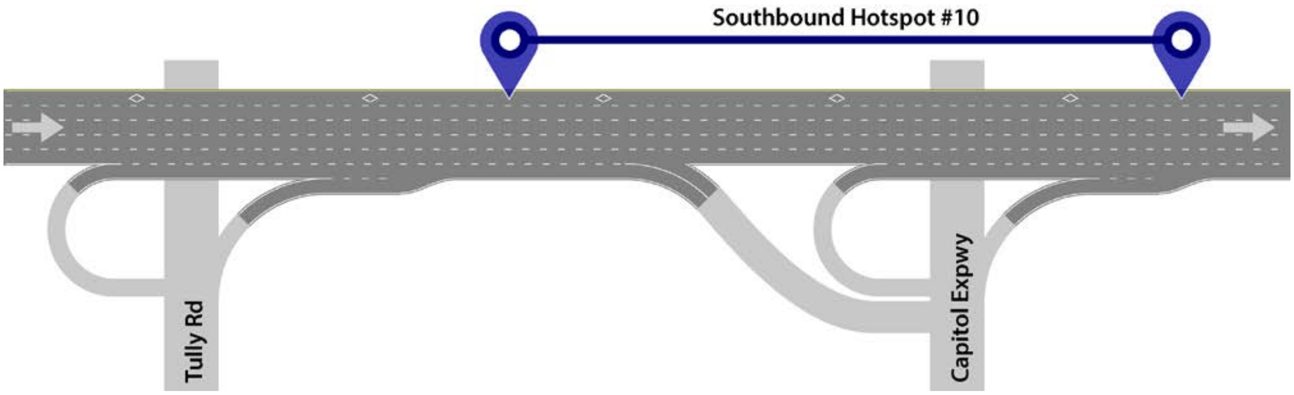


Table 4-11. Summary of Significant Crash Factors and Contextual Information for Southbound Hotspot #10

Factors	Significance
Prevailing Congestion Patterns	No significant congestion
Ramp Occurrence	Significantly higher than average (23%)
Significant Collision Types	N/A
Significant PCFs or Violations	N/A
Secondary Contributing Factors	N/A
Movements Prior to Collisions	Proceeding straight

4.2.11 Northbound Hotspot 1: Potrero Hill

As shown in Figure 4-15 and Table 4-12, two significant factors associated with the elevated collision rates at this location are higher-than-normal rates of rear-end crashes, and unsafe lane changing maneuvers. Rear-end crashes may be a result of the high traffic volumes and recurrent congestion through this segment, combined with the unusual terrain and roadway curvature at Potrero Hill. Unsafe lane changes may be occurring in advance of the major junction at I-80, due to relatively high demand for one of the two exits, which may motivate some drivers to attempt queue-jumping behavior in other faster-moving lanes and making abrupt, forced lane changes into the high-demand lanes just prior to the gore point.

Figure 4-15. Roadway Configuration in the Vicinity of Northbound Hotspot #1

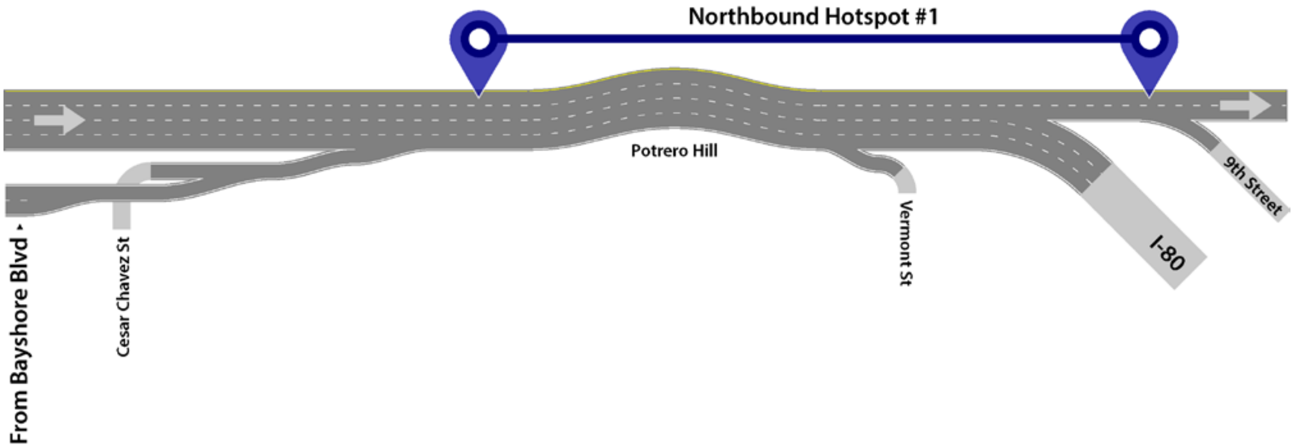


Table 4-12. Summary of Significant Crash Factors and Contextual Information for Northbound Hotspot #1

Factors	Significance
Prevailing Congestion Patterns	Bottleneck location: downstream end of slow traffic region
Ramp Occurrence	Significantly lower than average (2%)
Significant Collision Types	Rear-end
Significant PCFs or Violations	Unsafe lane change
Secondary Contributing Factors	N/A
Movements Prior to Collisions	Changing lanes

4.2.12 Northbound Hotspot 2: Cesar Chavez St

As shown in Figure 4-16 and Table 4-13, ramp traffic is not a major contributing factor associated with elevated crash rates at this location. However, rear-end crashes and lane-changing behavior both make statistically significant contributions to this hotspot. Rear-end crash occurrence may be a result of this hotspot’s position at the back end of the recurrent congestion queue on US 101 in this area, while the weaving section between I-280 and Bayshore Blvd may contribute to the high occurrence of sideswipe collisions arising from unsafe lane changes.

Figure 4-16. Roadway Configuration in the Vicinity of Northbound Hotspot #2

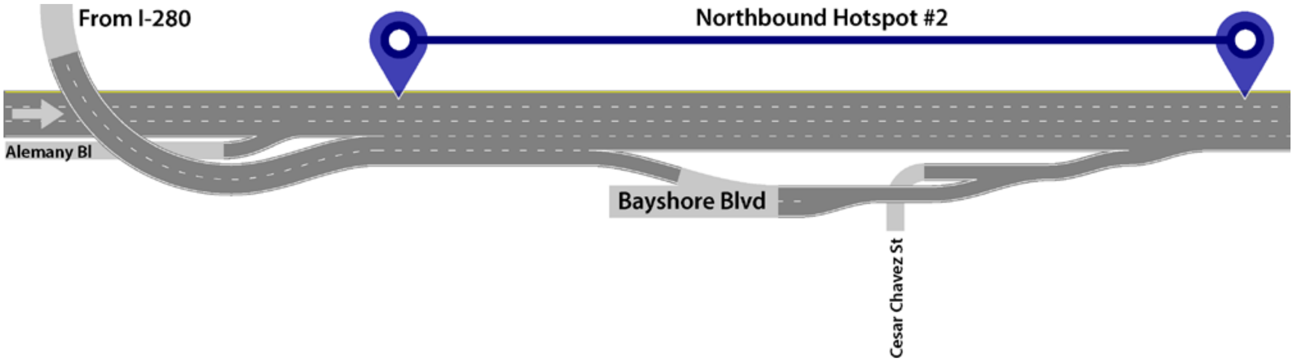


Table 4-13. Summary of Significant Crash Factors and Contextual Information for Northbound Hotspot #2

Factors	Significance
Prevailing Congestion Patterns	Back of queue: upstream end of slow traffic region
Ramp Occurrence	Significantly lower than average (7%)
Significant Collision Types	Rear-end, sideswipe
Significant PCFs or Violations	Unsafe lane change
Secondary Contributing Factors	N/A
Movements Prior to Collisions	Changing lanes

4.3 Northbound Hotspot 3: SR 92 Exit

As shown in Figure 4-17 and Table 4-14, a potential source of the elevated collision rates at this location is a speed differential between adjacent lanes that results in rear-end collisions and attribution of the cause as "unsafe speeds." This may be due to lateral spreading of queues from exit-related congestion leading up to SR 92, or it may be a consequence of traffic bound for SR 92 using the exit lane at relatively high speeds compared to the congested mainline during heavy traffic periods, resulting in elevated risk of rear-end collision when any unexpected or poorly timed lane changes occur between the slow-moving and relatively free-flowing lanes.

Figure 4-17. Roadway Configuration in the Vicinity of Northbound Hotspot #3

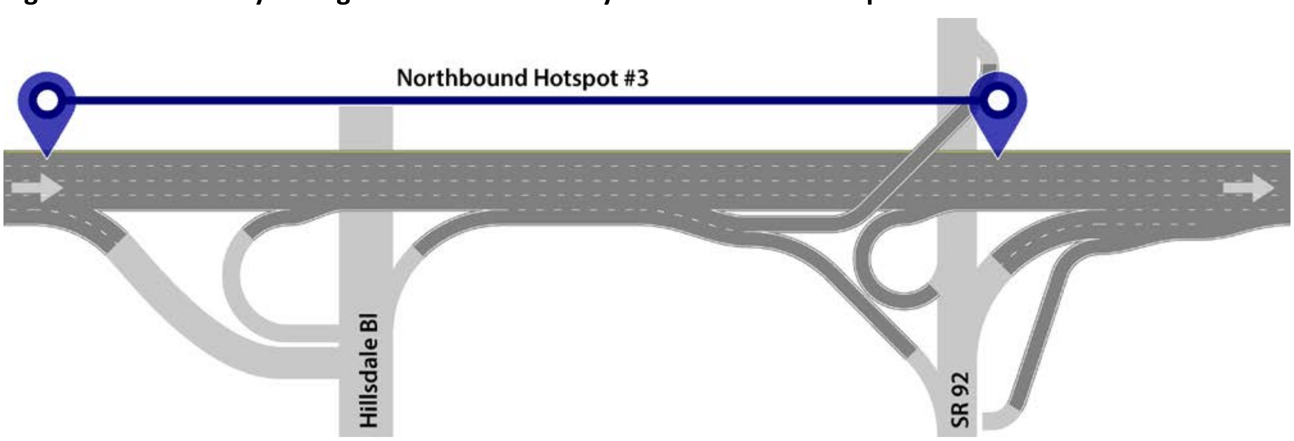


Table 4-14. Summary of Significant Crash Factors and Contextual Information for Northbound Hotspot #3

Factors	Significance
Prevailing Congestion Patterns	Bottleneck location: downstream end of slow traffic region, at certain times.
Ramp Occurrence	Not significantly different from the corridor average (15%)
Significant Collision Types	Rear-end
Significant PCFs or Violations	Unsafe speed
Secondary Contributing Factors	N/A
Movements Prior to Collisions	Proceeding straight

4.3.1 Northbound Hotspot 4: I-880

As shown in Figure 4-18 and Table 4-15, a leading cause of the elevated crash rates at this location is lane-changing during congested conditions. This may be due to the overlapping weaving sections that occur between Oakland Rd and Bayshore Highway, where traffic entering from Oakland Rd must weave left while traffic on US 101 intending to exit at Bayshore Highway must weave through this merging traffic to reach its exit. Furthermore, in the middle of this weaving section is another at I-880, where traffic coming from I-880 must weave two lanes left to access US 101 and any traffic on US 101 intending to exit onto I-880 must similarly weave two lanes to the right.

Figure 4-18. Roadway Configuration in the Vicinity of Northbound Hotspot #4

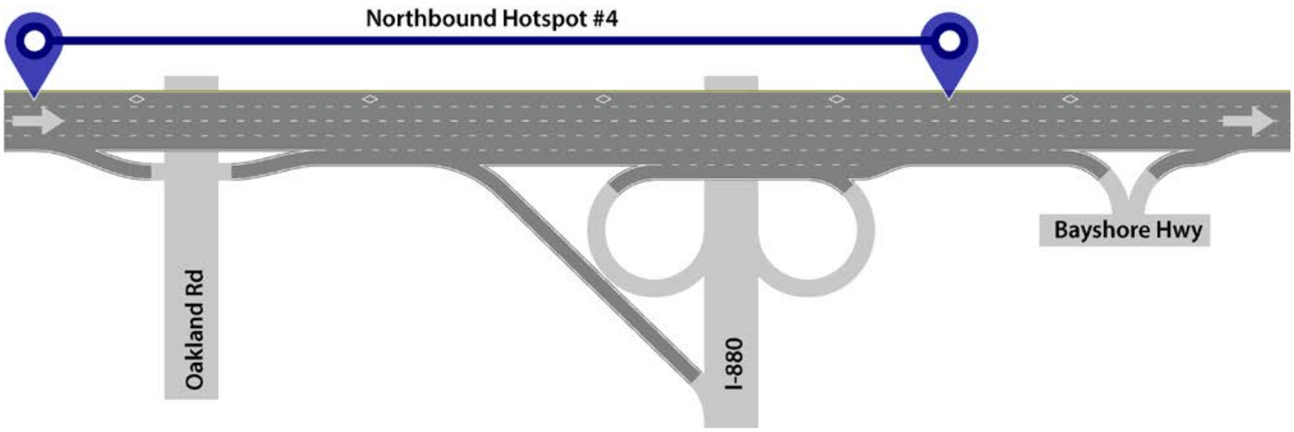


Table 4-15. Summary of Significant Crash Factors and Contextual Information for Northbound Hotspot #4

Factors	Significance
Prevailing Congestion Patterns	Partial bottleneck location: downstream end of slowest traffic region, at certain times
Ramp Occurrence	Not significantly different from the corridor average (13%)
Significant Collision Types	N/A
Significant PCFs or Violations	N/A
Secondary Contributing Factors	Stop-and-Go Conditions
Movements Prior to Collisions	Changing lanes

4.3.2 Northbound Hotspot 5: Tully Rd

As shown in Figure 4-19 and Table 4-16, a significant contributing factor to elevated crash rates at this location is unsafe lane changes, in addition to a partial contribution from ramp-related collisions. As this hotspot occurs just before a major junction, which also coincides with the location of a major corridor bottleneck, a potential source of high collision rates at this location could be late-merging traffic attempting to transition from fast-moving lanes into congested, slower-moving lanes near the ramp separation point for I-680.

Figure 4-19. Roadway Configuration in the Vicinity of Northbound Hotspot #5

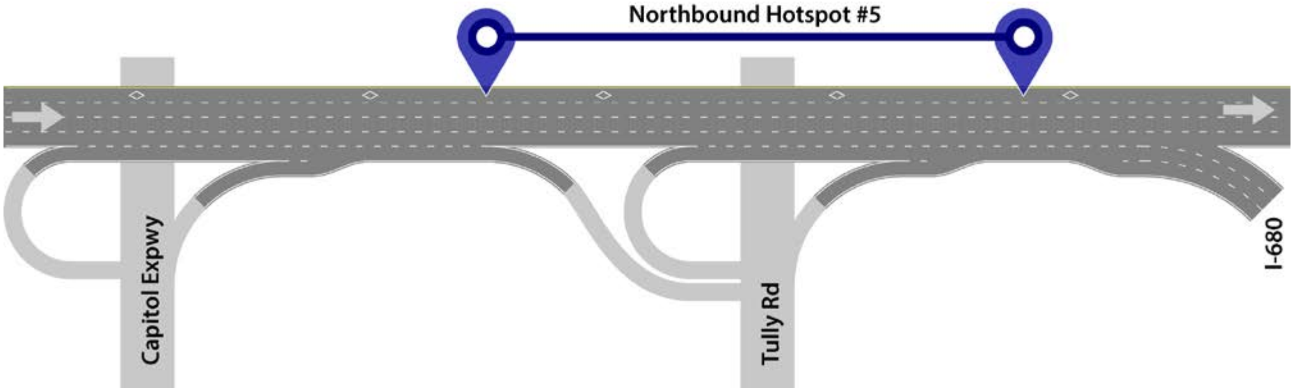


Table 4-16. Summary of Significant Crash Factors and Contextual Information for Northbound Hotspot #5

Factors	Significance
Prevailing Congestion Patterns	Bottleneck location: downstream end of slow traffic region
Ramp Occurrence	Not significantly different from the corridor average (19%)
Significant Collision Types	N/A
Significant PCFs or Violations	Unsafe lane change
Secondary Contributing Factors	Ramp-related crashes
Movements Prior to Collisions	Changing lanes

4.3.3 Northbound Hotspot 6: San Antonio Rd

As shown in Figure 4-20 and Table 4-17, a major contributing factor associated with elevated collision rates at this location is unsafe travel speed, resulting in a high occurrence of rear-end collisions. Because this location is not at the back end of a recurring queue, the crashes may be happening in the auxiliary lane between Rengstorff Ave and San Antonio Rd, or in the HOV lanes as vehicles attempt to merge between those free-flowing lanes and the relatively congested and slow-moving mainline.

Figure 4-20. Roadway Configuration in the Vicinity of Northbound Hotspot #6

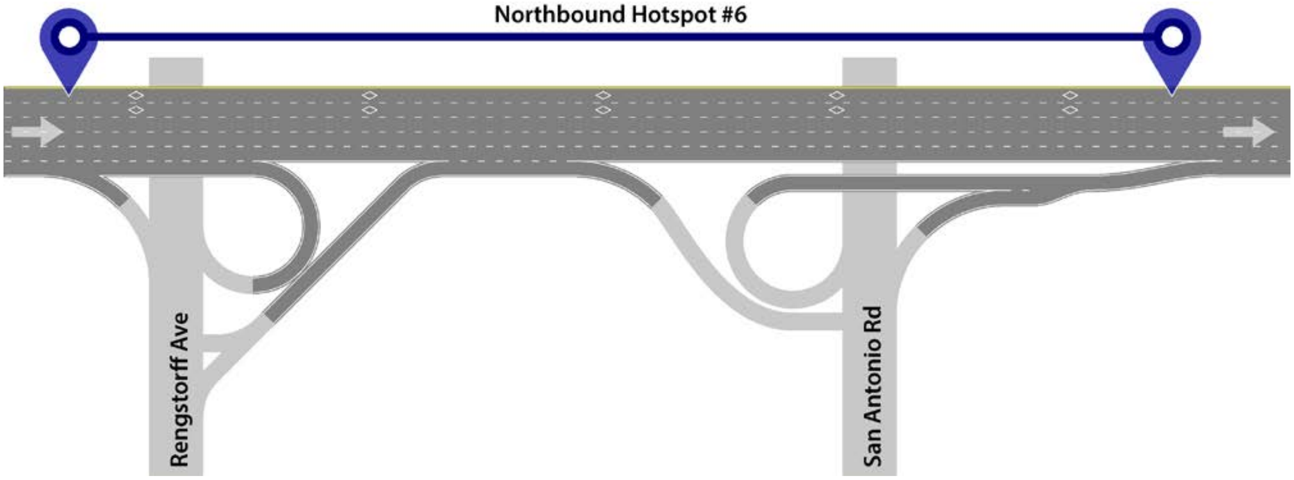


Table 4-17. Summary of Significant Crash Factors and Contextual Information for Northbound Hotspot #6

Factors	Significance
Prevailing Congestion Patterns	Mid-queue: Middle of slow traffic region, at certain times
Ramp Occurrence	Not significantly different from the corridor average (10%)
Significant Collision Types	Rear-end
Significant PCFs or Violations	Unsafe speed
Secondary Contributing Factors	N/A
Movements Prior to Collisions	Proceeding straight

4.4 Relationship between Congestion and Crash Concentrations

As Figure 4-3 and Figure 4-4 indicate, there is a correspondence between locations of congestion and the occurrence of major crash concentrations on the corridor. While not all of the crash hotspots are associated with recurrent congestion on the corridor, and not all locations of recurrent congestion are associated with elevated crash risk, the co-occurrence of the two is apparent by comparing Figure 2-11 and Figure 2-12 (i.e., locations of recurrent congestion on the corridor) to Figure 3-1 and Figure 3-3 (i.e., locations of elevated crash rates on the corridor). With respect to the 16 most severe crash hotspots identified in this chapter, 11 of them can be associated with a bottleneck from Table 2-5 and Table 2-6 as indicated in Table 4-18 and Table 4-19. This association gives further insight into potential mitigation factors for those locations of elevated crash occurrence, as described in the third column of the tables below.

Table 4-18. Association between Crash Hotspots and Major Bottlenecks, for US 101 South

Crash Hotspot	Associated Bottleneck	Potential Relationship
1. North of I-280	7. 3rd Street Entrance	Crashes at tail (upstream end) of queue
2. Potrero Hill	—	
3. Oregon Expy	8. Embarcadero Rd Entrance	Freeway traffic attempting to use the ramps to bypass the bottleneck.
4. San Antonio Rd	Rengstorff Ave (a minor recurring bottleneck)	High traffic volumes from Rengstorff Ave, combined with large speed differential between the left and right lanes.
5. Poplar Av	10. Before Peninsula Av	Elevated lane-changing behavior and speed differential between left/right lanes at this bottleneck
6. Past SR 92	4. Entrance from SR 92	Entering ramp traffic encountering unexpected congestion approaching the freeway due to the bottleneck.
7. Past I-880	1. Entrance from I-880 SB	Elevated lane-changing behavior in the right lanes, and speed differential between the right/left lanes due to high volumes of traffic merging from SB I-880 over a short distance.
8. SR 87 Split	5. Between De La Cruz Blvd and Guadalupe Pkwy	Weaving, elevated lane-changing behavior in the right lane, and speed differential between left/right lanes at this bottleneck.
9. Willow Rd	2. University Ave to Embarcadero Rd	Weaving, elevated lane-changing behavior, and speed differential between left/right lanes at this bottleneck.
10. Capitol Expwy	—	

A dash (—) indicates no apparent association between the crash hotspot and major bottlenecks.

Table 4-19. Association between Crash Hotspots and Major Corridor Bottlenecks, for US 101 North

Crash Hotspot	Associated Bottleneck	Potential Relationship
1. Potrero Hill	1. I-80 Connector	Traffic attempting to merge between congested and uncongested lanes at this bottleneck
2. Cesar Chavez St	1. I-80 Connector	Crashes at tail (upstream end) of queue
3. SR 92 Exit	2. SR 92 Exit **OR** 3. Marine Pkwy Entrance	Weaving, elevated lane-changing behavior, and speed differential between left/right lanes at this bottleneck.
4. I-880	10. Oakland Rd Entrance	Elevated lane-changing behavior in right lane, and speed differential between left/right lanes at this bottleneck.
5. Tully Rd	5. Capitol Expressway Entrance	Crashes at head (downstream end) of queue
6. San Antonio Rd	—	Elevated lane-changing behavior in right lane, and speed differential between left/right lanes at this bottleneck.

A dash (—) indicates no apparent temporal correlation between crash hotspot and nearby bottlenecks.

CHAPTER 5: TRANSIT SERVICE AND RIDERSHIP ASSESSMENT

This section provides a high-level scan of transit service and utilization data for routes and stations in the general vicinity of US 101 in the Bay Area. Figure 5-1 shows the approximate study limits for this exercise. The major transit providers that have been identified for consideration in this assessment are:

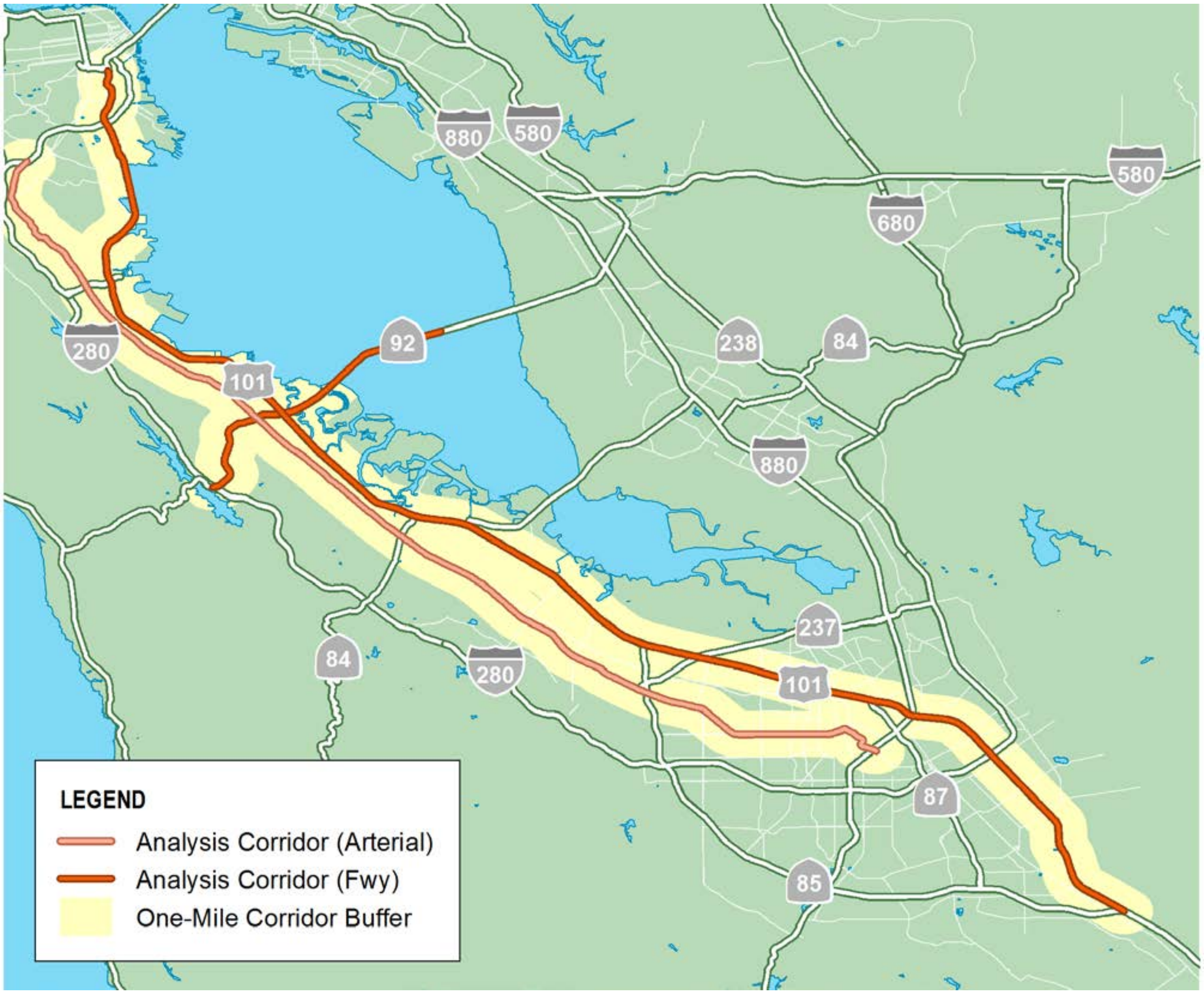
- SamTrans (transit bus service)
- VTA (transit bus service and light rail)
- BART (heavy/commuter rail)
- Caltrain (heavy/commuter rail)
- Private Shuttle Operators

For each of these transit service operators, the following have been provided whenever the data were reasonably available:

- Service descriptions in the form of:
  - **For transit buses:** Maps of routes traversing a significant portion of the study area routes shown in Figure 5-1, and a table/list of routes to accompany it.
  - **For private shuttles:** Map of screenlines for measurements.
  - **For light rail, commuter rail, heavy rail:** Maps of stations and routes in the vicinity of the study area routes shown in Figure 5-1, and a table/list of stations to accompany it. In general, this includes all stations on the peninsula between San Jose and San Francisco.
- Year of the data being used.
- Boardings, alightings, and capacity utilization by:
  - Station and Route;
  - Direction;
  - Time of Day (i.e., AM Peak, PM Peak, Mid-day Period); and,
  - Weekday versus weekend.

If the above data were unavailable for a given transit provider, but related data were available that offered insights into the above topic areas, those have been included instead.

Figure 5-1: Geographic Scope of Transit Service Assessment



5.1 SamTrans

San Mateo County Transit District (SamTrans) is the bus operator for San Mateo County and provides service from San Francisco to Menlo Park, as well as cross-county connections to San Francisco's Muni public transit system and VTA service at the Palo Alto Transit Center.[3]

Table 5-1 lists the routes that follow US 101 or El Camino Real for at least one mile. Route maps are provided in the appendix, effective as of January 10, 2016. As of 2015/2016 ridership data, SamTrans' El Camino Routes 397, 398, KX, and ECR carry 29% of SamTrans ridership at 12,191 riders per day in February 2016.[4] Ridership growth for fixed-route service is projected to increase at a rate of 2% per year.[5]

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[3] Grand Boulevard Existing Conditions Report, page 71.

[4] http://www.grandboulevard.net/existing-conditions/transportation-and-mobility/transit-ridership.

[5] http://www.samtrans.com/Assets/_Planning/SamTrans+Short+Range+Transit+Plan+FY14-23.pdf (Table 11. Fixed-route Service Levels and Ridership).

Table 5-1: Summary of SamTrans Routes along the US 101 Corridor

Route	Description	Weekday Hours	Daily Ridership	Weekday Frequency of Service
ECR	Daly City BART – Palo Alto Transit Center	3:57 AM to 2:21 AM	11,406	15 minutes
KX	San Francisco – Redwood City Transit Center - Serves SF Airport	Mornings to SF: 5:18 AM – 9:35 AM Afternoons to Redwood City Transit Center: 3:31 PM – 8:13 PM	170	60 minutes
292	San Francisco – Hillsdale Mall - Serves SF Airport	3:55 AM – 2:30 AM	—	30 minutes
397	San Francisco – Palo Alto Transit Center (Limited Overnight Service) - Serves SF Airport	12:46 AM – 6:23 AM	600 for Route 397 and 398 combined.	60 minutes
398	San Bruno BART – Redwood City Transit Center - Serves SF Airport	5:07 AM – 11:50 PM	600 for Route 397 and 398 combined.	60 minutes

A dash (—) indicates data that were not readily available.

5.2 Santa Clara Valley Transportation Authority (VTA)

Santa Clara Valley Transportation Authority (VTA) is an independent special district that provides bus, light rail, and paratransit services, as well as participates as a funding partner in regional rail service including Caltrain, Capital Corridor, and the Altamont Corridor Express. As the county's congestion management agency, VTA is responsible for countywide transportation planning, including congestion management, design and construction of specific highway, pedestrian, and bicycle improvement projects, as well as promotion of transit oriented development.[6]

Table 5-2 lists the bus routes in the general vicinity of the US 101 corridor, while Table 5-3 lists the light rail routes. Route maps and light rail ridership data by station are provided in the appendix.

[6] http://www.vta.org/about-us/inside-vta/about-vta.

Table 5-2: Summary of VTA Bus Routes along the US 101 Corridor

Route	Description	Weekday Hours	Weekday Ridership[7]	Weekday Freq. of Service
Core Route 22	Palo Alto Transit Center to Eastridge Transit Center via El Camino	3:22 AM – 4:12 AM	12,929 (12.5% of system ridership)	15 minutes
Core Route 522	Palo Alto Transit Center to Eastridge Transit Center	4:39 AM – 11:26 PM	5,228 (5.0% of system ridership)	15 minutes
Local Route 35	Downtown Mountain View to Stanford Shopping Center	5:45 AM – 9:59 PM	1,068 (1.0% of system ridership)	30 minutes
Express 104	Penitencia Creek Transit Center to Palo Alto	Westbound: 5:56 AM – 7:57 AM Eastbound: 4:00 PM – 6:15 PM	90 (0.1% of system ridership)	30 minutes
Express 121	Gilroy Transit Center to Lockheed Martin Transit Center/Moffett Park	Northbound: 4:30 AM – 9:20 AM Southbound: 2:54 PM – 7:39 PM	430 (0.4% of system ridership)	20 minutes
Express 122	South San Jose to Lockheed Martin/Moffett Industrial Park	Northbound: 5:52 AM – 6:45 AM Southbound: 4:48 PM – 6:02 PM	45 (<0.1% of system ridership)	Once per day

Table 5-3: Summary of VTA Light Rail Routes along the US 101 Corridor

Route	Description	Weekday Hours	Weekday Ridership[8]	Weekday Freq. of Service
Alum Rock – Santa Teresa Line (Blue)	Operates between the Santa Teresa Station in South San Jose and the Alum Rock Transit Center in East San Jose; 27 miles, 38 stations.	4 AM to 1 AM	Peak: 9,832 Midday: 8,134 Off-Peak: 2,846 Total: 20,813	15 minutes
Mountain View – Winchester Line (Green)	Operates between the Mountain View Transit Center in downtown Mountain View and the Winchester Transit Center in Campbell; 22 miles, 37 stations.	5 AM to 1 AM	Peak: 8,030 Midday: 4,071 Off-Peak: 1,915 Total: 14,015	30 minutes, with 15 minutes during peak periods
Light Rail Commuter Express Service (Yellow)	Trains make all stops between Santa Teresa and Ohlone/Chynoweth, then non-stop between Ohlone/Chynoweth and Convention Center. The trains then resume all-stop service between Convention Center and Baypointe.	3 northbound trains in AM Peak; 3 southbound trains in PM Peak	Peak: 386 Midday: 345 Off-Peak: 134 Total: 865	3 northbound trains in AM Peak; 3 southbound trains in PM Peak
Total			Peak: 18,248 Midday: 12,550 Off-Peak: 4,985 Total: 35,693	

The ridership time periods correspond to the following ranges: "Peak" is 5-9 AM and 3-7 PM, "Midday" is 9 AM to 3 PM, and "Off Peak" is 7 PM to 5 AM.

5.3 Bay Area Rapid Transit (BART)

BART connects the San Francisco Peninsula with Oakland, Berkeley, Fremont, Walnut Creek, Dublin/Pleasanton, and other cities in the East Bay. BART also connects to AC Transit, Caltrain, Muni, SamTrans, and other local transit systems throughout the Bay Area. Serving longer distances and

[7] http://vtaorgcontent.s3-us-west-1.amazonaws.com/Site_Content/FY1617atsp.pdf (page 27).
[8] http://vtaorgcontent.s3-us-west-1.amazonaws.com/Site_Content/FY1617atsp.pdf (page 33).

predominantly commute trips, this service complements and supports—rather than competes with—fixed route bus service.[9]

Table 5-4 lists the 2016 average weekday ridership data for BART stations that are captured by the highlighted region of Figure 5-1. All stations in San Mateo County are within ¼ mile of the US 101 corridor (which includes El Camino Real). An annotated system map is provided in the appendix. BART hours of operation are generally from 4 am to midnight on weekdays, 6 am to midnight on Saturdays, and 8 am to midnight on Sundays and major holidays. BART trains typically run every 15 minutes except weekends, when trains run about every 20 minutes.[10]

Table 5-4: Average Weekday Ridership by BART Station

Station	2016 Average Weekday Alightings[11]
Millbrae	6,872
San Francisco International Airport	6,788
San Bruno	4,059
South San Francisco	3,786
Colma	4,641
Daly City	9,813

5.4 Caltrain

Caltrain is a commuter rail system serving San Francisco, San Mateo and Santa Clara counties. It is operated by the Peninsula Corridor Joint Powers Board consisting of representatives from San Mateo, Santa Clara and San Francisco counties. The system spans 77.4 miles and includes 32 stations, 29 of which are used to provide weekday service (two stations are weekend-only stations, and one station is used for special events).[12] All Caltrain stations north of Morgan Hill Station in South San Jose are within 1 mile of the US 101 Corridor (which includes El Camino Real). A Caltrain route map is provided in the appendix.

As of January 1, 2011, Caltrain operates a total of 86 trains per day on weekdays between San Francisco and Gilroy. Operating hours are from 4:30 AM to 1:30 AM on weekdays, with up to five trains per hour per direction are operated during the peak hours with headways ranging from five minutes to one hour. Average weekday headways are 30 minutes, with 60-minute headways on weekends and during off-peak weekday periods. Since August 2009, Caltrain has reduced weekday service by 12 midday trains but expects to re-introduce service once budgetary resources are available. On weekends, Caltrain operates Local service at one hour intervals and four Express trains, two in the late morning and two in the evening.[13]

Table 5-5 lists the system ridership by direction and time of day using 2015 data, with additional data tables included in the appendix.

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[9] Grand Boulevard Existing Conditions Report (page 77).

[10] http://www.bart.gov/sites/default/files/docs/BasicsGuide%20ENG%20Sept%202015web.pdf.

[11] http://www.bart.gov/about/reports/ridership, Average Weekday Exits by Station.

[12] Caltrain 2015 Annual Passenger Count Key Findings.

[13] Grand Boulevard Existing Conditions Report (pages 74-75).

Table 5-5: Weekday Summary Ridership Data by Direction

Time Period	Maximum Load Point	Capacity	% Capacity
	Northbound Summary		
AM Peak	9,323	11,050	84.4%
Off Peak	2,965	7,800	38.0%
PM Peak	7,269	11,050	65.8%
Total	**19,557**	**29,900**	**65.4%**
	Southbound Summary		
AM Peak	6,512	10,400	62.6%
Off Peak	3,515	8,450	41.6%
PM Peak	9,836	11,050	89.0%
Total	**19,863**	**29,900**	**66.4%**
	Overall Summary		
Peak Directions	19,159	22,100	86.7%
Reverse Peak Directions	13,782	21,450	64.3%
Off Peak	6,480	16,250	39.9%
Total	**39,420**	**59,800**	**65.9%**

The ridership time periods correspond to the following ranges: "AM Peak" is 4:30-9 AM and "PM Peak" is 3-7 PM.
Source: Caltrain 2015 Annual Passenger Count Key Findings (page 30, 35)

5.5 Private Shuttles

In 2016, the Bay Area Council and MTC conducted a shuttle census project to gather data on public and private shuttle services in the Bay Area. This project focused on commuter shuttles and "last mile" services only, and did not include airport or charter transportation services. Many shuttles complement regional transit services by providing critical connections between trip ends and transit hubs. The major service providers captured in these data include the following:[14]

- ABM Industries
- Amazon Lab 126
- AMD
- App Dynamix
- Apple
- Apptus
- Althleta
- Bauers
- Bayer
- Black Tie Transportation Worldwide
- Cisco
- Clorox
- Loop
- Electronic Arts
- Facebook
- Genentech
- Google, Inc.
- Intuit
- Microsoft Silicon Valley
- Salesforce
- SAP
- Service Now
- SJSU Parking Services
- Stanford University Marguerite
- Sunset Development
- TubeMogul
- Twitter
- UC Berkeley
- Visa
- VM Ware
- Walmart
- WeDriveU
- Worldwide Ground Transportation Services (El Paseo Limo)
- XTime
- Yahoo

[14] http://mtc.ca.gov/sites/default/files/2016%20Bay%20Area%20Shuttle%20Census.pdf (page 5).

In aggregate, these 35-plus private shuttle services transported about 22,000 passengers in a typical weekday in 2016 (unidirectional trips), which accounted for about 13 percent of the total transit ridership in the corridor. Figure 5-2 presents the transit market share in Silicon Valley using date from year 2016.

Figure 5-2: Silicon Valley Transit Market Share in 2016

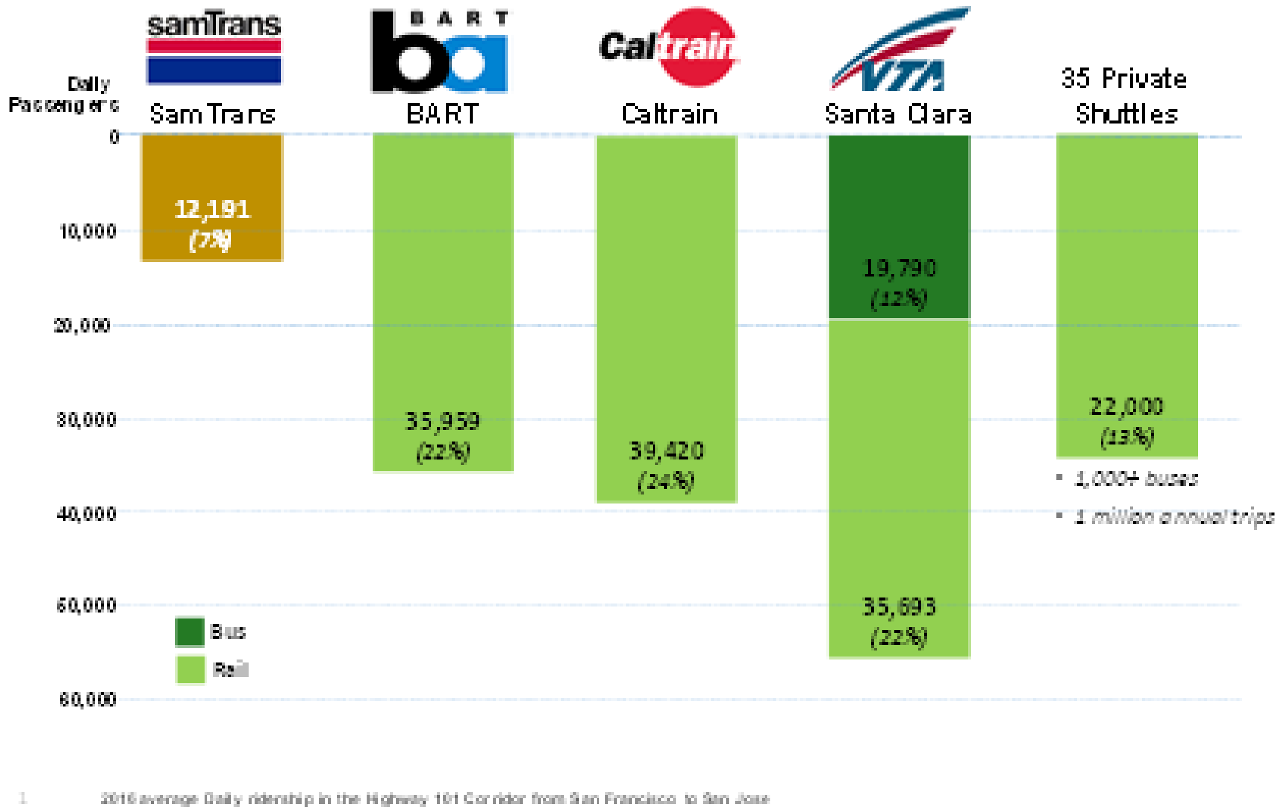
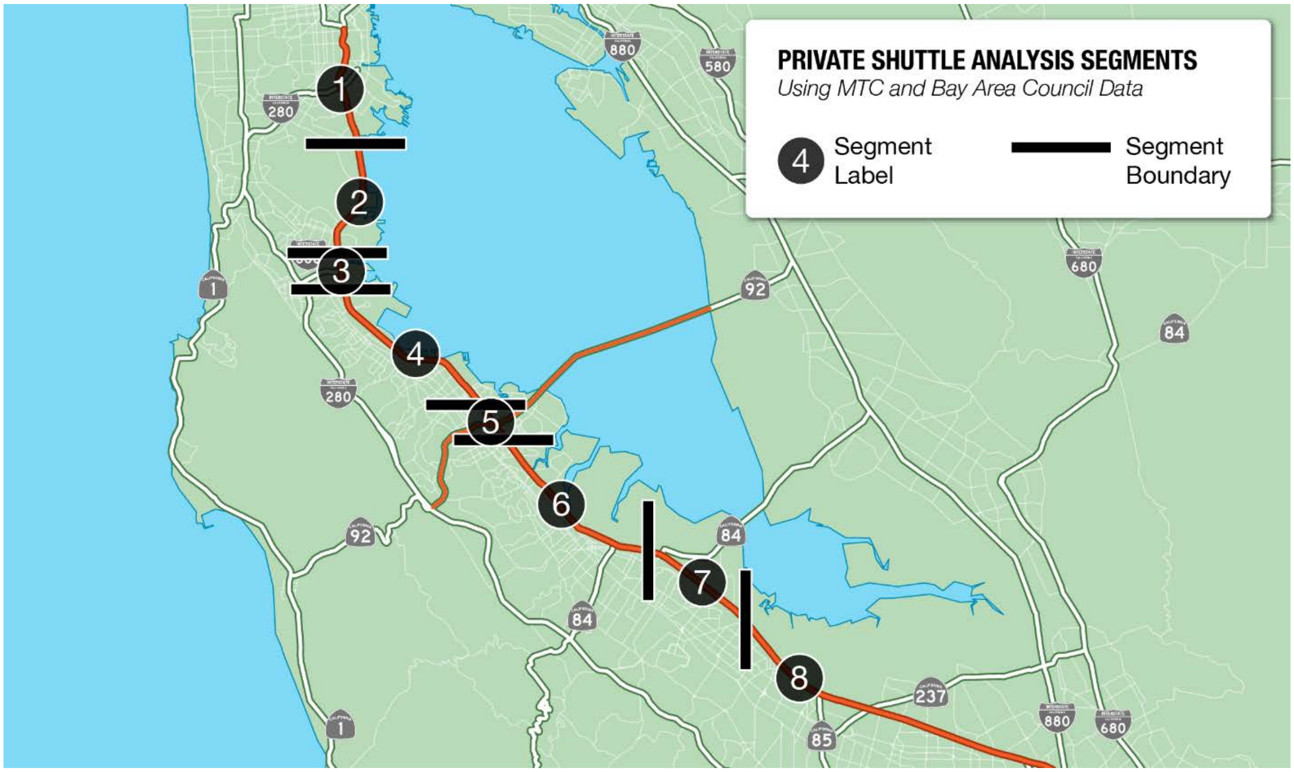


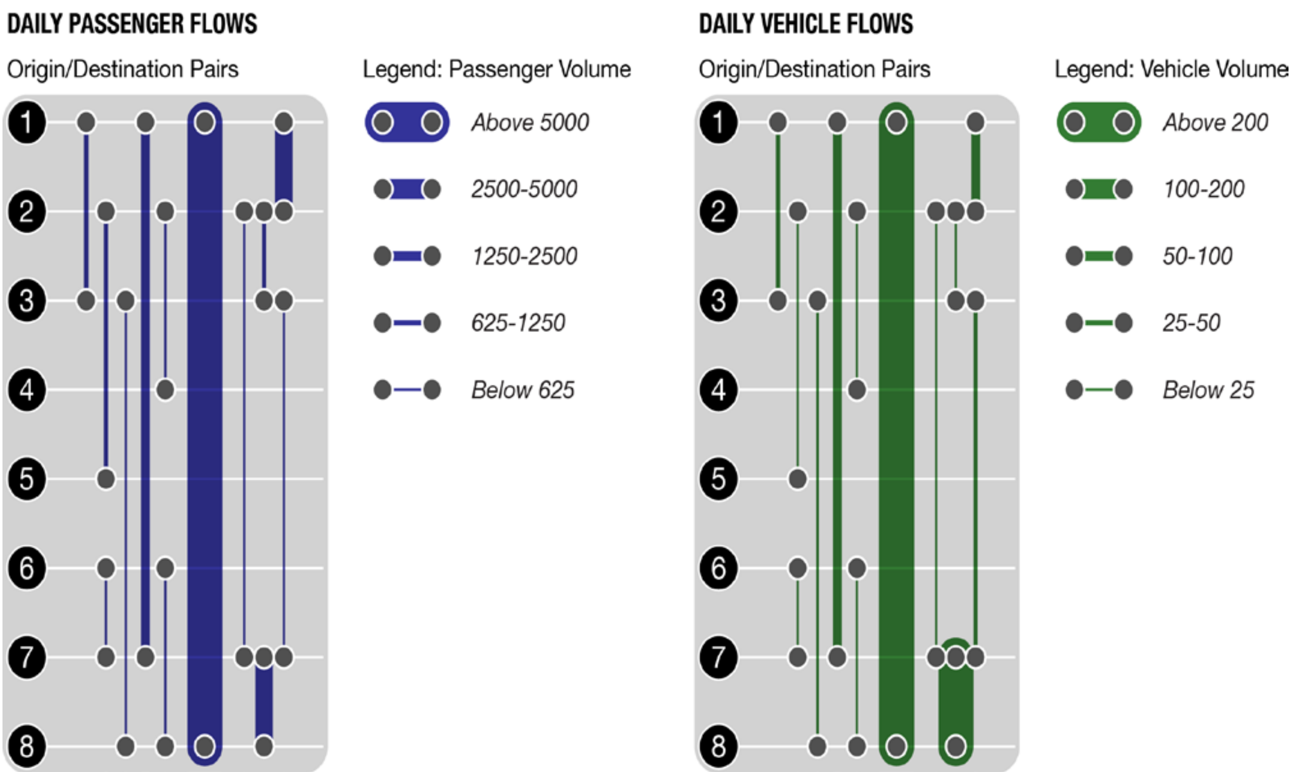
Figure 5-3 shows the different zones used in assessing shuttle trips for this study, while Figure 5-4 shows the overall daily flows of passengers and vehicles between each zone. Detailed data tables and other information are provided in the appendix.

Figure 5-3: Corridor Zones for Shuttle Census Data



Source: Cambridge Systematics, with data from MTC and Bay Area Council Request for Private Bus Service Data on US 101 Corridor.

Figure 5-4: Private Shuttle Daily Passenger and Vehicle Flows between Zones



Source: Cambridge Systematics, with data from MTC and Bay Area Council Request for Private Bus Service Data on US 101 Corridor.

CHAPTER 6: INTELLIGENT TRANSPORTATION SYSTEMS: CORRIDOR ASSETS AND INVENTORY

This section consolidates data from a range of sources related to available infrastructure and programs on the corridor to support ATM and TDM strategies. The specific assets that have been identified for consideration in this inventory discussion are:

- Transportation System Management Assets
  - Ramp Meters
  - Dynamic Message Signs
  - Freeway Service Patrol
- Transportation Demand Management Assets
  - Ridesharing Programs
  - Bus/Transit Programs
  - Bicycle Programs
- Supporting ITS Infrastructure
  - Traffic Detection
  - CCTV Locations
  - Fiber Communications
- Major corridor origins and destinations
  - Population and Employment Centers
  - Transit Hubs and Centers
  - Other Activity Centers

6.1 Transportation System Management Assets

Ramp metering is implemented on the majority of US 101 in both directions, with notable gaps in the vicinity of Mountain View on the northbound side, central San Jose on the southbound side, and San Francisco in both directions. There is a total of 144 ramp meters on the corridor, with 83 in Santa Clara County and 61 in San Mateo County. With respect to ramp metering timing plans, all metered locations in Santa Clara County on the southbound side are active during the PM Peak while all locations on the northbound side are active during the PM Peak. In contrast, in San Mateo County, all but two locations (i.e., northbound and southbound at Willow Rd) are active during both peak periods regardless of freeway direction. HOV by-pass lanes are available at the majority of metered entrance ramps in Santa Clara County (50 out of 83), but at only a minority of metered locations in San Mateo County (16 out of 61). Gaps in the Santa Clara County on-ramp metering system are being pursued for activation in the near future. This includes SCL-101 Northbound in the Mountain View/Palo Alto area between Fair Oaks Avenue (in Sunnyvale) and the San Mateo/Santa Clara County Line. A map of all metered locations by configuration is available in the appendix.

Dynamic message signs are located throughout the US 101 corridor on both sides of the freeway, with 10 on the northbound side and 13 on the southbound side. This translates into an average spacing of 5.7 miles on the northbound side and 4.4 miles on the southbound side. The largest gaps in dynamic message sign coverage are between Lafayette St and Embarcadero Rd on the northbound side (11.5 miles), and between Coyote Rd and Lawrence Expressway on the southbound side (13.6 miles). To provide optimal support for informed decision making by drivers in real time, these message signs would generally be deployed such that at least one sign is present in advance of each major decision point (i.e., junction) on either direction of the freeway corridor. Table 6-1 summarizes the availability of dynamic message signs in advance of such locations along the corridor, when considering all freeway routes as significant decision points. A map of all dynamic message sign locations is available in the appendix.

Table 6-1: Availability of Dynamic Message Signs in Advance of Decision Points

Decision Point	Availability of Dynamic Message Signs
SR 85 in South San Jose	Both directions
I-680/I-280	Northbound direction only.
I-880 & SR 87 Vicinity	Southbound direction only.
SR 237 & SR 85 in Mountain View	Both directions
SR 84	Both directions
SR 92	Both directions
I-380	Both directions
I-280 in San Francisco	Both directions
I-80 in San Francisco	Both directions

Freeway service patrol (FSP) provides basic vehicle repair and towing services to motorists with disabled vehicles on the highway, as a joint effort between MTC, Caltrans, and California Highway Patrol.[15] The US 101 analysis corridor is covered by five separate FSP beats, as summarized in Table 6-2. Among the types of assistance provided are: mechanical problems (14.3%), roadway debris (14.4%), flat tires (13.7%), vehicle collisions (9.3%), fuel needs (8.4%), abandoned vehicle (6.5%), overheating (4.3%), and miscellaneous problems (29.0%).[16] Additional FSP coverage and assistance density maps are provided in the appendix.

Table 6-2: Freeway Service Patrol Coverage Data for US 101

Segment	FSP Beat Number	Hours of Coverage	Assist Rate (Assists per Hour for Entire Beat)
US 101 in San Francisco	11	6 AM to 7 PM*	0.54
North San Mateo County Border to Millbrae Av	6	6 AM to 7 PM	0.79
Millbrae Av to SR 92	7	6-10 AM, 3-7 PM	0.46
SR 92 to Ellis St	10	6:30-10:30 AM, 3-7 PM	0.59
Ellis St to Blossom Hill Rd	8	6-10 AM, 3-7 PM	0.67

Source: http://www.fsp-bayarea.org.
**North of I-280 is on-call service.*

6.2 Transportation Demand Management Assets

Several programs are available along the corridor to facilitate and encourage the use of transit, non-motorized transportation, and other alternative modes of travel. These include strategies for facilitating

[15] http://www.fsp-bayarea.org/about-us.
[16] http://www.fsp-bayarea.org/statistics.

ridesharing, strategies for encouraging transit use, and strategies oriented toward bicycle roadway users. A summary of major projects and programs in each of these categories is provided in Table 6-3.

Table 6-3: Overview of Transportation Demand Management Projects and Programs

Mode	Projects and Programs
Bicycle and Pedestrian Roadway Users	• Santa Clara County has a countywide bicycle plan that establishes a network of continuous, complete bikeways across the county, and identifies ways to make it easier for people to use their bike with transit.[17] • San Mateo County has established a Countywide Bike Network of regionally significant bike routes in its Comprehensive Bicycle and Pedestrian Plan.[18] • San Francisco has a 2009 SFMTA Bicycle Plan,[19] a Bicycle Advisory Committee,[20] a Bicycle Coalition,[21] and support from MTC for bicycle- and pedestrian-oriented planning activities.[22] • A study of bicycle infrastructure needs and route deficiencies on the peninsula is underway, with the goal of developing a regional bike plan/vision along with recommendations for priority bicycle facility investments.[23] • Google Maps provides a bicycle network overlay for the Bay Area through its web interface. It also offers bicycle route guidance and pedestrian route guidance when providing users with directions. • Menlo Park is evaluating dedicated bike lanes on El Camino Real as part of its El Camino Real Corridor Study. More details are available in the project summary in the Related Projects section. • Palo Alto's California Avenue Transit Hub Corridor Project will improve the pedestrian environment on El Camino Real in the vicinity of California Avenue. More details are available in the City of Palo Alto project summaries in the Related Projects section. • Palo Alto's Embarcadero Road/El Camino Real Corridor and Intersection Improvements Project will improve the pedestrian environment on El Camino Real in the vicinity of Embarcadero Rd. More details are available in the City of Palo Alto project summaries in the Related Projects section. • Palo Alto's Quarry Road Improvements and Transit Center Access Project will improve the pedestrian environment on El Camino Real in the vicinity of Quarry Rd. More details are available in the City of Palo Alto project summaries in the Related Projects section. • The US 101/Willow Road Interchange project will improve bicycle and pedestrian facilities at this freeway crossing. More details are available in the project summary in the Related Projects section. • The US 101/Holly St Interchange project will improve bicycle and pedestrian facilities at this freeway crossing. More details are available in the project summary in the Related Projects section.
Ridesharing	• Carpool-matching apps such as Scoop, Waze Carpool, and RideScout are available in the Bay Area to facilitate matching commuters to available carpools. • Research into ridesharing incentives has identified several strategies for encouraging ridesharing, including cost incentives (discounts or rewards), free rides, and provisions for transportation service during unforeseen circumstances or emergencies.[24] • San Mateo County is working to identify and implement incentives for ridesharing.[25]

[17] http://www.vta.org/projects-and-programs/planning/bike-plan.

[18] http://ccag.ca.gov/wp-content/uploads/2014/07/CBPP_Main-Report__Sept2011_FINAL.pdf.

[19] https://www.sfmta.com/projects-planning/projects/2009-san-francisco-bicycle-plan.

[20] http://sfgov.org/bac/.

[21] https://www.sfbike.org/.

[22] http://mtc.ca.gov/our-work/plans-projects/bicycle-pedestrian-planning.

[23] http://www.jointventure.org/index.php?option=com_content&view=article&id=1404.

[24] pointC concept paper follow-up activities for transportation demand management on the US 101 corridor.

[25] http://www.commute.org/get-rewarded/apply-for-carpool-incentives.

Mode	Projects and Programs
Transit	• Ride-finding apps such as Lyft and Uber are available in the Bay Area for fulfilling last-mile connections to origins and destinations. • Caltrans maintains two park-and-ride lots along the corridor, at US 101/SR 92 and at US 101/3rd Ave. The 3rd Avenue surface lot offers only 13 parking spaces, while the SR 92 surface lot offers 174. Neither of these two parking lots offers bicycle lockers.[26] • Google Maps provides transit agency data in the Bay Area when providing users with directions. • SamTrans is evaluating the potential of increasing express bus service in San Mateo County on US 101 as part of its SamTrans Express Bus Study. More details are available in the project summary in the Related Projects section. • Additional bus service to ferry terminals may attract more transit riders, as proposed through an arrangement with Prop SF. More details are available in the Bay Area Council TDM Strategies project summary in the Related Projects section. • Palo Alto's Quarry Road Improvements and Transit Center Access Project will provide improvements to transit stops and facilities in the vicinity of the Palo Alto Intermodal Transit Center. More details are available in the City of Palo Alto project summaries in the Related Projects section.

6.3 Supporting ITS Infrastructure

Traffic speed and volume data are continually collected and archived along the US 101 corridor through Caltrans' publicly available PeMS database.[27] For each detector, a quality measure is also provided that indicates the extent to which that detector reported realistic data for a given time period. This quality measure is reported on a percent scale, where 100% indicates that all data from the detector appeared to be valid, while a rating of 0% indicates that the detector provided no realistic data during the time period of interest. Furthermore, as detectors are frequently being added or removed from the database as detectors are installed or become non-functional, there are additional detector locations for past time periods that are no longer available at present. Table 6-4 summarizes the number of detectors by direction along the corridor that are actively providing realistic data between 0% and 100% of the time, along with the number of detectors that are currently not active in the database but have been in the past. A map is provided in the appendix that shows these detector locations graphically.

Table 6-4: Summary of Detection on US 101 by Data Quality

Detector Status	Northbound	Southbound
No longer activated	52	46
Activated but not reporting data	32	28
Reporting data 1-25% of the time	5	5
Reporting data 26-50% of the time	11	8
Reporting data more than 50% of the time	101	101

When considering only those detectors with at least a 25% reporting rate, there are 112 in the northbound direction for an average coverage of 2.0 detectors per mile, and 109 in the southbound direction for an average coverage of 1.9 detectors per mile. The locations of significant gaps in data are shown in Table 6-5, where a gap of at least 1.5 miles between consecutive detectors was considered significant.

[26] http://www.dot.ca.gov/d4/parkandride/.

[27] http://pems.dot.ca.gov/.

Table 6-5: Locations with Detector Spacing Larger than 1.5 Miles on US 101

Approximate Location of Gap	County	Length of Detection Gap*
	Northbound Direction	
San Antonio Rd	Santa Clara	3.46
SR 237	Santa Clara	2.26
Story Rd	Santa Clara	1.93
Yerba Buena Rd	Santa Clara	1.77
McKee Rd	Santa Clara	1.624
I-80	San Francisco	1.61
Fair Oaks Av	Santa Clara	1.59
Marine Pkwy	San Mateo	1.52
	Southbound Direction	
McKee Rd	Santa Clara	2.624
San Antonio Rd	Santa Clara	2.39
Tully Rd	Santa Clara	2.28
I-80	San Francisco	2.279
Blossom Hill Rd	Santa Clara	2.072
Brokaw Rd	Santa Clara	1.86
Marine Pkwy	San Mateo	1.76
Bernal Rd	Santa Clara	1.66
Capitol Expwy	Santa Clara	1.62

**When considering only those detectors with at least a 25% reporting rate.*

CCTV cameras provide traffic monitoring capability to support management and verification of real-time conditions and ATM/TDM measures. Cameras typically include support for changing the horizontal and vertical angle of the image, as well as adjusting the extent of magnification. In the absence of physical obstructions, a camera may enable real-time monitoring of ½ mile in either direction through the adjustment of these camera controls. Because cameras typically support rotational movement, they can be used to monitor either direction of the roadway rather than being limited to the physical side on which the CCTV unit is installed. There are 59 deployed CCTV units on the corridor for an average spacing of 0.96 mile between each one. Furthermore, Caltrans has future plans to deploy an additional 39 CCTV units along this corridor, bringing the average spacing down to 0.58 miles. Current locations along the corridor where the spacing between consecutive CCTV units exceeds 1 mile are shown in Table 6-6. A map of all existing and planned CCTV locations on the corridor is provided in the appendix.

There is currently one section of US 101 that has fiber communications installed: University Ave to Woodside Rd in San Mateo (4.5 miles), deployed as part of the San Mateo Smart Corridor project. Additional sections of US 101 have 11.7 miles of empty conduit for future fiber communications, bringing the current and potential near-term future coverage to a total of 16.2 miles along the corridor. A map of current and potential future fiber locations is provided in the appendix.

Table 6-6: Locations with CCTV Spacing Larger than 1 Mile on US 101

Approximate Location of Gap	County	Length of CCTV Gap
SR 92	San Mateo	4.1
Whipple Av	San Mateo	3.1
South Brisbane	San Mateo	3.0
Tully Rd	Santa Clara	2.8
SFO Airport	San Mateo	2.7
South of Hellyer Av	Santa Clara	2.0
South of Woodside Rd	San Mateo	1.8
I-280	San Francisco	1.7
University Ave	San Mateo	1.7
Taylor St	Santa Clara	1.6
North of San Antonio Rd	Santa Clara	1.6
Anza Bl	San Mateo	1.5
South of Blossom Hill Rd	Santa Clara	1.4
North Brisbane	San Mateo	1.2
Mission College	Santa Clara	1.2
North of Holly St	San Mateo	1.1
I-880	Santa Clara	1.1

Currently in Santa Clara County, Caltrans and the Santa Clara County Valley Transportation Authority are exploring a Memorandum of Understanding to share certain existing and future fiber infrastructure in Santa Clara County, though no agreement has been formalized yet. This proposed arrangement would include communications to TOS elements and Express Lane Toll Operations infrastructure. From a planning perspective, Caltrans District 4 has a Fiber Communications Master Plan that envisions future fiber optic communications for TOS elements along the entire analysis corridor (on US 101).[28]

6.4 Major Origins and Destinations

A high-level spatial analysis of data from the 2015 MTC Bay Area Travel Model can be used to obtain insight into where travelers may be starting and ending their trips on the corridor. Specifically, the model data can be used to identify areas along the corridor with high densities of population or employment, as these may be reasonably expected to correlate with increased trip production and attraction rates. These data show concentrations of population along the corridor in the vicinity of San Francisco, central San Jose, central Mountain View, and southern Redwood City. These data also show concentrations of employment in the vicinity of San Francisco, central San Jose, and around the Central Expwy in Santa Clara. Detailed maps of these population and employment density data for the entire corridor are provided in the appendix.

Transit centers and stations are common additional centers of activity as well, and in the context of the US 101 Corridor, such locations include BART stations, Caltrain stations, and VTA light rail stations. Maps of

[28] Email communication with Mark Powers, Senior Engineer, TOS Development 'B' Branch, Caltrans District 4. 11/22/2016.

all three agency rail networks and their associated stations are available in the appendix for the chapter on transit.

Finally, the Grand Boulevard Initiative Existing Conditions Report identified several key destinations along the corridor in addition to major transit centers and stations, as listed below. These were focused on El Camino Real and generally included shopping centers, other commercial districts, and civic centers.[29]

- Daly City "Top of the Hill"
- Commercial District on Broadway and El Camino Real, Millbrae
- The Shops at Tanforan, San Bruno
- Broadway, Burlingame
- Downtown San Mateo
- Hillsdale Shopping Center, San Mateo
- Village Center, Belmont
- Laurel Street, San Carlos
- Downtown Redwood City and Sequoia Shopping Center, Redwood City
- Downtown Menlo Park
- Stanford Shopping Center, Palo Alto
- University Avenue, Palo Alto
- California Avenue, Palo Alto
- San Antonio Shopping Center, Mountain View
- Castro Street, Mountain View
- Commercial District on The Alameda, San Jose

[29] Grand Boulevard Initiative Existing Conditions Report, November 2011.

CHAPTER 7: RELATED PROJECTS

To provide additional background and context for identifying relevant ATM/TDM strategies for improving corridor performance on US 101 between San Jose and San Francisco, this chapter presents a high-level scan of several projects and programs on or near US 101 that are expected to have an impact on the freeway and/or nearby arterials. The major projects that have been identified for consideration in this assessment are:

1. San Mateo Smart Corridor Project
2. Menlo Park El Camino Real Corridor Study
3. SamTrans Express Bus Study
4. San Mateo 101 Managed Lanes Project
5. Bay Area Council TDM Strategies
6. City of Palo Alto Projects
7. Grand Boulevard Initiative
8. Caltrans Capital Improvement Interchange Projects including:
    a. US 101/SR-84 Woodside Road Interchange
    b. US 101/Willow Road Interchange
    c. US 101/Broadway Interchange
    d. US 101/Holly Street Interchange
    e. US 101/SR-85 (Stevens Creek Freeway) Express Lanes Project (Phase 3)
    f. US 101/Zanker Road Interchange
    g. US 101/Blossom Hill Road Interchange
9. The Caltrain Electrification Project

For most of these projects, the following information is provided whenever the information was reasonably available:

- Project Overview
- Expected Start Date and Expected Date of Completion.
- Approximate extents of the project.
- Expected significant direct mobility/safety impacts to the US 101 corridor, based on the available project information (these may be found most readily in press releases or other material intended for public audiences.)
- Expected direct mobility/safety impacts to the El Camino Real corridor.

7.1 San Mateo Smart Corridor Project

This project enables corridor stakeholders (e.g., Caltrans, cities, and the County) to implement traffic management strategies through the deployment of ITS elements (i.e., traffic signal upgrades, directional signs, fixed or pan-tilt-zoom CCTVs, communications infrastructure, arterial dynamic message signs, vehicle detection systems, Center-to-Center communications between San Mateo County Hub and District 4 TMC, power supply line and equipment) along state routes and major local streets. During major collisions, this Smart Corridor project is intended to enable Caltrans to control and optimize traffic signal phasing on predetermined routes to improve traffic flow around the collision. During normal operations, the Smart Corridor project allows the corridors to be coordinated and monitored to optimize traffic flow along

El Camino Real and local city streets.[30] Table 7-1 provides a summary of potential significant impacts of the project on the US 101 Corridor. A project map is included in the appendix.

Table 7-1: Overview of San Mateo Smart Corridor Project Impacts on the US 101 Corridor

Key Dates	Project initiated 2008. Construction started 2011. Construction completed November 2016.
Project Extents	The project is located along predefined designated arterial routes, parallel to US-101, connecting US-101 to El Camino Real including but not limited to SR 82 (El Camino Real) between I-380 and the Santa Clara County line.[31]
Expected significant direct mobility/safety impacts to US 101	• Improve traffic flow in the case of an accident on US 101 between SR 92 and Hillsdale Boulevard using optimized traffic signal phasing on predetermined diversion routes. • Enable coordinated operations among agencies along US 101 and SR 82 (El Camino Real) corridor such as remote control of signals, traffic information and monitoring in the project area and shared access of real time traffic video and monitoring by Caltrans, cities and the County.
Expected significant direct mobility/safety impacts to El Camino Real	• Enable normal operations to be coordinated and jointly monitored to optimize traffic flow along El Camino Real and local arterials. • Help direct traffic to relieve congestion to the San Mateo Event Center for scheduled events. • Improve sharing of resources between agencies for more unified transportation management operations across jurisdictions.
Sources	• San Mateo County Smart Corridor Construction Completion Press Release[32] • County of San Mateo Public Works San Mateo County Smart Corridors Project[33] • City of San Mateo SMART Corridor[34] • U.S. 101/San Mateo County Smart Corridor Project presentation[35]

7.2 Menlo Park El Camino Real Corridor Study

The City of Menlo Park is conducting a study to review potential transportation and safety improvements to El Camino Real. This study will consider alternatives the following alternatives: (1) continuous three lanes between Encinal Avenue and Roble Avenue, (2) buffered bike lanes, or (3) separated bicycle facility between Sand Hill Road and Encinal Avenue, and will evaluate potential impacts to traffic, active transportation, safety, parking and aesthetics.[36]

Table 7-2 provides a summary of potential significant impacts of the project on the US 101 Corridor.

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30 http://publicworks.smcgov.org/san-mateo-county-smart-corridors-project.

31 http://publicworks.smcgov.org/san-mateo-county-smart-corridors-project.

32 http://ccag.ca.gov/wp-content/uploads/2016/11/CCAG-Press-Release-Smart-Corridor.pdf.

33 http://publicworks.smcgov.org/san-mateo-county-smart-corridors-project.

34 http://www.cityofsanmateo.org/index.aspx?NID=2186.

35 http://www.itscalifornia.org/Content/AnnualMeetings/2013/PRESENTATIONS/Tue%20Tech%20Session%204%20-%20San%20Mateo%20Smart%20Corridor%20ITS%20CA%20Presentation-%20Final-%20Nozarri.pdf.

36 https://www.menlopark.org/698/El-Camino-corridor-study.

Table 7-2: Overview of Menlo Park El Camino Real Corridor Project Impacts on the US 101 Corridor

Key Dates	The corridor study concluded in June 2015. In August 2015, the council unanimously approved a one-year pilot project that would replace all of the parallel car parking on the city's 1.5-mile section of El Camino with either buffered or separated bike lanes. However, since then, the project has been delayed multiple times.
Project Extents	El Camino Real within Menlo Park city limits
Expected significant direct mobility/safety impacts to US 101	*None.*
Expected significant direct mobility/safety impacts to El Camino Real	• The expected mobility and safety outcomes associated with this project depend significantly on which alternative is eventually selected.
Sources	• W-Trans El Camino Real Corridor Study final report[37] • City of Menlo Park El Camino Real Corridor Study FAQs[38] • Menlo Park El Camino Real Bike Lanes Delayed Again article[39]

7.3 SamTrans Express Bus Study

The SamTrans US-101 Express Bus Feasibility Study will examine the financial and operational feasibility of a network of long-distance express buses operating on US-101 through San Mateo County, potentially integrated with a managed lane.[40] The study will work in partnership with San Francisco and Santa Clara counties as well.

Table 7-3 provides a summary of potential significant impacts of the project on the US 101 Corridor.

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[37] https://www.menlopark.org/DocumentCenter/Home/View/7805.

[38] https://www.menlopark.org/Faq.aspx?QID=181.

[39] http://sf.streetsblog.org/2016/06/23/menlo-park-el-camino-real-bike-lanes-delayed-again/.

[40] http://www.samtrans.com/Planning/Planning_and_Research/US-101_Express_Bus_Feasibility_Study.html.

Table 7-3: Overview of SamTrans Express Bus Project Impacts on the US 101 Corridor

Key Dates	The study will begin in 2017.
Project Extents	To be determined.
Expected significant direct mobility/safety impacts to US 101	• Decrease travel time for commuters by utilizing HOV or managed lanes on US 101. • Slightly improved travel time for general purpose traffic, due to the expected reduction in the number of single-occupant vehicles that may have shifted to public transportation. • Potential increase in travel time for HOV or managed lane users, due to additional bus traffic.
Expected significant direct mobility/safety impacts to El Camino Real	• Potential for increased congestion on arterials, depending on the express bus pick-up locations.
Sources	• SamTrans US-101 Express Bus Feasibility Study[41] • Green Caltrain blog[42]

7.4 San Mateo 101 Managed Lanes Project

The purpose of this proposed project is to provide a continuous lane in each direction on US 101 from the terminus of the Santa Clara County Express Lanes to I-380 in northern San Mateo County that would be managed in real time to achieve maximum efficiency and operations. Project Sponsors are considering a range of alternatives that include a combination of converting existing High Occupancy Vehicle (HOV) lanes to Express Lanes, and the addition of new Express Lanes on US 101 between Whipple Road to the I-380 interchange in San Mateo County. The project scope may include removing or replacing existing auxiliary lanes between interchanges; reconstructing ramp connections to US 101; and installing electronic toll collection infrastructure.[43]

Table 7-4 provides a summary of potential significant impacts of the project on the US 101 Corridor.

[41] http://www.samtrans.com/Planning/Planning_and_Research/US-101_Express_Bus_Feasibility_Study.html.

[42] http://www.greencaltrain.com/2016/08/samtrans-to-study-express-bus-service-on-101/.

[43] http://www.dot.ca.gov/d4/101managedlanes/.

Table 7-4: Overview of San Mateo 101 Managed Lanes Project Impacts on the US 101 Corridor

Key Dates	Product scoping meeting was conducted in Fall 2016. Environmental report approval is scheduled for Fall 2018.
Project Extents	The Southern Segment of the San Mateo 101 Managed Lanes Project would begin at the end of the Santa Clara County Express Lanes at Matadero Creek and extend to Whipple Avenue Interchange in San Mateo County. This Southern Segment would involve the conversion of an existing HOV lane to an Express Lane. The Northern Segment on US 101 is from the Whipple Avenue Interchange in San Mateo County to north of the I-380 Interchange. This Northern Segment would involve the addition of a new managed lane.
Expected significant direct mobility/safety impacts to US 101	Express Lanes projects in general have the potential to: • Reduce congestion in the corridor. • Improve travel time reliability for all users. • Increase sustainability of existing general purpose lanes. • Increase person throughput. • Produce longer queues at bottlenecks downstream of the end of the lanes due to increased section throughput. • Generate negative construction-related impacts on the corridor during the project itself.
Expected significant direct mobility/safety impacts to El Camino Real	*None*
Sources	• SM 101 Managed Lanes Project Meeting Notice[44] • Caltrans SM 101 – Managed Lanes Project[45] • SM 101 Managed Lanes Project presentation[46]

7.5 Bay Area Council TDM Strategies

This project seeks to expand ferry service to the Peninsula and South Bay. The Bay Area Council's Water Transit Committee met with the Port of Redwood City in November 2016, which gave a thorough update on its plans to move forward with the development of a ferry terminal that will be designed to support both private service in the near term and public service in the long term. The committee also heard a presentation from Prop SF, a private ferry business that will begin high speed private ferry service to Redwood City in January. Prop SF also announced at the meeting a new partnership with Chariot, the private bus service, which will provide first and last mile connections to and from terminals for commuters choosing the commute on the water.[47]

Table 7-5 provides a summary of potential significant impacts of the project on the US 101 Corridor.

[44] https://sanbruno.ca.gov/civicax/filebank/blobdload.aspx?BlobID=27404

[45] http://www.dot.ca.gov/d4/101managedlanes/

[46] http://www.dot.ca.gov/d4/101managedlanes/docs/rev_sm-101-mlp-scoping-meeting-presentation-web-version.pdf

[47] http://www.bayareacouncil.org/economy/exciting-news-for-expanding-ferry-service-to-silicon-valley/

Table 7-5: Overview of Bay Area Council TDM Project Impacts on the US 101 Corridor

Key Dates	Ferry service from Port of Redwood City to the South Bay is to be determined. Ferry service from San Francisco to Redwood City was expected to begin as early as January 2017.
Project Extents	Port of Redwood City to South Bay. Port of Redwood City to San Francisco, Berkeley, or Alameda.
Expected significant direct mobility/safety impacts to US 101	• Commuters switching to the new ferry service may result in lower traffic volumes on US 101 in both directions, with the additional possibility of increased traffic volumes near the Port of Redwood City.
Expected significant direct mobility/safety impacts to El Camino Real	• Potential for an increase in the number of buses along this corridor which will be used for first/last mile connections with the Port of Redwood City and other ferry pick up/drop off locations. No new shuttle routes confirmed yet.
Sources	• Exciting news for expanding ferry service to Silicon Valley[48] • Prop SF planned new routes[49]

7.6 City of Palo Alto Projects

The City of Palo Alto is working on the following projects which intersect with El Camino Real:

- **California Avenue – Transit Hub Corridor Project:** The California Avenue Transit Hub Corridor Streetscape Improvements Project provides streetscape and utility improvements along California Avenue that include sidewalk widening to accommodate wider pedestrian scale lighting, traffic calming treatments, a reduction from four lanes to two lanes of travel, and improvements to the Park Boulevard Project.

- **Embarcadero Road/El Camino Real Corridor and Intersection Improvements Project:** Improvements may include, but are not limited to: traffic signal modifications, sidewalk realignment, high visibility crosswalks, signing and striping, bicycle treatments, landscaping and traffic calming elements. This project will also examine bicycle/pedestrian connection opportunities using the existing multi-use trail adjacent to the Caltrain tracks which crosses over Embarcadero Road, rather than the current crosswalk between Town and Country and Paly.
- **Quarry Road Improvements and Transit Center Access Project:** Improvements to and within the public right of way to enhance the pedestrian and bicycle connection from the west side of El Camino Real to Welch Road and the Palo Alto Intermodal Transit Center, including way finding, wider bicycle lanes, as necessary on Quarry Road, enhanced transit nodes for bus and/or shuttle stops, prominent bicycle facilities, lighted pedestrian pathway, and other landscaping improvements.

Table 7-6 provides a summary of potential significant impacts of these projects on the US 101 Corridor.

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[48] http://www.bayareacouncil.org/economy/exciting-news-for-expanding-ferry-service-to-silicon-valley/.
[49] http://www.propsf.net/public-commuter/.

Table 7-6: Overview of Palo Alto El Camino Real Master Planning Impacts on the US 101 Corridor

Key Dates	Construction for the Quarry Road Improvements and Transit Center Access Project is tentatively scheduled to begin early Fall 2016 with construction completion of Spring 2017.
Project Extents	• The California Avenue Transit Hub Corridor Project is along California Avenue, between El Camino Real and the California Avenue Caltrain Station. • The Embarcadero Road/El Camino Real Corridor and Intersection Improvements Project is focused on that specific intersection. • The Quarry Road Improvements and Transit Center Access Project follows Quarry Rd from El Camino Real to Welch Road and the Palo Alto Intermodal Transit Center.
Expected significant direct mobility/safety impacts to US 101	*None*
Expected significant direct mobility/safety impacts to El Camino Real	• The California Avenue Transit Hub Corridor Project may increase pedestrian volumes on El Camino Real in the vicinity of California Avenue. • The Embarcadero Road/El Camino Real Corridor and Intersection Improvements Project may increase pedestrian and bicycle volumes on El Camino Real in the vicinity of Embarcadero Road, and may result in slower travel times through the area due to traffic calming. • The Quarry Road Improvements and Transit Center Access Project may increase pedestrian and bicycle volumes on El Camino Real in the vicinity of Quarry Road.
Sources	• El Camino Real Master Planning Study[50] • City of Palo Alto transportation project list[51]

The City of Palo Alto also completed its El Camino Real Master Planning Study in 2007, though this was not adopted by City Council. The Master Plan applied concepts of Context Sensitive Design (CSD) and multi-modal transportation planning to El Camino Real. The project goal was to support El Camino Real's role as a regional north/south arterial on the Peninsula, allow for increased multi modal transportation in El Camino Real, and position the corridor for federal, State, and other funding opportunities. The project promoted safety on the corridor through designs that discourage excessive speeds by vehicular traffic.[52]

7.7 Grand Boulevard Initiative

The Grand Boulevard Initiative seeks to create people-friendly places along the El Camino Real corridor, through projects that establish safer environments for pedestrians and other non-motorized users. The Grand Boulevard Initiative is currently assembling a list of relevant projects, though this list has not yet been released.[53]

Table 7-7 provides a summary of potential significant impacts of the project on the US 101 Corridor.

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50 http://www.cityofpaloalto.org/civicax/filebank/documents/14213.

51 http://www.cityofpaloalto.org/gov/depts/pln/transit/projects.asp.

52 http://www.paloaltocompplan.org/ExistingConditions/8/files/basic-html/page29.html.

53 http://www.grandboulevard.net/projects/gbi-project-list (accessed 12-12-2016).

Table 7-7: Overview of Grand Boulevard Initiative Project Impacts on the US 101 Corridor

Key Dates	The Grand Boulevard Initiative is a long term, incremental project that will be implemented city-by-city.
Project Extents	The 43-mile stretch of the El Camino Real roadway between Daly City and downtown San Jose as well as the ½-mile area of surrounding streets and neighborhoods on either side of the roadway.
Expected significant direct mobility/safety impacts to US 101	*To be determined.*
Expected significant direct mobility/safety impacts to El Camino Real	• One of the main project goals is to make El Camino Real less car-centric. Projects will be geared towards improving the safety of biking and walking and making public transportation faster and more convenient. This may result in lower vehicular traffic volumes and associated capacity, particularly during peak traffic times.
Sources	• Grand Boulevard Initiative website[54]

7.8 US 101/Willow Road Interchange

This improvement project addresses the operational deficiencies of the interchange by eliminating traffic weaving and provide adequate storage on the off-ramps. The project is expected to:

- Reconstruct the overcrossing to provide eight lanes, sidewalks, and bike paths
- Realign and widen the diagonal off-ramps to provide additional storage, HOV bypass lane(s), and construct signalized intersections at the realigned diagonal off-ramp terminals
- Close the existing loop off-ramps
- Realign and widen the southbound loop on-ramp to provide two mixed flow lanes
- Install or modify existing ramp metering system
- Modify and realign frontage roads adjacent to the overcrossing

Table 7-8 provides a summary of potential significant impacts of the project on the US 101 Corridor.

[54] http://www.grandboulevard.net/.

Table 7-8: Overview of the US 101 Willow Road Interchange Project Impacts on the US 101 Corridor

Key Dates	Construction scheduled for 2016-2018.
Project Extents	US 101/Willow Road Interchange
Expected significant direct mobility/safety impacts to US 101	• Improving overall operation and safety of the interchange by elimination of the weaving movements at this interchange and metering entrance flows. • Travel time on 101 and Willow Road will be reduced as a result of improved traffic flow through the interchange. • Accessibility of the Dumbarton Bridge from US 101 will be improved. • New overcrossing built to current seismic and design standards replaces a 60-year-old structure.
Expected significant direct mobility/safety impacts to El Camino Real	*None.*
Sources	• US 101/Willow Road Project[55]

7.9 US 101/Broadway Interchange

The project will provide improvements to US-101 entrances and exits at Broadway, Rollins Road, Bayshore Highway, and Airport Boulevard. The arterial overcrossing will also be widened, and nearby arterials will be realigned.[56] A diagram of the anticipated interchange improvements is provided in the appendix.

Table 7-9 provides a summary of potential significant impacts of the project on the US 101 Corridor.

[55] http://www.smcta.com/Assets/__Agendas+and+Minutes/TA/Board+of+Directors/Presentations/2016/2016-02-04+TA+BOD+US+101-Willow+Rd+Project.pdf.

[56] https://www.burlingame.org/index.aspx?page=3481#.

Table 7-9: Overview of the US 101 Broadway Interchange Project Impacts on the US 101 Corridor

Key Dates	Construction started September 2014 and is scheduled to be completed by the fall of 2017.
Project Extents	This project consists of the reconstruction of the existing Broadway/US-101 interchange.
Expected significant direct mobility/safety impacts to US 101	• Reconfiguration of all ramp connections to US-101 in the north and southbound directions and the installation of ramp meters on the north and southbound on-ramps to US-101 will reduce traffic congestion. • Improve performance of the Broadway Interchange by improving traffic movements and access around the interchange. • Caltrans' de-construction of the existing Broadway overcrossing and construction of new approaches causes highway lane closures on US 101. Traffic will be detoured onto nearby local streets. Various lane and ramp closures will also be necessary for this work. Changeable message signs will be in place 3 days prior to closing.
Expected significant direct mobility/safety impacts to El Camino Real	*None.*
Sources	• City of Burlingame, Broadway – US 101 Interchange Reconstruction Project[57] • US 101/Broadway Interchange Project general information presentation[58] • 9/28/16 Construction Update[59]

7.10 US 101/Holly Street Interchange

The project will convert the existing full cloverleaf configuration to a partial cloverleaf design by eliminating two of the existing loop off-ramps of the interchange, and realign the diagonal entrances and exits into signalized T-intersections with local streets. Pedestrian and bicycle improvements will also be provided on Holly Street.[60]

Table 7-10 provides a summary of potential significant impacts of the project on the US 101 Corridor.

[57] https://www.burlingame.org/index.aspx?page=3481#.

[58] https://www.burlingame.org/modules/showdocument.aspx?documentid=11672.

[59] http://www.dot.ca.gov/d4/newsreleases/US101BROADWAYCONSTRUCTIONUPDATE-9-28-16.pdf.

[60] http://www.cityofsancarlos.org/civicax/filebank/blobdload.aspx?blobid=12157.

Table 7-10: Overview of the US 101 Holly Street Interchange Project Impacts on the US 101 Corridor

Key Dates	Summer 2015 start date, spring 2018 estimated completion date.
Project Extents	US 101/Holly Street Interchange
Expected significant direct mobility/safety impacts to US 101	• Reconfiguration of ramp connections to US-101 will eliminate weaving and improve throughput. • Signalization improvements may reduce delays for exiting freeway traffic.
Expected significant direct mobility/safety impacts to El Camino Real	*None.*
Sources	• US 101/Holly Street Pedestrian Overcrossing Project initial study[61] • City of San Carlos US 101/Holly St. Interchange project[62]

7.11 Peninsula Caltrain Electrification

Over the last decade, Caltrain has experienced a substantial increase in ridership and anticipates further increases in ridership demand as the Bay Area's population grows. The Caltrain Modernization Program, scheduled to be implemented by 2020/early 2021, will electrify and upgrade the performance, operating efficiency, capacity, safety and reliability of Caltrain's commuter rail service.

Table 7-11 provides a summary of potential significant impacts of the project on the US 101 Corridor.

Table 7-11: Overview of the Caltrain Electrification Project Impacts on the US 101 Corridor

Key Dates	Fall of 2017 start date, 2021 estimated completion date.
Project Extents	From Tamien in the south to San Francisco in the north
Expected significant direct mobility/safety impacts to US 101	• Improved train performance is expected to bring increased ridership because of more frequent and/or faster train service to more riders, some of which may come from SOV users on the US 101 freeway corridor.
Expected significant direct mobility/safety impacts to El Camino Real	*None.*
Sources	• Peninsula Corridor Electrification Fact Sheet

[61] http://www.dot.ca.gov/dist4/documents/101-holly-street-pedestrian-overcrossing/hollystpoc_public-review-draftis_dec2015_signed_v7.pdf.

[62] http://www.cityofsancarlos.org/civicax/filebank/blobdload.aspx?blobid=12157.

CHAPTER 8: POTENTIAL MITIGATION STRATEGIES

This chapter presents information for several candidate strategies to address the causes of congestion and crash concentrations identified in the US 101 corridor. Specifically, this chapter explores the following:

- The most significant locations and causes of major bottleneck locations and crash concentrations on the corridor.
- Common traffic management strategies for addressing the types of bottlenecks and crash concentrations present on this corridor.
- Specific relevance of traffic management strategies for various types of crash and bottleneck causes.
- Feasibility considerations for the traffic management strategies introduced in this chapter.
- Typical or documented high-level outcomes of the traffic management strategies introduced in this chapter.

Based on this preliminary analysis, three types of next steps are recommended, including:

- **More Detailed Analysis** to develop an effective and integrated combination of mitigation strategies. The analysis will help decision-makers identify technical and implementation gaps, evaluate different mitigation strategies, and invest in the combination of strategies that would most minimize congestion and produce the greatest benefits. Comprehensive analysis and modeling would increase the likelihood of success and help lower the risk associated with implementation.
- **Stakeholder Engagement** to help build awareness, create partnerships and facilitate the adoption of ATM/ICM and TDM strategies on the US-101 corridor through a series of stakeholder meetings and outreach activities. This can be accomplished by assembling and convening an expert panel of stakeholders that consists of representatives from regional and corridor entities.
- **Development of a Concept of Operations** to define a prioritized set of strategies for deployment on the US-101 corridor. The strategies will primarily consist of ATM/ICM and TDM solutions that can be deployed in the next 3 to 5 years.

8.1 Bottlenecks and Crash Concentrations

To provide context and motivation for the exploration and consideration of various traffic management strategies for US 101, this section provides a high-level summary of the major mobility and safety issues identified on the corridor from Chapters 2 and 4. Specifically, this section lists the major bottlenecks and crash concentrations by general location along the corridor by direction in Table 8-1, based on the results shown previously in Table 2-5, Table 2-6, and Table 4-1. Furthermore, crash concentrations that were associated with corridor bottlenecks as indicated in Table 8-1 have been consolidated into a single row in the Table 8-1 given that the underlying causes of both may be traced to a single issue (i.e., the underlying cause of the bottleneck).

To provide a common metric for combining the safety and mobility impacts, both have been monetized according to the factors available in the latest version of Caltrans' Cal-B/C benefit/cost estimation tool. More precisely, crashes are assumed to have an average cost of $185,600 per occurrence, and delays are assumed to have an hourly cost to travelers of $18.95. Delay costs have been annualized by multiplying the average weekday figures from Table 2 5 and Table 2 6 by a factor of 250, to reflect the number of workdays in a typical year. Analogously, crash costs have been annualized by dividing the three-year collision counts from Table 4 1 by a factor of three, to recover annual rates. The resulting total costs associated with crashes and delays at various locations along the corridor are used to sort the results of Table 8-1 in order of decreasing severity (or magnitude of cost).

Table 8-1: Locations of Major Corridor Delay and Collision Hot Spots, and Associated Annual Impacts

Location	Annual Delay Cost	Bottleneck Causal Factors	Annual Crash Cost	Crash Causal Factors	Annual Total Cost
NB from Cesar Chavez to I-80*	$10,839,400	Capacity/speed reduction(s)	$32,480,000	Congestion at diverge; roadway curvature and terrain	$43,319,400
SB after I-880	$13,681,900	Merge bottleneck	$8,475,733	Merging and weaving of ramp traffic	$22,157,633
NB at SR 92 Exit	$6,997,288	Weave bottleneck	$11,754,667	Unsafe speeds near merge	$18,751,954
SB, south of I-280	$1,823,938	Merge bottleneck	$16,518,400	Rear-end collisions at back of queue	$18,342,338
SB, Willow to Embarcadero	$9,740,300	Weave bottleneck	$7,795,200	Bottleneck-related congestion; weaving section	$17,535,500
SB after SR 92	$5,936,088	Merge bottleneck	$8,475,733	Exiting or entering ramp traffic	$14,411,821
SB at Potrero Hill	N/A		$12,435,200	Roadway curvature and terrain/grade	$12,435,200
NB before I-880	$885,913	Merge bottleneck	$11,074,133	Stop-and-go traffic; weaving of ramp traffic	$11,960,046
SB at SR 87	$2,937,250	Weave bottleneck	$8,413,867	Stop-and-go traffic; unsafe speeds	$11,351,117
SB after Embarcadero Rd	$1,681,813	Merge bottleneck	$8,723,200	Exiting or entering ramp traffic	$10,405,013
SB near Poplar Av	$1,610,750	Horizontal curve	$8,537,600	Merging in advance of lane drop	$10,148,350
NB, Capitol Expwy to Tully Rd	$2,202,938	Merge bottleneck	$7,857,067	Bottleneck-related congestion; diverge bottleneck	$10,060,004
SB at San Antonio Rd	N/A		$8,599,467	Unsafe speeds and merging traffic	$8,599,467
NB at San Antonio Rd	N/A		$7,547,733	Unsafe speeds and merging traffic	$7,547,733
SB at Capitol Expwy	N/A		$7,485,867	Queue spillback from exit ramp	$7,485,867
SB at Great America Pkwy/San Tomas Expwy	$6,324,563	Weave bottleneck	N/A		$6,324,563
NB at Ralston Av/Marine Pkwy	$5,874,500	Merge bottleneck	N/A		$5,874,500
NB, Lawrence Expwy to Fair Oaks Av	$5,287,050	Weave bottleneck	N/A		$5,287,050
SB at Airport Access Rd & Millbrae Av	$2,667,213	Weave bottleneck	N/A		$2,667,213
SB at Willow Entrance	$1,639,175	Merge bottleneck	N/A		$1,639,175
NB at Sierra Point Pkwy	$1,392,825	Merge bottleneck	N/A		$1,392,825
NB at Embarcadero Rd	$1,189,113	Merge bottleneck	N/A		$1,189,113
NB at Trimble Rd	$1,046,988	Merge bottleneck	N/A		$1,046,988
NB at SR 92 Entrance	$933,288	Merge b/n with lane drop	N/A		$933,288

"N/A" indicates either that no crash concentration was identified at the specified location, or that no bottleneck was identified at the specified location.

**This location had two crash concentrations associated with it: one at I-80 (at the downstream end of the bottleneck queue) and one at Cezar Chavez (at the upstream end of the bottleneck queue).*

It should be noted that, as shown in Figure 2-17, approximately 14% of the delay costs are attributable to the delays associated with incidents, such that the total impact of incidents at each location are the sum of 14% of the dollar values in the "Annual Delay Cost" column and the full dollar amounts in the "Annual Crash Cost" column, whereas the approximate non-incident impacts of the bottlenecks at each location are 53.9% of the values shown in the "Annual Delay Cost" column.

8.2 Mitigation Strategy Overview

This section introduces the concepts of active traffic management (ATM), integrated corridor management (ICM), and travel demand management (TDM), and provides an overview of several common strategies across these three categories.

8.2.1 Active Traffic Management (ATM) Strategies

Active traffic management (ATM) strategies are designed to be dynamic and responsive to evolving real-time conditions (for example, adaptive ramp metering and signal control), in contrast to traditional operational strategies that follow predetermined schedules and plans (for example, time-of-day timing plans for ramp meters or traffic signals), and conventional capital improvement strategies that take a narrower focus on construction-oriented capacity expansion only (for example, freeway widening). ATM strategies provide appreciable and significant improvements in mobility, safety, and environmental performance of a facility relative to these traditional and conventional methods, at substantially lower cost than capital improvement projects. ATM strategies are ideally suited for heavily congested corridors in urban areas where right-of-way expansion is prohibitively expensive and where the nature (e.g., duration, severity, and causes) of the congestion is capable of being addressed by feasible ATM methods.

8.2.2 Integrated Corridor Management (ICM) Strategies

Integrated corridor management (ICM) strategies are a related class of traffic management strategies that focus on the coordinated consideration of multiple facilities in a region that collectively comprise a corridor, and may span different routes (e.g., nearby parallel freeways), modes (e.g., private auto, commuter rail, bus rapid transit), and networks (e.g., multiple bus networks or rail agencies). These strategies often focus on dynamic real-time operational strategies and therefore overlap substantially with ATM strategies, though they may also include planning-oriented strategies and agency coordination/collaboration strategies (which often supply necessary institutional support and data that enable active traffic management strategies). Examples of ICM strategies that extend beyond the domain of ATM include incident management, work zone planning, and inter-agency data-sharing agreements.

8.2.3 Travel Demand Management (TDM) Strategies

Travel Demand Management (TDM) strategies are aimed at reducing the demand for roadway travel, particularly targeting single occupancy vehicles (SOVs). These strategies address a wide range of externalities associated with driving, including mobility, environmental, economic, and health impacts. TDM strategies are designed to reduce travel demand, either throughout the day or during peak periods only. Some strategies use price signals to convey to drivers the true cost of their travel decisions, thereby incentivizing travelers to drive less or avoid high demand periods/locations. Other TDM strategies seek to make alternatives to SOV driving more attractive, such as through transit incentives and improvements.

8.2.4 Introduction to Common Strategies

Table 8-2 briefly describes several of the most common ATM, ICM, and TDM strategies, with additional detail available in the appendix. Note that the definitions of ATM, ICM, and TDM are not exclusive, such that any given strategy may qualify as more than one type. For example, dynamic pricing is a form of ATM in that prices are dynamically set in response to real-time conditions, it is a form of TDM in that the prices are intended to manage demand and encourage drivers to seek less congested alternate transport options, and it is a form of ICM in that it can readily be integrated into a broader cross-jurisdictional coordinated corridor management and response framework.

Table 8-2: Basic Principles and Classification of Common Traffic Management Strategies

Strategy	ATM	ICM	TDM	Basic Operational Principle or Objective
Queue Warning Systems	✓	✓		Alerts drivers to congestion ahead based on real-time conditions.
Hard Shoulder Running	✓	✓		Uses the freeway shoulder as a supplemental traffic lane
Bus-on-Shoulder Operations	✓	✓	✓	Gives buses access to the shoulder as a dedicated bus lane
Variable Speed Limits or Speed Harmonization	✓	✓		Provides targeted speed guidance to smooth out stop-and-go behavior
Dynamic Lane Management	✓	✓		Opens and closes lanes in response to incidents or traffic needs
Dynamic Pricing	✓	✓	✓	Uses dynamic prices to manage lane usage in response to demand
Dynamic HOV Lanes	✓	✓	✓	Adjusts the carpool lane requirements based on current available capacity
Dynamic Junction Control	✓	✓		Reallocates lanes at junctions for more efficient operations
Advanced Traveler Info and Dynamic Routing	✓	✓		Gives drivers current or forecasted traffic info for more informed decisions
Adaptive Ramp Metering	✓	✓	✓	Controls freeway entrance flows in response to real-time conditions
Reversible or Contraflow Lanes	✓	✓		Allocates certain lanes to the direction that currently needs them the most
Transit Signal Priority	✓	✓	✓	Gives extra preference to buses at intersections
Adaptive Traffic Signal Control	✓	✓		Adjusts traffic signal timing in real-time based on current conditions
Arterial Signal Coordination with Ramp Meters	✓	✓		Ensures ramp meters and nearby traffic signals are working well together
Active Parking Management	✓	✓	✓	A suite of strategies to help drivers find parking when they need it
Enhanced Incident Management and Response	✓	✓		Mitigates impacts of incidents through coordination and collaboration
Express Bus Service		✓	✓	Incentivizes commuter transit usage through competitive travel times
Park-and-Ride Lots			✓	Facilitates transfers to public transit, carpools, and vanpools
Alternative Work Schedules and Telework			✓	Reduces travel demand through flexible work arrangements

8.3 Relevance of ATM Strategies

As Table 8-2 suggests, each of the traffic management strategies introduced in this chapter target different types of safety and mobility issues through different methods of operation. Table 8-3 elaborates on this by describing the specific conditions and situations that each strategy is best suited to address. This table can be cross-referenced against the descriptions of causal factors provided in Table 8-1 to evaluate the most relevant potential strategies for each of the bottleneck and crash concentration locations identified for the US 101 corridor.

Table 8-3: Typical Applications for Common Traffic Management Strategies

Strategy	Mobility Applications	Safety Applications
Queue Warning Systems	—	• Rear-end collisions at upstream end of queues.
Hard Shoulder Running	• Bottlenecks caused by lane drops, particularly if flow constraint is limited to a short distance.	• General congestion-related collisions.
Bus-on-Shoulder Operations	• Corridors with recurring congestion, high frequency of buses with high occupancy, and no existing bus lane.	—
Variable Speed Limits or Speed Harmonization	• Bottleneck capacity reductions caused by shock waves and alternating periods of low/high bottleneck departure flows.	• Occurrence of collisions in stop-and-go traffic. • Rear-end collisions due to excessive or unsafe speed.
Dynamic Lane Management	• Locations with limited sight distances. • Locations where incidents are a major contributing factor to delays.	• Locations with difficult access for emergency vehicles. • Locations with frequent secondary incident occurrence.
Dynamic Pricing	• Corridors with recurring congestion and reserve capacity in existing managed lanes (e.g., HOV lanes). • Corridors with low travel time reliability. • Corridors with recurring congestion and	• General congestion-related collisions.
Dynamic HOV Lanes	• Corridors with recurring congestion and periods of available remaining capacity in existing managed lanes (e.g., HOV lanes), or periods with congestion in existing managed lanes. • Corridors with low travel time reliability for HOV users.	—
Dynamic Junction Control	• Junctions (merge or diverge locations) where the ratio of mainline to ramp traffic varies substantially over time.	• Increased occurrence of collisions near congested merges or diverges.
Advanced Traveler Info and Dynamic Routing	• Congested freeway corridor segments with alternate routes or modes available to travelers.	• Rear-end collisions due to excessive or unsafe speed. • General congestion-related collisions.
Adaptive Ramp Metering	• Bottlenecks caused by (or exacerbated by) high flows from freeway entrances. • Entrances that commonly have platoons or groups of vehicles entering simultaneously.	• Increased occurrence of sideswipe collisions at ramp merges.
Reversible or Contraflow Lanes	• Congested freeway corridor segments where the congestion is largely limited to one direction at a time (e.g., corridors that exhibit significant peaks in opposite directions during the AM and PM peak periods).	—

Strategy	Mobility Applications	Safety Applications
Transit Signal Priority	• Arterials with high frequency of buses with high occupancy, and high control delay (i.e., delay at signalized intersections). • Arterials with low travel time reliability for transit vehicles.	—
Adaptive Traffic Signal Control	• Arterials with relatively widely spaced intersections where conventional coordination is not effective. • Arterials with variable demand levels and congestion, resulting in excessive delays to drivers when signal timing plans fail to accommodate these demands.	—
Arterial Signal Coordination with Ramp Meters	• Freeway entrances with queues that often spill back onto arterial facilities. Metered freeway entrances that are signalized at their upstream ends, and have limited storage capacity.	—
Active Parking Management	• Areas where parking facilities regularly reach capacity, and/or where other alternate facilities exist that remain underutilized.	—
Enhanced Incident Management and Response	• Corridors with low travel time reliability due to incident occurrence.	• Corridors with high occurrence of secondary incidents. • Corridors with high occurrence of severe incidents.
Express Bus Service	• Corridors with high transit demand for long-distance trips. • Corridors with low transit travel time reliability during commute periods.	—
Park-and-Ride Lots	• Congested freeway corridor segments with alternate transit modes available to travelers.	• Corridors with high occurrence of incidents related to double-parking or illegal parking. • General congestion-related collisions.
Alternative Work Schedules and Telework	• Congested corridors that function as commuter routes to major employment centers.	—

8.4 Feasibility of Relevant ATM Strategies

While it is beyond the scope of this chapter to evaluate the specific relevance of individual strategies to each of the locations listed in Table 8-1, the appendix materials provide key high-level factors that typically need to be taken into consideration when evaluating the feasibility of implementing any of the strategies discussed in this chapter. Of particular relevance are the discussions of associated infrastructure and systems to support the successful deployment of each strategy type, as the feasibility of each strategy at a given site or bottleneck will be largely impacted by the nature or state of these factors at that location.

8.5 Expected High-Level Outcomes of Feasible and Relevant ATM Strategies

Once a set of relevant and feasible candidate traffic management strategies have been identified for a given bottleneck and/or crash concentration (see Table 8-3), Table 8-4 can be used to preliminarily evaluate the expected impacts that each of those strategies might produce if deployed on US 101 by applying the percent adjustment factors for delays and crash occurrence to the estimated delay and crash costs in Table 8-1. These statistics are based on outcomes of past deployments of the same types of strategies on other facilities throughout the United States in recent years, with detailed citations available for all reported values in the appendix.

In Table 8-4, mobility impacts are reported as percent reductions in delays when available, as travel time improvements if delay reduction statistics were not available, or as other quantitative results as noted when neither travel time nor delay improvement statistics were available. Safety impacts are indicated as percent reductions in crash frequency for primary incidents.[63]

Table 8-4: Documented Impacts of Common Traffic Management Strategies[64]

Strategy	Mobility Improvements (Delay Reduction)	Safety Improvements (Crash Frequency Reduction)
Queue Warning Systems	—	• 4–42%
Hard Shoulder Running	• Up to 90% decrease in delay	• 5–70%
Bus-on-Shoulder Operations	• 68–92% increase in transit on-time performance	—
Variable Speed Limits or Speed Harmonization	• 13–27% decrease in travel times	• 11–37%
Dynamic Lane Management	• 3–22% increase in capacity	• 3–30%
Dynamic Pricing	• Up to 15% decrease in travel times	• 5%
Dynamic HOV Lanes	• 9% increase in transit on-time performance	—
Dynamic Junction Control	• Up to 93% decrease in delay	• 30–53%
Advanced Traveler Info and Dynamic Routing	• 5–25% decrease in travel times	• Up to 5%
Adaptive Ramp Metering	• Up to 18% decrease in delay	• 20–50%
Reversible or Contraflow Lanes	• 13% decrease in travel times	—
Transit Signal Priority	• 35% for transit vehicles	—
Adaptive Traffic Signal Control	• 5–42% decrease in delay	—
Active Parking Management	• 8% decrease in traffic volumes near parking facilities	—
Enhanced Incident Management and Response	• 10–45% decrease in travel times	• 11%
Express Bus Service	• 6–40% decrease in travel times for transit vehicles	—
Park-and-Ride Lots	• No mobility statistics available	• 36%
Alternative Work Schedules and Telework	• 0.8% decrease in VMT	—

[63] A thorough search of impacts for Arterial Signal Coordination with Ramp Meters did not reveal any quantitative data on benefits.

[64] Sources for improvement ranges are provided in the appendix.

CHAPTER 9: RECOMMENDATIONS AND NEXT STEPS

9.1 Summary of Findings

The following key findings are distilled from the detailed assessment of existing conditions, assets, projects and opportunities in the US 101 corridor.

- **Trip Volumes.** On a typical weekday, the corridor (including freeways, arterials, private shuttles, BART and other transit) carries approximately 1,740,000 Single Occupant Vehicle (SOV) trips, 705,000 High Occupancy Vehicle (HOV) person trips, 22,000 private shuttle trips, 36,000 BART trips, 32,000 bus trips (of which 2% are Express Bus trips), 39,000 Caltrain trips, and 36,000 light rail trips, for a total of 2,610,000 trips. For more details, refer to Chapter 2.
- **Weekday Trends.** The US-101 corridor's non-holiday weekday (daily) traffic volumes have increased by about 10% over the past five years (an average increase of 2% per year). The associated vehicular delays on the US-101 corridor over the same five-year period increased by more than 91% (an average delay increase of over 18% per year). For more details, refer to Chapter 2.
- **Weekend Trends.** The US-101 corridor's Saturday (daily) volumes have increased by over 15% over the past five years (an average increase of over 3% per year). The associated vehicular delays on the US-101 corridor over the same five-year period increased by more than 172% (an average delay increase of over 34% per year). For more details, refer to Chapter 2.
- **Major Corridor Bottlenecks.** The most significant bottlenecks on the corridor occur at I-80 in the northbound direction and I-880 in the southbound direction. Of the top 10 bottlenecks in each direction of US 101, the leading causal factor identified is merging traffic from entrances (at 60% of locations), followed by weaving sections (at 30% of locations). For more details, refer to Chapter 2.
- **Detailed Delay Trends.** Based on a regression analysis of delays on the corridor, the ratio of delays caused by recurrent bottlenecks to delays caused by incidents was roughly 4 to 1. This ratio varied substantially across the corridor, with outcomes as high as 10 to 1 in San Francisco County and as low as 3.4 to 1 in Santa Clara County. For more details, refer to Chapter 2.
- **Crash Occurrence.** Incident occurrence directly correlates with congestion. When controlling for volume, incident rates rise by as much as 300% between the midday period and the PM peak. When congestion is addressed fewer incidents are expected to occur, including fewer secondary incidents as well. For more details, refer to Chapter 3.
- **Crash Types.** Predominant incident types are rear-end (2018 annually) and side swipes (710 annually). Rear-ending is associated with stop and go conditions and smoothing traffic can significantly reduce the occurrence of this type of incident; variable speed limits and other Active Traffic Management strategies can have a significant impact on the occurrence of rear-end crashes. Side swipes are primarily caused by lane changing which in turn can be caused by slower traffic ahead, or by excessive merging and weaving of traffic. Undesired merging effects can be successfully managed by implementing ramp metering at freeway entrances. For more details, refer to Chapter 3.
- **Major Crash Concentrations.** The most significant concentration of incidents on the corridor occur at Potrero Hill in the northbound direction and approaching I-280 (near San Francisco) in the southbound direction. Of the crash concentration location in each direction of US 101 with rates exceeding 40 per year, 81% of them are correlated with known recurring bottlenecks on the corridor. For more details, refer to Chapter 4.

- **Transit Service and Ridership.** The major transit service providers on the corridor are SamTrans with 12,191 passengers a day on the corridor, Santa Clara Valley Transportation Authority with 19,790 bus passengers and 35,693 rail passengers a day on the corridor, BART with 35,959 alightings per day within the corridor, and Caltrain with 39,420 passengers per day. Private shuttles account for another 22,000 trips along the corridor, with the majority of these trips occurring between San Francisco and San Jose. For more details, refer to Chapter 5.
- **Traffic Management Assets.** Intelligent Transportation Systems (ITS) infrastructure in the corridor includes: 389 loop detectors, 43% of which are not operating properly; 59 CCTV cameras with an additional 39 expected to be deployed in the near future; 4.5 miles of fiber connectivity; freeway service patrol; 144 ramp meters; and 23 dynamic message signs in advance of key interchanges. For more details, refer to Chapter 6.
- **Demand Management Assets.** These include: mobile apps for carpool matching, transit guidance, and bicycle routing; two Park-and-Ride lots; and eight major projects along the corridor that will enhance transit service, pedestrian accessibility, and bicycle facilities. For more details, refer to Chapter 6.
- **Current Corridor Projects.** Several improvement projects and mobility programs are already being undertaken by individual jurisdictions along this corridor, but these are generally focused on specific portions of the corridor only, rather than considering the full length between San Jose and San Francisco. For more details, refer to Chapter 7.
- **Coordination.** Corridor management policies and strategies are often discontinuous at major jurisdictional boundaries, as evidenced by the current and planned limits of managed lanes, the locations of different ramp metering policies implemented, the time-of-day availability of freeway service patrol, and the availability and distribution of various other existing corridor assets and programs. For more details, refer to Chapters 6 and 7.
- **Costs of Bottlenecks.** The preliminary total delay costs associated with the top ten bottlenecks in each direction of US 101 are $85 million annually, while the total costs associated with the top ten crash concentrations along the corridor are approximately $166 million annually, for an overall cost of $251 million per year. The bottleneck at I-80 and associated congestion upstream in the northbound direction of US 101 accounts for $43 million of this annually, while the bottleneck at I-880 in the southbound direction accounts for another $22 million annually. For more details, refer to Chapter 8.
- **Potential Traffic Management Strategies.** Of 19 potentially relevant active traffic management (ATM), travel demand management (TDM), and integrated corridor management (ICM) strategies for US 101 discussed in this report, the ones with the greatest bottleneck mitigation potential based on a preliminary analysis are: hard shoulder running, dynamic junction control, and enhanced incident management. In addition to these, the strategies with the greatest crash mitigation potential based on documented past outcomes are: adaptive ramp metering, queue warning systems, and speed harmonization (or variable speed limits). As recommended in Chapter 9 of this report more detailed analysis will be required to identify the most appropriate mitigation strategies for different parts of the corridor. For more details, refer to Chapter 8.

9.2 Recommendations and Next Steps

During 2014 the US DOT constructed a vision of the year 2045 in an effort to facilitate discussion on the need for change in investment in transportation infrastructure in the US, over the next 30 years. The initiative, entitled “Beyond Traffic[65]”, quantified challenges that investments in transportation infrastructure must overcome. Central to this core set of challenges is traffic congestion. Beyond Traffic and other data-driven research into the effectiveness of new roadway capacity concludes that capacity enhancements alone are no longer affordable, practical or effective at reducing congestion in most economically vital regions.[66] New tactics are needed to extract more congestion relief from new and existing capacity and ensure these short term gains are not overwhelmed by induced demand. These tactics may be grouped under two types of strategies: Intelligent Transportation Systems (ITS) and Transportation Demand Management (TDM).

Many of the most effective ITS strategies applicable to a highly congested corridor such as the US 101 may be grouped under Active Traffic Management (ATM). ATM holds both near and long term promise for reducing congestion. In general, ATM utilizes real-time measurement of highway usage, in conjunction with decision support systems and communication technologies, to modify vehicle operation and manage elements that control traffic flow. The operational objectives are often to increase peak throughput, mitigate conditions that lead to breakdown, to improve safety and to recover from incidents more rapidly – when they do occur. ATM tactics including variable speed limits, hard-shoulder running and coordinated and adaptive ramp-metering have been implemented successfully throughout the world. TDM tactics may also be deployed to reduce congestion. This could include alternate work schedules, bus-only lanes, dynamic HOV or managed lanes and dynamic congestion pricing (Express Lanes) as well as other tactics.

The US 101 corridor's weekday traffic volumes have increased by an average of 2 percent per year for the past five years, but job growth in Silicon Valley over the same period has increased by between 3.5 and 4.3 percent. With the demand for more workers growing about twice as fast as traffic volumes, a reasonable explanation could conclude that the corridor capacity is saturated and each year’s incremental growth produces disproportionate growth in congestion. In fact, vehicle hours of delay on corridor over the same five-year period increased by more than 91 percent, an average increase of over 18 percent per year, which in turn has led to a 300 percent increase in accidents. Under such saturated conditions, any additional capacity is likely to be overwhelmed by pent-up demand from commuters who are diverting to off-peak travel times or alternative routes or modes. This leads to an essential strategy of travel demand management, which would be added to the strategies of (1) adding capacity, especially at bottlenecks, and (2) managing the optimal operation of the corridor capacity. Travel demand management can involve various methods, including congestion pricing, diverting travel to outside the peak period, to less-congested alternative routes, and to alternative modes of transportation including carpooling.

Three types of next steps are recommended, including:

- **More Detailed Analysis** to develop an effective and integrated combination of mitigation strategies.
- **Stakeholder Engagement** to help build awareness, create partnerships and facilitate the adoption of congestion mitigation strategies on the US 101 corridor.
- Development of a **Concept of Operations** to define a prioritized set of strategies for deployment on the US-101 corridor. The strategies will primarily consist of ATM/ICM and TDM solutions that can be deployed in the next 3 to 5 years.

[65] www.dot.gov/beyondtraffic.

[66] The Fundamental Law of Road Congestion: Evidence from US Cities, Gilles Duranton and Matthew A. Turner, American Economic Review, Vol. 101, No. 6, October 2011, (pp. 2616-52).

9.2.1 More Detailed Analysis

In order to move forward with an effective and integrated combination of mitigation strategies, more detailed analysis is needed to:

- Offer US 101 corridor agencies a predictive forecasting capability that they lack today to help them **determine which combinations of mitigation strategies are likely to be most effective and under which conditions**. The analysis will help decision-makers identify technical and implementation gaps, evaluate different mitigation strategies, and invest in the combination of strategies that would most minimize congestion and produce the greatest benefits. Comprehensive analysis and modeling increases the likelihood of success and helps minimize any unintended consequences. It provides an enhanced understanding of existing corridor conditions and deficiencies, allowing for the improved ability to match and configure proposed mitigation strategies to the situation at hand.
- Allow corridor agencies to **"see around the corner"** and discover optimum combinations of mitigation strategies, as well as potential conflicts or unintended consequences inherent in certain combinations of strategies that would otherwise be unknowable before full implementation: Analysis and modeling helps agencies estimate the benefits resulting from ICM/ATM and TDM strategies across different transportation modes and traffic control systems. Furthermore, it helps agencies to align these estimates with specific assumptions about corridor conditions and mitigation strategies. Without being able to predict the effects of mitigation strategies corridor transportation agencies may not take the risk of making the institutional and operational changes needed to optimize corridor operations.
- **Lower risk associated with implementation —** The detailed analysis facilitates the development of concepts of operations and requirements by corridor stakeholders, and helps corridor managers define and communicate the project scope, partner roles, and partner responsibilities. Also, the analysis may help identify flaws or technical issues in the Implementation Plan or Concept of Operations that may have been otherwise overlooked. The analysis also helps to communicate the scope of the project and appropriately set expectations among differing project stakeholders (e.g., planners, operators, data analysts, modelers, and agency management from State, local, and/or regional transportation agencies), and provides a clearer definition of expected roles and responsibilities.

The goal of this analysis will be to perform a detailed assessment of traffic conditions and transportation management assets on the US-101 corridor. In this next phase, the corridor can be divided into 3-5 reporting segments (segregating bottlenecks and congestion areas) for a more detailed operational performance evaluation, including a congestion causality assessment. The work will identify and rank corridor segments by problem severity, complexity and potential for greatest improvement. Focused treatments at major freeway interchanges might be necessary to alleviate the congestion surrounding critical choke points; broad-brush approaches and one-size-fits-all solutions/mitigations could very well fall short of delivering the best remedies; opportunities for better performance might be overlooked if detailed assessments are not performed at select locations. A one size fits all approach could result in an ill-fitting and ineffective implementation strategy, mainly because the corridor's various bottlenecks will not respond in the same way to the proposed strategies. Equally important, governing policies and operational agreements vary from county to county.

Additionally, an operational analysis of the major connecting corridors with heavy linkages to US-101 might prove beneficial, such as I-380 and SR 92 in San Mateo County, I-880 & I-280/680 in Santa Clara County, I-80 & I-280 in San Francisco County. Likewise, an evaluation of the capacity-carrying ability (in terms of remaining vehicular capacity and potential transit capacity) of El Camino Real and other important parallel arterial corridors needs to be incorporated into the US-101 corridor assessment and congestion mitigation process.

The analysis will provide information about the existing physical characteristics and the existing operational conditions of the corridor. This work should leverage existing data sources such as Caltrans PEMS and other agency-owned databases. In recent years, MTC has procured INRIX Real-Time traffic information and INRIX Analytics. This MTC-INRIX agreement allows MTC to share the data with its public agency partners at no additional cost. The INRIX travel-time data cover the major arterial streets along with the mainline US-101 corridor, complementing the Caltrans PeMS dataset and extending the data analytics to the US-101 corridor.

Caltrans freeway, county and local major arterial roadway incident and collision data will be collected and evaluated leveraging data from credible sources like the Caltrans Traffic Accident Surveillance and Analysis System (TASAS), the Transportation Injury Mapping System (TIMS), and Caltrans PeMS CHP incident logs. Technical analytics performed using these collision and incident databases will reveal incident hot spots. Analytical techniques can be used to fuse these incident databases with PeMS traffic volume and INRIX travel-time data to quantify non-recurrent congestion (impacts) attributable to collisions and other roadway incidents. These analyses will provide valuable information to the decision process by showing the proportion of the overall congestion that is recurrent (i.e., attributable to bottlenecks) as opposed to non-recurrent, and sheds light to placement of changeable message signage and the likely effectiveness of motorist information systems.

9.2.2 Stakeholder Engagement

In addition to conducting more detailed analysis, a critical next step involves the engagement of private and public stakeholders. The over a dozen of the largest high tech corporations in the world have their headquarters concentrated along the corridor. They will be critical to advancing an effective congestion mitigation strategy, and they could help leverage public funding with private investment. The corridor's high tech campuses situated along this corridor constitute more corporate wealth than any other stretch of freeway in the world. The corridor functions as their life blood connecting their corporate headquarters to the most sought after workers in the world. These corporations also have significant influence in with State legislators, so may prove critical to leveraging State funding and securing quickly regulatory authorization for implementing ITS/ATM strategies. For all their formidable influence and wealth, however, they are extremely focused on their business and their senior leadership remains reluctant to engage with public agencies, especially if they do not regard the process as likely to advance feasible, short-term solutions.

The corridor transects or abuts about 17 local jurisdictions, each of which has significant authority and desire to determine which strategies and capacity investments are deployed and how they are designed and operated. These local stakeholders from 14 cities and three counties must be engaged, in discussing the analysis findings and the trade-offs between strategies, including the likely outcomes of no additional investment or management. The goal would be to obtain a modest consensus among stakeholders regarding overall objectives and a performance framework within which specific performance metrics and numeric targets could be developed.

The stakeholder engagement will help build awareness, create partnerships and facilitate the adoption of recommended strategies on the US-101 corridor through a series of stakeholder meetings and outreach activities. This can be accomplished by assembling and convening an expert panel of stakeholders that consists of representatives from the following entities:

- Caltrans representatives from headquarters and District 4.
- Regional and local agencies with an interest in improving traffic on US-101 including MTC, SMCTA, C/CAG, SFMTA, and VTA.
- Academic specialists from UC Berkeley in the areas of traffic operations, ITS, regional planning, business and other related departments.
- Representatives from the private sector that are impacted by traffic on US-101 including the Bay Area Council and major employers in the corridor.

9.2.3 Concept of Operations

This next step will take the initial set of recommended ITS/ATM and TDM strategies, combined with the results of the stakeholder engagement, and conduct follow-up investigations to define a prioritized set of strategies for deployment on the US-101 corridor. The strategies will primarily consist of ITS/ATM and TDM solutions that can be deployed in the next 3-5 years, including but not limited to:

- Coordinated ramp metering
- Dynamic Lane Management (HOV, HOT, transit-only)
- Dynamic speed limits
- Advanced Traveler Information Systems
- Incident Management
- Interface with Arterial Management System
- Dynamic shoulder lanes (Hard shoulder running)
- Queue warning
- Transit signal priority/HOV ramp metering bypass lanes
- Dynamic ridesharing and shared mobility
- Other transit-focused strategies and incentives

Recommended strategies will build on and leverage findings from previous work efforts – focusing mainly on Caltrans and Bay Area performance evaluation projects and/or performance monitoring efforts. The strategies will be bundled into logical operational scenarios where it makes sense. For example, one scenario might combine dynamic speed limits with queue warning applications and advanced traveler information systems. Also, while the focus will be on deployment of near-term strategies, consideration will be given for how these strategies provide a migration path to longer term solutions such as expanded HOV lanes and an environment that supports connected and automated vehicles. Ultimately, the recommended strategies and operational scenarios will be documented in a Preliminary Concept of Operations report that describes the who, what, when, where, why and how for each scenario.

The Preliminary Concept of Operations will document the vision and goals of the US-101 stakeholders and define the role of each stakeholder for all of the operational scenarios. This produces solutions that are adopted by the users, which then translate into changes in operations that provide the real-world performance benefits. The final desired outcome of the Concept of Operations is to develop a set of strategies that are recommended for immediate deployment, another set of strategies that are recommended for further evaluation using advanced modeling and simulation techniques, and the remaining strategies dropped from consideration. High-level cost estimates should be developed for each of the strategies that are recommended for deployment.

TECHNICAL APPENDIX

This technical appendix includes supplementary data and detail associated with the various components of this existing conditions assessment, and is organized into the following sections:

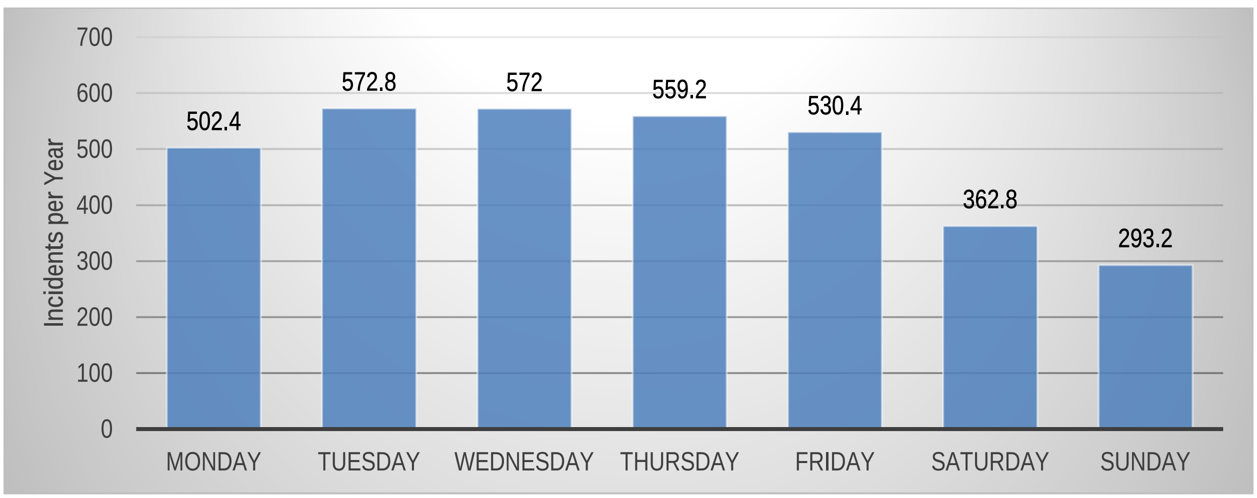
- Additional data and supporting information for the corridor crash analysis.
- Additional data and supporting information for the diagnosis of contributing crash factors.
- Additional data and supporting information for transit service and ridership.
- Additional data and supporting information for ITS assets along the corridor.
- Additional data and supporting information for current and near-term future related projects on the corridor.

Additional Data and Supporting Information for the Corridor Crash Analysis

The following supplemental crash data are provided in this section of the technical appendix:

- Detailed incident rates per mile per year, by segment, direction, and severity (Figure A.1)
- Annual incident rates by day of week, for the full US 101 corridor (Table A-1)
- Hour with highest incident frequency by segment and direction (Table A-2)

Figure A.1: Annual Incident Rates by Day of Week, for the Full US 101 Corridor



Source: Cambridge Systematics, using SWITRS 2013-2015 Data

Table A-1: Incidents per Mile per Year, by Segment, Direction, and Severity

Southbound Segment	Incidents per Mile per Year: Property Damage Only	Complaint of Pain	Visible Injury	Severe/Fatal Injury	Northbound Segment	Incidents per Mile per Year: Property Damage Only	Complaint of Pain	Visible Injury	Severe/Fatal Injury
I-80 to I-380	0.73	3.27	8.82	22.12	I-380 to I-80	0.20	2.73	9.84	26.98
I-380 to Marine Pkwy	0.54	2.67	7.46	18.59	3rd Av to I-380	0.44	1.50	4.78	12.61
Marine Pkwy to SR 84	0.57	1.62	4.57	10.86	SR 84 to 3rd Av	0.54	1.73	6.42	23.31
SR 84 to SR 85 (Mtn View)	0.33	1.06	6.69	26.41	SR 85 (Mtn View) to SR 84	0.16	2.08	6.73	21.80
SR 85 (Mtn View) to I-680	0.24	1.73	4.67	21.42	I-680 to SR 85 (Mtn View)	0.45	2.06	4.94	22.45
I-680 to SR 85 (San Jose)	0.24	1.32	3.48	13.79	SR 85 (San Jose) to I-680	0.52	1.32	3.44	17.88
All	**0.42**	**1.99**	**6.10**	**19.92**	**All**	**0.38**	**1.95**	**6.06**	**21.31**

Source: Cambridge Systematics, using SWITRS 2013-2015 Data.

Table A-2: Hour with Highest Incident Frequency by Segment and Direction

Southbound Segment	Hour of Peak Incident Rate	Northbound Segment	Hour of Peak Incident Rate
I-80 to I-380	5-6 PM	I-380 to I-80	3-4 PM
I-380 to Marine Pkwy	6-7 PM	3rd Av to I-380	5-6 PM
Marine Pkwy to SR 84	5-6 PM	SR 84 to 3rd Av	6-7 PM
SR 84 to SR 85 (Mountain View)	6-7 PM	SR 85 (Mountain View) to SR 84	6-7 PM
SR 85 (Mountain View) to I-680	6-7 PM	I-680 to SR 85 (Mountain View)	8-9 AM
I-680 to SR 85 (San Jose)	6-7 PM	SR 85 (San Jose) to I-680	8-9 AM

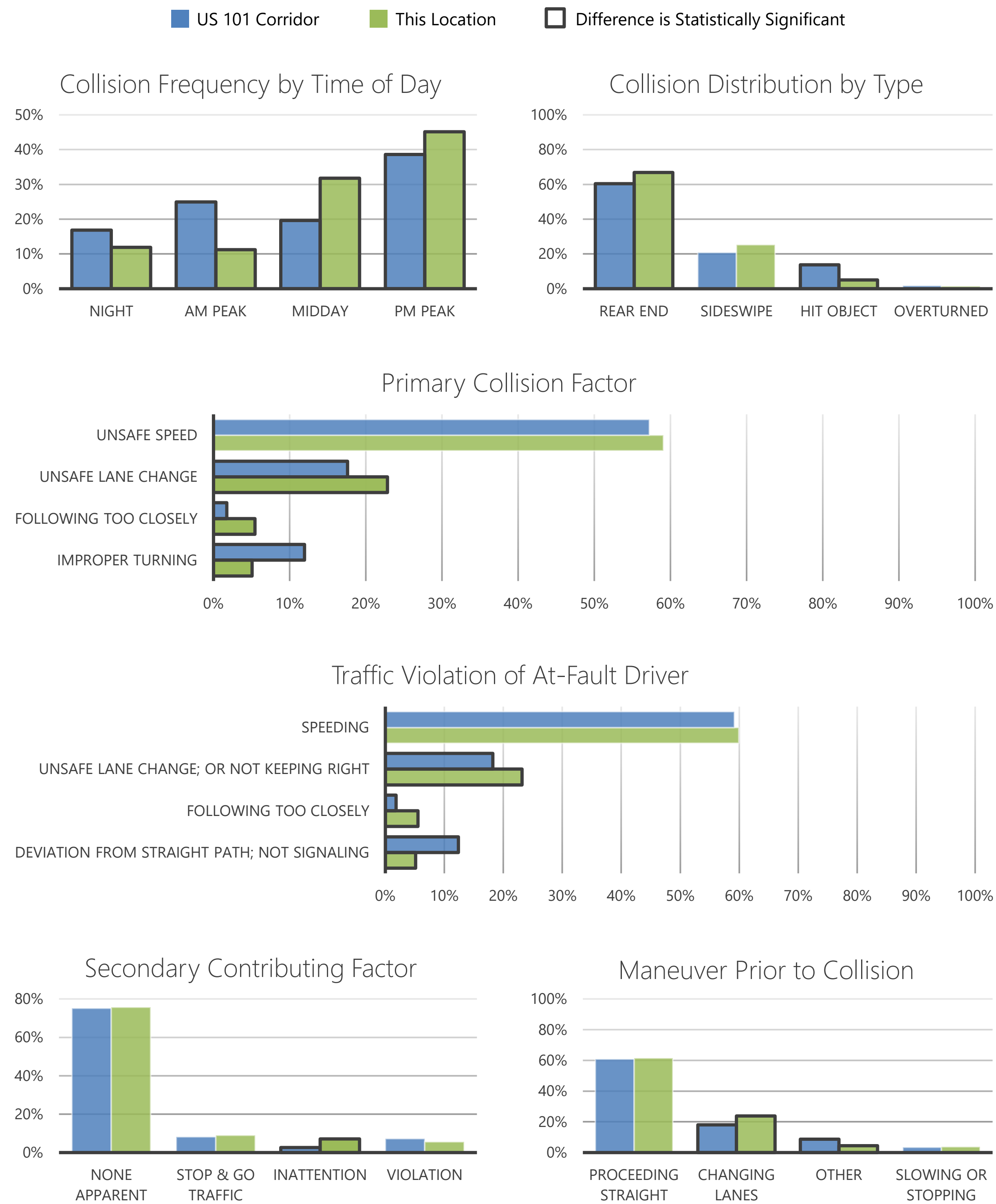
Source: Cambridge Systematics, using SWITRS 2013-2015 Data.

Additional Data and Supporting Information for the Diagnosis of Contributing Crash Factors

The following supplemental causal crash data are provided in this section of the technical appendix:

- Crash frequency distributions for each hotspot location, with respect to:
  - Time of day
  - Type of collision
  - Primary collision factor
  - Traffic violation for the at-fault driver
  - Any secondary contributing factors associated with the incidents
  - Maneuvers made prior to collision, for the at-fault driver

Figure A-2: Northbound Crash Hotspot #1: Incident Data at Potrero Hill

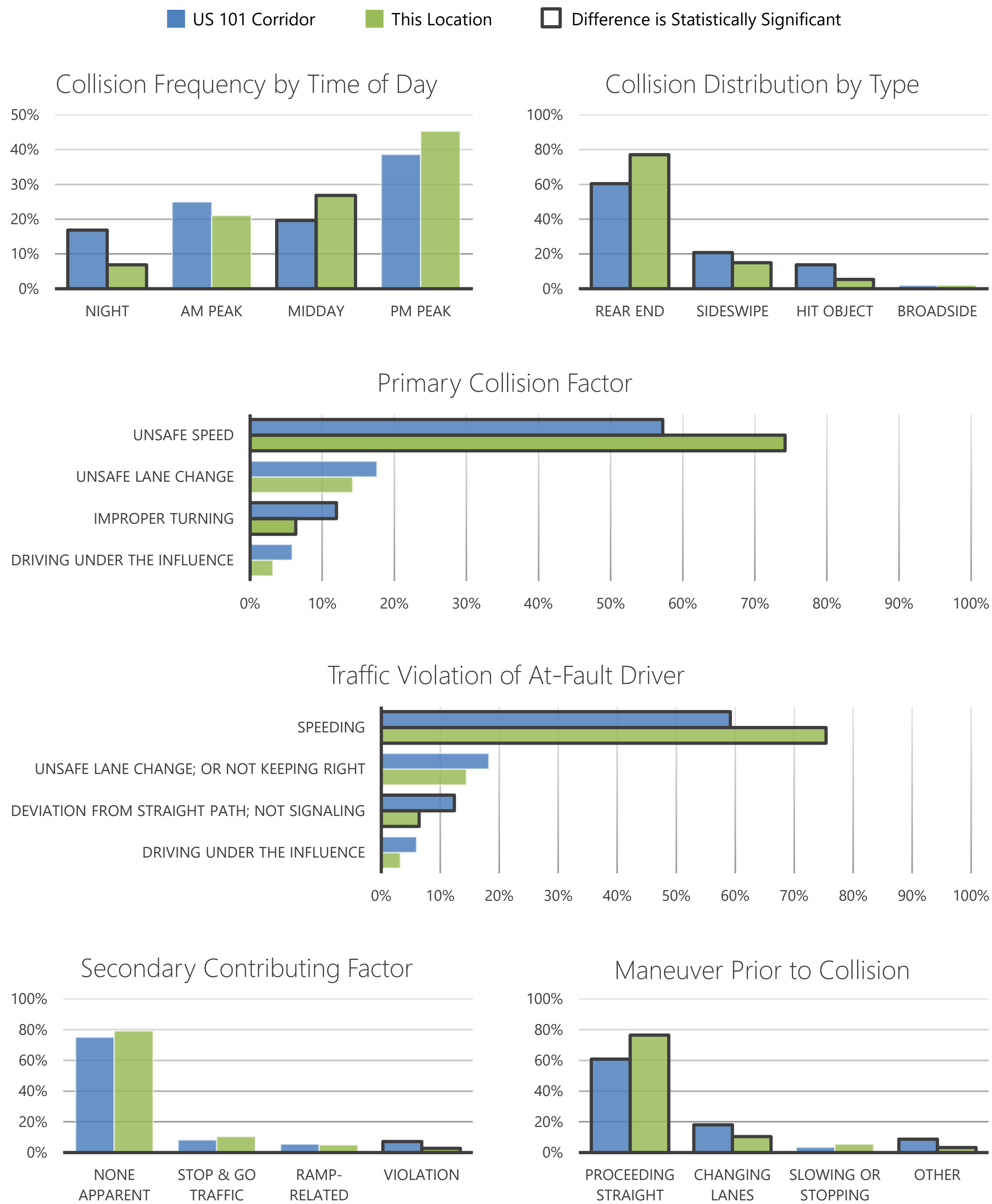


Source: Cambridge Systematics, using SWITRS 2013-2015 Data.

Figure A-3: Northbound Crash Hotspot #2: Incident Data Approaching Potrero Ave Junction

Source: Cambridge Systematics, using SWITRS 2013-2015 Data.

Figure A-4: Northbound Crash Hotspot #3: Incident Data Approaching SR 92 Junction

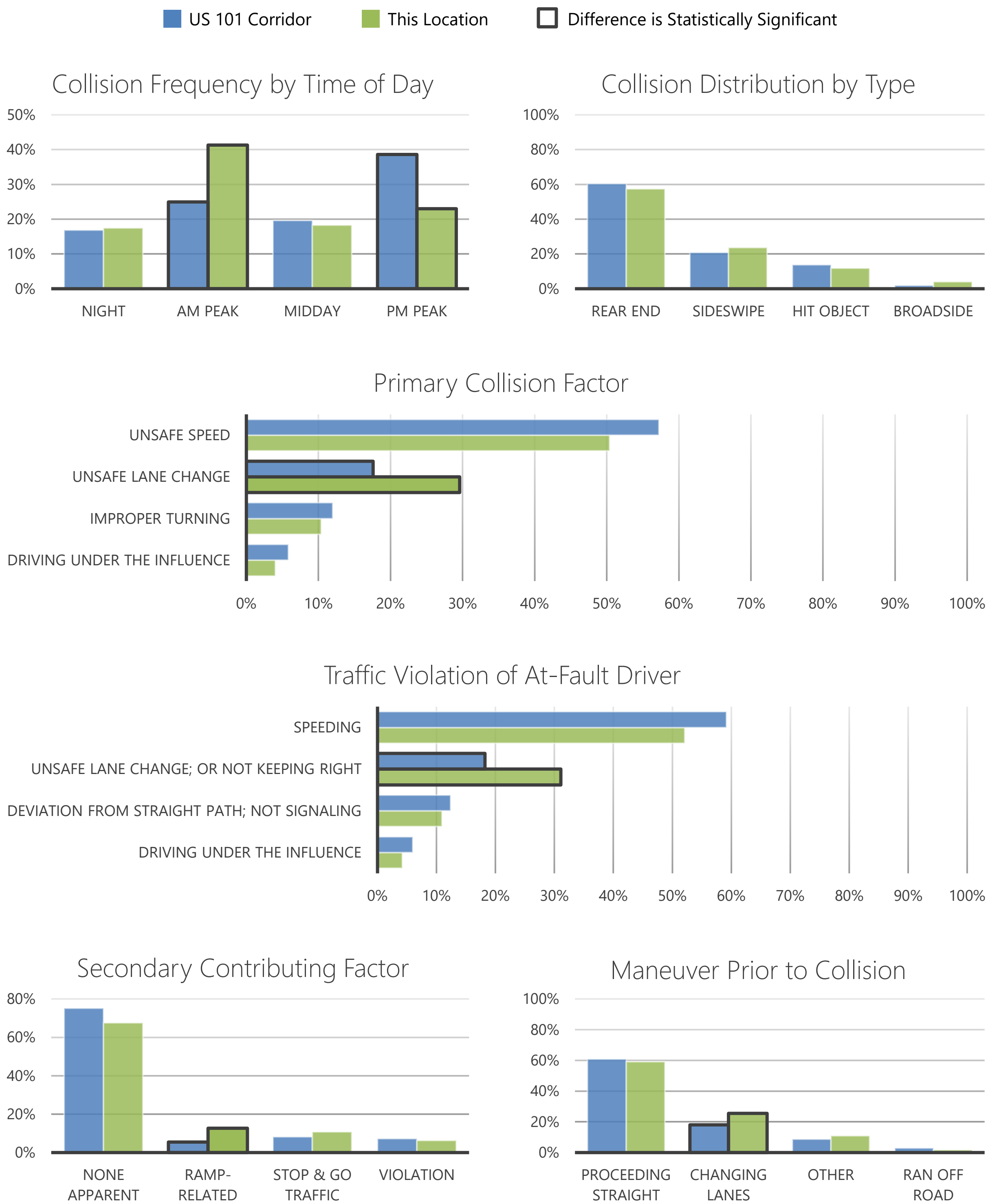


Source: Cambridge Systematics, using SWITRS 2013-2015 Data.

Figure A-5: Northbound Crash Hotspot #4: Incident Data Approaching I-880 Junction

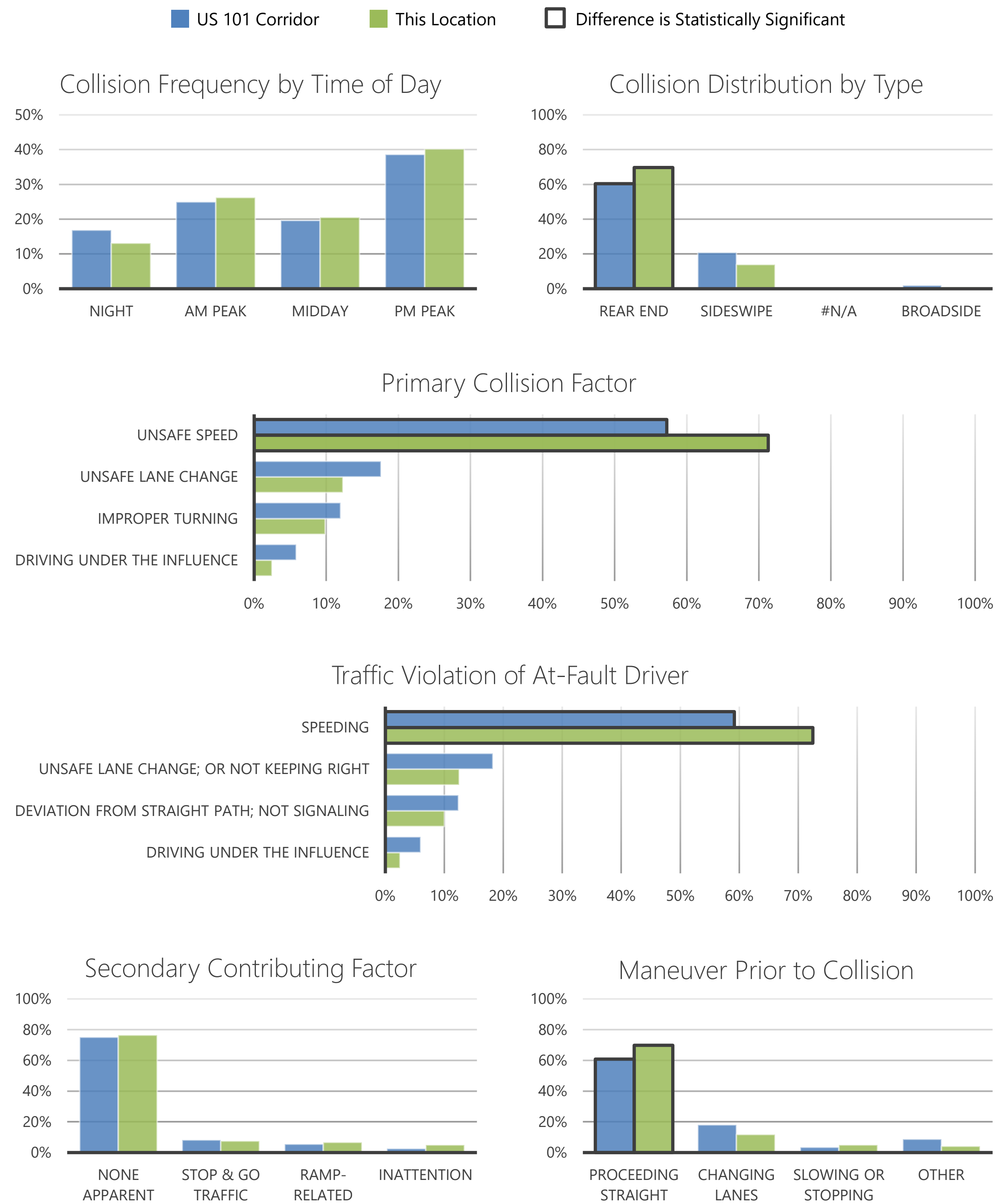
Source: Cambridge Systematics, using SWITRS 2013-2015 Data.

Figure A-6: Northbound Crash Hotspot #5: Incident Data at Tully Rd



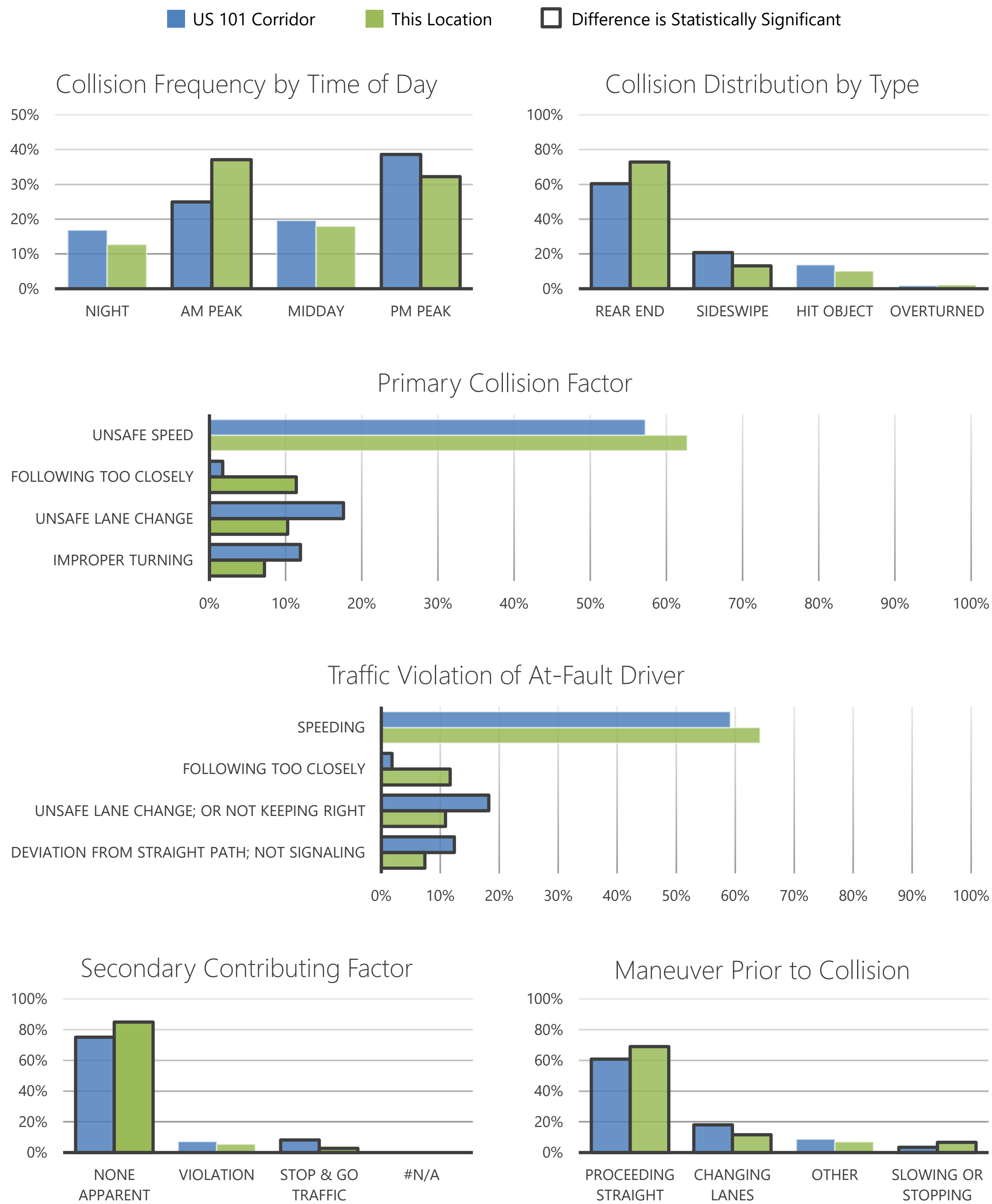
Source: Cambridge Systematics, using SWITRS 2013-2015 Data.

Figure A-7: Northbound Crash Hotspot #6: Incident Data at San Antonio Rd



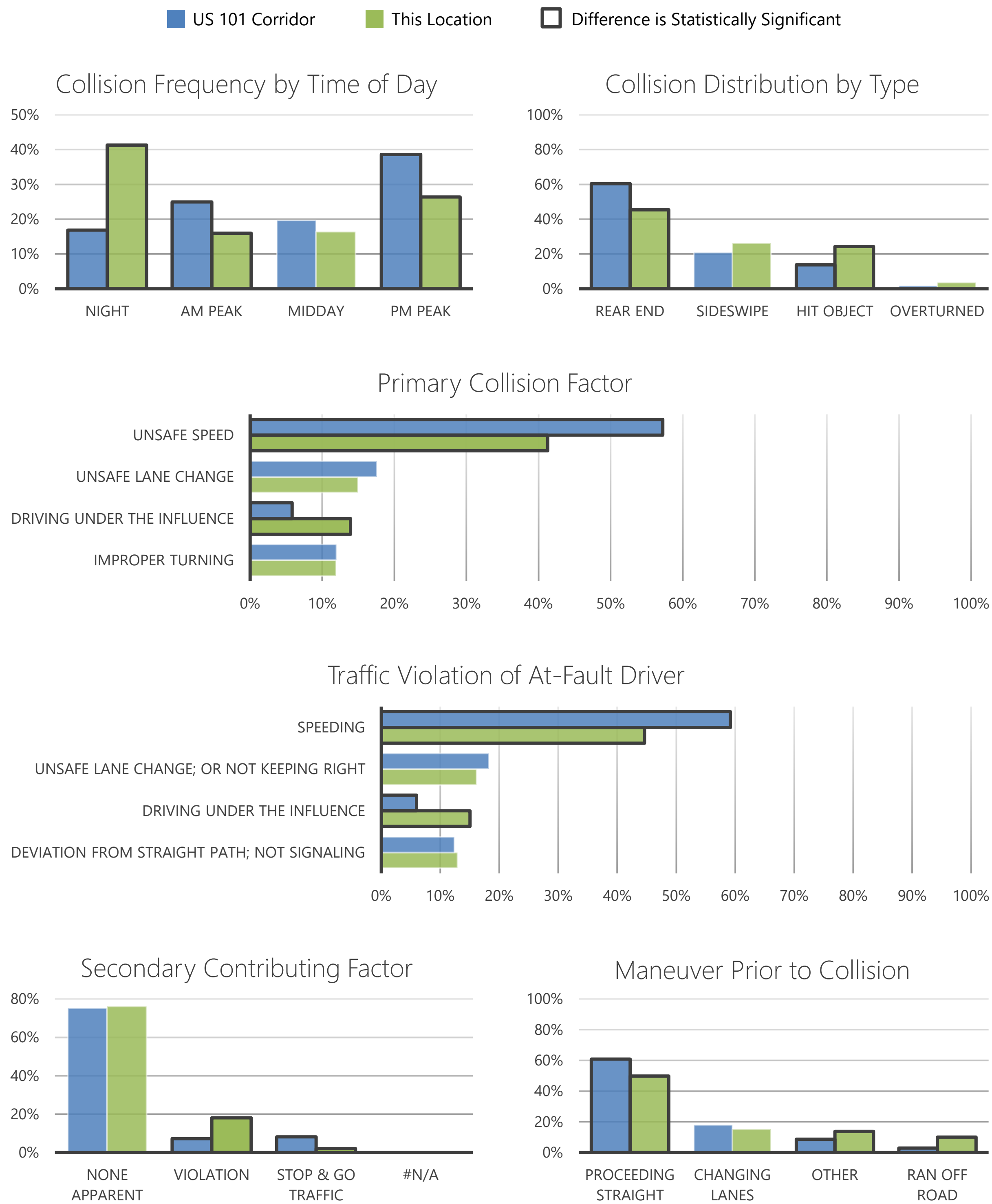
Source: Cambridge Systematics, using SWITRS 2013-2015 Data

Figure A-8: Southbound Crash Hotspot #1: Incident Data Approaching I-280 (San Francisco)



Source: Cambridge Systematics, using SWITRS 2013-2015 Data.

Figure A-9: Southbound Crash Hotspot #2: Incident Data at Potrero Hill

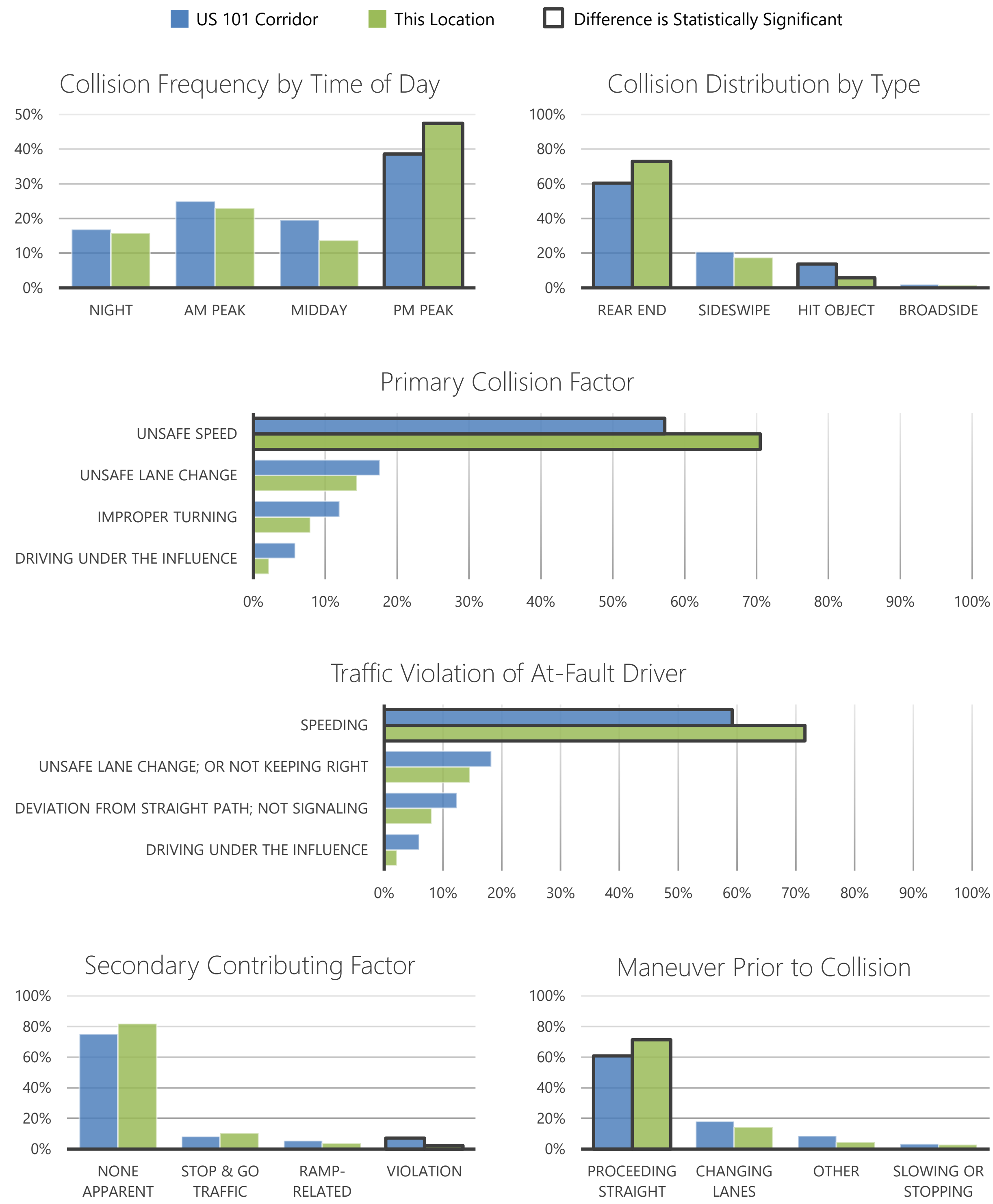


Source: Cambridge Systematics, using SWITRS 2013-2015 Data.

Figure A-10: Southbound Crash Hotspot #3: Incident Data at Oregon Expressway Junction

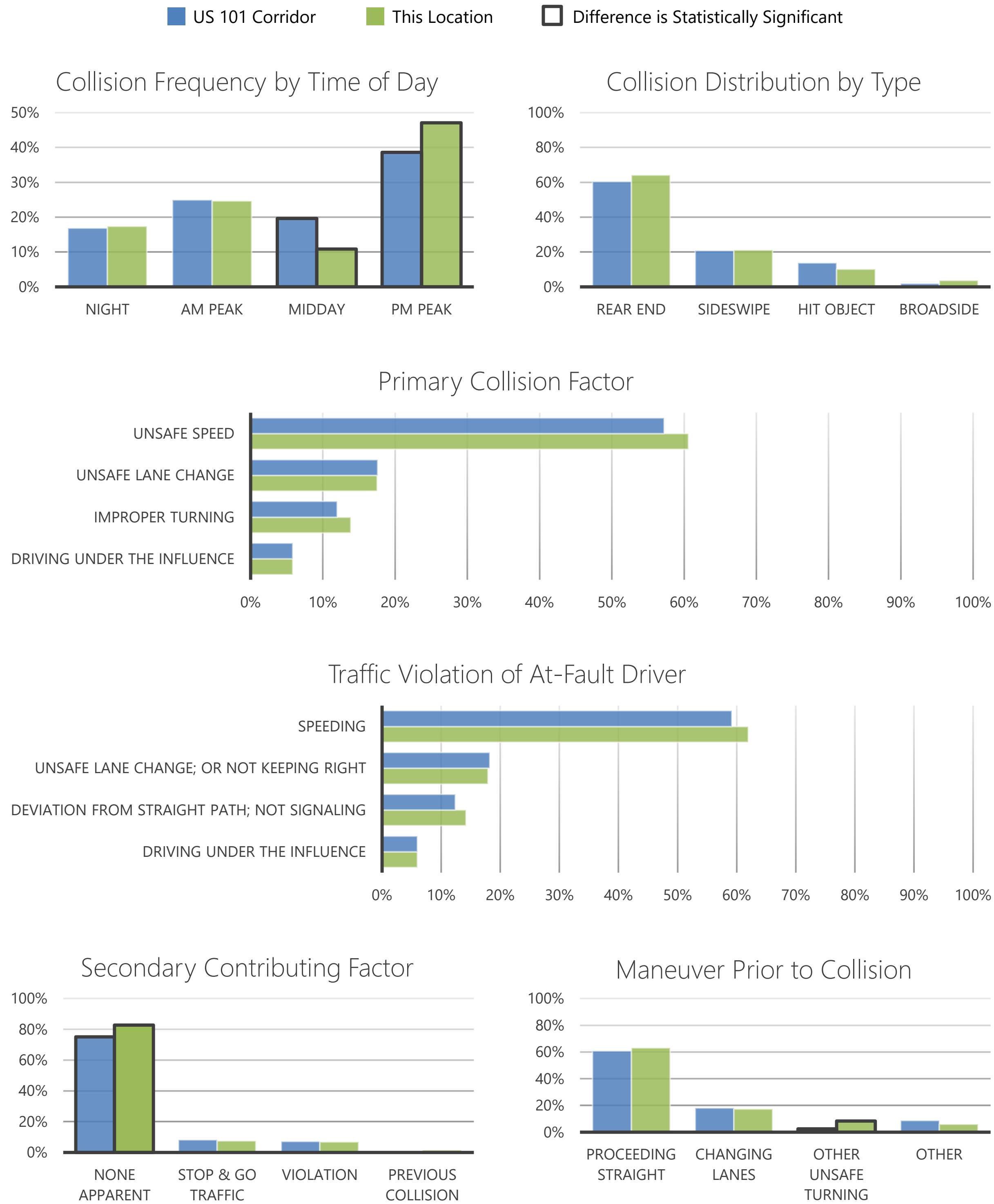
Source: Cambridge Systematics, using SWITRS 2013-2015 Data.

Figure A-11: Southbound Crash Hotspot #4: Incident Data at San Antonio Rd



Source: Cambridge Systematics, using SWITRS 2013-2015 Data.

Figure A-12: Southbound Crash Hotspot #5: Incident Data at Poplar Av

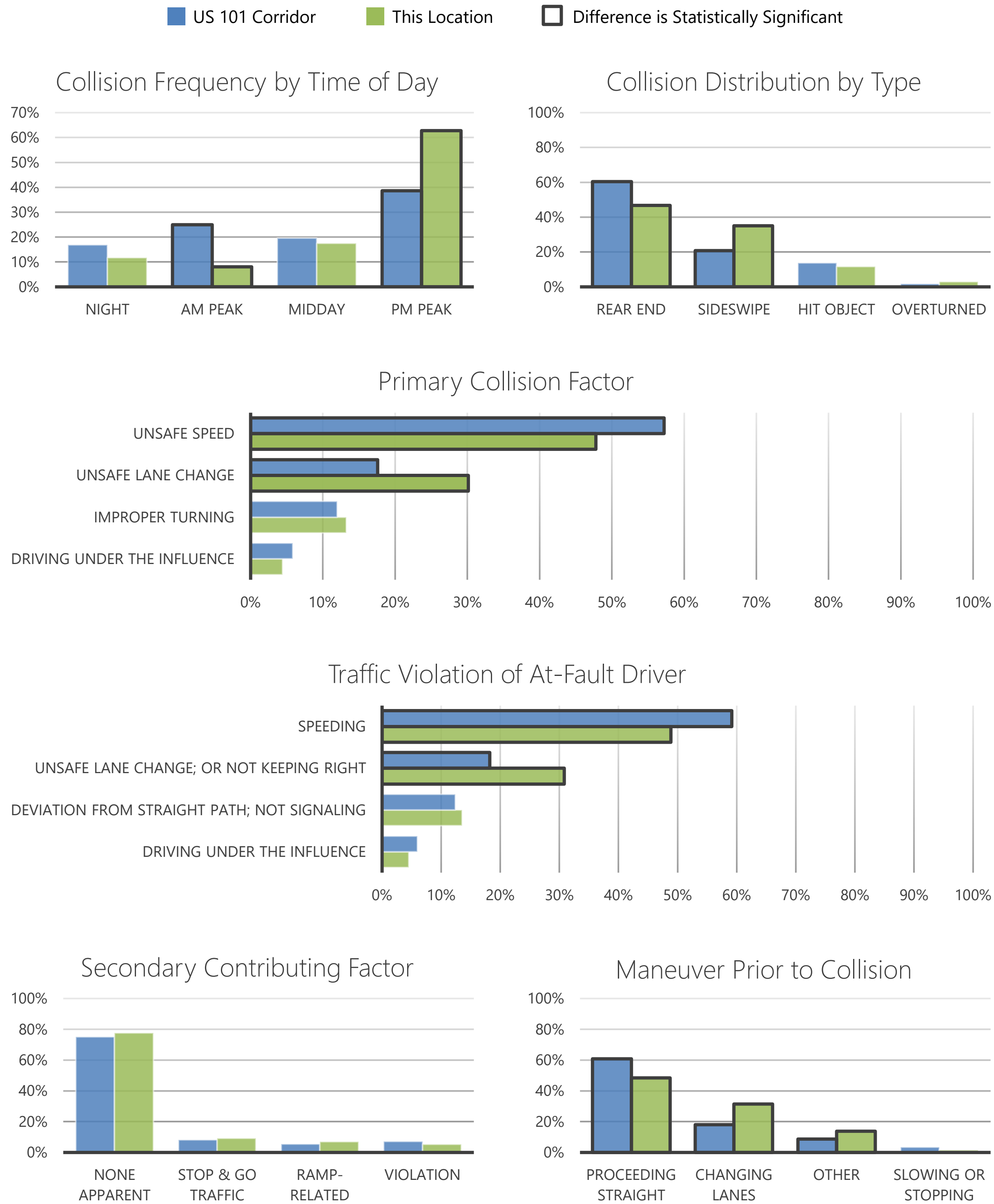


Source: Cambridge Systematics, using SWITRS 2013-2015 Data.

Figure A-13: Southbound Crash Hotspot #6: Incident Data After SR 92 Junction

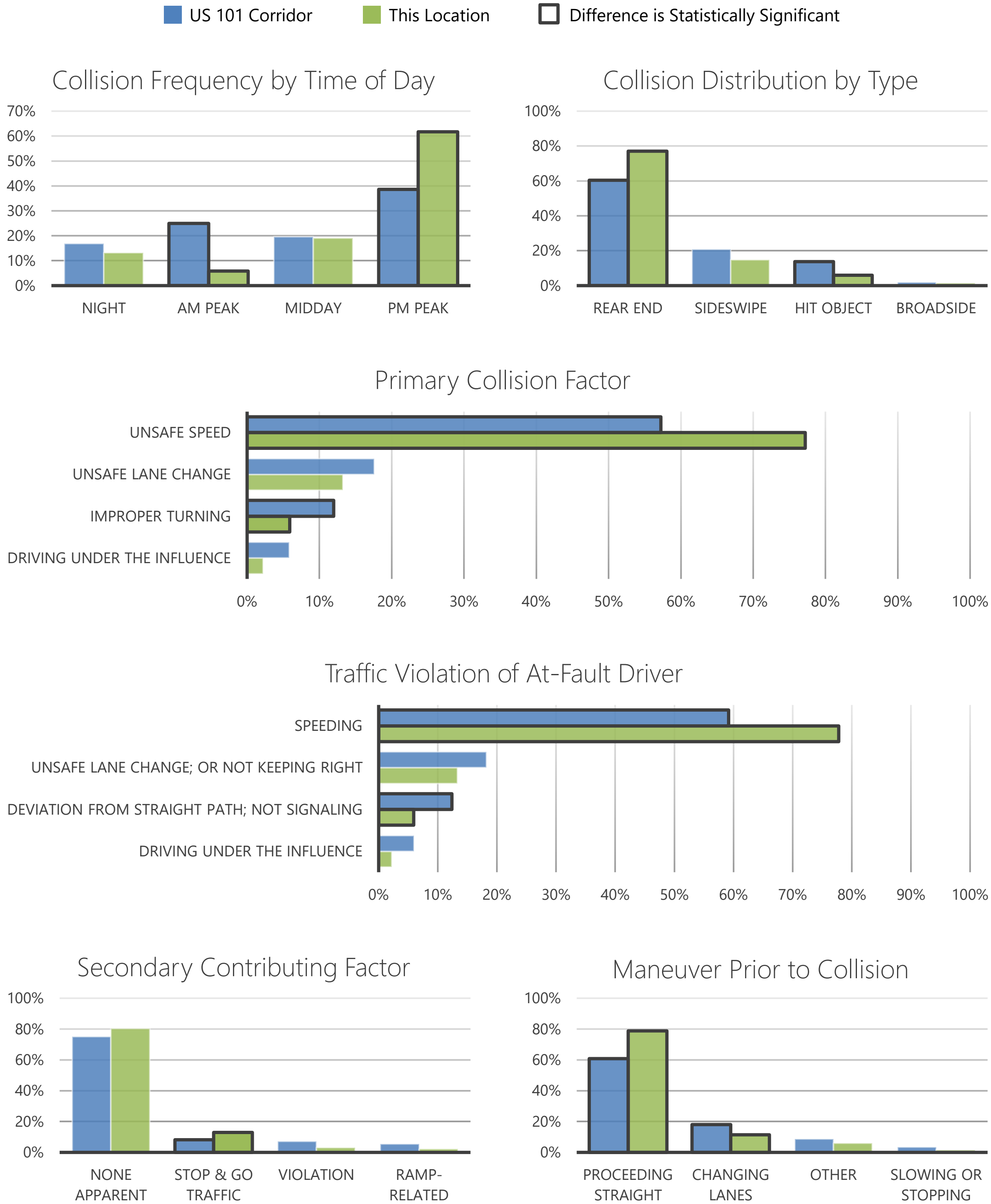
Source: Cambridge Systematics, using SWITRS 2013-2015 Data.

Figure A-14: Southbound Crash Hotspot #7: Incident Data at Oakland Rd



Source: Cambridge Systematics, using SWITRS 2013-2015 Data.

Figure A-15: Southbound Crash Hotspot #8: Incident Data at SR 87 Junction

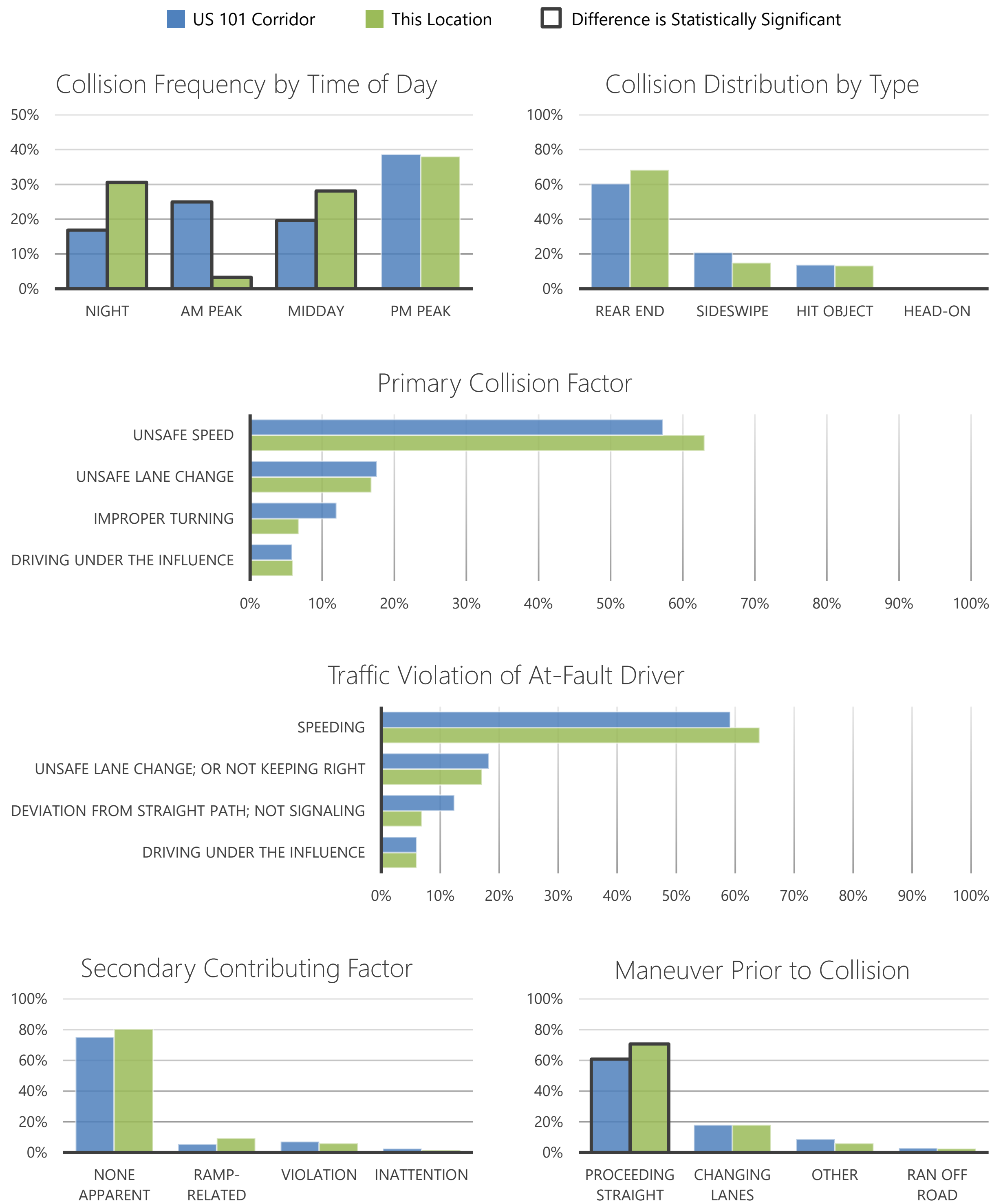


Source: Cambridge Systematics, using SWITRS 2013-2015 Data.

Figure A-16: Southbound Crash Hotspot #9: Incident Data After Willow Rd

Source: Cambridge Systematics, using SWITRS 2013-2015 Data.

Figure A-17: Southbound Crash Hotspot #10: Incident Data at Capitol Expressway Junction



Source: Cambridge Systematics, using SWITRS 2013-2015 Data.

Additional Data and Supporting Information for Transit Service and Ridership

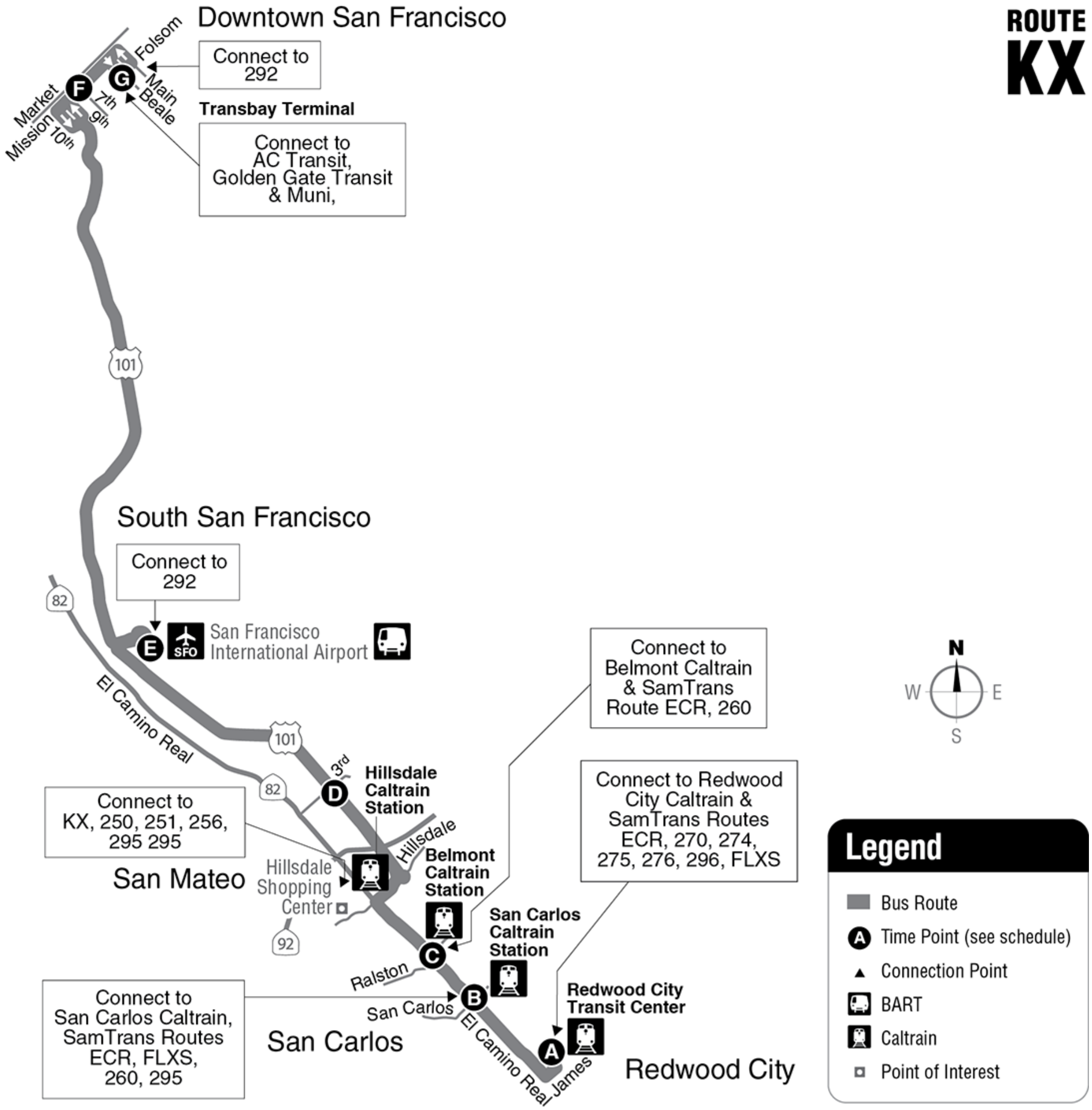
The following supplemental transit data are provided in this section of the technical appendix:

- SamTrans Route Maps (Figure A-18 through Figure A-22)
- VTA Route Maps (Figure A-23 through Figure A-29)
- VTA Light Rail Ridership Data by Station (Table A-3)
- BART Routes Map (Figure A-30)
- Caltrain Route Map (Figure A-31)
- Additional Caltrain Ridership Tables (Table A-4 through Table A-7)
- Additional Private Shuttle Data (Figure A-32 and Table A-8)

Figure A-18: Map for SamTrans Route ECR

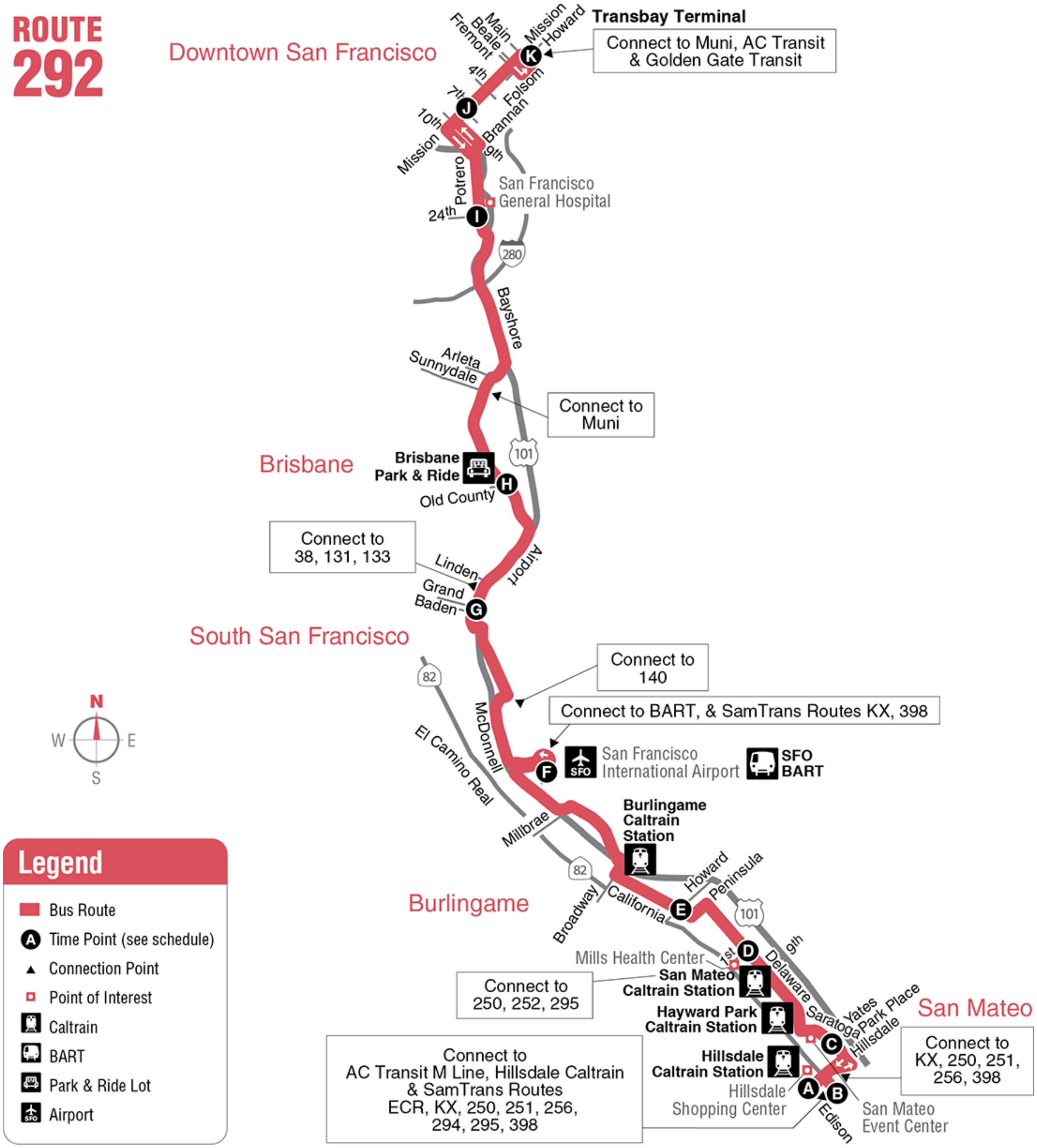
Source: http://www.samtrans.com/schedulesandmaps/timetables/ECR.html.

Figure A-19: Map for SamTrans Route KX



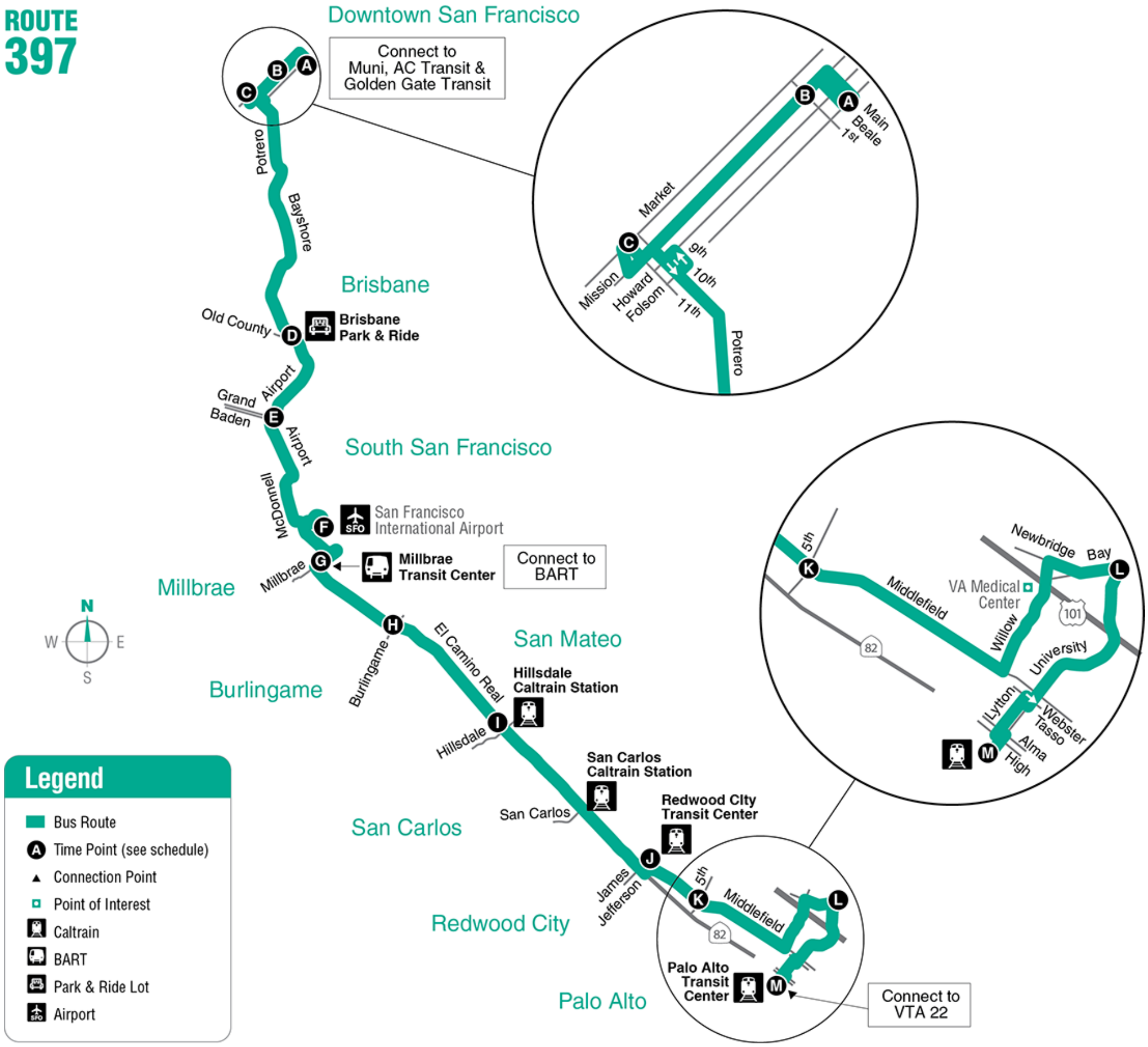
Source: http://www.samtrans.com/schedulesandmaps/timetables/KX.html.

Figure A-20: Map for SamTrans Route 292



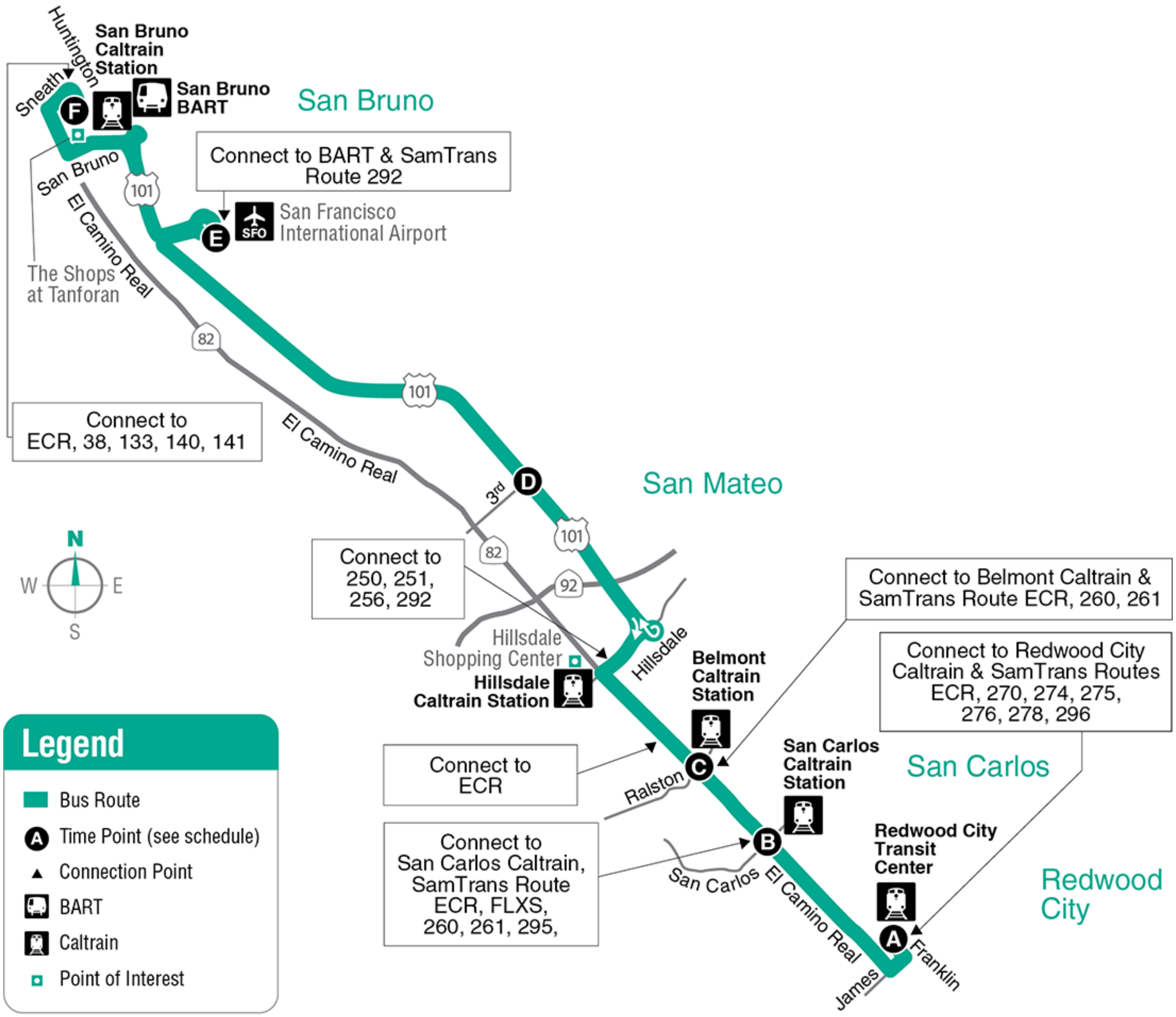
Source: http://www.samtrans.com/schedulesandmaps/timetables/292.html.

Figure A-21: Map for SamTrans Route 397



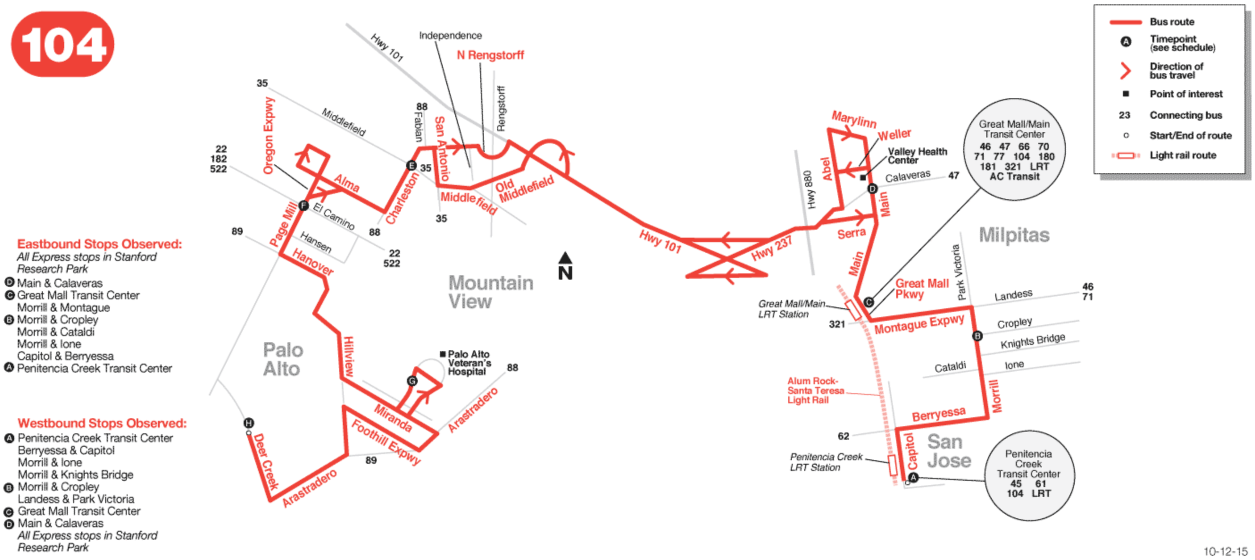
Source: http://www.samtrans.com/schedulesandmaps/timetables/397.html.

Figure A-22: Map for SamTrans Route 398



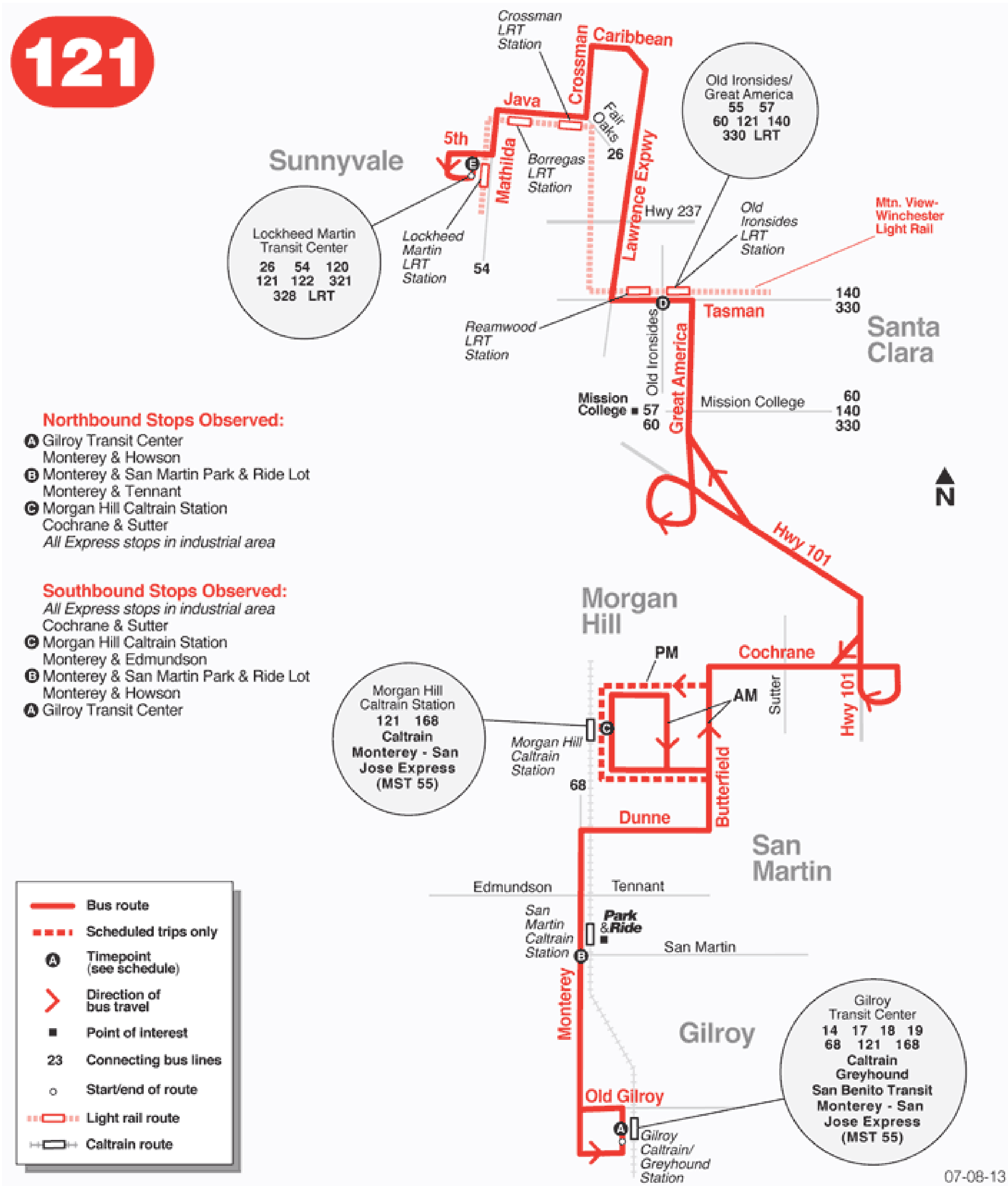
Source: http://www.samtrans.com/schedulesandmaps/timetables/398.html.

Figure A-23: Map for VTA Route 104



Source: http://www.vta.org/routes/rt104.

Figure A-24: Map for VTA Route 121

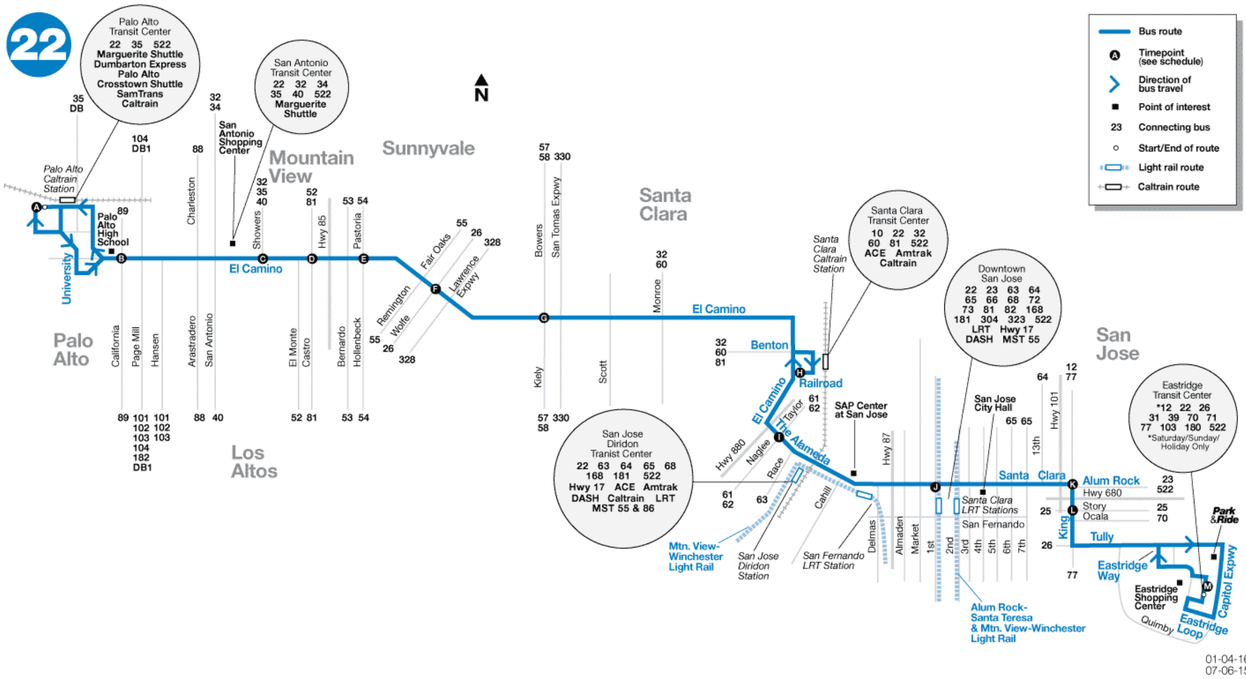


Source: http://www.vta.org/routes/rt121.

Figure A-25: Map for VTA Route 122

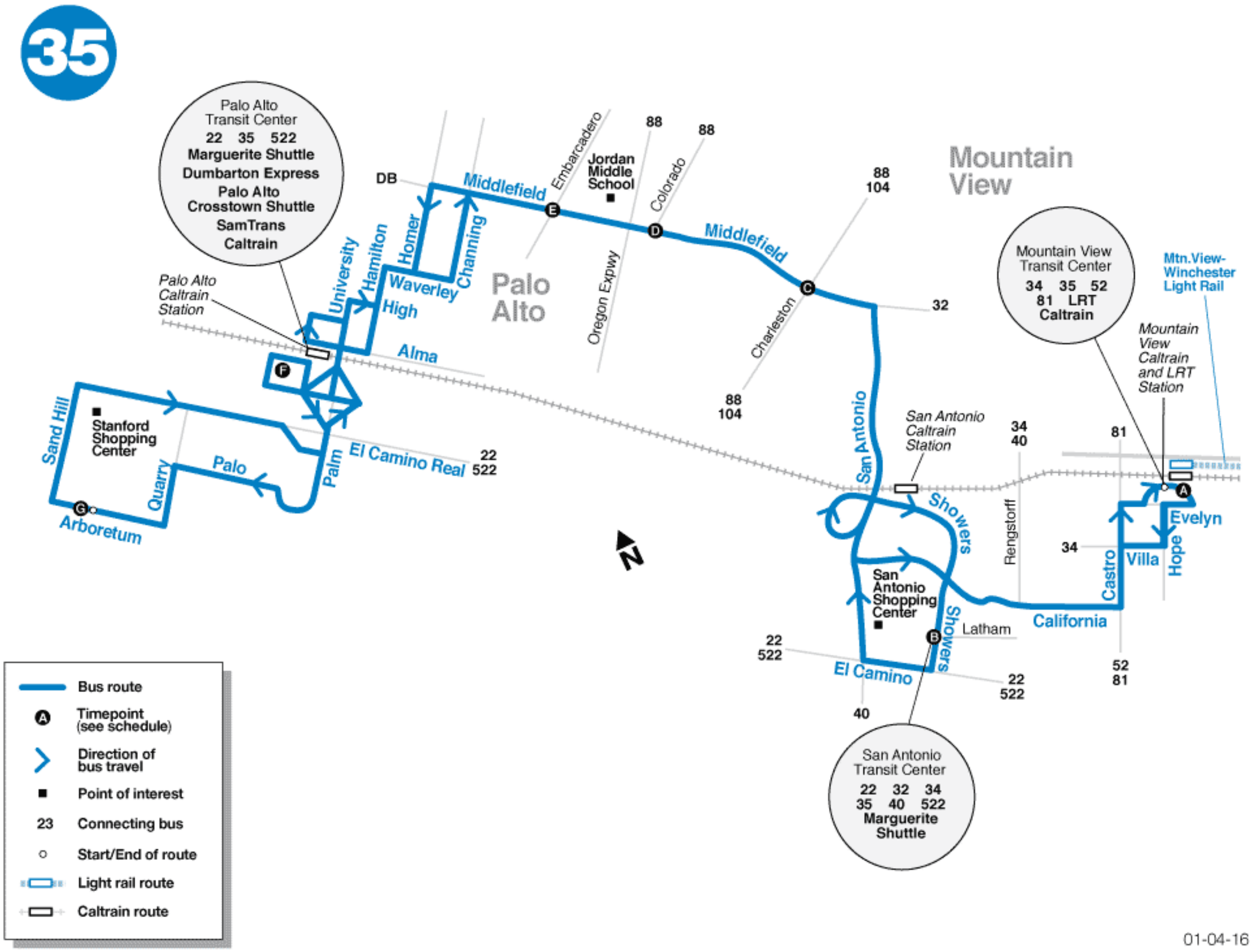
Source: http://www.vta.org/routes/rt122.

Figure A-26: Map for VTA Route 22



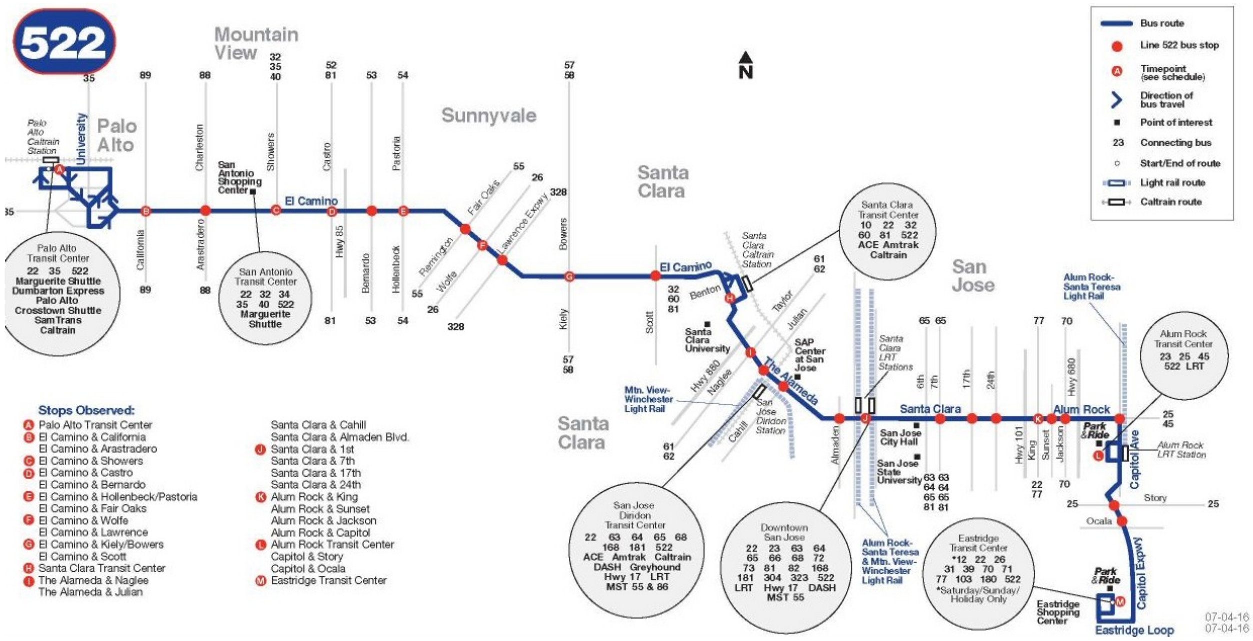
Source: http://www.vta.org/routes/rt22.

Figure A-27: Map for VTA Route 35



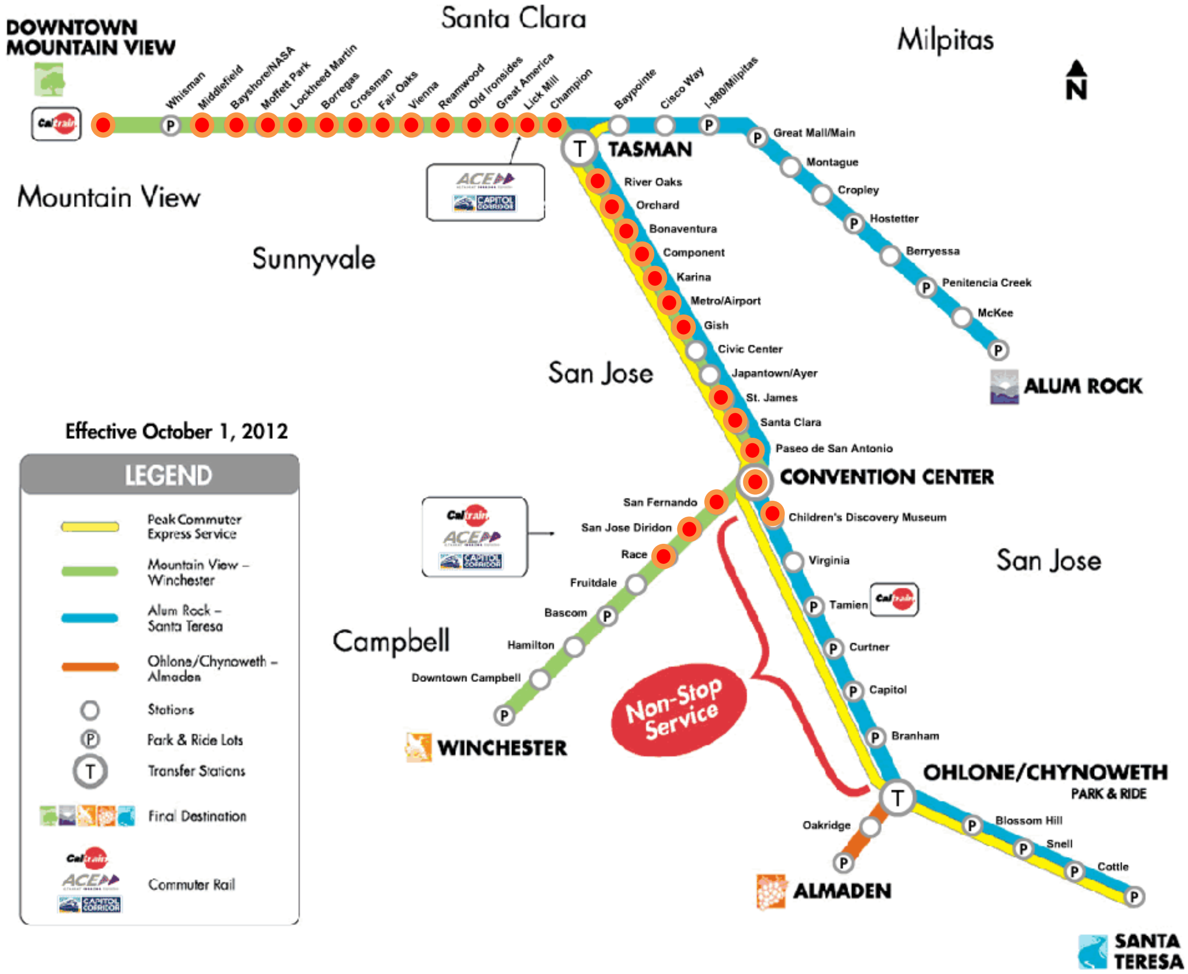
Source: http://www.vta.org/routes/rt35.

Figure A-28: Map for VTA Route 522



Source: http://www.vta.org/routes/rt522.

Figure A-29: Map of VTA Light Rail System



Source: http://www.vta.org/getting-around/interactive-light-rail-map.
Note: Red dots mark stations within the highlighted area of Figure 5-1.

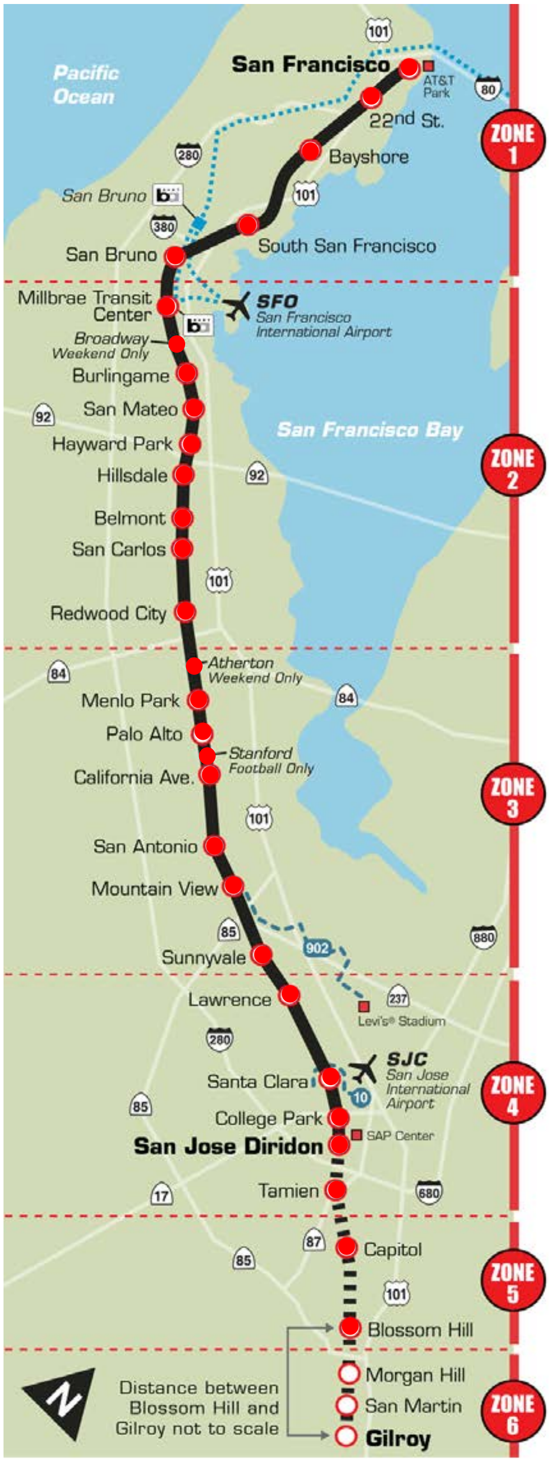
Table A-3: Average VTA Weekday Light Rail Ridership by Station from July 2014 – December 2014

Station	Weekday Ridership
Downtown Mountain View	1,244
Whisman	124
Middlefield	276
Bayshore/NASA	75
Moffett Park	146
Lockheed Martin	319
Borregas	144
Crossman	122
Fair Oaks	344
Vienna	130
Reamwood	155
Old Ironsides	452
Great America	419
Lick Mill	338
Champion	208
River Oaks	521
Orchard	197
Bonaventura	154
Component	288
Karina	587
Metro/Airport	606
Gish	972
St. James	679
Santa Clara	2,554
Paseo de San Antonio	2,723
Convention Center	1,276
Children’s Discovery Museum	334
San Fernando	205
San Jose Diridon	694
Race	322

Figure A-30: BART System Map

Source: http://www.bart.gov/stations.
Note: Red dots mark stations within the highlighted area of Figure 5-1.

Figure A-31: Caltrain System Map



Source: http://www.caltrain.com/stations/systemmap.html.
Note: Red dots mark stations within the highlighted area of Figure 5-1.

Table A-4: Overall Weekday Ridership Data for Caltrain

	Northbound		Southbound		Total	
STATION	**On**	**Off**	**On**	**Off**	**On**	**Off**
San Francisco	0	13,626	13,571	0	13,571	13,626
22nd Street	30	1,613	1,600	21	1,629	1,634
Bayshore	36	207	219	41	254	249
South SF	195	277	277	190	472	467
San Bruno	279	404	403	274	682	678
Millbrae	549	3,057	2,986	521	3,536	3,578
Burlingame	499	488	499	502	998	990
San Mateo	1,003	1,020	1,058	1,040	2,061	2,060
Hayward Park	187	189	181	194	367	383
Hillsdale	1,669	1,015	1,036	1,701	2,706	2,716
Belmont	367	306	332	360	699	666
San Carlos	768	695	667	769	1,435	1,464
Redwood City	2,093	1,136	1,140	2,073	3,233	3,209
Menlo Park	1,033	750	730	1,054	1,762	1,804
Palo Alto	4,588	2,582	2,609	4,845	7,197	7,427
California Ave.	1,047	472	506	960	1,553	1,432
San Antonio	692	152	181	610	872	762
Mountain View	4,022	448	548	3,939	4,570	4,387
Sunnyvale	2,625	182	256	2,659	2,881	2,841
Lawrence	715	136	141	692	856	828
Santa Clara	951	57	55	929	1,006	986
College Park	56	46	26	108	82	154
San Jose Diridon	4,005	47	155	4,313	4,160	4,360
Tamien	1,089	138	13	896	1,102	1,035
Capitol	42	1	1	39	43	40
Blossom Hill	115	5	5	95	120	100
Morgan Hill	172	0	0	159	172	160
San Martin	71	1	0	61	71	62
Gilroy	153	0	0	146	153	146
TOTAL	**29,050**	**29,050**	**29,195**	**29,195**	**58,245**	**58,245**

Source: Caltrain 2015 Annual Passenger Count Key Findings (page 24).

Table A-5: Weekday AM Peak Ridership Data for Caltrain

Station	Northbound		Southbound		Total	
	On	Off	On	Off	On	Off
San Francisco	0	8,251	3,155	0	3,155	8,251
22nd Street	5	79	1,320	12	1,325	91
Bayshore	27	27	111	3	138	30
South SF	100	170	66	54	166	224
San Bruno	192	99	178	24	370	123
Millbrae	374	906	1,249	83	1,623	989
Burlingame	295	91	247	62	542	153
San Mateo	544	311	507	227	1,051	537
Hayward Park	63	55	70	54	132	108
Hillsdale	1,165	352	479	251	1,644	603
Belmont	149	84	129	66	278	149
San Carlos	321	205	352	283	673	488
Redwood City	860	478	352	768	1,212	1,246
Menlo Park	315	408	195	515	510	923
Palo Alto	911	1,800	255	2,936	1,166	4,736
California Ave.	320	276	64	408	384	685
San Antonio	342	55	39	123	381	178
Mountain View	1,618	225	105	1,613	1,723	1,838
Sunnyvale	1,947	108	32	183	1,979	291
Lawrence	280	86	22	267	302	353
Santa Clara	448	34	9	197	457	231
College Park	2	46	0	104	2	150
San Jose Diridon	2,470	43	1	685	2,471	728
Tamien	1,032	138	0	19	1,032	157
Capitol	42	1	0	0	42	1
Blossom Hill	115	5	0	0	115	5
Morgan Hill	172	0	0	0	172	0
San Martin	71	1	0	0	71	1
Gilroy	153	0	0	0	153	0
Total	**14,332**	**14,332**	**8,937**	**8,937**	**23,268**	**23,268**

Source: Caltrain 2015 Annual Passenger Count Key Findings (page 26).

Table A-6: Saturday Ridership Data for Caltrain Stations

	Northbound		Southbound		Total	
Station	**On**	**Off**	**On**	**Off**	**On**	**Off**
San Francisco	0	4,800	4,374	0	4,374	4,800
22nd Street	7	316	288	15	295	331
Bayshore	21	148	120	15	141	163
South SF	66	122	106	73	172	195
San Bruno	86	152	132	93	218	245
Millbrae	139	1,061	997	109	1,136	1,170
Broadway	77	90	77	55	154	145
Burlingame	253	217	218	201	471	418
San Mateo	365	305	298	326	663	631
Hayward Park	113	82	78	112	191	194
Hillsdale	441	253	249	410	690	663
Belmont	213	82	76	170	289	252
San Carlos	274	122	85	224	359	346
Redwood City	719	294	292	651	1,011	945
Atherton	67	36	22	62	89	98
Menlo Park	334	150	176	270	510	420
Palo Alto	1,209	408	388	1,100	1,597	1,508
California Ave.	403	96	103	348	506	444
San Antonio	321	64	48	274	369	338
Mountain View	1,041	128	164	978	1,205	1,106
Sunnyvale	813	50	53	845	866	895
Lawrence	205	29	20	176	225	205
Santa Clara	451	17	6	425	457	442
San Jose Diridon	1,404	0	0	1,438	1,404	1,438
Total	**9,022**	**9,022**	**8,370**	**8,370**	**17,392**	**17,392**

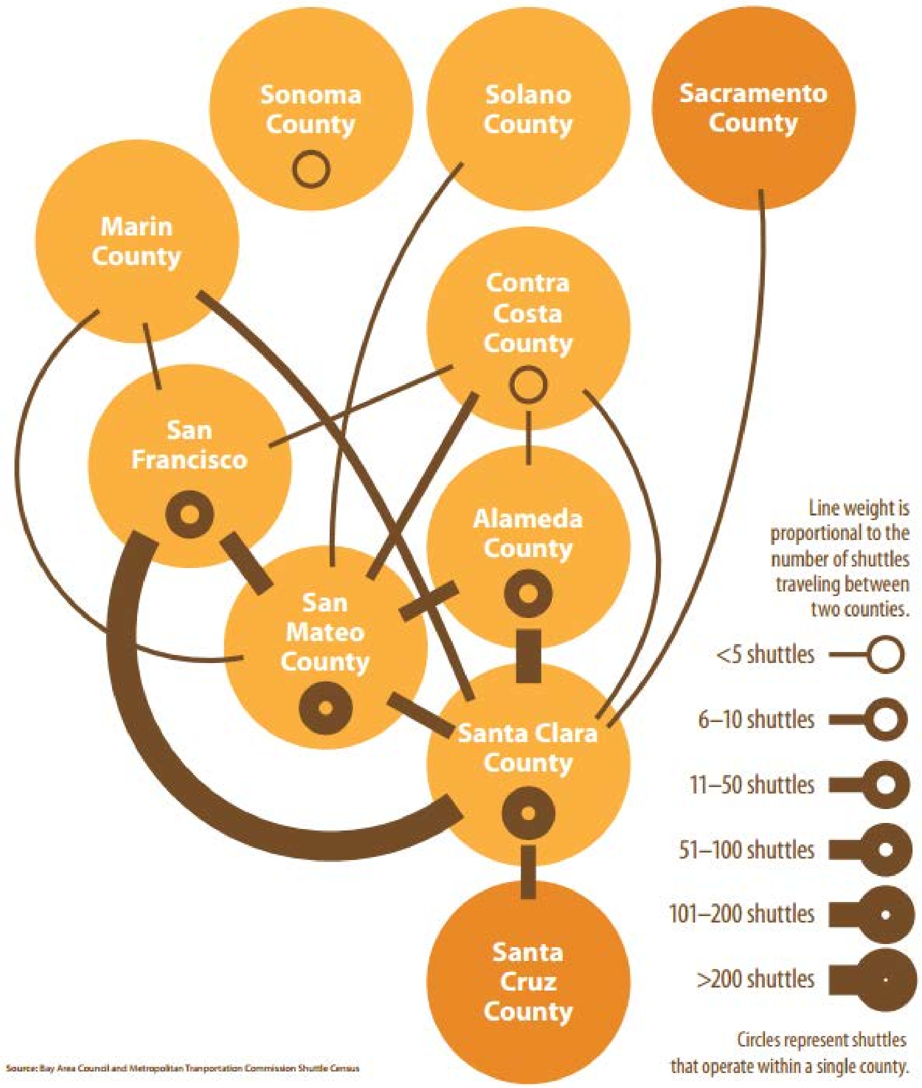
Source: Caltrain 2015 Annual Passenger Count Key Findings (page 35).

Table A-7: Sunday Ridership Data for Caltrain Stations

	Northbound		Southbound		Total	
Station	**On**	**Off**	**On**	**Off**	**On**	**Off**
San Francisco	0	1,950	2,301	0	2,301	1,950
22nd Street	3	119	168	3	171	122
Bayshore	6	57	128	7	134	64
South SF	26	44	47	34	73	78
San Bruno	32	79	75	36	107	115
Millbrae	52	549	703	54	755	603
Broadway	25	51	38	26	63	77
Burlingame	94	110	122	85	216	195
San Mateo	151	174	152	175	303	349
Hayward Park	52	42	33	53	85	95
Hillsdale	146	126	152	173	298	299
Belmont	105	59	60	131	165	190
San Carlos	107	71	68	108	175	179
Redwood City	293	147	132	344	425	491
Atherton	16	21	6	25	22	46
Menlo Park	159	95	118	152	277	247
Palo Alto	520	227	202	604	722	831
California Ave.	183	58	49	211	232	269
San Antonio	132	26	31	168	163	194
Mountain View	561	68	79	592	640	660
Sunnyvale	331	29	30	375	361	404
Lawrence	108	18	13	119	121	137
Santa Clara	241	10	12	250	253	260
San Jose Diridon	787	0	0	994	787	994
Total	**4,130**	**4,130**	**4,719**	**4,719**	**8,849**	**8,849**

Source: Caltrain 2015 Annual Passenger Count Key Findings (page 36).

Figure A-32: Private Shuttle Daily Travel Patterns in the Bay Area



Source: http://mtc.ca.gov/sites/default/files/2016%20Bay%20Area%20Shuttle%20Census.pdf.

Table A-8: Private Shuttle Screenline Counts from February 2016

			6-7 AM			7-8 AM			8-9 AM			9-10 AM			4-5 PM			5-6 PM			6-7 PM			All Day			
Direction (N/S)	Entry Segment (1-8)	Exit Segment (1-8)	Buses/Period	Passengers/Period	Passengers/Bus	Buses/Period	Passengers/Period	Passengers/Bus	Buses/Period	Passengers/Period	Passengers/Bus	Buses/Period	Passengers/Period	Passengers/Bus	Buses/Period	Passengers/Period	Passengers/Bus	Buses/Period	Passengers/Period	Passengers/Bus	Buses/Period	Passengers/Period	Passengers/Bus	Buses/Day	Passengers/Day	Passengers US Bus	Vehicle Capacity (Passengers/Bus)
S	1	2	12	316	26	15	523	35	13	372	29	8	134	17										48	1345	28	48
S	1	3	5	30	6	5	200	40	3	120	40	5	90	18	1	15	15	0	0		1	5	5	20	460	23	60
S	1	7	9	218	24	11	334	30	9	266	30	6	119	20										40	1069	22	55
S	1	8	48	1586	33	60	2193	37	21	1008	48	26	725	28	2	70	35	0	0	0	1	20	20	176	5515	31	57
S	2	3													5	191	38	2	86	43	2	37	19	10	360	36	60
S	2	4													2	54	27	4	75	19	2	11	6	12	182	15	40
S	2	5													6	245	41				2	35	18	11	393	36	54
S	2	7													2	111	56	1	47	47	1	13	13	5	222	44	63
S	3	2	1	25	25	1	47	47	2	53	27													4	125	31	52
S	3	7	2	44	22	4	60	15	3	66	22	3	32	11										12	202	22	47
S	3	8	0	0		2	80	40	1	60	60	5	100	20	1	20	20	2	50	25	1	20	20	12	330	28	60
S	6	7				3	31	10	3	45	15	3	33	11										9	109	22	32
S	6	8	0	0		1	30	30	1	50	50	0	0		0	0		0	0		0	0		2	80	40	60
S	7	8	10	400	40	10	450	45	10	400	40	5	160	32	11	169		14	181		18	202		106	2099	28	49
N	2	1													14	520	37	11	355	32	9	122	14	46	1209	26	47
N	3	1	0	0		0	0		0	0		0	0		5	100	20	5	150	30	10	150	15	20	400	20	60
N	3	2	1	24	24	2	101	51	1	68	68	2	64	32										6	257	43	63
N	4	2	2	23	12	3	65	22	3	79	26	2	27	14										11	201	18	43
N	5	2	3	145	48	2	67	34	1	20	20	3	98	33										9	330	37	55
N	7	1													9	262		9	221		8	173		42	959	22	55
N	7	2	1	39	39	2	103	52	1	33	33	1	33	33										5	208	42	63
N	7	3													3	90		3	35		3	54		14	234	22	44
N	7	6													1	4		3	26		3	48		9	105	22	34
N	8	1	1	40	40	2	50	25	1	20	20	1	20	20	50	2000	40	34	1334	1	17	712	42	106	3965	40	59
N	8	3	0	0		0	0		1	30	30	2	40	20	0	0		1	30	30	0	0		4	100	25	60
N	8	6	0	0		0	0		0	0		0	0		1	50	50	0	0		1	25	25	2	75	38	60
N	8	7	2	4	2	18	214	12	18	245	14	16	210	13	15	570	38	10	340	34	5	200	40	98	1843	27	49

Source: MTC and Bay Area Council Request for Private Bus Service Data, 101 Shuttles Data for pointC 02.16.xlsx.

Additional Data and Supporting Information for ITS Assets along the Corridor

The following supplemental inventory data for TDM and ATM strategy support are provided in this section of the technical appendix:

- Transportation System Management Assets
  - Ramp meter locations on the corridor, by configuration (see Figure A-33)
  - Dynamic message sign locations on the corridor (see Figure A-34)
  - Freeway Service Patrol coverage map (see Figure A-35) and assistance density map (see Figure A-36).
- Supporting ITS Infrastructure
  - Inductive Loop Locations on the corridor, by data quality (see Figure A-37)
  - CCTV Locations on the corridor, by status (see Figure A-38)
  - Fiber Communications on the corridor, by type (see Figure A-39)
- Major corridor population centers (see Figure A-40) and employment centers (see Figure A-41)

Figure A-33: Ramp Meter Locations and Configuration for US 101

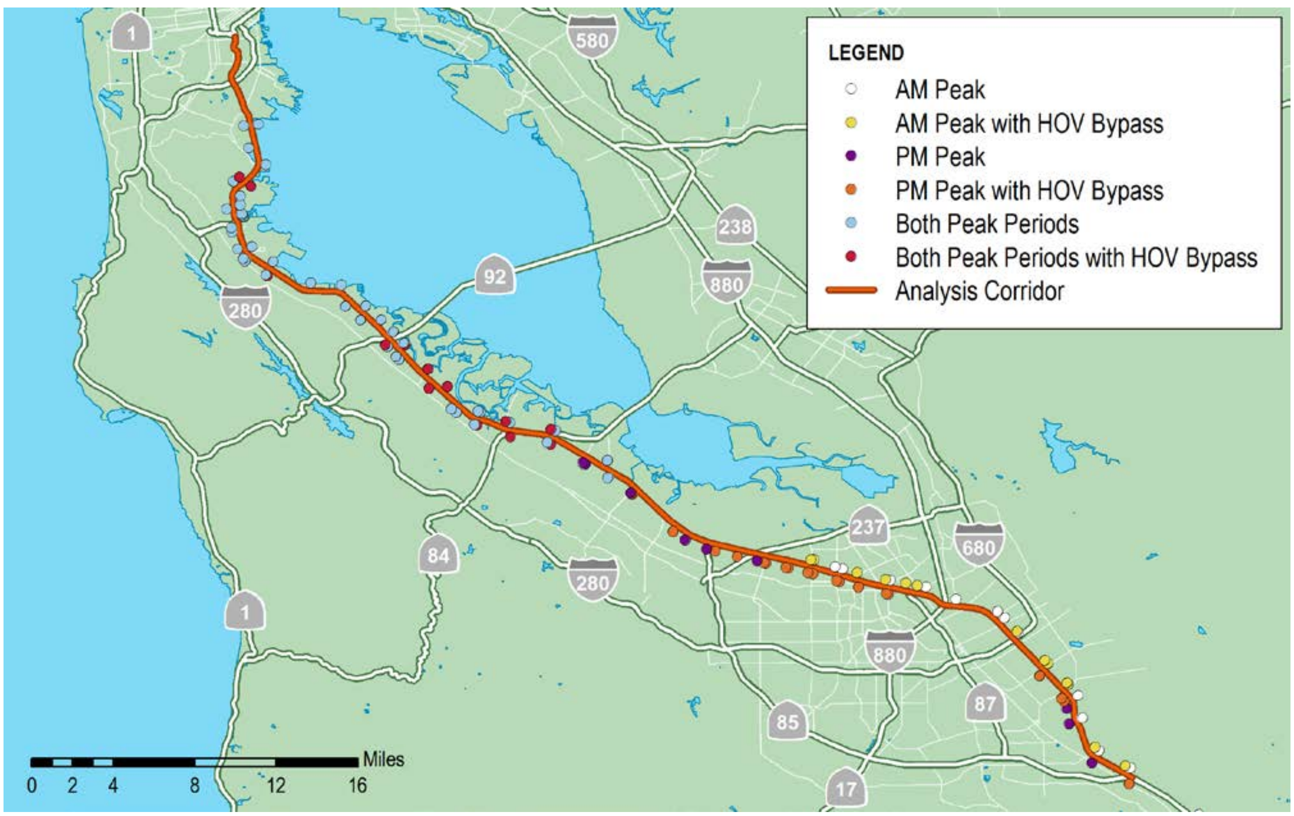


Figure A-34: Dynamic Message Signs on US 101

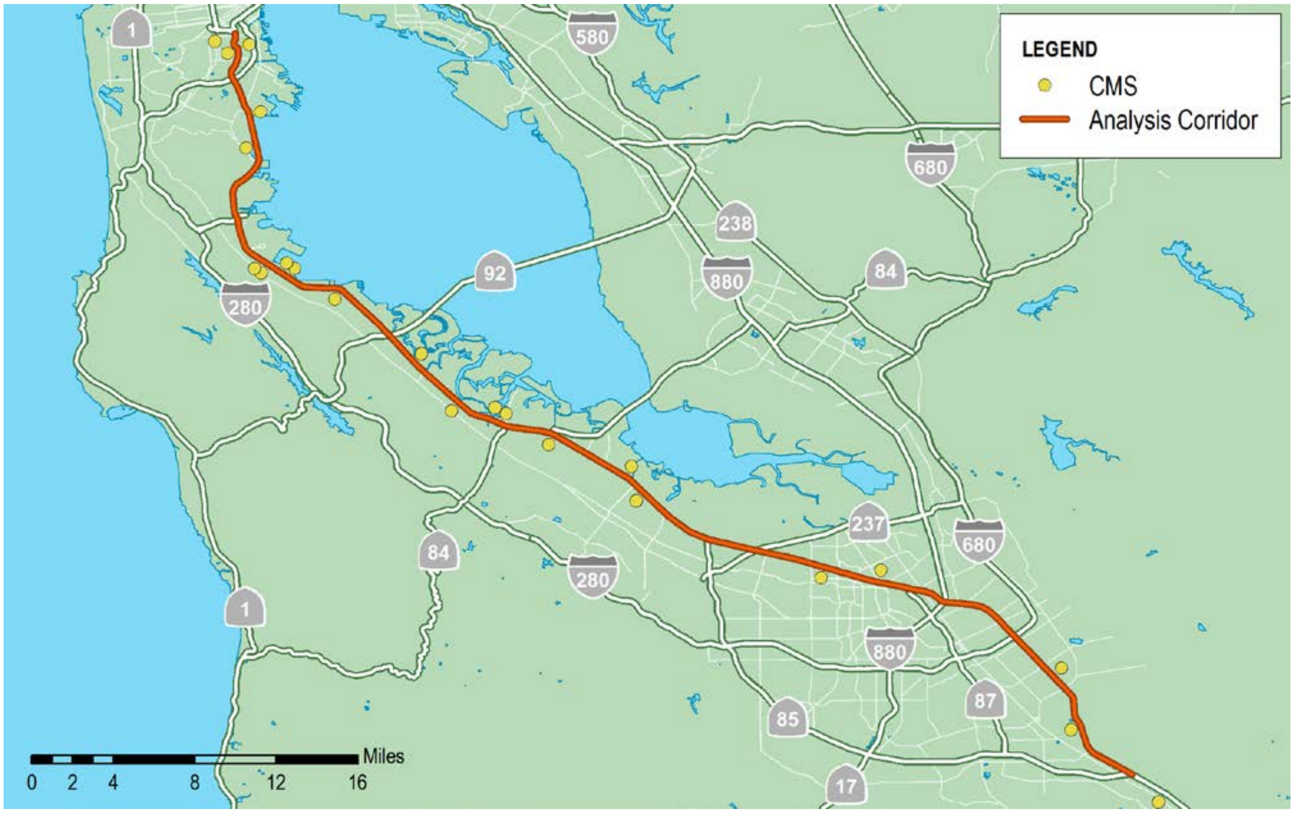
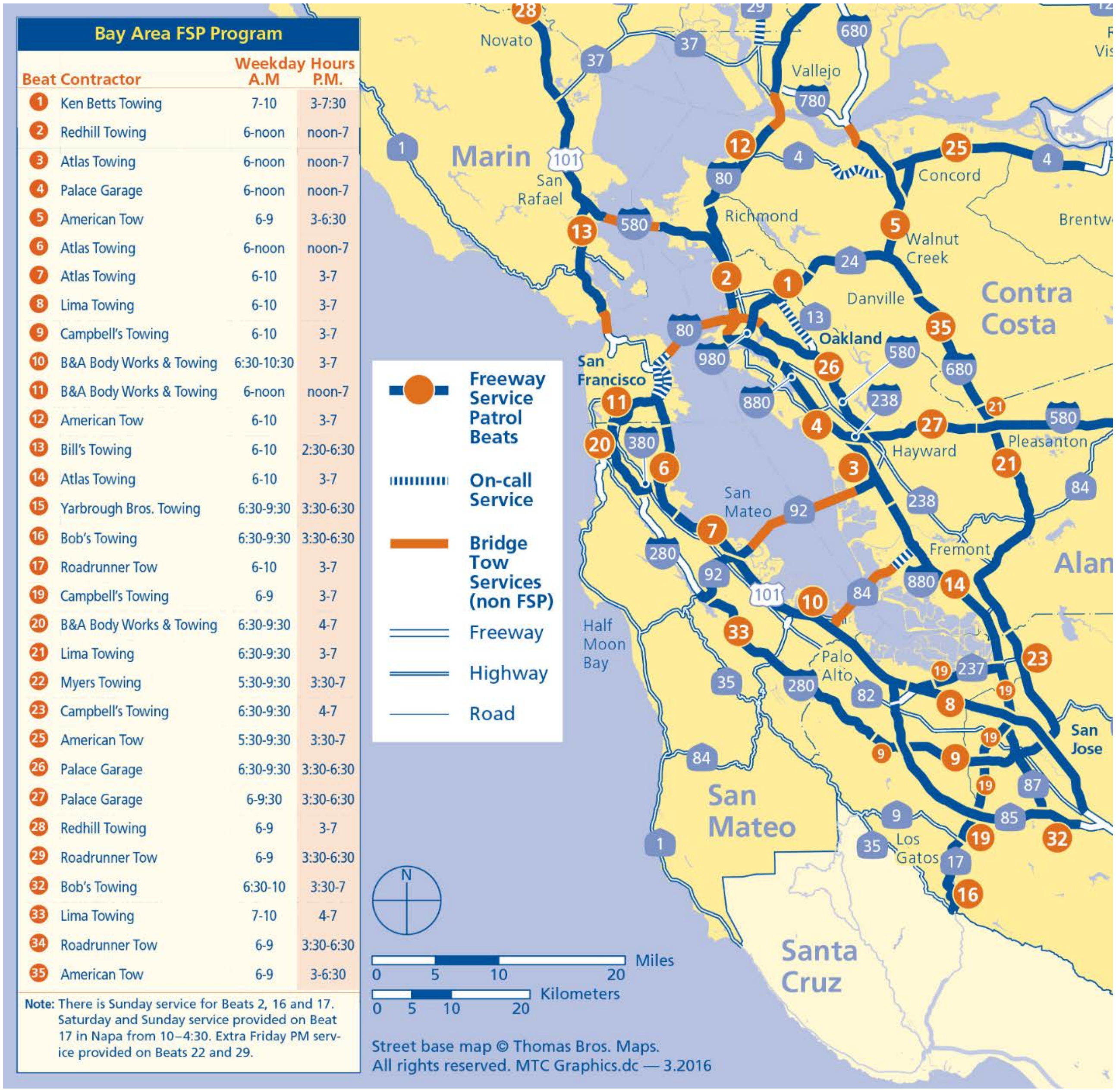
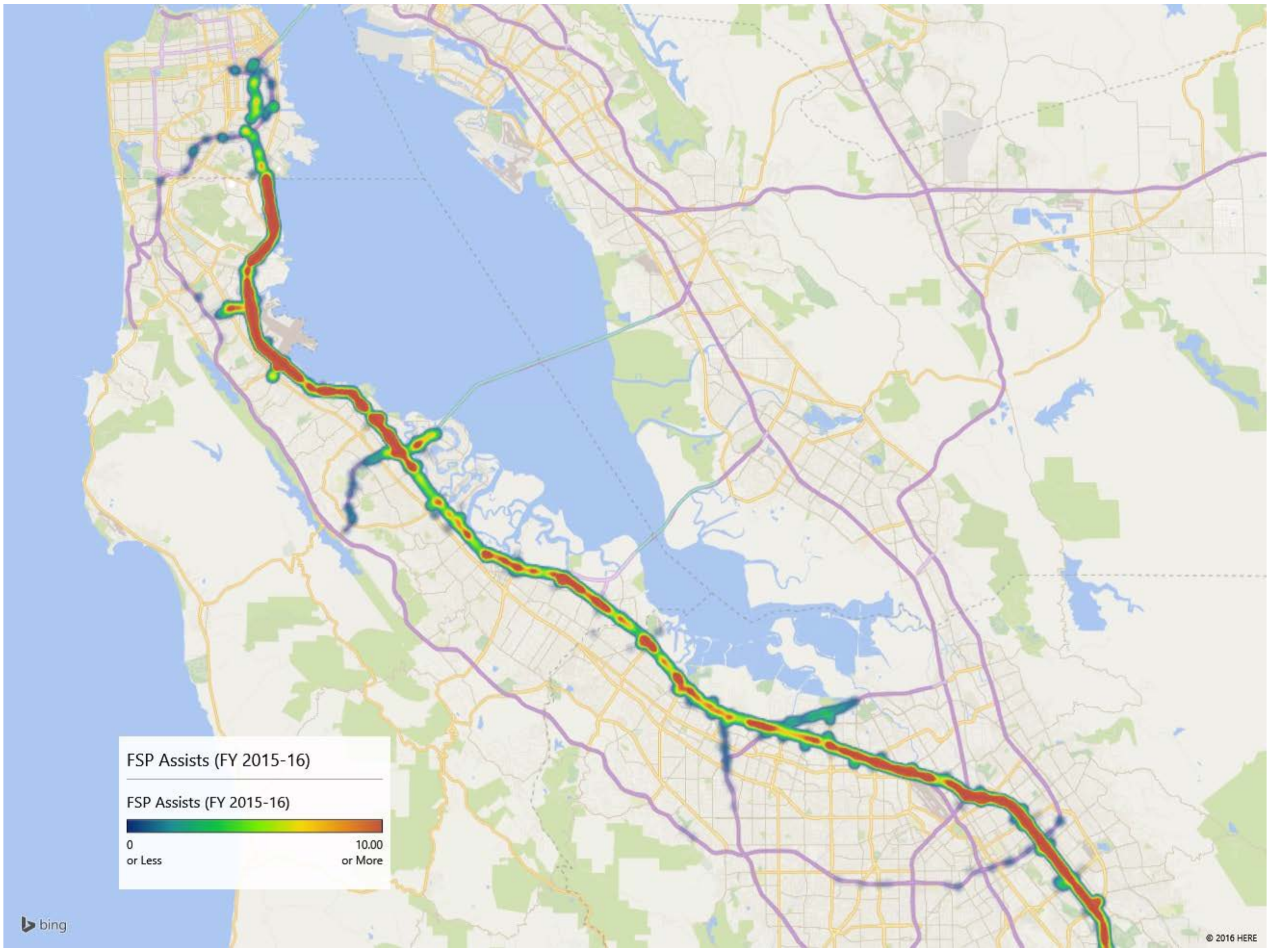


Figure A-35: Freeway Service Patrol Map of Coverage Beats



Source: http://www.fsp-bayarea.org/.

Figure A-36: Freeway Service Patrol (FSP) Assist Density for US-101 Coded Assists



Source: California PATH.

Figure A-37: Inductive Loop Mainline Data from PeMS, by Data Quality as of August 2016

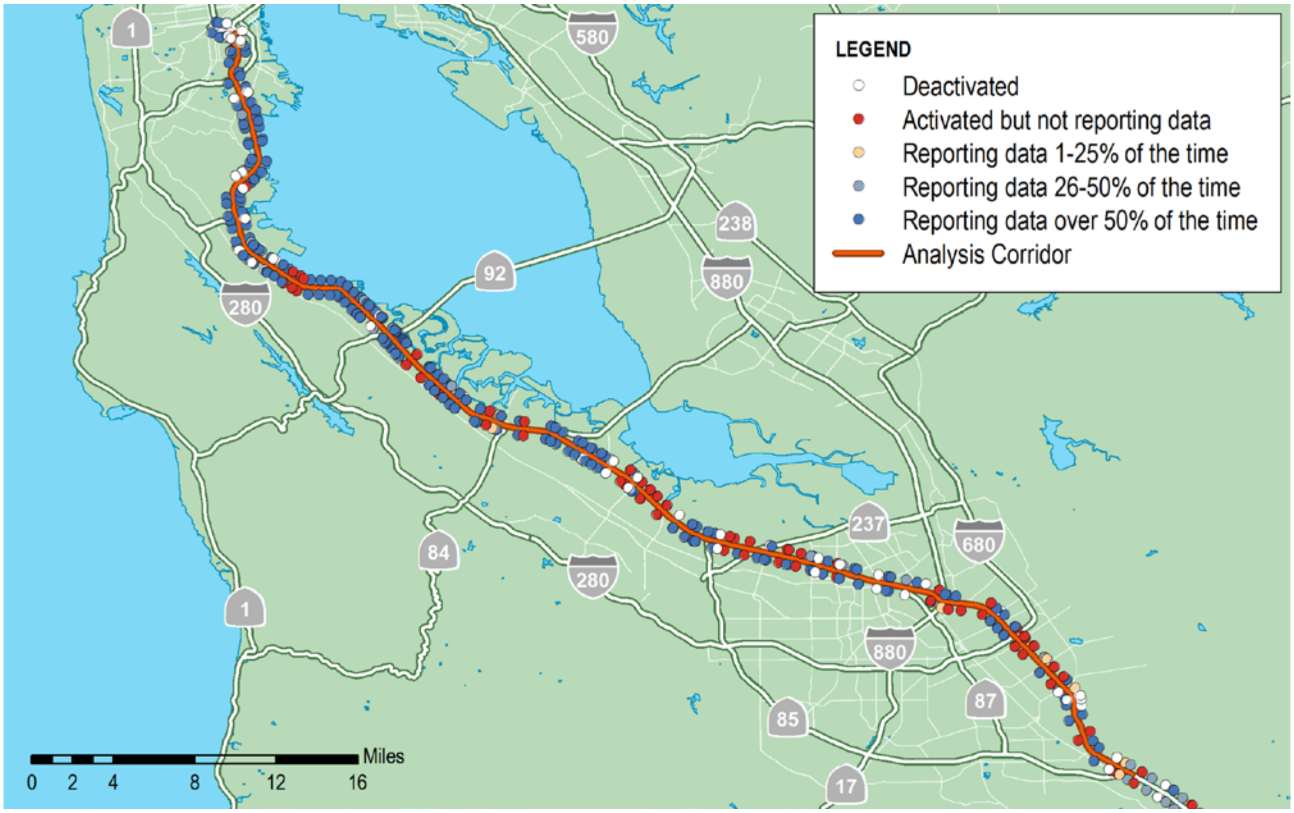


Figure A-38: CCTV Locations on US 101 by Deployment Status

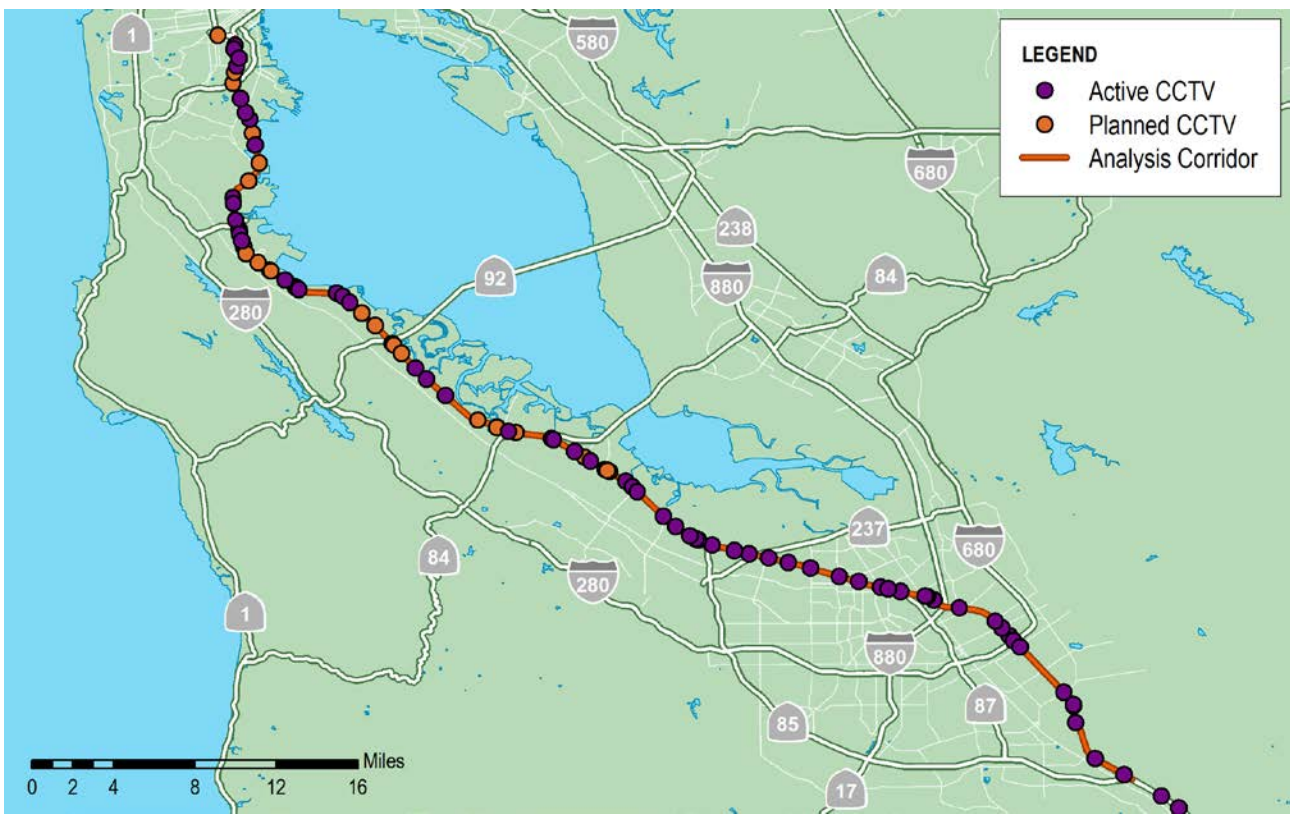


Figure A-39: Fiber Communications Infrastructure on US 101 by Type

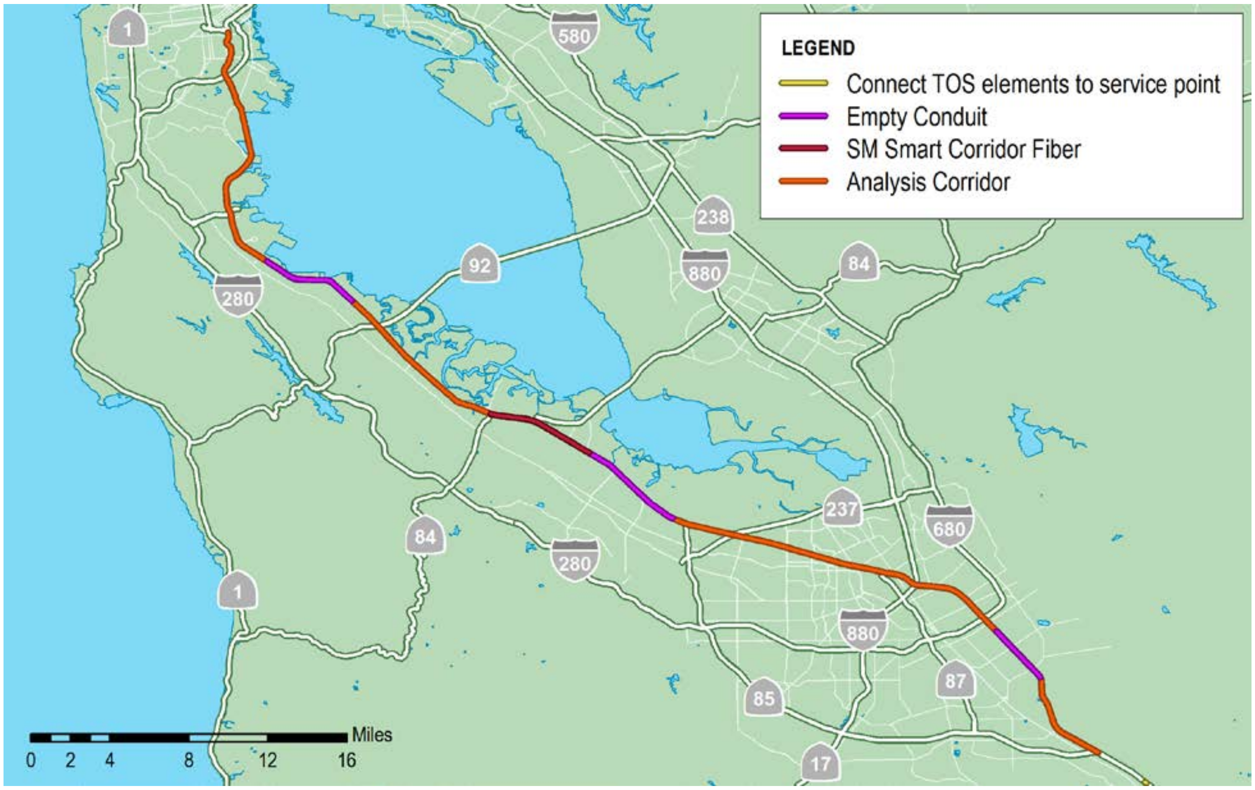
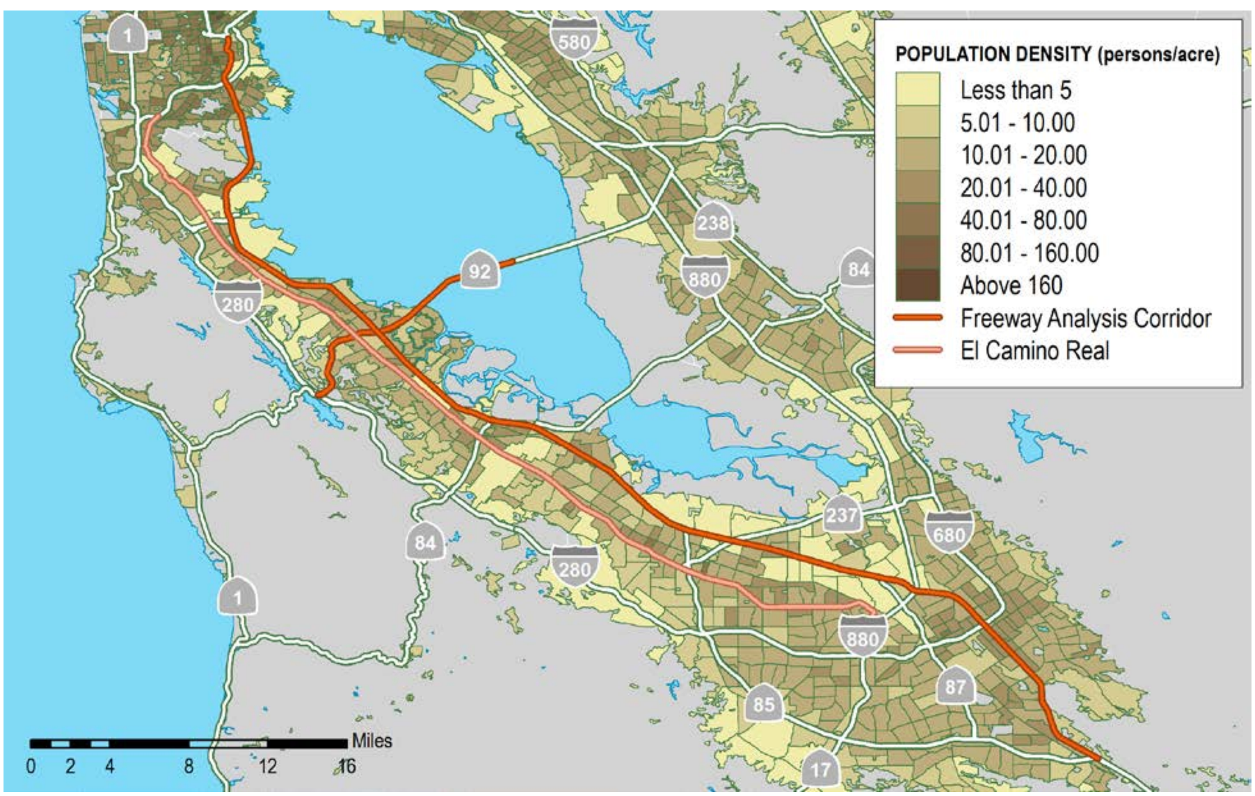
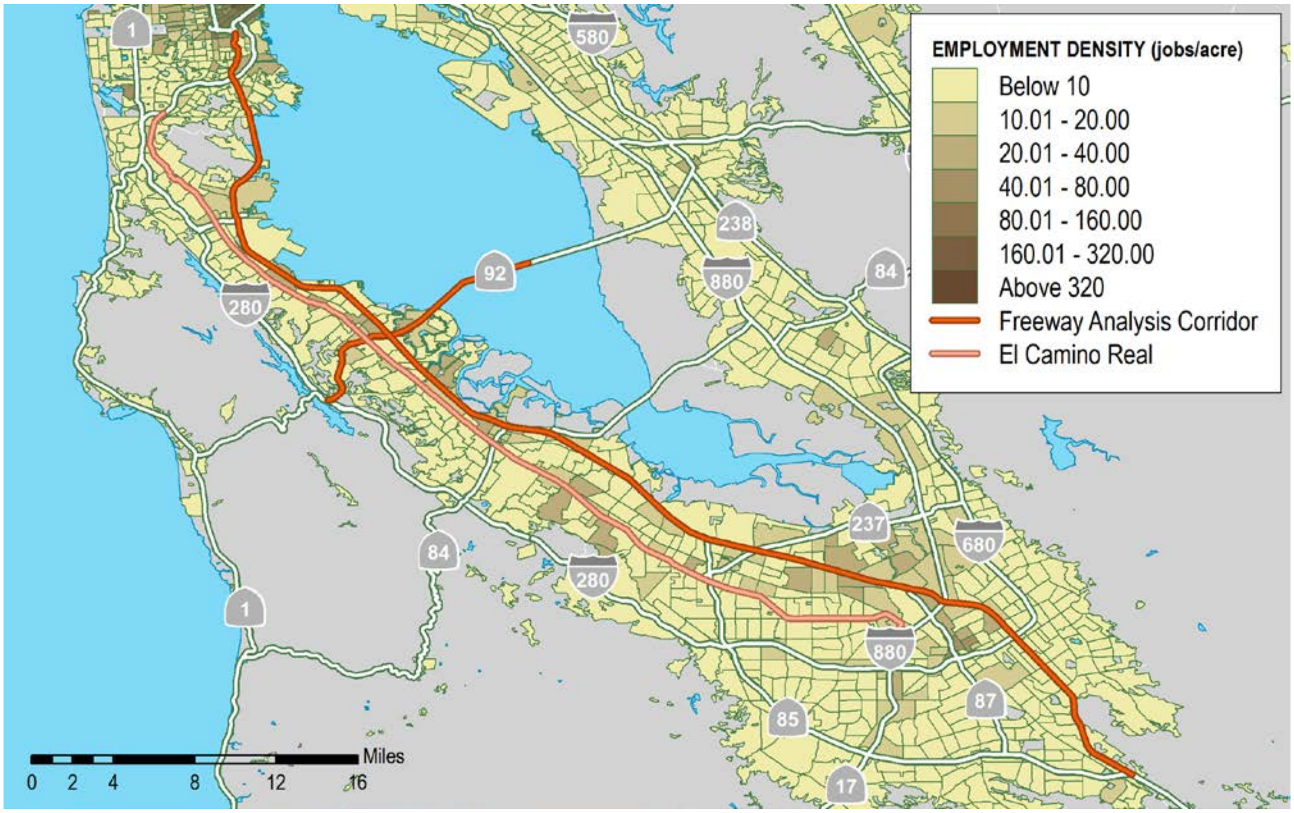


Figure A-40: Population Density Distribution along the US 101 Corridor



Source: Cambridge Systematics, using MTC Bay Area Travel Model.

Figure A-41: Employment Density Distribution along the US 101 Corridor



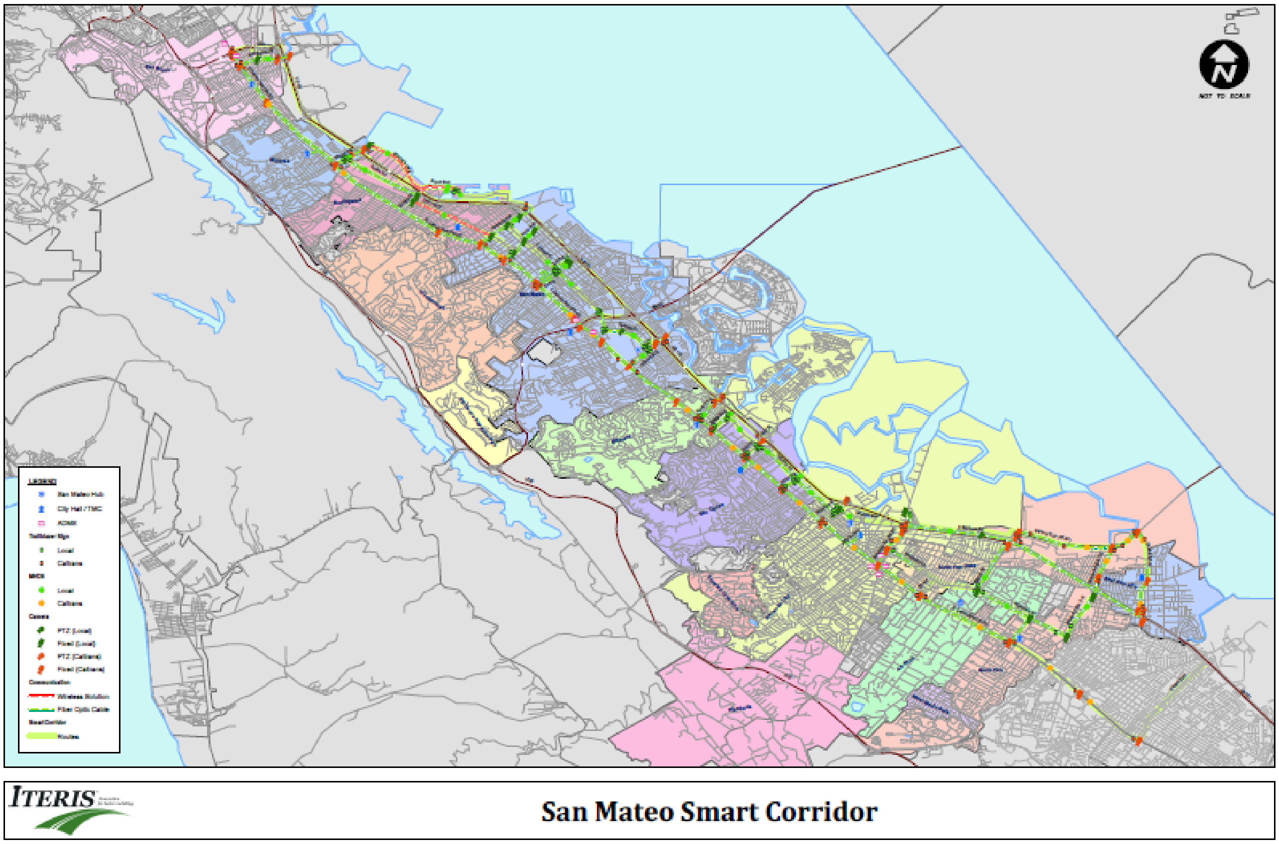
Source: Cambridge Systematics, using MTC Bay Area Travel Model.

Additional Data and Supporting Information for Current and Near-Term Future-Related Projects on the Corridor

The following supplemental data for current and near-term future projects in the vicinity of the US 101 corridor are provided in this section of the technical appendix:

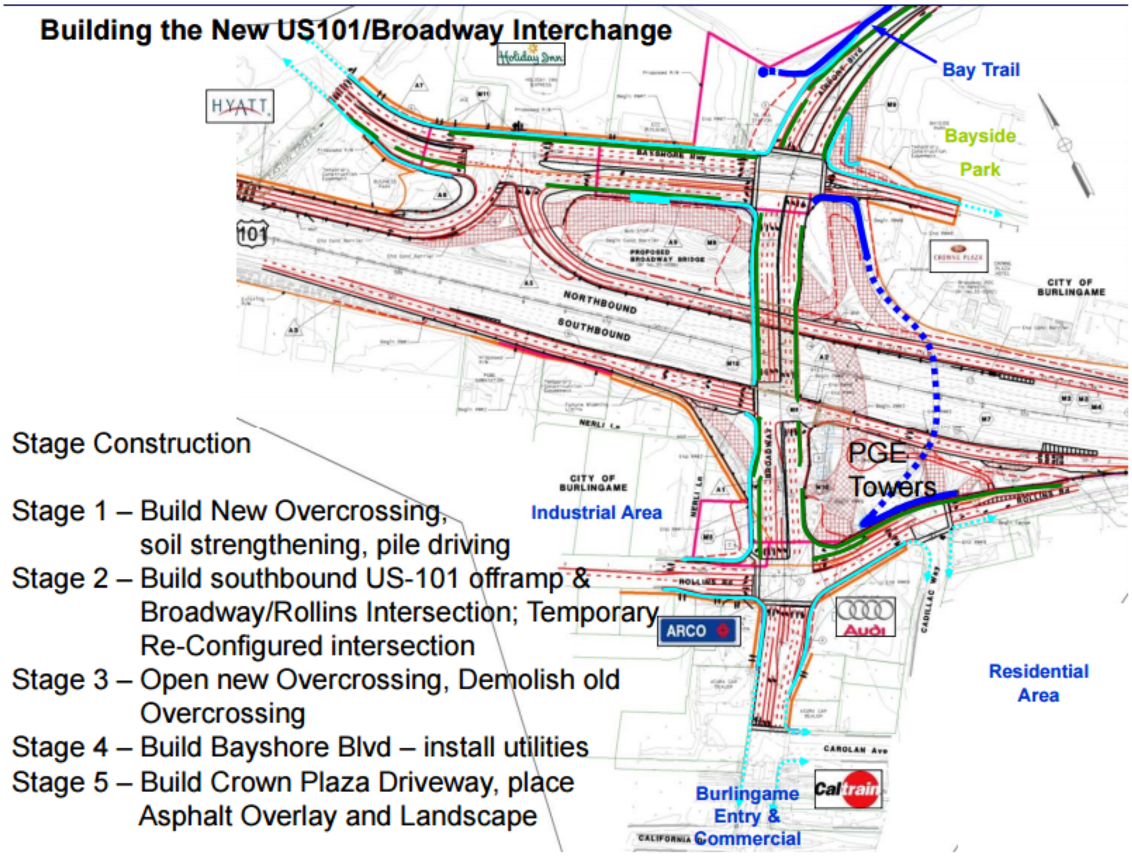
- San Mateo Smart Corridor Project
  - Project map (see Figure A-42)
- Caltrans Capital Improvement Interchange Projects
  - US 101/Broadway Interchange Improvements diagram (see Figure A-43)

Figure A-42: San Mateo Smart Corridor Project Extents



Source: http://publicworks.smcgov.org/san-mateo-county-smart-corridors-project.

Figure A-43: Planned Improvements to the US 101 Interchange at Broadway



Source: https://www.burlingame.org/modules/showdocument.aspx?documentid=11672.

Additional Feasibility Consideration and Benefit Ranges for ATM and TDM Strategies

This appendix includes additional background information about each of the ATM and TDM strategies discussed in the main body of this report. Specifically, the following are provided for each strategy when available/applicable:

- A short description of the underlying principle(s) or idea of each strategy, along with a figure or photo when available.
- Experienced benefits and outcomes — a summary of the more significant observed outcomes associated with the strategy, based on past deployments.
- Infrastructure and systems feasibility considerations — various roadway characteristics, infrastructure assets, and geometric factors that have been found from past deployments to be crucial to the success and/or efficacy of the strategy.
- Institutional feasibility considerations — inter-agency collaboration and data sharing needs on which the strategy depends.
- Other complementary strategies — a listing of any other particularly relevant ATM strategies that may perform a key role in the success of the given strategy.

Queue Warning Systems

Using real-time traffic detection to inform travelers of downstream stop-and-go traffic caused by incidents, work zones, etc. Flashing lights or dynamic message signs (DMS) can be used to warn the driver to be prepared to slow down or direct through traffic to alternate lanes. Queue Warning Systems (QWS) are intended to assist driver reaction to unanticipated speed reductions, particularly those in excess of 10 mph. QWS can potentially reduce the number of rear-end crashes caused by stop-and-go traffic. (Photo licensed to Cambridge Systematics)

Experienced Benefits and Outcomes:

- Primary Incident Reductions: 4%[67]-42%[68]
- Secondary Incident Reductions: 40%[69]-50%[70]
- Decrease in speed variability in the traffic stream, particularly at the onset of congestion.[71]

Infrastructure and Systems Feasibility Considerations:

- Clearance for overhead or side-mounted signs is generally required, at spacings of 2-3 per mile.
- CCTV cameras and closely-spaced traffic detection (including before and after ramps) are useful for monitoring conditions on the facility at all times and overriding the automated operation of the system if required. CCTV density should be such that all parts of the facility can be monitored.
- Portable message signs can be used when queues form in areas where there are no permanent CMSs available.

Institutional Feasibility Considerations:

- Coordination between operations staff and maintenance crews is required for effective work zone queue warning implementations.

Other Complementary Strategies:

- Variable speed limits and lane control signals that provide incident management capabilities can be combined with queue warnings.

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[67] Advance Warning of Stopped Traffic on Freeways: Current Practices and Field Studies of Queue Propagation Speeds. http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/4413-1.pdf.

[68] Advance Warning of Stopped Traffic on Freeways: Current Practices and Field Studies of Queue Propagation Speeds. http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/4413-1.pdf (accessed 11-1-2013).

[69] Planning for Active Traffic Management in Virginia: International Best Practices and Implementation Strategies. http://www.virginiadot.org/vtrc/main/online_reports/pdf/13-r1.pdf (accessed 12/7/2016).

[70] Planning for Active Traffic Management in Virginia: International Best Practices and Implementation Strategies. http://www.virginiadot.org/vtrc/main/online_reports/pdf/13-r1.pdf (accessed 12/7/2016).

[71] Planning for Active Traffic Management in Virginia: International Best Practices and Implementation Strategies. http://www.virginiadot.org/vtrc/main/online_reports/pdf/13-r1.pdf (accessed 12/7/2016).

Hard Shoulder Running

Using the roadway shoulder (inside or outside) as a travel lane during congested periods to alleviate recurrent (bottleneck) congestion for all or a subset of users such as transit buses. Hard shoulder running can also be used to manage traffic and congestion immediately after an incident. (Photo courtesy of FHWA)[72]

Experienced Benefits and Outcomes:

- Increase in capacity: 7%[73]–50%.[74]
- Decrease in delay up to 90%.[75]
- Decrease in congestion: 30%[76]–82%.[77]
- Decrease in crash rates: 5%[78]–70%.[79]
- Decrease in travel times: 9%[80]–27%.[81]
- Reduction in emissions by 4%,[82] fuel use by 10%.[83]

Infrastructure and Systems:

- Continuous lighting of the shoulder may be required.
- Refuge areas with 25 m entrance taper and 45 m exit taper are needed for emergency and/or enforcement use when hard shoulder running is active (approximately 3-4 per mile is preferable).
- Overhead lane control signs must be installed such that one is visible to drivers at all times (typically 2-4 per mile). Horizontal and vertical curves may affect the feasibility of overhead gantries.

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72 http://ops.fhwa.dot.gov/freewaymgmt/publications/frwy_mgmt_handbook/revision/jan2011/mgdlaneschp8/sec8.htm.

73 Planning for Active Traffic Management in Virginia: International Best Practices and Implementation Strategies. http://www.virginiadot.org/vtrc/main/online_reports/pdf/13-r1.pdf (accessed 12/7/2016).

74 Speed Harmonization and Peak-period Shoulder Use to Manage Urban Freeway Congestion. http://www.utexas.edu/research/ctr/pdf_reports/0_5913_1.pdf.

75 Freeway Geometric Design for Active Traffic Management in Europe. http://international.fhwa.dot.gov/pubs/pl11004/pl11004.pdf.

76 Freeway Geometric Design for Active Traffic Management in Europe. http://international.fhwa.dot.gov/pubs/pl11004/pl11004.pdf.

77 Speed Harmonization and Peak-period Shoulder Use to Manage Urban Freeway Congestion. http://www.utexas.edu/research/ctr/pdf_reports/0_5913_1.pdf.

78 Planning for Active Traffic Management in Virginia: International Best Practices and Implementation Strategies. http://www.virginiadot.org/vtrc/main/online_reports/pdf/13-r1.pdf (accessed 12/7/2016).

79 Freeway Geometric Design for Active Traffic Management in Europe. http://international.fhwa.dot.gov/pubs/pl11004/pl11004.pdf.

80 Planning for Active Traffic Management in Virginia: International Best Practices and Implementation Strategies. http://www.virginiadot.org/vtrc/main/online_reports/pdf/13-r1.pdf (accessed 12/7/2016).

81 Freeway Geometric Design for Active Traffic Management in Europe. http://international.fhwa.dot.gov/pubs/pl11004/pl11004.pdf (accessed 11-1-2013).

82 Planning for Active Traffic Management in Virginia: International Best Practices and Implementation Strategies. http://www.virginiadot.org/vtrc/main/online_reports/pdf/13-r1.pdf (accessed 11-1-2013).

83 Planning for Active Traffic Management in Virginia: International Best Practices and Implementation Strategies. http://www.virginiadot.org/vtrc/main/online_reports/pdf/13-r1.pdf (accessed 12/7/2016).

- CCTV cameras and traffic detection are useful for monitoring conditions on the facility at all times and closing the shoulder in the case of an incident or disabled vehicle. CCTV density should be such that all parts of the facility can be monitored.
- Drainage infrastructure may need to be upgraded to ensure proper drainage of the shoulder during precipitation.

Institutional Considerations:

- This strategy is best deployed in close coordination with emergency responders and enforcement personnel, so that the needs of those stakeholders to perform their functions are not compromised by the HSR operation.

Other Complementary Strategies:

- VSLs can be used to decrease speed limits when HSR allowed in right lanes.
- Where HSR begins or terminates at a ramp junction, junction control is often required to maintain lane continuity and safe operations.
- Ramp metering may facilitate bus weaving movements at on-ramp conflict points.

Bus-on-Shoulder Operations

Allowing buses to use shoulders of freeways and major arterial streets during peak congestion periods to bypass congestion in the general purpose lanes. While most of the current applications have buses using the right-side shoulder, several projects using the inside or left-side shoulder exist as well. Bus-on-Shoulder (BOS) applications carry lower volumes of traffic compared to opening shoulders to HOV and general traffic during peak congestion hours.[84] (Photo courtesy of FHWA)[85]

Experienced Benefits and Outcomes:

- Bus on-time performance improvement of 68%[86]–92%.[87]
- Travel speed increase by 75%.[88]

Infrastructure and Systems:

- Auxiliary lanes can help insulate bus-on-shoulder operations from the effects of ramp merge and weaving areas.

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84 Transit Cooperative Research Program, A Guide for Implementing Bus on Shoulder (BOS) Systems, 2012, http://www.tcrponline.org/PDFDocuments/TCRP_RPT_151.pdf.

85 http://www.ops.fhwa.dot.gov/publications/fhwahop13013/images/f22.png.

86 Texas Transportation Institute, The Active Transportation and Demand Management Program (ATDM): Lessons Learned, Federal Highway Administration FHWA-HOP-13-018, March 2013. http://ops.fhwa.dot.gov/publications/fhwahop13018/fhwahop13018.pdf.

87 Texas Transportation Institute, The Active Transportation and Demand Management Program (ATDM): Lessons Learned, Federal Highway Administration FHWA-HOP-13-018, March 2013. http://ops.fhwa.dot.gov/publications/fhwahop13018/fhwahop13018.pdf.

88 http://letsgetmoving.org/cms/wp-content/uploads/2015/09/COTA-Bus-on-shoulder-FINAL-Dec-28-2007.pdf (assuming a speed limit of 35 mph at shoulder and 20 mph speed in general traffic lanes).

- Shoulders should be at least 10 feet wide (12-foot shoulders recommended).
- Dual-lane off- and on-ramps and restricted sight distances can complicate BOS operations.
- There must be sufficient clearance for signs to be installed along the highway shoulder designating begin and end points.
- Ramp traffic volumes in excess of 1,000 vph cause issues at weaving points. This can be mitigated by having buses merge back into general traffic before these high volume interchanges.
- Additional clearance may be required for left-shoulder bus-on-shoulder operations at the downstream end of the facility to ensure smooth merging back into the mainline.
- Generally, the same infrastructure and systems considerations that apply to hard shoulder running also apply to Bus-on-Shoulder operations.

Institutional Considerations:

- These strategies are most effective when implemented in close coordination with transit agencies, to ensure that bus operators understand how the strategies work, and so that any concerns regarding lateral clearance, merge conflicts, or other operational issues are properly addressed.
- Enforcement personnel may also be included in the conversation to ensure that the lane restrictions are properly observed.

Other Complementary Strategies:

- Ramp metering may facilitate bus weaving movements at on-ramp conflict points.
- VSLs can be used to decrease speed limits when HSR allowed in right lanes.
- Where HSR begins or terminates at a ramp junction, junction control is often required to maintain lane continuity and safe operations.

Variable Speed Limits or Speed Harmonization

Reducing risk of collisions and enhancing throughput by avoiding sudden changes in speed caused by congestion or atypical roadway conditions (e.g., fog, work zones) by gradually slowing traffic down ahead of a congested area. When implemented as speed harmonization, the objective is to minimize the occurrence of traffic shock waves, which improves freeway throughput. (Photo courtesy of Caltrans)[89]

Experienced Benefits and Outcomes:

- Increase in capacity up to 10%.[90]
- Decrease in crash rates: 11%[91]–37%.[92]

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[89] http://80smartcorridor.org/.

[90] Planning for Active Traffic Management in Virginia: International Best Practices and Implementation Strategies. http://www.virginiadot.org/vtrc/main/online_reports/pdf/13-r1.pdf (accessed 12/7/2016).

[91] Evaluation of Variable Speed Limits on I-270/I-255 in St. Louis. http://library.modot.mo.gov/RDT/reports/Ri08025/or11014rpt.pdf (accessed 11-1-2013).

[92] Speed Harmonization and Peak-period Shoulder Use to Manage Urban Freeway Congestion. http://www.utexas.edu/research/ctr/pdf_reports/0_5913_1.pdf (accessed 11-1-2013).

- Decrease in travel time 13%[93]–27%.[94]
- Increase in average speed up to 10 mph.[95]
- Decrease in speed variability.[96]
- Decrease in emissions: 2%[97]–17%.[98]

Infrastructure and Systems:

- Clearance for overhead or side-mounted signs is generally required, at spacings of 2-3 per mile.
- Traffic sensors to support VSL operation must be installed at close spacings, including before and after ramps.
- If different speeds will be posted for different lanes, overhead gantries may offer better performance.
- CCTV cameras and traffic detection are useful for monitoring conditions on the facility at all times and overriding the automatically-set speeds if needed. CCTV density should be such that all parts of the facility can be monitored.
- Weather station data and visibility-measuring equipment may be required for proper interpretation of meteorological conditions for setting suitable speed limits.

Institutional Considerations:

- Enforcement staff may request that there be sufficient space on shoulder to permit enforcement officers to perform traffic stops.
- For more efficient maintenance, signs may need to be designed to be removed and replaced quickly.

Other Complementary Strategies:

- An accompanying Queue Warning System can contribute to the success of a VSL deployment by indicating to drivers the cause for reduced speed limits.
- Due to potential driver confusion regarding signage, VSL should be deployed with caution when a dynamic lane management system is in place.

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[93] Evaluation of Variable Speed Limits on I-270/I-255 in St. Louis. https://library.modot.mo.gov/RDT/reports/Ri08025/or11014rpt.pdf (accessed 12/7/2016).

[94] Evaluation of Variable Speed Limits on I-270/I-255 in St. Louis. http://library.modot.mo.gov/RDT/reports/Ri08025/or11014rpt.pdf.

[95] Evaluation of Variable Speed Limits on I-270/I-255 in St. Louis. http://library.modot.mo.gov/RDT/reports/Ri08025/or11014rpt.pdf.

[96] Evaluation of Variable Speed Limits on I-270/I-255 in St. Louis. http://library.modot.mo.gov/RDT/reports/Ri08025/or11014rpt.pdf.

[97] Planning for Active Traffic Management in Virginia: International Best Practices and Implementation Strategies. http://www.virginiadot.org/vtrc/main/online_reports/pdf/13-r1.pdf (accessed 11-1-2013).

[98] Speed Harmonization and Peak-period Shoulder Use to Manage Urban Freeway Congestion. http://www.utexas.edu/research/ctr/pdf_reports/0_5913_1.pdf.

Dynamic Lane Management (Lane Signals)

Opening and closing of lanes on a facility in response to real-time conditions and the associated mechanisms to communicate the changes to drivers downstream. Congested conditions may warrant the opening of reversible lanes or shoulder lanes, while traffic incidents may cause the closure of affected lanes. (Photo courtesy of Caltrans)[99]

Experienced Benefits and Outcomes:

- Increase in throughput: 3%[100]–7%.[101]
- Increase in capacity: 3%[102]–22%.[103]
- Decrease in primary incidents: 3%[104]–30%.[105]
- Decrease in secondary incidents: 40%[106]–50%.[107]
- Decrease in emissions: 2%[108]–8%.[109]

Infrastructure and Systems:

- CCTV cameras and traffic detection are useful for monitoring conditions on the facility at all times and responding in the event of incidents. CCTV density should be such that all parts of the facility can be monitored.
- Clearance for overhead signs is generally required, at spacings of 2-3 per mile.

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99 http://80smartcorridor.org/.

100 FHWA 2006 International Scan of ATM systems in Europe. As reported in Exhibit 33 of the I-95 Design Management and Review Report, Pennsylvania DOT, March 2012.

101 FHWA 2006 International Scan of ATM systems in Europe. As reported in Exhibit 33 of the I-95 Design Management and Review Report, Pennsylvania DOT, March 2012.

102 FHWA 2006 International Scan of ATM systems in Europe. As reported in Exhibit 33 of the I-95 Design Management and Review Report, Pennsylvania DOT, March 2012.

103 FHWA 2006 International Scan of ATM systems in Europe. As reported in Exhibit 33 of the I-95 Design Management and Review Report, Pennsylvania DOT, March 2012.

104 FHWA 2006 International Scan of ATM systems in Europe. As reported in Exhibit 33 of the I-95 Design Management and Review Report, Pennsylvania DOT, March 2012.

105 FHWA 2006 International Scan of ATM systems in Europe. As reported in Exhibit 33 of the I-95 Design Management and Review Report, Pennsylvania DOT, March 2012.

106 FHWA 2006 International Scan of ATM systems in Europe. As reported in Exhibit 33 of the I-95 Design Management and Review Report, Pennsylvania DOT, March 2012.

107 FHWA 2006 International Scan of ATM systems in Europe. As reported in Exhibit 33 of the I-95 Design Management and Review Report, Pennsylvania DOT, March 2012.

108 Evaluation of the Managed Motorway System on the M25 (London Orbital) in the United Kingdom. As reported in Exhibit 33 of the I-95 Design Management and Review Report, Pennsylvania DOT, March 2012.

109 Evaluation of the Managed Motorway System on the M25 (London Orbital) in the United Kingdom. As reported in Exhibit 33 of the I-95 Design Management and Review Report, Pennsylvania DOT, March 2012.

Institutional Considerations:

- Coordinating with maintenance crews may facilitate the development of procedures for sign maintenance without requiring any lane closures.

Other Complementary Strategies:

- Dynamic lane use signals are often deployed alongside variable speed limits to reduce shock waves in advance of congested areas with lane closures.
- Incident management strategies complement dynamic lane use, as lane closures are often in response to incidents and can facilitate scene access for emergency responders.

Dynamic Pricing

Managing limited roadway capacity supply during periods of high demand. Prices may be set to maintain a prescribed level of performance on the facility (e.g., minimum acceptable speed). Also known as Congestion Pricing, Express Lanes or High-Occupancy Toll (HOT) lanes are limited-access (potentially barrier-separated) highway lanes that provide free or reduced cost access to qualifying HOVs. (Photo courtesy of MTC)[110]

Experienced Benefits and Outcomes:

- Increase in transit ridership of 5%.[111]
- Travel time improvement of up to 15%.[112]
- Decrease in crash rates: by 5%.[113]

Infrastructure and Systems:

- Variable message signs are needed near entry points to convey information about fees to motorists.
- Electronic toll collection systems are needed for toll collection at access points.
- Automatic Vehicle Classification (AVC) sensors may be needed if different tolls will be charged for different vehicle classes.
- CCTV cameras and traffic detection are useful for monitoring conditions on the facility at all times and responding in the event of incidents. CCTV density should be such that all parts of the facility can be monitored.
- There may need to be additional lateral clearance for restriping or barrier installation between the mainline lanes and the priced facility.

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[110] http://mtc.ca.gov/

[111] ExpressLane Corridor Performance Update (4/30/2013). https://www.metroexpresslanes.net/en/about/ExpressLanes_Performance_Update_20130719.pdf

[112] http://www.ops.fhwa.dot.gov/publications/fhwahop08023/02summ.htm (accessed 12-7-2016)

[113] TOPS-BC v1.2, "Investigate Impacts" Summary Module

Institutional Considerations:

- Coordination with enforcement staff can reduce toll violation occurrences and promote greater efficacy of this strategy.
- Coordination with transit agencies also ensures that the lanes are operated in a way that promotes smooth operations for buses.

Other Complementary Strategies:

- Dynamic pricing of roadway facilities may also be combined with dynamic HOV requirements to more efficiently allocate capacity of HOV/HOT lanes.
- Lane Use Signals may be used to dynamically allocate different numbers of lanes to the priced facility during different times of the day.

Dynamic HOV Lanes

Dynamically adjusting HOV lane use requirements to efficiently allocate limited lane capacity as demand fluctuates. Also includes converting HOV lanes to a general purpose lane when congestion is light or limiting access to transit vehicles only when congestion is severe. (Photo courtesy of FHWA)[114]

Experienced Benefits and Outcomes:

- Increase in transit ridership of 5%.[115]
- Increase in transit on-time performance of 9%.[116]

The above benefits are for dynamic HOV lanes combined with dynamically-priced lanes.

Infrastructure and Systems:

- Toll collection systems may be required if 2-person carpools will be allowed access to the lane for a fee during 3+ carpool requirement periods.
- CCTV cameras and traffic detection are useful for monitoring conditions on the facility at all times and responding in the event of incidents. CCTV density should be such that all parts of the facility can be monitored.

Other Complementary Strategies:

- Hard shoulder running can be used in conjunction with dynamic HOV lanes for facilities that lack dedicated HOV lanes; in this case, hard shoulder running is used to add a general purpose lane to the freeway, while the median lane is simultaneously converted into an HOV lane.

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[114] http://ops.fhwa.dot.gov/freewaymgmt/publications/managed_lanes/crosscuttingstudy/chapter3.htm

[115] ExpressLane Corridor Performance Update (4/30/2013). https://www.metroexpresslanes.net/en/about/ExpressLanes_Performance_Update_20130719.pdf.

[116] ExpressLane Corridor Performance Update (4/30/2013). https://www.metroexpresslanes.net/en/about/ExpressLanes_Performance_Update_20130719.pdf.

- Dynamic pricing of roadway facilities may also be combined with dynamic HOV requirements to more efficiently allocate capacity of HOV/HOT lanes.

Dynamic Junction Control

Adjusting the lane configuration at a ramp merge or diverge to accommodate current traffic demands. When entrance volumes are high and mainline volumes are not, a dynamic junction control system may close the shoulder lane of the freeway upstream of the merge point to accommodate a higher volume of traffic from the entrance ramp. Alternatively, when exiting volumes are particularly high at a junction, the system may reallocate one of the through lanes as an exit lane to accommodate the excessive demand. (Photo courtesy of Caltrans)[117]

Experienced Benefits and Outcomes:

- Decrease in delays up to 93%.[118]
- Decrease in primary incidents: 30%[119]–53%.[120]
- Decrease in travel times: 7%[121]–8%.[122]
- Decrease in mainline travel times: 4%[123]–7%.[124]
- Decrease in ramp travel times: 8%[125]–13%.[126]

Infrastructure and Systems:

- If in-pavement lighting is pursued, it will need to be designed in cooperation with maintenance crews in areas of winter snowfall to ensure plowing does not damage the equipment.
- CCTV cameras and traffic detection are useful for monitoring conditions at the junction during dynamic allocation of lanes and overriding the dynamically specified lane assignments if needed.

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117 http://www.dot.ca.gov/dist07/Publications/Inside7/story.php?id=678.

118 Active Traffic Management Guidebook. Prepared for FHWA by Parsons Brinckerhoff, April 2012.

119 Caltrans D7 SR 110 Dynamic Lanes Project. http://managedlanes.org/wp-content/uploads/2012/07/Dynamic-Lane-Management-System-on-I-110-in-Los-Angeles-3.pdf (accessed 11-1-2013).

120 Active Traffic Management Guidebook. Prepared for FHWA by Parsons Brinckerhoff, April 2012.

121 Planning for Active Traffic Management in Virginia: International Best Practices and Implementation Strategies. http://www.virginiadot.org/vtrc/main/online_reports/pdf/13-r1.pdf (accessed 11-1-2013).

122 Planning for Active Traffic Management in Virginia: International Best Practices and Implementation Strategies. http://www.virginiadot.org/vtrc/main/online_reports/pdf/13-r1.pdf (accessed 12/7/2016).

123 Planning for Active Traffic Management in Virginia: International Best Practices and Implementation Strategies. http://www.virginiadot.org/vtrc/main/online_reports/pdf/13-r1.pdf (accessed 12/7/2016).

124 Freeway Geometric Design for Active Traffic Management in Europe. http://international.fhwa.dot.gov/pubs/pl11004/pl11004.pdf.

125 Freeway Geometric Design for Active Traffic Management in Europe. http://international.fhwa.dot.gov/pubs/pl11004/pl11004.pdf.

126 Planning for Active Traffic Management in Virginia: International Best Practices and Implementation Strategies. http://www.virginiadot.org/vtrc/main/online_reports/pdf/13-r1.pdf (accessed 12/7/2016).

- Wide shoulders in the vicinity of the junction provides additional flexibility for other supporting strategies (e.g., HSR) at the junction in the future.

Other Complementary Strategies:

- Coordination with arterial operations may be required.
- Dynamic lane use signals can be used to provide better traffic control by lane in advance of the junction.
- Predictive traveler information systems can be used to proactively operate a dynamic junction system in anticipation of future demands.

Advanced Traveler Info and Dynamic Routing

Capturing, monitoring, and disseminating real-time traveler information allows agencies to be proactive about management strategies, and travelers to make more informed decisions for pre-trip planning and en-route adjustments. With dynamic routing, alternate route guidance is provided to drivers heading for designated destinations when conditions on the primary route have deteriorated below a prescribed threshold due to congestion, weather conditions, or other situations. This strategy is closely related to decision support systems—a common component of ICM. (Photo courtesy of FHWA)[127]

Experienced Benefits and Outcomes:

- Increase in transit on-time performance: 5%[128]–13%.[129]
- Travel time improvement of 5%[130]–25%.[131]
- Decrease in crash rates up to 5%.[132]
- Decrease travel times in congested networks by 3% to 9%.[133]

Infrastructure and Systems:

- Densely spaced traffic detectors can provide crucial travel time and demand data, to more accurately predict future traffic conditions.
- Dynamic message signs (DMS) in advance of decision points are often required to communicate predicted travel times to drivers while the information is still actionable.

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[127] http://www.ops.fhwa.dot.gov/publications/fhwahop16036/images/f5.png.

[128] Intelligent Transportation Systems: Benefits, Costs, Deployment, and Lessons Learned. http://www.benefitcost.its.dot.gov/its/benecost.nsf/images/reports/$file/bcdll-14412_full.pdf.

[129] Intelligent Transportation Systems: Benefits, Costs, Deployment, and Lessons Learned. http://www.benefitcost.its.dot.gov/its/benecost.nsf/images/reports/$file/bcdll-14412_full.pdf.

[130] TOPS-BC v1.2, "Investigate Impacts" Summary Module.

[131] TOPS-BC v1.2, "Investigate Impacts" Summary Module.

[132] TOPS-BC v1.2, "Investigate Impacts" Summary Module.

[133] http://www.sciencedirect.com/science/article/pii/S0895717798000533.

Institutional Considerations:

- Future demand forecasts can be shared with transit agencies to allow them to dynamically dispatch additional vehicles as needed.
- Transit agencies, maintenance crews, and organizers of large events can provide crucial future demand predictions or capacity reduction estimates, to enhance the reliability of the predictive traffic conditions information.
- Coordination with emergency responders regarding anticipated clearance times can further improve the reliability of traffic forecasts.
- For dynamic routing onto arterials, the individual jurisdictions along the corridor must be coordinated with to ensure that their facilities are capable of handling the added volumes and ready to receive diverted traffic.

Other Complementary Strategies:

- Adaptive signal control and/or adaptive ramp metering may be beneficial to use in conjunction with real time traveler information, to accommodate fluctuations in travel demand due to dynamic routing.

Adaptive Ramp Metering

Dynamically adjusting ramp metering rates up or down based on traffic volumes in the immediate vicinity of the freeway entrance, and/or system-wide facility performance and available capacity. The objective is to prevent merging vehicles from disrupting the smooth flow of traffic on a freeway. (Photo courtesy of MTC)[134]

Experienced Benefits and Outcomes:

- Increase in throughput of 5%[135] to 14%[136].
- Decrease in Vehicle Hours Traveled: 4%[137]–8%.[138]
- Decrease in incidents: 20%[139]–50%.[140]
- Increase in speeds: 5%[141]–8%.[142]

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134 http://mtc.ca.gov/.

135 Caltrans District 4 observations regarding expected gains from Ramp Metering projects.

136 Planning for Active Traffic Management in Virginia: International Best Practices and Implementation Strategies. http://www.virginiadot.org/vtrc/main/online_reports/pdf/13-r1.pdf (accessed 12/7/2016).

137 Adaptive Ramp Metering Simulation. http://www.clr-analytics.com/Files/JTE_2004.pdf.

138 Adaptive Ramp Metering Simulation. http://www.clr-analytics.com/Files/JTE_2004.pdf.

139 TOPS-BC v1.2, "Investigate Impacts" Summary Module.

140 TOPS-BC v1.2, "Investigate Impacts" Summary Module.

141 Planning for Active Traffic Management in Virginia: International Best Practices and Implementation Strategies. http://www.virginiadot.org/vtrc/main/online_reports/pdf/13-r1.pdf (accessed 12/7/2016).

142 Planning for Active Traffic Management in Virginia: International Best Practices and Implementation Strategies. http://www.virginiadot.org/vtrc/main/online_reports/pdf/13-r1.pdf (accessed 12/7/2016).

- Decrease in travel times by 5%[143]–48%.[144]
- Decrease in delay ranging up to 18%.[145]
- Decrease in emissions up to 24%.[146]

Infrastructure and Systems:

- Traffic sensors are required at each entrance and throughout the corridor to provide the adaptive system with an accurate awareness of corridor demands at any given time.
- Adaptive ramp metering requires robust communications infrastructure between the field and the TMC.
- CCTV cameras are useful for monitoring conditions on the corridor and tuning or overriding the automatically set metering rates as needed.
- Entrance ramps must have sufficient acceleration distances after the ramp meter limit line, and sufficient storage capacity upstream of the meter for the vehicle queues (e.g., 400 feet).

Institutional Considerations:

- Ramp metering strategies often require close coordination with local jurisdictions to mitigate any potential negative impacts of queue spillback from freeway entrances onto local streets.
- Enforcement may be required to ensure compliance with meters during restrictive rate periods.

Other Complementary Strategies:

- Queue warnings in advance of ramp queues can enhance safety.
- Incident management strategies can be used in conjunction with adaptive ramp metering to manage demand during capacity-constrained situations.
- Coordination with arterial signals can mitigate the effects of queue spillback during restrictive metering periods.
- Predictive traveler information systems can inform ramp metering rates in a proactive, rather than reactive, manner.

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[143] TOPS-BC v1.2, "Investigate Impacts" Summary Module.

[144] Planning for Active Traffic Management in Virginia: International Best Practices and Implementation Strategies. http://www.virginiadot.org/vtrc/main/online_reports/pdf/13-r1.pdf (accessed 12/7/2016).

[145] Planning for Active Traffic Management in Virginia: International Best Practices and Implementation Strategies. http://www.virginiadot.org/vtrc/main/online_reports/pdf/13-r1.pdf (accessed 12/7/2016).

[146] TOPS-BC v1.2, "Investigate Impacts" Detailed Data Sheets.

Reversible or Contraflow Lanes

Designating a lane (or lanes) on a facility whose direction of travel can be adjusted to the direction that would be most beneficial based on current traffic conditions. This is a specialized form of dynamic lane management. Allows transportation agencies to make better use of existing infrastructure by aligning the supply with the demand. Reversible arterial lanes can be used on an ad hoc basis for emergency evacuations, maintenance of traffic in work zones. (Photo courtesy of FHWA)[147]

Experienced Benefits and Outcomes:

- Travel time improvement of 13%.[148]

Infrastructure and Systems (freeway application):

- Overhead clearance for lane control signs is recommended for reversible lanes.
- Additional clearance may be required on both lateral edges of the reversible lane(s) to accommodate wider lane markings or barriers to distinguish/separate the reversible lane from the conventional lanes.[149]
- CCTV cameras and traffic detection are necessary for monitoring conditions on the facility at all times and responding in the event of incidents. Redundancy of CCTV coverage is recommended.
- Permanent barriers segregating the reversible lanes from the rest of the freeway facility can improve safety of reversible lane operations, with gates to control access at the entrances and exits. [150] Moveable barriers provide similar benefits and can be retrofitted onto an existing facility; depending on the design, this may require additional lateral clearance in the freeway median for barrier storage when not in use.
- Access points for reversible lanes are generally at least three miles apart.
- Direct ramp access from arterials to the reversible lane facility can improve operations.

Institutional Considerations (freeway application):

- Coordination with transit agencies can be used to foster a multimodal approach to reversible lanes, where the facility entrances and exits are strategically positioned to provide convenient access to transit centers, Park-and-Ride lots, and transit traffic.

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[147] http://ops.fhwa.dot.gov/freewaymgmt/publications/frwy_mgmt_handbook/revision/jan2011/mgdlaneschp8/sec8.htm.

[148] I-70 Reversible Lane Georgetown to Floyd Hill Phase II Feasibility Study (Page 4), http://www.i70solutions.org/files/6014/2982/4930/I-70-Reversible-Lane-Feasibility-Study_Dec2010.pdf (accessed 11-1-2016).

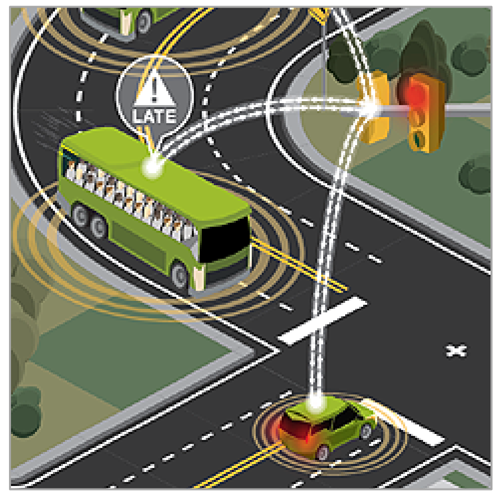
[149] Reversible Lane Operation for Arterial Roadways: The Washington, DC, USA Experience, 2011, http://nacto.org/wp-content/uploads/2015/04/reversible_lane_operation_for_arterial_roadways-dc_soumya.pdf.

[150] Managed Lane Chapter for the Freeway management and Operations Handbook, 2011, http://ops.fhwa.dot.gov/freewaymgmt/publications/frwy_mgmt_handbook/revision/jan2011/mgdlaneschp8/sec8.htm.

Other Complementary Strategies (Freeway Application):

- Reversible lanes may be subjected to additional restrictions such as HOV or pricing restrictions, making this strategy a potential complement to dynamic HOV or dynamic pricing strategies.
- Variable speed limits may be required to maintain safe traffic speeds when the reversible lane is active, if the reversible lanes are not barrier-separated.
- Dynamic lane management can be used to further expand upon the reversible lane concept by potentially allowing any lane to be dynamically converted to the opposing direction, if the reversible lanes are not barrier-separated.
- Predictive traveler information can be used to operate a reversible lane proactively rather than reactively.

Transit Signal Priority



Traffic signals which are programmed to extend the green phase until an approaching transit vehicle passes through the intersection, or reduce the duration of the active red phase to move a waiting transit vehicle more quickly through the intersection. In order to minimize person-hours of delay, these Transit Signal Priority (TSP) systems may give more *or* less priority to a transit vehicle based on its current schedule adherence and occupancy. (Photo courtesy of USDOT)[151]

Experienced Benefits and Outcomes:

- Decrease in travel time: 1.5%[152]–25%.[153]
- Decrease in bus delay at intersections of 35%.[154]
- Decrease in fuel consumption: 2%[155]–3%.[156]

Infrastructure and Systems:

- Unless the entire transit fleet will be equipped with transponders, it will be necessary to ensure that the subset of vehicles that are properly equipped are also consistently deployed on the TSP-enabled corridor.

151 http://www.its.dot.gov/infographs/eco_traffic_signal.htm.

152 Intelligent Transportation Systems: Benefits, Costs, Deployment, and Lessons Learned, http://www.benefitcost.its.dot.gov/its/benecost.nsf/images/reports/$file/bcdll-14412_full.pdf, pg. 81, (accessed 12/7/2016).

153 TOPS-BC v1.2, "Investigate Impacts" Summary Module.

154 Los Angeles Transit Signal Priority. http://www.itsbenefits.its.dot.gov/its/benecost.nsf/ID/633C546777C6AD4985257B65005ECE88?OpenDocument&Query=Home.

155 Intelligent Transportation Systems: Benefits, Costs, Deployment, and Lessons Learned. http://www.benefitcost.its.dot.gov/its/benecost.nsf/images/reports/$file/bcdll-14412_full.pdf.

156 Intelligent Transportation Systems: Benefits, Costs, Deployment, and Lessons Learned. http://www.benefitcost.its.dot.gov/its/benecost.nsf/images/reports/$file/bcdll-14412_full.pdf.

- Fiber communications or other interconnects between signals may be required to support TSP operations. Interconnects may also be required between the field equipment and a central TMC control center. [157]
- Traffic signal controllers may require upgrading to support TSP functionality.
- Steep grades may require placement of additional transponders/receivers, or investment in a GPS-based system instead.

Institutional Considerations

- TSP implementation often involves close coordination between transit dispatchers, vehicle operators, and signal systems staffs.

Other Complementary Strategies:

- TSP may benefit from real-time traveler information systems (e.g., automatic vehicle location systems) to anticipate bus arrivals much farther in advance (i.e., prior to direct communication between the vehicle and the traffic signal controller).
- Adaptive signal control can help mitigate any negative impacts of TSP on other conflicting movements that do not receive priority.

Adaptive Traffic Signal Control

Operating a signalized intersection, corridor, or network of arterials such that the timing parameters are set based on current traffic conditions (instead of pre-timed). The splits, offsets, and cycle lengths are incrementally adjusted over time to best suit the evolving needs of the individual approaches and intersections throughout the day. These systems can respond reactively to atypical traffic conditions (e.g., high demands caused by special events, congestion caused by vehicle crashes or work zone areas), or proactively to anticipated recurrent congestion based on historical data. (Photo courtesy of LADOT)[158]

[157] Florida Department of Transportation Central Office, Transit Signal Priority Implementation Guidance, 2014, http://www.fdot.gov/transit/Pages/FDOTTSPImplementationGuidelinesFinalReport.pdf.

[158] http://trafficinfo.lacity.org/.

Experienced Benefits and Outcomes:

- Decrease in travel time of 13%.[159]
- Decrease in delay: 5%[160]–42%.[161]
- Decrease in number of stops: 10%[162]–41%.[163]

Infrastructure and Systems:

- Sufficient detection upstream of each adaptively controlled intersection is required, with detection on each approach and lane recommended.
- Pedestrian and bicycle detection systems may also be required to properly accommodate all intersection traffic.
- Traffic signal controllers may require upgrading to support adaptive signal control functionality.
- Fiber communications or other interconnects between signals may be required to support adaptive operations on a corridor. Interconnects may also be required between the field equipment and a central TMC control center for a network deployment of adaptive signal control.
- CCTV can be helpful for identifying problems and situations that the adaptive system is not handling properly. Cameras can also be used to better manage operations in inclement weather conditions.[164]

Institutional Considerations:

- Adaptive signal control systems may perform poorly during oversaturated conditions; coordination with enforcement staff can provide an effective backup method of traffic control during such situations.

Other Complementary Strategies:

- Adaptive signal control can be integrated with ramp metering strategies to provide improved coordination between the two.
- Predictive traveler information can be used to operate an adaptive signal system proactively rather than reactively.

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[159] Los Angeles ATCS (Part of ATSAC). http://www.techtransfer.berkeley.edu/newsletter/10-4/edc-asct.php.

[160] Intelligent Transportation Systems: Benefits, Costs, Deployment, and Lessons Learned. http://www.benefitcost.its.dot.gov/its/benecost.nsf/images/reports/$file/bcdll-14412_full.pdf.

[161] Intelligent Transportation Systems: Benefits, Costs, Deployment, and Lessons Learned. http://www.benefitcost.its.dot.gov/its/benecost.nsf/images/reports/$file/bcdll-14412_full.pdf.

[162] Intelligent Transportation Systems: Benefits, Costs, Deployment, and Lessons Learned. http://www.benefitcost.its.dot.gov/its/benecost.nsf/images/reports/$file/bcdll-14412_full.pdf.

[163] Intelligent Transportation Systems: Benefits, Costs, Deployment, and Lessons Learned. http://www.benefitcost.its.dot.gov/its/benecost.nsf/images/reports/$file/bcdll-14412_full.pdf.

[164] Massachusetts Department of Transportation, Adaptive Signal Control for Corridor Management, 2016, http://scote.transportation.org/Documents/2016%20SCOTE%20Meeting/Tuesday%207JUN17/BoudreauN_AdaptiveSignalControl_June7_SCOTE.pdf.

Arterial Signal Coordination with Ramp Meters

Ramp metering and arterial signal control systems have traditionally been independent from each other, such that both operate in isolation without any consideration of what the other system is doing. This can lead to excess congestion particularly at the infrastructure interfaces between the two. In a coordinated system, ramp metering rates are generally used to inform signal operations on nearby arterials, so that their operations complement—rather than conflict with—each other. (Photo courtesy of MTC)[165]

Infrastructure and Systems:

- This strategy requires the integration of the different signal systems (e.g., ramp systems, arterial traffic signal systems) in fine detail. The different hardware types and systems must be interoperable or compatible.
- Communication between traffic control systems and traffic controller needs to be enabled, allowing coordinated operations and control.

Institutional Considerations:

- Requires coordination between arterial signal operators (e.g., local authorities) and freeway ramp meter operators (e.g., state DOTs).
- System operation can be conceived as part of a regional Traffic Management Center operation, where traffic can be monitored in real-time, and strategies can be implemented accordingly.

Other Complementary Strategies:

- Adaptive signal control can be complementary to this strategy, given the shared application to arterial intersections. [166]
- Adaptive ramp metering can be a relevant complementary strategy, along with any other strategies that improve ramp throughput (e.g., dynamic junction control), which can reduce occurrence of ramp queue spillback to arterial intersections and impact operations of coordinated arterial signal control with ramp meters.

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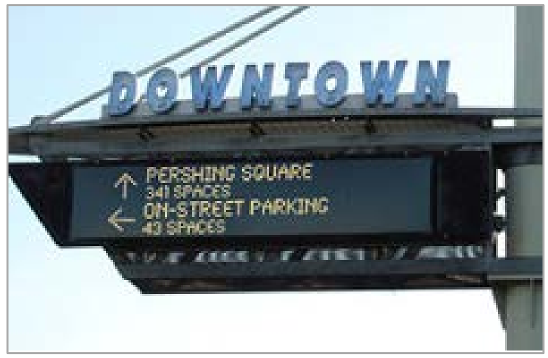
[165] http://mtc.ca.gov/.

[166] California PATH Program, University of California at Berkeley. http://www.path.berkeley.edu/sites/default/files/documents/Coord_Frwy_Art_Final_Report_031014.pdf.

Active Parking Management



Parking is a limited resource particularly in dense urban environments, and active parking management strategies provide real-time methods for efficiently allocating supply and proactively responding to demand. Strategies include providing drivers with real-time guidance to parking facilities with available capacity, adjusting prices for parking in response to prevailing demand/availability, and activating overflow parking facilities when existing ones approach capacity.[167] (Photo courtesy of FHWA)[168]

Experienced Benefits and Outcomes:

- Increase parking occupancy in high-demand areas by 31%. [169]
- Decrease parking search time by 43%[170]
- Decrease traffic volume in high-demand areas by 8%[171].

Infrastructure and Systems:

- Parking sensors (e.g., inductive loops, video detection) may be needed in individual stalls to enable jurisdictions to monitor parking in real-time. Alternatively, occupancy may be estimated by measuring inflows and outflows from a parking facility.
- Communication is needed between individual parking sensors and a central monitoring center.
- Information dissemination systems to support active parking management include dynamic message signs and mobile phone applications.

Institutional Considerations

- Active Parking Management may require establishing a dedicated internal group or department for monitoring and managing parking, if one does not exist.
- Operations staff may need to work closely with parking enforcement, traffic control officers, and parking system operators, to ensure proper driver compliance and system operations.

Sample Parking Management Strategies

- Dynamic Parking Pricing allows parking authorities to dynamically adjust parking fees in areas according to current demand for more efficient allocation of resources. This strategy allows authorities to incentivize the use parking in areas with lower demand by decreasing the parking fees.
- A Dynamic Parking Reservation System allows users to reserve parking spaces at their destinations in advance (e.g., web site, mobile app), thereby reducing cruising for parking upon arrival.

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[167] Active Parking Management. http://ops.fhwa.dot.gov/atdm/approaches/apm.htm (accessed 12-29-2016).

[168] http://ops.fhwa.dot.gov/atdm/approaches/apm.htm.

[169] http://sfpark.org/wp-content/uploads/2014/06/SFpark_Pilot_Project_Evaluation.pdf.

[170] http://sfpark.org/wp-content/uploads/2014/06/SFpark_Pilot_Project_Evaluation.pdf.

[171] http://sfpark.org/wp-content/uploads/2014/06/SFpark_Pilot_Project_Evaluation.pdf.

- Dynamic Wayfinding allows operators to guide users to specific parking spaces through dynamic routing, thereby reducing cruising for parking upon arrival.
- Dynamic Overflow Parking Facilities allow parking managers to open other nearby underutilized parking lots (which may have been formerly restricted or closed) when normal facilities are nearing capacity.[172]

Enhanced Incident Management

Traffic Incident Management (TIM) seeks to improve coordination between various organizations and agencies during incidents, to reduce incident clearance time, mitigate congestion impacts, reduce secondary incident occurrences, and improve situational awareness for agencies and the public. (Photo courtesy of FHWA)[173]

Experienced Benefits and Outcomes:

- Travel time improvement of 10%[174]–45%[175]
- Decrease in crash rates: 11%.[176]
- Decrease in emissions: 12%[177]–27%.[178]

Infrastructure and Systems:

- CCTV cameras and traffic detection are useful for monitoring conditions, confirming incident details, and assessing situations. CCTV density should be such that all parts of the facility can be monitored.
- Performance monitoring systems can provide crucial post-incident data to responders and operators, to help identify procedural bottlenecks or areas where incident management may be improved.
- Computer-aided dispatch systems can help consolidate all information related to a particular event or incident in one location, for ease of coordination, collaboration, and general information exchange.

Institutional Considerations:

- Coordination between emergency responder staffs and operations staffs is essential. Responder types to coordinate with include: law enforcement, fire and rescue, emergency medical services, towing and recovery, hazardous materials contractors, coroners and medical examiners, emergency management agencies, and environmental/natural resources/departments of health.
- Incident info dissemination requires coordination with public information officers and the media.
- Proactive incident management requires coordination with planning and maintenance personnel, to ensure that procedures are in place for various types of incidents and situations before they occur.

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[172] http://ops.fhwa.dot.gov/atdm/approaches/apm.htm.

[173] http://www.ops.fhwa.dot.gov/publications/manag_demand_tis/travelinfo.htm.

[174] TOPS-BC v1.2, "Investigate Impacts" Summary Module.

[175] TOPS-BC v1.2, "Investigate Impacts" Summary Module.

[176] http://www.mobilityauthority.com/IH35%20HERO%20PROGRAM_CAMPO_FINAL%20WITH%20ATTACHMENTS.pdf (Page 2) (accessed 11-1-2016).

[177] TOPS-BC v1.2, "Investigate Impacts" Summary Module.

[178] TOPS-BC v1.2, "Investigate Impacts" Summary Module.

- Anticipating major events allows for proactive incident management. Parties to coordinate with include planners and organizers of large events, maintenance crews, and construction contractors.
- Coordination with local jurisdictions ensures that local traffic control is available when needed.
- Support from political leaders and decision makers can provide logistical support for incident management (e.g., quick clearance legislation, performance targets and mandates, response plans).
- Debriefing meetings can provide valuable insight into the successes/issues associated with an event or incident, as a strategy for improving future incident response, coordination, and management.

Other Complementary Strategies:

- Advanced traveler info systems enable real-time incident information dissemination to the public.
- Dynamic routing can be effective for mitigating capacity constraints created by major incidents.

Express Bus Service

The primary role of Express Bus Service is to connect commuters from outlying suburban areas to urban employment centers/areas and schools. To maintain high travel speeds and level-of-service, Express Buses make fewer stops relative to conventional bus service. Express Bus Service offers competitive travel times compared to passenger vehicles, especially when operating on highway, freeway, or expressway HOV priority lanes. (Photo courtesy of VTA)[179]

Experienced Benefits and Outcomes:

- Bus travel time improvement of 6%[180]-40%[181]
- Increase in transit ridership of 24%-33%[182]
- Reduction of bus travel time variability by 35%[183]

Infrastructure and Systems:

- Dedicated bus lanes, if used, can increase bus travel speeds and reduce collisions on arterial roads. These may require CCTV monitoring.
- Low-cost infrastructure elements that can increase the speed and reliability of bus service include bus turnouts at stops, queue jump lanes, bus boarding islands, and curb realignments.

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179 http://www.vta.org/sfc/servlet.shepherd/version/download/068A0000001FZVM.

180 Mineta National Transit Research Consortium, Economic Impacts of Bus Rapid Transit in Southeast Michigan, http://transweb.sjsu.edu/PDFs/research/1237-economic-impacts-of-bus-rapid-transit-in-southeast-michigan.pdf (Page 17).

181 El Camino Real BRT Phasing Plan: BRT industry Review, Fehr & Peers and Arup, 2013, http://www.samtrans.com/Assets/_Planning/BRT/BRT+Industry+Review.pdf. (Page 34).

182 Institute of Urban and Regional Development, University of California at Berkeley, Bus Rapid Transit: An Efficient and Competitive Mode of Public Transport, 2013, http://iurd.berkeley.edu/wp/2013-01.pdf (Page 7).

183 El Camino Real BRT Phasing Plan: BRT industry Review, Fehr & Peers and Arup, 2013, http://www.samtrans.com/Assets/_Planning/BRT/BRT+Industry+Review.pdf. (Page 35).

- Fare kiosks allow riders to pick up tickets before boarding, which reduces lines and boarding delays by allowing riders to enter and exit the bus through all doors.

Institutional Considerations:

- Right-of-way is a key consideration for efficient Express Bus Service; this may require coordination with many different jurisdictions and agencies along the bus corridor, including cities, counties, and the DOT.

Other Complementary Strategies:

- Transit Signal Priority can be used to reduce bus delay at intersections and improve schedule adherence.
- Traveler information in the form of real-time vehicle arrival estimates at transit stations, at transfer points, or through traveler information apps can help passengers more efficiently plan their trips.
- Contraflow lanes can be used during peak hours to provide a lane for Express Bus Service in areas with highly directional flow and constrained right-of-way.

Park-and-Ride Lots

Park-and-Ride Lots help make transit and ridesharing services more accessible to travelers that do not start their trips near transit routes or stops, thereby reducing the number of cars on the road by facilitating the use of alternative modes. These short-term parking facilities offer a convenient and safe place for travelers to make intermodal transfers between transit, carpools, and walking/bicycling. (Photo licensed to Cambridge Systematics)

Experienced Benefits and Outcomes:

- Reduction of energy consumption by 21%[184]
- Decrease in crashes by 36%[185]

Infrastructure and Systems:

- Existing, underutilized, privately-owned/operated parking facilities may need to be leased to provide capacity for this strategy. Ideal candidate facilities would be close to major commuter routes or transit routes, away from traffic bottlenecks, and near residential areas or other trip origins.
- Parking structures and lots must be capable of accommodating longer vehicles (e.g., wide turning radii for buses).
- Pedestrian and bicycle routes may need to be modified to provide safe and convenient access to the park-and-ride facilities.
- Street and facility lighting may be required to provide a safe, comfortable environment for users.
- Signage is needed to provide directions and information to users and to advertise to nearby commuters.

[184] Caltrans, Cost-Benefit Analysis of Park & Ride/Intermodal Strategies within the State highway System in Southern California, 2013, http://dot.ca.gov/dist12/docs/planning_reasearch_grp/PnR_Final_Report_November_2013.pdf (Page A19).

[185] Caltrans, Cost-Benefit Analysis of Park & Ride/Intermodal Strategies within the State highway System in Southern California, 2013, http://dot.ca.gov/dist12/docs/planning_reasearch_grp/PnR_Final_Report_November_2013.pdf (Page A19).

- A use fee or permit system may be necessary to ensure that only authorized vehicles use the parking spaces.

Institutional Considerations:

- Maintenance staff at the DOT are generally responsible for ensuring the park-and-ride facilities remain safe and usable. Resources to support maintenance activities must be identified before a lot is leased or developed.
- Public information officers and other outreach-oriented staff may be engaged to publicize the facility to potential users.

Other Complementary Strategies:

- Active Parking Management Systems can provide real-time parking guidance to help drivers find available spaces efficiently.
- Adjacent HOV facilities such as HOV direct connectors and managed freeway lanes can be used to provide further incentives for ridesharing and transit use.

Alternative Work Schedules and Telework

Alternative work schedules and telework refer to flexible employer work arrangements where employees are given the ability to either work remotely from locations closer to home (including home offices), or to follow non-traditional work schedules that do not require commute trips during peak periods every day. This reduces the number of vehicles during peak traffic times and/or removes them from the road altogether. (Photo licensed to Cambridge Systematics)

Experienced Benefits and Outcomes:

- Reduction of vehicle miles traveled by 0.8%[186]
- Reduction of greenhouse gas emissions by 40%[187]
- Reduction in energy use by 0.01%-0.4%[188]

Infrastructure and Systems:

- Employers must offer portable equipment (e.g., notebook computers) and remote access to network resources if computers are core productivity tools for its employees.
- There may be incremental increases in facility costs associated with extended hours of operation to support flexible work scheduling (e.g., lighting/heating from 7 AM – 7 PM instead of 9 AM – 5 PM).

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[186] Does telecommuting reduce vehicle-miles traveled? An aggregate time series analysis for the U.S., 2005, http://sites.udel.edu/broadbandplanning/files/2012/01/Telecommuting-VMT.pdf.

[187] United States Government Accountability Office, Federal Telework: Better Guidance Could Help Agencies Calculate Benefits and Costs, 2016, http://www.gao.gov/assets/680/678465.pdf (Page 25).

[188] Telework Adoption and Energy Use in Building and Transport Sectors in the United States and Japan, 2005, http://ascelibrary.org/doi/abs/10.1061/(ASCE)1076-0342(2005)11%3A1(21).

Institutional considerations:

- Companies must have well-defined policies and protocols for working remotely, including education and training program for both employees and supervisors.

Other Complementary Strategies:

- Active Parking Management and Dynamic Pricing strategies can offer access to reserved lanes and parking spaces at reduced prices during off-peak periods, which further incentivizes employees to commute during off-peak hours when possible.