STATE OF CALIFORNIA • DEPARTMENT OF TRANSPORTATION
TECHNICAL REPORT DOCUMENTATION PAGE
TR0003 (REV 10/98)

1. REPORT NUMBER	2. GOVERNMENT ASSOCIATION NUMBER	3. RECIPIENT'S CATALOG NUMBER
CA18-2758		

4. TITLE AND SUBTITLE Investigating Relationships Between Highway System Performance and Transit System Management	5. REPORT DATE 12/19/2016
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR Madeline Brozen	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS UCLA Institute of Transportation Studies 3320 Public Affairs Building Los Angeles, CA 90095-1656	10. WORK UNIT NUMBER
	11. CONTRACT OR GRANT NUMBER 65A0528 TO 011
12. SPONSORING AGENCY AND ADDRESS California Department of Transportation Division of Research, Innovation and System Information 1727 30th St. MS#83 Sacramento, CA 95816	13. TYPE OF REPORT AND PERIOD COVERED FINAL
	14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT
This research reported on the latest literature on, and state of practice in, Integrated Corridor Management (ICM) and Urban Partnership Agreements (UPA). The study draws goals and insights from case studies, identifies measures that could be used for tracking changes in highway corridors, presents a matrix of considerations, and offers results and recommendations. The goal of this research was to inform Caltrans of the context and conditions of successful ICMs and UPA implementations.

17. KEY WORDS	18. DISTRIBUTION STATEMENT	
Transit, Highway System Performance, Transit System Management, Integrated Corridor Management, Urban Partnership Agreements	Unclassified	
19. SECURITY CLASSIFICATION *(of this report)*	20. NUMBER OF PAGES	21. COST OF REPORT CHARGED
Unclassified	109	

DISCLAIMER STATEMENT

INVESTIGATING RELATIONSHIPS BETWEEN HIGHWAY SYSTEM PERFORMANCE AND TRANSIT SYSTEM MANAGEMENT

Agreement Number 65A0528
Task Order Number TO 011 A01

OCTOBER 31, 2016

Prepared for Caltrans

UCLA Institute of Transportation Studies

INTEGRATED COORIDOR MANAGEMENT AND TRANSIT SERVICE

Deliverable 1: Literature Review of goals and strategies to achieve management goals

Agreement Number 65A0528
Task Order Number TO 011 A01

DECEMBER 19, 2016

Prepared for Caltrans

UCLA Institute of Transportation Studies

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Contents

1.0 Document Overview

This document reports on the latest literature on, and state of practice in, Integrated Corridor Management (ICM) and Urban Partnership Agreements (UPA), draws goals and insights from case studies, identifies measures that could be used for tracking changes in highway corridors, presents a matrix of considerations, and offers results and recommendations. The goal of this report is to inform Caltrans managers of the context and conditions of successful ICMs and UPA implementations.

2.0 Introduction

This section discusses the current state of the literature on integrated corridor management (ICM) and urban partnership agreements (UPA). Because only limited and preliminary data are available for ICM and UPA projects, this literature review focuses on the goals and objectives developed for each project as reflecting the latest state of research and practice.

3.0 Program Backgrounds

Both ICM and Urban Partnerships are sets of strategies that increase the throughput of people and goods in an existing transportation corridor. Such strategies incorporate a multimodal management approach that improves corridors' effective capacity without new construction and seeks to reduce the number of single occupancy vehicle (SOV) trips per capita.

3.1 Integrated Corridor Management

Integrated corridor management originated in Long Island, NY during the mid-1970s. The New York State Department of Transportation, in cooperation with the Federal Highway Administration sought to demonstrate "the use of the latest existing techniques in traffic surveillance, control, motorist aid, and motorist information applied in an integrated manner to achieve coordinated management of traffic in a freeway corridor" (Dunn, et al., 175, 1980). The project was initiated by the Office of Research within the FHWA and centered on a corridor of the Long Island Expressway in the New York City region. Many of the goals of this earliest demonstration project are key features of integrated corridor management approaches today. The Northern Long Island Corridor project featured monitoring traffic conditions, displaying warning signs to motorists, metering freeway entrance ramps, coordinating signals along adjacent arterial streets and coordinating emergency and other services for emergency situations (Dunn, Powers, & Zove, 1980). This management approach came to be known as the Integrated Motorist Information System or IMIS. The evaluation of the New York demonstration continued throughout the 1980's. The technology has since dramatically improved, but many of the key strategies from this early demonstration remain the same to this day.

Transportation agencies planned and implemented more Intelligent Transportation Systems throughout the 1980's. The Los Angeles Automated Traffic Surveillance and Control System for the 1984 Summer Olympics and great advances in route guidance systems are among many notable technology improvements. By the middle of the 1980's, the FWHA Traffic Systems Division partnered with universities to research and explore improvement freeway management and advanced traffic signal control.

The Intermodal Surface Transportation Efficient Act (ISTEA) passed in 1991 ushered in the modern age of federal involvement in US surface transportation policy. This bill included creating the federal ITS research program and one of the three priorities for the then known Intelligent Vehicle Highway System program was to promote technology transfer activities among priority corridors that received funding to develop operational tests for new and emerging technology. By the mid-1990's, USDOT created the ITS Joint Program Office who has since led the federal program on improvement corridor management.

The idea of Integrated Corridor Management which emerged through this Joint Powers Office proposed four "generic" goals (Gonzalez, Hardesty, Hatcher, Mercer, & Waisley, 2012) all of which serve to make more efficient use of existing infrastructure through the active coordination of highway, arterial, bus, fixed guideway, and public safety systems in a corridor or "travelshed":

1) Managing demand

2) Balancing loads

3) Responding to incidents

4) Expanding effective capacity

ICM uses existing infrastructure and manages travel corridors as systems instead of as individual facilities, which provides greater system performance and operational flexibility. Among the benefits of this broader scope are reduced travel times, delays, fuel consumption, emissions, and incidents, as well as improved travel time reliability for people, goods, and services (Cronin, Mortensen, & Thompson, 2008).

3.2 Urban Partnership Agreements

UPAs represent strategies for applying innovative solutions to the problem of urban congestion. Most Urban Partnerships implement tolling, improve transit services, and promote telecommuting to reduce the number of trips along the corridor during peak periods. Each Urban Partnership includes deadlines for implementing project components (while ICM projects have a more flexible or indeterminate timeline for implementation.) In contrast to ICMs which focus on managing incident-related congestion and minimizing changes to corridor capacity when incidents occur, Urban Partnerships are oriented toward addressing recurrent "everyday" traffic congestion.

4.0 Sites

4.1 ICM Sites

Table 1 below shows the initial "pioneer" ICM sites, and the facilities that were integrated at each location starting in 2007.

Table 1: "Pioneer" ICM sites and the facilities integrated at each

		ICM Corridor Facilities									
		Freeway			Arterial	Bus			Rail		
Site Location (*ICM demonstration site)	**Corridor**	**HOV**	**Tolling**	**Value Pricing**	**Real-time control**	**Fixed route**	**Express Buses**	**BRT**	**Commuter Rail**	**Light Rail**	**Subway/Heavy rail**
Dallas*	US 75	♦	♦		♦	♦	♦			♦	
Houston	I-10	♦	♦	♦	♦	♦	♦	♦			
Minneapolis*	I-394	♦	♦	♦	♦	♦	♦	♦			
Montgomery County, Maryland	I-270	♦			♦	♦	♦		♦		♦
Oakland	I-80	♦	♦		♦	♦	♦	♦	♦		♦
San Antonio	I-10				♦	♦	♦				
San Diego*	I-15	♦	♦	♦	♦	♦	♦	♦			
Seattle	I-5	♦			♦	♦	♦		♦	♦	

Source: *Integrated Corridor Management (ICM) Pioneer Sites: Leaders, Innovators in Congestion Management* (Cronin, Mortensen, Sheehan, & Thompson, 2007)

A "second round" of sites followed in 2015 and includes the following locations:

- Los Angeles County: I-210
- Broward County (South Florida): I-95
- Austin: I-35
- San Francisco Bay Area: SR 4
- Buffalo/ Niagara Falls: I-90

I-80 in the San Francisco Bay Area is under construction. In addition, US-50 in Sacramento and El Dorado Counties and I-95 and I-395 in Northern Virginia are proposed but the construction is presently unfunded.

Several ICM projects which were awarded funding are *not* covered in this review because public information on them is limited to a funding announcement. These projects all received funding in February 2015 and include:

- Maryland: I-95, US 1, and I-295
- New York City: I-495, the Queens-Midtown Tunnel, and the Lincoln Tunnel
- New Jersey: US 1, US 9, and I-95
- Portland, Oregon: I-84
- El Paso: I-10, US 54, and I-110
- Salt Lake City: I-15
- Northern Virginia: I-66, SR 267, SR 7, US 29, and US 50
- San Francisco Bay Area: I-880

4.2 UPA Sites

Urban Partnerships sites included the following:

- Seattle: SR 520
- Minneapolis: I-35W
- Miami-Dade County: I-95
- Atlanta: I-85
- Los Angeles: I-10 and I-110
- San Francisco Bay Area[1]

5.0 Project Status

5.1 ICM Status

ICM has not yet been fully implemented at any site as of the date of this research. The ICM projects for Sacramento/El Dorado Counties' US-50 and Northern Virginia's I-95/395 are concepts and plans with no funding or timetables. Los Angeles County's I-210, Austin's I-35, Phoenix's I-10, San Francisco Bay Area's SR 4, and Broward County's I-95 corridors received funding in February 2015 to implement ICM (Singer, 2015). Publicly available information about those projects is limited to their Concept of Operations documents released prior to selection for funding.

ICM projects at Dallas' US-75, Minneapolis' I-394, San Diego's I-15, and Oakland's I-80 are the farthest along in development, with preliminary results from ICM implementation.

There are, however, no formal publications available to the public summarizing preliminary findings as of September 2015. In advance of a full system evaluation, researchers at UC Berkeley PATH program released a report detailing early results from the I-15 project in San Diego[2] (Dion & Skabardonis, 2015). Their results are inserted throughout this document.

5.2 UPA Status

Urban Partnerships have implemented nearly all measures required under federal funding, and preliminary results are available.

6.0 Goals

This section discusses the goals identified in the reviewed projects' Concept of Operations. Strategies proposed or pursued at ICM sites and on UPA projects are discussed separately in Section 7.0 (Strategies)

A review of available Concept of Operations reports reveals a variety of ICM goals at each site, reflecting the different purposes ICM can serve depending on the site's context and regional conditions. Table 2 shows what goals appear in Concept of Operations reports and at what sites. The most common goals are: 1) Reduce travel time or costs, 2) Reduce travel time variability, 3) Increase corridor throughput and

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[1] The San Francisco Bay-Area Urban Partnership Agreement was largely focused on managing congestion through changes to parking policy and not focused on corridor management. Therefore, this project is not relevant in this review.

[2] The PATH program oversees the Connected Corridors Program which focuses on integrated corridor management. The connected corridors program is involved in the I-210 corridor, among other research.

efficiency, 4) Improve incident management and response, 5) Enable intermodal travel decisions. These are discussed in greater detail below.

Table 2: Goals from select ICM sites (for which data are available)

Goal	Northern Virginia	Dallas	San Diego	Minneapolis	Montgomery Co.	Oakland	Phoenix
Reduce congestion/demand	♦						♦
Reduce delay	♦						
Reduce travel time or costs	♦		♦		♦		
Reduce truck traffic delay						♦	
Reduce travel time variability	♦	♦		♦	♦		
Reduce primary/secondary crashes	♦				♦		
Reduce SOV volume/promote SOV alternatives	♦				♦		
Increase corridor throughput/efficiency	♦	♦				♦	♦
Improve incident management		♦	♦	♦	♦	♦	♦
Enable intermodal travel decisions		♦	♦	♦	♦	♦	♦
Improve safety			♦				
Improve transit operations						♦	

Sources: *I-95/I-395 Integrated Corridor Management Initiative, Concept of Operations – Dallas Integrated Corridor Management (ICM) Management Project, Concept of Operations for the I-15 Corridor in San Diego, California, Concept of Operations for the I-394 Corridor in Minneapolis, Minnesota, Concept of Operations for the I-270 Corridor in Montgomery County, Maryland, Interstate 80 Integrated Corridor Mobility Project Concept of Operations, I-10 Integrated Corridor Management System: Concept of Operations Final Report* (DKS Associates, 2010; Kimley-Horn and Associates, 2007; MN Department of Transportation, 2008; Montgomery County Pioneer Site Team, 2008; San Diego Pioneer Site Team, 2008; Sripathi, 2012; US Department of Transportation, 2010).

6.1 Reduce Travel Time

One of the most common goals of ICM is to reduce travel time for corridor travelers. While this is partly achieved through the improved traffic flow made possible by ICM's increased availability of information to travelers and improved incident management, additional travel time reducing strategies, (discussed further in Section 7.0) were pursued at ICM sites include:

- Synchronizing signals on arterial roads (San Diego Pioneer Site Team, 2008);
- Allowing hard shoulder running (allowing traffic on the highway shoulder) (Sripathi, 2012)
- Installing ramp metering (Sripathi, 2012)

6.2 Improve Travel Time Reliability

Improving the reliability for trips along the corridor is a common ICM goal.

Increasing travel time reliability is a primary goal on Dallas' US-75 (US Department of Transportation, 2010), Montgomery County's I-270 (Montgomery County Pioneer Site Team, 2008), Los Angeles County's I-210 (Dion, 2015), Northern Virginia's I-95/395 (Sripathi, 2012), Buffalo/Niagara Falls' I-90 (Eng-Wong, Taub and Associates, 2009) and Seattle's SR 520 (Battelle, 2014) projects. San Diego's I-15 stakeholders will coordinate arterial signals to reduce travel time variation (San Diego Pioneer Site Team, 2008), while the other projects do not assign specific strategies they intend to use to reach this goal. The only project to quantify a goal to improve travel time reliability is Buffalo/Niagara Falls' I-90 project, which intends to reduce variation by 25% within 5 years of ICM implementation.

6.2.1 Travel Time Reliability for People Using Transit

The Dallas US-75, San Diego I-15 , Broward County I-95, Contra Costa County SR 4, and Minneapolis I-394 ICM projects have a specific focus on transit travel time reliability (Contra Costa County Transportation Authority, 2016; Edelstein, 2013; MN Department of Transportation, 2008; San Diego Pioneer Site Team, 2008; US Department of Transportation, 2010).

Improving travel time reliability for transit users in a corridor involves different strategies. People traveling by bus on a corridor will, of course, benefit from improvements for roadway users, but more specific improvements for these travelers further improve travel time reliability. These interventions include:

- Synchronizing signals on arterial streets (including bus transit signal priority);
- Disseminating information to travelers pre-trip and en-route to publicize traffic incidents and alternative travel routes and modes

In addition, travel time reliability for people traveling by train in the corridor or using more than one mode, would be improved by shortening the time spent waiting for transfers. Dallas' US-75 and Oakland's I-880 will prioritize transit connections between rail and buses (US Department of Transportation, 2010; Zhang, Li, Shladover, & Li, 2008). For example, Oakland's I-880 plan calls for close coordination between BART, local buses, and AC Transit to facilitate connections "during a major event or incident mitigation" (Zhang, Li, Shladover, & Li, 2008: 27) to bus routes with long headways.

6.3 Increase Corridor Throughput

Increasing the efficiency with which people can travel through the corridor by any mode is another common ICM goal. Typically, ICM can achieve a higher throughput of people through a variety of strategies, including strategies that work for other goals, such as:

- Disseminating information to travelers pre-trip and en-route to enable "load balance" on corridor facilities, whereby some travelers detour to other routes, modes, or times in response to traffic congestion or reported incidents.
- Active traffic management
- Allowing the running of buses on the hard shoulders of freeways (DKS Associates, 2010)
- Adaptive ramp metering
- Traffic signal synchronization/centralized traffic signal management

- Improved incident response (to prevent congestion-causing secondary accidents)
- HOV and HOT lanes

6.4: Improve Incident Management

Unforeseen traffic "shocks" can be caused by a range of incidents including natural or weather events, human error, severe infrastructure failure, and terrorism. Such incidents can occur with little notice and force one or more travel corridors to close as happened notably on San Diego's I-15 when wildfires struck in both 2003 and 2007 (San Diego Pilot Site Partners, 2008). Preparing transportation systems for emergencies is crucial because in such situations, local authorities need to plan and implement complex traffic operations as quickly as possible with a minimum of preventable human error and delay.

By improving coordination among corridor agencies, incident response can be faster and thus lowering the impacts to roadway congestion. A wide variety of approaches are used by regions hosting ICM projects (as seen in Table 3). The following table shows specific management methods proposed by each site/corridor for achieving improved conditions during traffic incidents.

Table 3: Incident management methods by strategy, and sites that have adopted them

Improve Incident Response Time	**Create and execute pre-planned incident response plans** • Montgomery County I-270 (Maryland DOT, 2008) • Houston I-10 (Gaynor, 2011)
	Focus on improving interagency coordination and communication • Montgomery County I-270 (Maryland DOT, 2008) • Los Angeles County I-210 (Dion, 2015) • Dallas US-75 (US DOT, 2010)
	Focus on technological upgrades and compatibility • Buffalo/Niagara Falls I-90 (Eng-Wong, Taub, and Associates, 2009)
	Install and improve incident detection capabilities along part of the corridor • No. Virginia I-95/395 (Sripathi, 2012)
	Develop common vehicle towing policy • Dallas US-75 (US DOT, 2010)
	Install lane control signs so authorities can reserve a lane of traffic for law enforcement during an incident • I-35W (MN Department of Transportation, 2014)
Increase transit use during incidents	**Increase mode shift to transit during incidents** • Minneapolis I-394 (Papayannoulis et al., 2010) • Broward County I-95 (Edelstein, 2013)
	Set up temporary parking at malls and churches to accommodate higher transit ridership • Minneapolis I-394 (Minnesota DOT, 2008)
Increase corridor throughput during incidents[3]	**Open HOV/HOT lanes to general traffic during incidents** (US-75 and I-15 already do this.) • Dallas US-75 (US DOT, 2010) • San Diego I-15 (Lee & Krile, 2012) • Minneapolis I-394 (Minnesota DOT, 2008)
	Develop a technology platform that will guide travelers off impacted freeways along alternative routes • Oakland I-880 (Zhang et al, 2008)
Information coordination during incidents	**Enter construction information into a multi-agency information clearinghouse** • Minneapolis I-394 (Minnesota DOT, 2008) • Oakland I-880 (Zhang et al, 2008)

[3] Transportation routing smart-phone applications (e.g Waze) can assist with increasing corridor throughput and disseminating information about incidents. These applications largely did not exist when these case studies were implemented and explains their omission from Table 3.

	Develop common guidelines for infrastructure repair and construction hours after a natural disaster • Oakland I-880 (Zhang et al, 2008)
	Set up a common incident reporting platform • Dallas US-75 (US DOT, 2010) • Minneapolis I-394 (Minnesota DOT, 2008)
Reduce incidents related to queuing	**Install variable speed limits to reduce traffic shocks and warn motorists of traffic queues** • Minneapolis I-394 (Minnesota DOT, 2008) • No. Virginia I-95/395 (Sripathi, 2012) • Seattle SR 520 (Batelle et al, 2014)
	Install end-of-queue warnings along highway ramps to notify signal operators when to relax meters and prevent a ramp queues from spilling onto arterial roads • Oakland I-80 (Caltrans, 2012)

Of all ICM and Urban Partnership sites, Minneapolis (I-394) drafted the most thorough incident response plan. Project managers have proposed opening HOT lanes to general traffic during severe incidents. Stakeholders intend to install Dynamic Message Signs on arterial roads and warn travelers of highway delays before they enter. Stakeholders found that traffic signals on the eastern end of the corridor were prone to losing power during windy periods, and propose installing backup generators for signals at key intersections in that area. They also want to waive state legislation that caps wait time at ramp meters at four minutes, and instead allow the ramps to filter traffic as slowly as needed in extreme conditions (Minnesota DOT, 2008).

6.5: Enable Intermodal Travel

Enabling corridor travelers to choose between modes is a common ICM goal that supports other goals such as improving corridor throughput. An example of enabling intermodal travel is providing more park and ride lots within the corridor, as is discussed in several Concept of Operations reports. More details follow in the next section.

7.0 Strategies

Prevalent strategies for meeting the goals identified previously appear in Table 4. Table 5 shows strategies by site/corridor.

Table 4: Prevalent Strategies by Goal

	Reduce travel time/costs	Increase travel reliability	Increase corridor throughput	Improve incident management	Enable intermodal travel
Signal synchronization/centralized signal management	♦	♦	♦		
Information dissemination to travelers (ATIS)	♦	♦	♦	♦	♦
Promote mode shift/Increase transit ridership			♦		♦
HOT lanes		♦	♦[4]		
Promote carpooling/ridesharing			♦		
Increased Park & Ride			♦		♦
Route shift		♦	♦		

Source: *Interstate 80 Integrated Corridor Mobility Project: Concept of Operations* (DKS Associates, 2010)

[4] Variable pricing recommended for achieving highest throughput (DKS Associates, 2010)

Table 5: Strategy by Site/Corridor

	Dallas	San Diego	Minneapolis	I-95/I-395 (VA)
Integrated management	♦	♦	♦	♦
Coordinated incident management	♦	♦	♦	♦
Dynamic ramp metering		♦		♦
HOV/HOT/Managed lanes	♦	♦	♦	♦
Increasing transit ridership		♦		
Congestion avoidance rewards		♦		
Shift time of travel				♦
Facilitate rideshare connections				♦
Integrated operational systems	♦			
Increased park and ride capacity	♦			♦
Multi-agency data exchange			♦	♦
Transit signal priority			♦	♦
Signal timing			♦	♦
Active traffic management/hard shoulder running				♦

Sources: *I-95/I-395 Integrated Corridor Management Initiative, Concept of Operations – Dallas Integrated Corridor Management (ICM) Management Project, Concept of Operations for the I-15 Corridor in San Diego, California, Concept of Operations for the I-394 Corridor in Minneapolis, Minnesota* (MN Department of Transportation, 2008; San Diego Pioneer Site Team, 2008; Sripathi, 2012; US Department of Transportation, 2010)

7.1.1 Signal Coordination

Many regions implementing ICM and Urban Partnerships prioritize improving arterial signal management across jurisdictions and agencies. The most widespread reasons for why sites prioritize signal coordination are to increase throughput and prevent queue formation during recurrent traffic conditions (I-880 [Zhang et al, 2008], I-95/395, I-90 [Eng-Wong, Taub, and Associates, 2009]), reduce bus travel time (I-95/395, SR 4 [Contra Costa Transportation Authority, 2012], I-90 [Eng-Wong, Taub, and Associates, 2009], I-80 [Caltrans, 2012]), and to respond to traffic incidents (I-10 in San Antonio [Southwest Research Institute, 2008], I-10 in Phoenix [Kimley-Horn and Associates, 2007], I-394). I-880 and I-394 stakeholders want to pre-program signals for traffic to and from events at local stadiums. Additional reasons for signal coordination include reducing travel time variation (I-15 [San Diego Pioneer Site Team, 2008], I-394 [Minnesota DOT, 2008]), managing construction on the primary highway (I-10 in Phoenix), and responding more effectively to extreme weather (I-394).

In addition, several sites are working on synchronizing arterial signals with buses. Bus transit signal priority cuts the traffic signal's cycle short or extends a green signal by a couple of seconds to reduce travel time for buses. In turn, shorter bus travel times make riding the bus more appealing to commuters. Stakeholders on the I-35W (Minnesota DOT, 2014) and I-10/110 Urban Partnerships (Schroeder, 2012) already installed and expanded bus transit signal priority, respectively. Stakeholders on the I-394 (Minnesota DOT, 2008), I-880 (Zhang et al, 2008), I-270 (Montgomery County Pioneer Site Team, 2008), I-95/395 (Sripathi, 2012), I-90 (Eng-Wong, Taub, and Associates, 2009) and US-75 projects also intend to install transit signal priority, though the US-75 project will only use this technology to help late buses catch up to schedule (US DOT, 2010).

Transit signal priority is one strategy to help make transit travel times consistent and reliable, but it primarily benefits transit riders at low-volume intersections with minimal queuing (Albright & Figliozzi, 2012). Another variation of transit signal priority gives buses greater leeway as ridership increases. Dynamic signal priority reduces delay for all passengers by 9.5% and delay for bus riders by 35.5% compared to signal management that optimizes vehicle throughput (Christofa & Skabardonis, 2011). Transit signal priority is ineffective, even counterproductive, in heavy traffic when V/C ratios are above 0.95 (Balke, Dudek, & Urbanik II, 2000). Therefore, its usefulness in peak hours, when many highways are at or above capacity, remains in question.

7.1.2 Information Dissemination to Travelers

Providing pre-trip and en-route information in real-time about travel conditions, route and mode options serves a number of purposes in many ICM projects: as shown in Table 6, providing information is a strategy for achieving multiple goals.

Table 6: Information Dissemination Method/Goal by Site/Corridor

Information Dissemination Method or Goal	Site/Corridors
Goal • Promote transit and carpooling	• San Antonio I-10 (Southwest Research Institute, 2008) • Minneapolis I-394 (Minnesota DOT, 2008) • Montgomery County I-270 (Montgomery County Pioneer Site Team, 2008) • Minneapolis I-35W (Minnesota DOT, 2014) • Seattle SR 520 (Battelle, 2014) • Buffalo/Niagara Falls I-90 (Eng-Wong, Taub, and Associates, 2009) • Oakland I-880 (Zhang et al, 2008)
Method • Provide unnamed "incentives" for travelers to use transit instead of driving	• Minneapolis I-394 (Minnesota DOT, 2008)
Method • Real-time parking information Goal • Promote Park-and-Ride use	• Minneapolis I-35 W (Minnesota DOT, 2014) • No. Virginia I-95/395 (Sripathi, 2012) • Dallas US-75 (US DOT, 2010) • Oakland I-880 (Zhang et al, 2008)
Method • Variable pricing on parking Goal • Keep 10-30% of parking spaces open and reduce number of cars circulating in central business districts looking for parking	• Urban Partnerships in San Francisco and Los Angeles (Schroeder, 2012; Zimmerman, Klein, & Schroeder, 2014)
Method • Real-time transit information for drivers Goal • Reduce uncertainty over next departure time for transit routes and improve drivers' ability to schedule switching to transit	• Phoenix I-10 (Kimley-Horn and Associates, 2007) • Oakland I-880 (Zhang et al, 2008) • Contra Costa County SR 4 (Contra Costa Transportation Authority, 2012) • Buffalo/Niagara Falls I-90 (Eng-Wong, Taub, and Associates, 2009) • Montgomery County I-270 (Maryland DOT, 2008)
Method • Real-time comparative travel time between modes of transportation Goal • Raise awareness and use of transit options that may be faster than driving	• Dallas US-75 (US DOT, 2010) • Minneapolis I-394 (Minnesota DOT, 2008) • No. Virginia I-95/395 (Sripathi, 2012)
Method • Real-time comparative travel time between routes Goal • Better distribute vehicle traffic between various highway and arterial roads	• Minneapolis I-394 (Minnesota DOT, 2008) • No. Virginia I-95/395 (Sripathi, 2012)

Through the methods above, transportation agency managers hope to provide more options for suburban and exurban travelers who currently use single-occupancy vehicles for most trips. After ICM and Urban Partnership implementation, planners hope travelers will be more aware of, and comfortable using, alternative travel modes and routes.

All of the information strategies above hope to elicit voluntary travel behavior changes from drivers. The strategies rest on an assumption that, when single-occupancy vehicle drivers know when the next express bus is leaving, they will be willing to park their cars and take the bus. Are voluntary measures that tell drivers when the next bus is leaving - or that a bus is 5-10 minutes faster than driving - sufficient to alleviate peak-hour congestion? There are indications that these strategies have an impact at the margin, but are not sufficient in and of themselves. This paper will return to the effectiveness of voluntary congestion management measures in the discussion section.

7.1.3 Mode Shift

Nearly all ICM and Urban Partnerships advocate a mode shift from single-occupancy cars, whether to buses, trains, carpools, telecommuting, or biking.

Table 7: Mode Shift Method/Goal by Site/Corridor

Mode Shift Feature or Goal	Project/ Corridor
Goal • Encourage mode shift to transit	• I-10 in Phoenix (Kimley-Horn and Associates, 2007) • I-10 in San Antonio (Southwest Research Institute, 2008) • I-394 (Minnesota DOT, 2008) • I-270 (Maryland DOT, 2008) • I-10/110 (Schroeder, 2012) • I-95 in Broward County (Edelstein, 2013) • I-90 (Eng-Wong, Taub, and Associates, 2009) • US-75 (US DOT, 2010)
Method • Establish ferry service and expand BART	• SR 4 (Contra Costa Transportation Authority, 2012)
Goal • Move travelers from highways over capacity to transit with spare capacity	• US-75 (US DOT, 2010) • I-95/395 (Sripathi, 2012) • I-394 (Minnesota DOT, 2008)
Goal • Increase transit capacity	• I-10 in San Antonio (Southwest Research Institute, 2008)

7.1.4 Increase Corridor Transit Ridership

Several project teams state they want to increase transit ridership. Increasing transit ridership is one way to shift travelers behavior and decrease the modal split for single occupancy vehicles. Decreasing the percentage of travelers who are driving alone is a broader goal than seeking to increase transit ridership. Transit ridership across the U.S. is relatively low, and less than 2% of all trips are made on public transit (Santos, McGuckin, Nakamoto, Gray, & Liss, 2011). Nevertheless, transit is a prominent part of some, though not all, ICM and Urban Partnerships. The relative advantage of transit arises on corridors with high travel demand at peak hours. Transit can funnel high volumes of people along a corridor more effectively than single-occupant cars. As a result, many ICM and Urban Partnership projects along congested highways emphasize transit as a way to increase throughput during periods of high travel demand along corridors with limited extra space (Hanson & Giuliano, 2004). As seen below in Table 8, nine projects state they would like to increase transit ridership, only two disclose tangible goals to achieve that.

Table 8: Transit Method/Goal by Site/Corridor

Transit Method or Goal	Project/ Corridor
Goal: • Increase transit ridership	• Montgomery County I-270 (Montgomery County Pioneer Site Team, 2008) • Dallas US-75 (US DOT, 2010) • Oakland I-880 (Zhang et al, 2008) • San Diego I-15 (San Diego Pioneer Site Team, 2008) • Contra Costa County SR 4 (Contra Costa Transportation Authority, 2012) • Minneapolis I-35W (Minnesota DOT, 2014) • Phoenix I-10 (Kimley-Horn and Associates, 2007) • Buffalo/Niagara Falls I-90 (Eng-Wong, Taub, and Associates, 2009) • Sacramento/El Dorado Counties US-50 (System Metrics Group, Inc., Parsons Corporation, & Cechini Transportation Management Services, 2016)
Goal: • 5% year-on-year transit ridership increase	• Contra Costa County SR 4 (Contra Costa Transportation Authority, 2012)[5]
Goal: • Increase transit ridership 1.5 times faster than increase in traffic volume	• Buffalo/Niagara Falls I-90 (Eng-Wong, Taub, and Associates, 2009)
Method: • Simplify bus-to-rail transfers	• Montgomery County I-270 (Maryland DOT, 2008)
Method: • Promote real-time cross-network connections	• Dallas US-75 (US DOT, 2010) • San Diego I-15 (San Diego Pioneer Site Team, 2008) • Oakland I-880 (Zhang et al, 2008)
Method: • Double track eastern part of Gold Line for more frequent service	• Sacramento/El Dorado Counties US-50 (Caltrans, 2014)
Method: • Urban Partnerships provided federal funds for bus purchases and increasing service frequency	• Minneapolis I-35W (Minnesota DOT, 2014) • Los Angeles I-10/110 (Schroeder, 2012) • Seattle SR 520 (Batelle et al, 2014)

[5]More specifically, this project's goal was to increase daily ridership west of the Bay Point BART station to 4,000.

Project teams differed in their level of financial and rhetorical commitment to increasing transit ridership. On the ambitious side, stakeholders on the I-85 Urban Partnership in Atlanta envision the Park-and-Ride expansions and bus purchases entailed by the agreement as the beginning of a long-term multi-stage transit upgrade for the region (Georgia Department of Transportation, n.d.). The Contra Costa County SR 4 proposal also calls for ambitious transit improvements within the scope of the ICM project (Contra Costa Transportation Authority, 2012). Dallas US-75 (US DOT, 2010) and San Diego I-15 (Lee and Krile, 2012) stakeholders hedge their support for increased transit ridership with statements that they want to minimize the increase in operating costs. They could pursue this by prioritizing traveler information provision over increased bus service. To take the least ambitious example, Phoenix is not prepared to make transit a significant component of ICM implementation. As stated in their 2007 Concept of Operations Report, the authors noted that the I-10 corridor does not have HOV lanes which could prioritize transit service (Kimley-Horn and Associates, 2007). This decision is a direct result of project focus. The plans and strategies seek to improve management during incidents and freeway closures rather than long-term modal shifts (Maricopa Association of Governments, 2013).

7.1.5 Travel Time, Transfers, and Ridership

More ICM and Urban Partnership sites have goals to increase transit ridership than have strategies to achieve them. Sites with public strategies aim to increase transit capacity, frequency, and ease connections. Easing connections, in particular, is a cost-effective way to reduce anxiety about transit vehicle arrival times among riders and promote ridership.

To accomplish this goal, transit agencies can either implement ways to send more information to travelers to lower perceived wait times. Or, they can increase the number of vehicles and reduce transit headways to lower actual wait times. A 2012 study estimated that travelers find travel time spent outside a transit vehicle three times as onerous as travel time on a bus or train (Iseki, Smart, Taylor, & Yoh, 2012). Travelers overestimate their wait time by 9-13% with next-arrival information, while they overestimate by 24-30% without it (Yoh, Iseki, Smart, & Taylor, 2011).Next-arrival information reduces the amount of time travelers believe they are waiting for transit. As riders experience more reliable, predictable trips, they may ride more. Travel time on transit vehicles also affects ridership. A study in the 1960s found that a 10% increase in travel time onboard results in a 3.9% decrease in demand for travel, while a 10% increase in wait time for the vehicle to arrive results in a 7% decrease in travel demand (cited in Krizek & El-Geneidy, 2007). Vehicle purchases and headway reductions at Urban Partnerships address this aspect of attracting ridership.

An agencies existing assets play a large role in their ability either lower these perceived wait times or increase transit headways. In the Dallas I-75 project, Dallas Area Rapid Transit (DART) lacked access to real-time transit arrival information prior to the ICM project. As a part of their ICM deployment, automatic passenger counters (APC) and other communication technology were added to transit vehicles and transit stations along the demonstration site. The deployment focused on the Red Line LRT. APC and communications technology not only allowed travelers to have more information about transit vehicle arrival, the passenger counters allowed system managers to make same-day decisions and add or reduce train capacity based on real demand.

This deployment did come with its own set of challenges related to the other existing assets. DART (and other agencies) may find that these technologies can help aid real time information. But, they may face other network and organizational capacity challenges which inhibit achieving other transit ridership goals (Plesko & Gorman, 2013).

Projects in Minneapolis and San Diego took a slightly different approach to achieving their transit improvement goals. Both projects implemented signal priority for buses along arterials that paralleled the ICM highway corridor. Limited information exists about these strategies effectiveness. In a 2015 writing, researchers at the California PATH program detailed the proposed transit service along the San Diego I-15 corridor but did not include anything related to the resulting changes (Dion & Skabardonis, 2015). Ideally, future ICM evaluation reports will provide more information about the effectiveness of these projects to improve corridor transit service.

7.1.6 HOT Lanes and Transit

When local agencies converted HOV lanes to HOT lanes, transit ridership increased on I-95 in Miami, I-394 and I-35W in Minneapolis, and SR 167 in Seattle by between 13% and 57% (Newmark, 2014). HOV to HOT conversions on I-25 in Denver and on SR 91 in Orange County did not yield increases in transit ridership. It is also unclear to what degree HOT lanes encourage single-occupancy vehicle drivers to take transit. A 2011 study of the Miami HOT lanes concluded over 75% of express bus riders previously took local buses or Tri-Rail (commuter rail) before the express buses started operating (cited in Newmark, 2014).

HOT lanes can increase freeway throughput, generate a travel time advantage for transit, and raise money for transit improvements, if planners design fare policies and revenue-sharing rules carefully. In a 2007 article, "the political calculus of congestion pricing" authors King, Manville and Shoup explain how congestion pricing, the technique that high-occupancy toll lane use, can best generate political support by distributing the toll revenue to cities with targeted investment back into the freeway corridor (King, Manville, & Shoup, 2007). In general, projects that include congestion pricing techniques suffer from a lack of political support (Basso, Guevara, Gschwender, & Fuster, 2011; Finkleman, Casello, & Fu, 2011).

Minnesota state statute requires revenue generated by toll lanes must be used in the corridor where those tolls were collected. The funds were first used to pay for up to $1 million in operating costs and then additional revenues funded transit expenses. The Minnesota Department of Transportation plans to upgrade all regional HOV lanes to HOT lanes, in what many would call a great success of the ICM program. Obtaining political support through these funding commitments, and they add "pricing projects are more likely to generate support if linked to transit improvements" (Buckeye, 28, n.d) appears to be a key part of their successful equation (Buckeye, n.d.).

7.1.7 Carpooling and Ridesharing

Several projects stated they intended to increase person throughput on congested highways through promoting carpooling and rideshares. As seen below in Table 9, only two programs (Los Angeles and Phoenix) came up with concrete proposals to increase rideshares, and no information is available on how effective they were. As previously discussed, the Phoenix project focuses more on incident response and behavioral changes like using carpooling and ridesharing are receive lower priority in the plans and implementation

Table 9 Carpooling Method/Goal by Site/Corridor

Carpooling Goal or Method	Project/Corridor
Goal: • Increase highway throughput	• I-10/110 (Schroeder, 2012) • I-10 in Phoenix (Kimley-Horn and Associates, 2007) • I-394 (Minnesota DOT, 2008)
Method: • Establish 100 new vanpools during tolling implementation	• I-10/110 (Schroeder, 2012)
Method: • Purchase 33 vans for at-capacity vanpool program	• I-10 in Phoenix (Kimley-Horn and Associates, 2010)

Carpools were more important for Urban Partnerships relative to ICM sites because most Urban Partnerships introduced highway lane tolling that carpools could enter without paying tolls. Studies conducted after tolling implementation along I-85 and SR 520 (Battelle et al, 2014) concluded that tolling reduced average vehicle occupancy, though it also increased throughput. In a review of the effect of HOT lanes on carpools, Burris et al (2014) found the effects of these lanes on carpool occupancy to vary by facility, but overall that HOT lanes decreased carpooling, overall (Burris, Alemazkoor, Benz, & Wood, 2014). The eight cases in this research do not perfectly match with the ICM and Urban Partnership projects, some of the previously discussed projects were included (I-15 San Diego, I-394 in Minneapolis, I-85 in Atlanta). Overall, the evidence that ICM strategies can increase carpooling is weak and increases in transit ridership appear to outpace any the net change in carpooling, across sites that pursued both strategies.

7.1.8 Park-and-Ride

Efforts to shift drivers onto transit or into carpools require places for commuters to park and shift into a higher-density mode of transportation. Park-and-Ride facilities allow residents who did not live in the immediate area of a transit station to drive to the facility and park, usually for free. Travelers then board buses, commuter rail, urban rail, or carpool. Travelers who use Park-and-Ride lots bypass searching for scarce and expensive parking in central business districts, and may realize travel time savings if they gain access to an HOV or HOT lane, or to grade-separated transit. However, researchers have found conflicting results over whether Park-and-Ride lots increase or decrease VMT among users (Zijlstra, Vanoutrive, & Verhetsel, 2015). Up to a third of Park-and-Ride users at any location previously used another location. They may drive less to get to the new location, but they are not new transit users either.

In the United Kingdom, successful Park-and-Ride facilities opened outside historic centers where little space remained for parking expansions that could also damage tourism (Ison & Rye, 2008). Park-and-Ride collect user fees as parking fees and/or in bus fare. Parking fee advocates note that collecting bus fares increases bus travel time, whereas travelers can pay for parking without holding up the bus. Norwich Park-and-Ride facilities issue users two tickets. The ‘park’ ticket goes on their car’s windshield as validation, while the ‘ride’ ticket admits them on the bus. An all-day parking fee equals two hours of parking in city center.

Ison and Rye conclude that promoting Park-and-Ride lots without also introducing 'carrots' to reduce travel demand by car creates negative externalities. It generates extra trips, many Park-and-Ride lots in the suburbs are built on former parkland, and Park and Ride buses have low load factors. However, using Park-and-Ride lots remain a politically popular congestion management approach.

Dutch researchers conducted a meta-analysis of Park-and-Ride studies and concluded they are relatively inefficient. They found that lots located next to rail stations and in exurbs reduce trips to the city center by 15-29 cars per 100 parking spaces, while bus-based lots and lots on the edge of urban development reduce trips by 37-50 cars per 100 spaces. Even the more effective Park-and-Ride lots offer 2.5 spaces for every avoided/diverted car trip, as less than half of users previously drove to the city center. The remainder used to bike, ride transit, or walk to the lot, and/or park at the lot for purposes unrelated to traveling to city center. The most successful Park-and-Ride facilities were part of low-ridership transit systems where car use predominated (Zijlstra, Vanoutrive, and Verhetsel, 2015). Park-and-Ride may therefore shield auto-dependent suburbs from negative effects of car reliance and prolong dispersed, single-family land use patterns.

Several Urban Partnership and ICM sites intend(ed) to promote and expand Park-and-Ride use. Stakeholders for the I-95/395 (Sripathi, 2012), I-35W, SR 4 (Contra Costa Transportation Authority, 2012), I-10 in Phoenix (Kimley-Horn and Associates, 2007), and I-10/110 (Schroeder, 2012) have or plan to expand Park-and-Ride facilities to accommodate greater mode shifts. The US-75 project (US DOT, 2010) and I-95 ICM proposal in Broward County (Edelstein, 2013) intend to increase Park-and-Ride use by 10 and 20 percent, respectively. These proposals may likely increase support for transit and the ICM projects, but they do come with their own set of opportunity and financial costs as these parking lots may take up scarce land near transit stations (Duncan & Christensen, 2013). Existing research about the effectiveness of Park-and-Ride facilities is limited in the United States. Existing sources point to the fact that expanding these facilities is a relatively costly approach and may not achieve all desired outcomes, particularly if the parking provided for free. (Duncan & Christensen, 2013; Syed, Golub, & Deakin, 2009; Zhong & Li, 2016)

7.1.9 Route Shift

Congestion may occur persistently or as a result of a specific traffic related incident. To handle incident related congestion, agencies can use strategies that redirects travelers from highways to adjacent arterial streets. This strategy does not address the long-term condition or persistency occurring congestion. However, route shifts can still reduce congestion as part of a suite of actions during extreme traffic incidents like the 2007 Minneapolis bridge collapse or traffic during Thanksgiving weekend. Stakeholders on the I-10 project in San Antonio (Southwest Research Institute, 2008), I-10 in Phoenix (Kimley-Horn and Associates, 2007), I-15 (San Diego Pioneer Site Team, 2008), I-394 (Minnesota DOT, 2008), and I-880 (Zhang et al, 2008) include this as a strategy to increase throughput. Please refer to section 7.1.1 Signal Coordination for more information on a tactic many stakeholders are promoting to accommodate large shifts of traffic off of freeways onto arterial roads.

7.1.10 Improve Goods Movement

Freight trucks and traffic congestion are inextricably linked and freight movement is a critical part of the economy. The freight transportation system moves 55 million tons of goods, at an estimated worth of more than $49 billion each day (US Department of Transportation, 2015). The National Freight Strategic Plan discusses how expected growth in the amount of freight tonnage and the continued population growth in congested urban areas are key challenges in planning for freight in the years ahead. Most ICM projects do not explicitly focus on increasing the throughput of goods and rather focus on increasing the throughput of people in the corridor, with two notable exceptions.

The Oakland I-880 (Zhang et al, 2008) and Phoenix I-10 projects (Kimley-Horn and Associates, 2007) are the only projects that discuss freight considerations at length. I-880 connects the port of Oakland, the fifth largest in the country, to Silicon Valley. To reduce truck delay, stakeholders are developing an electronic identification system for incoming shipments so truck drivers can track the status of cargo they will pick up. Authorities will also share estimated travel times with truck drivers before they leave the port so drivers can adjust their departure time. I-10 has a similar emphasis on providing truck drivers with accurate travel times.

The Austin I-35 project briefly mentions reducing toll fees for trucks that divert from I-35 to toll roads that bypass central Austin to the east (Texas Department of Transportation, 2015).

8.0 Conclusion

Reducing congestion, particularly congested traffic incident related congestion is one of the principle objectives for Integrated Corridor Management projects. Urban Partnership sites, those that precede the current federally funded ICM efforts, were more focused on persistently occurring traffic congestion. As this literature review indicates, however, the relative simplicity of those objectives belies the heterogeneity of goals that agencies have established for their ICM and Urban Partnership sites strategies. These goals are numerous and varied, as outlined in this document. Across both of these federal programs, it appears that projects which focuses and prioritized one goal were more likely to be able to achieve their goals.

In addition to this literature review, this project created additional products which aimed to assist Caltrans in delivering future ICM projects. Deliverable 2 outlines freeway corridors in California that have sufficient transit service to be integrated into an ICM corridor; Deliverable 3 evaluates the interaction between traffic and transit in four case studies; Deliverable 4 revisits the goals identified in this document to discuss performance measures that address those goals; Deliverable 5 outlines those performance measures and describes some of the interactions between them; and Deliverable 6 is a policy brief summary of this process that embellishes on recommendations from the Statewide Transit Strategic Plan with information found in this research effort.

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LIST OF SELECTED HIGHWAY CORRIDORS FOR ICM CONSIDERATION

Deliverable 2

Investigating Relationships Between Highway System Performance and Transit System Management

Agreement Number 65A0528
Task Order Number TO 011 A01

December 21, 2016

Prepared for Caltrans

UCLA Institute of Transportation Studies

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Contents

1.0 Integrated Corridor Management Potential: Transit Service Allocation

Rows highlighted in yellow have extremely high amounts of adjacent transit service allocated and are identified as Caltrans "Top Priority" ICM corridors. These three corridors likely have the best environment to improve management and shift demand to public transit.

District	Highway	Beginning	End	Currently prioritized?
3	I-80	Intersection with I-99 in Sacramento	Eastern point at Camp Spaulding	Yes. Currently identified as ICM priority corridor to the Sacramento county border. ICM potential extends past this border to the identified eastern end
3	I-80	Western Sacramento County boundary	Eastern intersection with I-5	No
3	CA-50	Intersection with the I-99 in Sacramento	Eastern Sacramento County boundary	Yes. Priority area has transit coordination potential
3	I-5	Northern intersection with the I-80	Southern intersection with I-5/I-580 junction	No
4	I-80	Northern intersection near the I-780 in City of Vallejo	Southern terminus in San Francisco at Highway 101	Yes. Top Priority corridor. The section crossing the San Francisco Bay and in Berkeley is prioritized but the entire corridor has ICM potential
4	I-580	Western intersection with I-80	Southern intersection with I-238	Yes. confirmed high potential for ICM management
4	I-880	Western intersection with I-80	Southern intersection with I-280	Currently identified as priority corridor from Berkeley border at northern end to Milpitas at southern end. Corridor could be extended to the north and south for enhanced management.
4	I-680	Northern intersection with I-780	Southern intersection with I-580	No

District	Highway	Beginning	End	Currently prioritized?
4	I-280	Northern terminus in San Francisco	Southern terminus at the CA-101	No
4	CA-101	Northern terminus in San Francisco	Southern point in City of Gilroy	Yes
5	CA 1	Northern boundary with City of Santa Cruz	Southern boundary with City of Watsonville	No
5	CA-101	Northern San Luis Obispo City boundary	Southern boundary of San Luis Obispo County	No
6	CA-99	Northern section near Delano	Southern intersection with I-5	Yes
6	CA-41	Fresno		Yes
7	I-5	Northern Los Angeles County boundary	Southern Los Angeles County boundary	No
7	I-405	Northern terminus at I-5	Southern Los Angeles County boundary	Yes
7	I-105	Western terminus at Los Angeles County boundary	Eastern terminus at I-605	Yes
7	I-10	Western terminus at Los Angeles County boundary	Eastern terminus at Los Angeles County boundary	Yes
7	CA-60	Western terminus at I-5	Eastern terminus at Los Angeles County boundary	Yes
7	**I-110**	**Northern terminus at CA-210**	**Southern terminus in City of Long Beach**	**Yes – Top Priority Corridor**
7	CA-605	Northern terminus at CA-210	Southern Los Angeles County boundary	No
7	CA 710	Northern terminus at CA-210	Southern terminus in City of Long Beach	No
7	**CA-210 / I-210**	**Western terminus at I-5**	**Eastern terminus at Los Angeles County boundary**	**Yes – Top Priority Corridor**
10	CA-99	Northern Stanislaus County boundary	Southern Stanislaus County boundary	No
11	I-5	Northern San Diego County boundary	Southern terminus at San Diego County boundary	Yes
11	I-805	Northern terminus with I-5	Southern intersection with I-5	Yes
11	I-8	Western terminus	Eastern San Diego County boundary	No
12	I-5	Northern Orange County boundary	Southern Orange County boundary	Yes

2.0 Summarizing Results

Many corridors currently managed by Caltrans could leverage adjacent transit service to improve corridor throughput. According to an internal Caltrans spreadsheet received in June 2015, Caltrans has identified five corridors as top priority. We found that three of these five top priority corridors include substantial amounts of adjacent public transit service. These include the I-80 corridor in District 4, and the I-210 and I-110 corridors in District 7. Although the proposed corridors in District 12 may hold promise for integrated corridor management, we do not recommend that public transit be included in these corridors' management strategy.

As noted from the table above, many corridors currently contain public transit service along adjacent streets which may be used to alleviate pressure from future growth and travel demand. We encourage staff from individual districts to review the maps at the end of this document to understand where transit service can be used to improve person throughput in these selected highway corridors.

3.0 Description by District

3.1 Districts 1, 2 and 9

These districts were excluded from the analysis because little to no transit currently operates in these districts. Therefore, their inclusion would not be helpful to this analysis Additionally, these districts have very few highway miles within their boundaries.

3.2 District 3

Our analysis demonstrated that two of the three proposed ICM corridors contain substantial public transit service. The I-80 corridor stretching eastward from the City of Sacramento is currently identified as an ICM priority corridor and our analysis reveals this corridor could be extended further north beyond the current priority corridor selection.

We further concluded that the I-80 corridor connecting the City of Davis to the City of Sacramento has enough transit service to consider incorporating transit in I-80 corridor management plans.

3.3 District 4

District 4 contains both a high number of ICM priority corridors and a high density of public transit along congested freeway corridors; unique among the Caltrans districts, nearly all District 4 corridors contain a number of transit lines along one mile of the highway/freeway corridor.

The previously selected ICM corridors all align well with high density transit networks. Coordination with the adjacent transit service is a likely key to success for these priority corridors. Based on our analysis, some of these priority corridors could be expanded (i.e., the I-80 corridor in the City of Berkeley and the CA 101 corridor along the South Bay). Both of these corridors contain transit service beyond the currently selected priority corridors.

We identified further corridors in District 4 which contain adjacent transit service: the I-680 corridor near Walnut Creek and the I-280 corridor near the southern boundary of the City of San Francisco.

District 4 is the most urbanized Caltrans district that will experience the most pressure from future growth. We encourage planners in District 4 to leverage the abundance of transit service as a way to increase corridor throughput along highway and freeway corridors.

3.4 District 5

District 5 is less urbanized than other districts we examined, with many square miles of agricultural land. The current Caltrans ICM priority listing includes no projects in District 5 and our analysis supports this decision. The two areas with the greatest potential include the CA-1 corridor near Santa Cruz and the CA-101 corridor near the City of San Luis Obispo. Because of the lack of urbanization outside of these city core areas, the segments are lower priority for transit service coordination and integrated management.

3.5 District 6

Similar to District 5, District 6 also has a relatively small amount of urbanized area. The two previously selected Caltrans ICM priority corridors have adjacent transit service, although it is very limited. The corridor near Bakersfield holds some promise for highway and transit coordination but there is little to no transit service currently available near the Fresno ICM corridor.

3.6 District 7

Similar to District 4; District 7 has large urbanized areas, large amounts of future growth and substantial transit service allocated near freeway and highway corridors. All of the ICM corridors proposed by Caltrans contain adjacent transit service. Therefore, ICM projects in District 7 should leverage this existing transit service adjacent to proposed ICM corridors.

Overall, our analysis confirms the ICM corridors proposed by Caltrans are well suited for integrated corridor management that includes coordination with transit service on adjacent surface streets.

3.7 District 8

District 8 contains two proposed ICM corridors: along the I-15; and CA-91. Neither these nor any other highway corridors in District 8 were found to have sufficient transit service (as defined as 50 or more transit lines within 1 mile) for supporting incorporation with corridor management plans. ICM strategies for the I-15 and CA-91 corridors should instead focus on toll lanes or other strategies for meeting ICM objectives; adjacent transit service is not currently sufficient to support significant mode.

3.8 District 10

Caltrans identified two priority corridors in District 10. Our analysis revealed that the proposed ICM corridor along CA-99 could be extended south. This extension could leverage existing adjacent transit to increase corridor throughput.

The ICM priority corridor along CA-132 has little adjacent transit. Therefore, ICM strategies proposed along this corridor cannot rely on current transit to improve corridor management.

3.9 District 11

Caltrans' two priority ICM corridors in District 11, the I-5 and I-805, contain adjacent transit which could be incorporated into the corridors' management. Our analysis revealed the I-8 corridor also contains adjacent transit service and should be considered for future integrated corridor management. Other freeway corridors in District 11 contain adjacent transit but report less transit density.

3.10 District 12

This district holds promise for a number of ICM projects as many highway corridors in this district currently contain high-occupancy/toll lanes and many more of these HOV/HOT projects are proposed in the future. Our analysis showed that of the four proposed ICM corridors (CA-57, CA-91, I-405 and I-5), I-5 contains the most transit service in the adjacent area. In addition, I-5 also contains an HOV lane. This HOV lane is currently planned to be converted to a HOT lane. We recommend the current existing assets (transit service and HOV lane) be leveraged to improve corridor throughput.

4.0 Methodology and Documentation

The goal of this analysis was to identify highway corridors that could leverage adjacent transit service in future integrated corridor management efforts. Our secondary goal was to review currently proposed ICM corridors to determine which of these corridors could include transit service allocation as one strategy in future ICM plans.

4.1 Agency selection process

Multiple agencies for this project were selected based on several criteria. Since this is a study intended for the California Department of Transportation (Caltrans), only transportation agencies which operate within the state were chosen. After reviewing transit agencies operating in California from the National Transit Database, agencies that operate buses, rail lines, and ferries (or any combination of the three) were all found relevant to our analysis. A handful of agencies on the list however were excluded from our study such as university transportation departments, dial-a-ride services, or agencies that also have operations outside of the state, because their limited services made them less applicable for this analysis.

4.2 The Process for Acquiring Data

Nearly every effort was made to obtain shapefiles that display transit routes for all the agencies represented on the list. We searched publically available information to see if such information was present in any sort of database, association/council of governments' page, county open data, or on the website of the transit agency itself. If this search did not yield results, we searched Google's General Transit Feed Specification (GTFS) to see if any useful files were available. If our search yielded no data, then agencies were personally contacted via email or phone to see if they could provide us directly with such information. If appropriate, contractors for the agencies were contacted for relevant shapefile data, such as the 511 service in Northern California.

Data were also acquired for state freeways and related features such as current, planned, and under construction High Occupancy Vehicle Lanes (HOV) and High Occupancy Toll (HOT) Lanes. All of these data were obtained from the Caltrans GIS data portal (http://www.dot.ca.gov/hq/tsip/gis/datalibrary/). Lastly, we created a spatial data file based on the ICM priority listing received from Caltrans staff.

4.3 Documentation of Processing and Analysis

The highway file was then edited to break up and highlight the segments which fall under Caltrans's ICM priority list. We then combined this shapefile with our other highway data about HOV and HOT current and proposed projects.

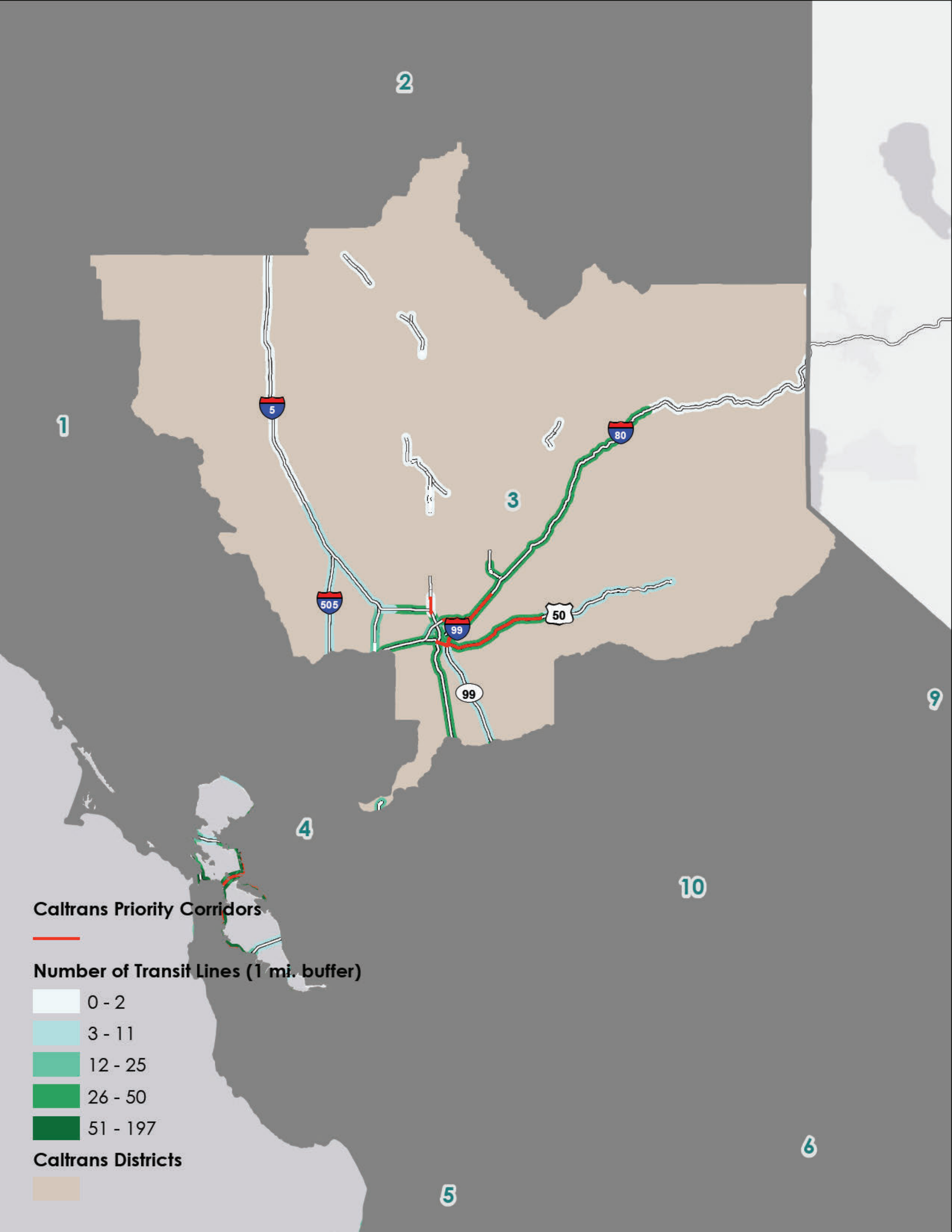
We categorized these highway segment data into categories depending on their feasibility and readiness for improvement in management techniques. These categories were numbered between 1-5, with 5 indicating the greatest potential, and 1 the lowest. Existing and under-construction HOT Lanes were assigned a 5, while HOT lanes that were planned were given a 4. Similarly, existing and under construction HOV Lanes were given a 3, while HOV lanes being planned a 2. Finally, general freeway lanes were assigned a 1.

We then added a one-mile buffer to the merged freeway shapefile and conducted a spatial analysis to calculate the number of transit lines adjacent to these freeway segments (i.e., within the one-mile buffer). Our initial plan included calculating the ratio of highway miles to adjacent transit miles. This ended up becoming problematic due to inconsistencies between the different transit datasets. Some transit files contained two lines (one for each direction of travel) and some files contained only one line. As a compromise, we ultimately decided to count the number of transit lines within the highway buffer.

5.0 Results

We created two map series from this analysis. The first shows the count of transit lines near highway segments with an overlay of current ICM priority corridors. The second shows a more detailed breakdown and displays the highway segment data with information about current and proposed high occupancy vehicle (HOV), high occupancy toll (HOT) lanes, and detailed information regarding bus and rail lines.

Appendix A: Map Series 1 – Transit Lines Adjacent to Highway and Freeway Corridors



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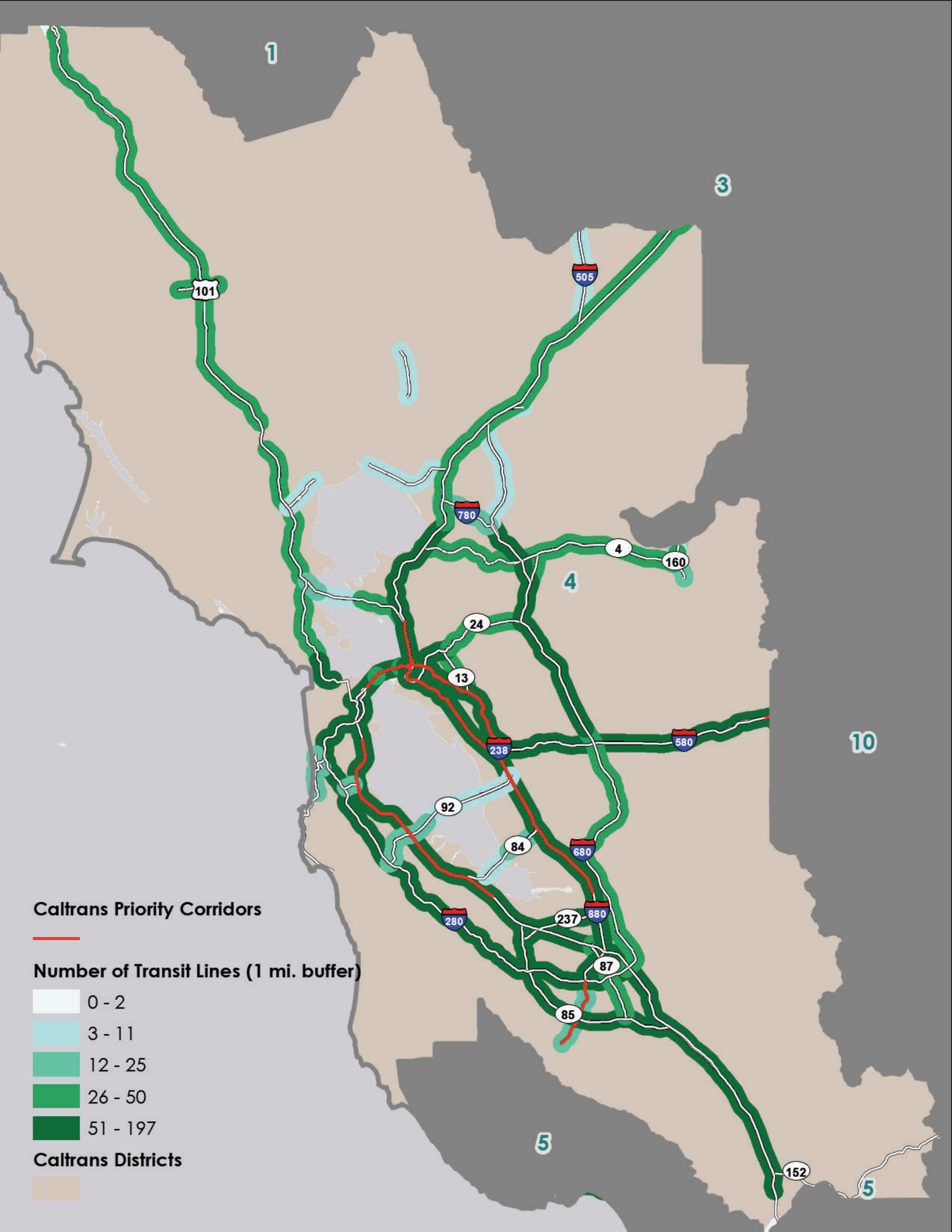
Caltrans Priority Corridors
Number of Transit Lines (1 mi. buffer)
0 - 2
3 - 11
12 - 25
26 - 50
51 - 197
Caltrans Districts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Caltrans Priority Corridors
Number of Transit Lines (1 mi. buffer)
0 - 2
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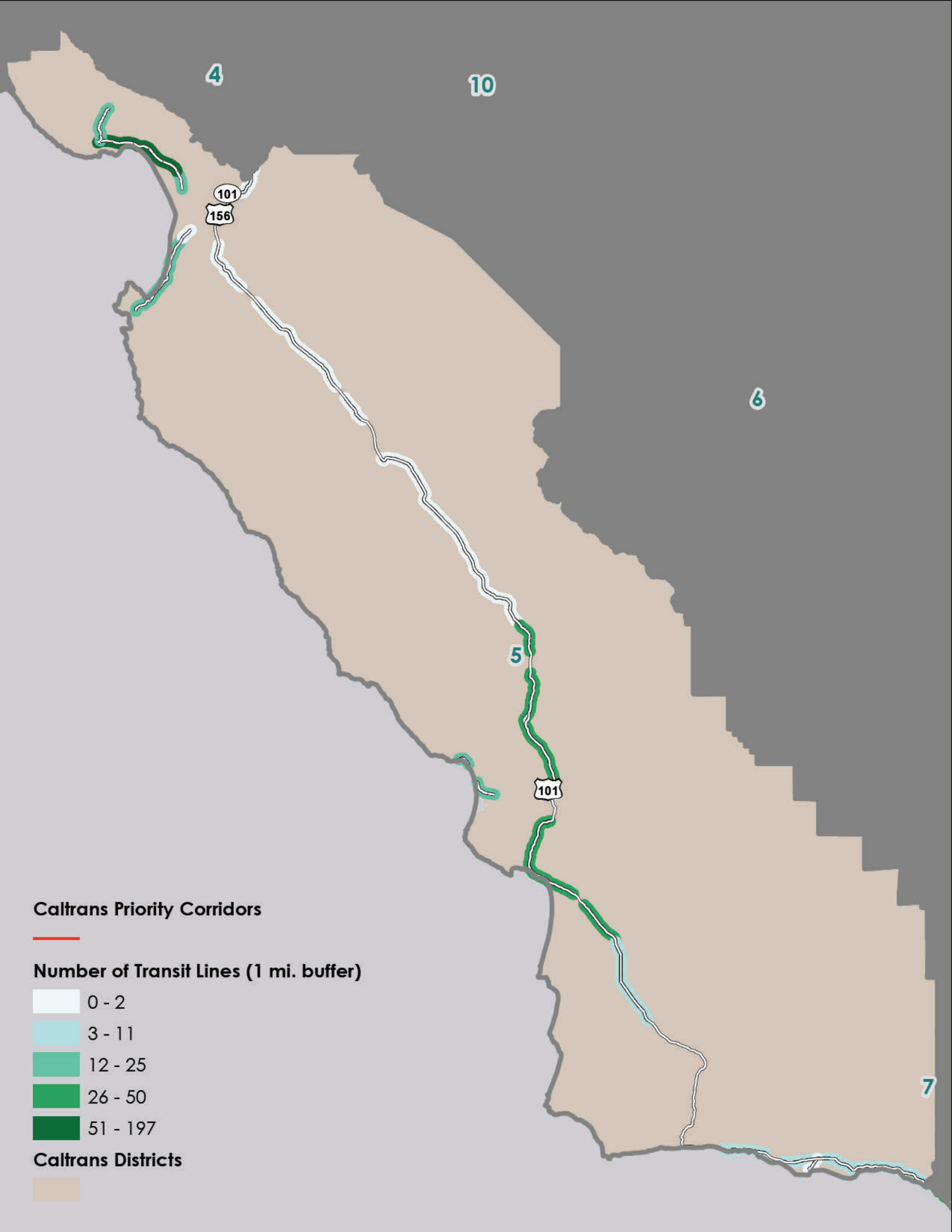
12 - 25
26 - 50
51 - 197
Caltrans Districts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Caltrans Priority Corridors
Number of Transit Lines (1 mi. buffer)
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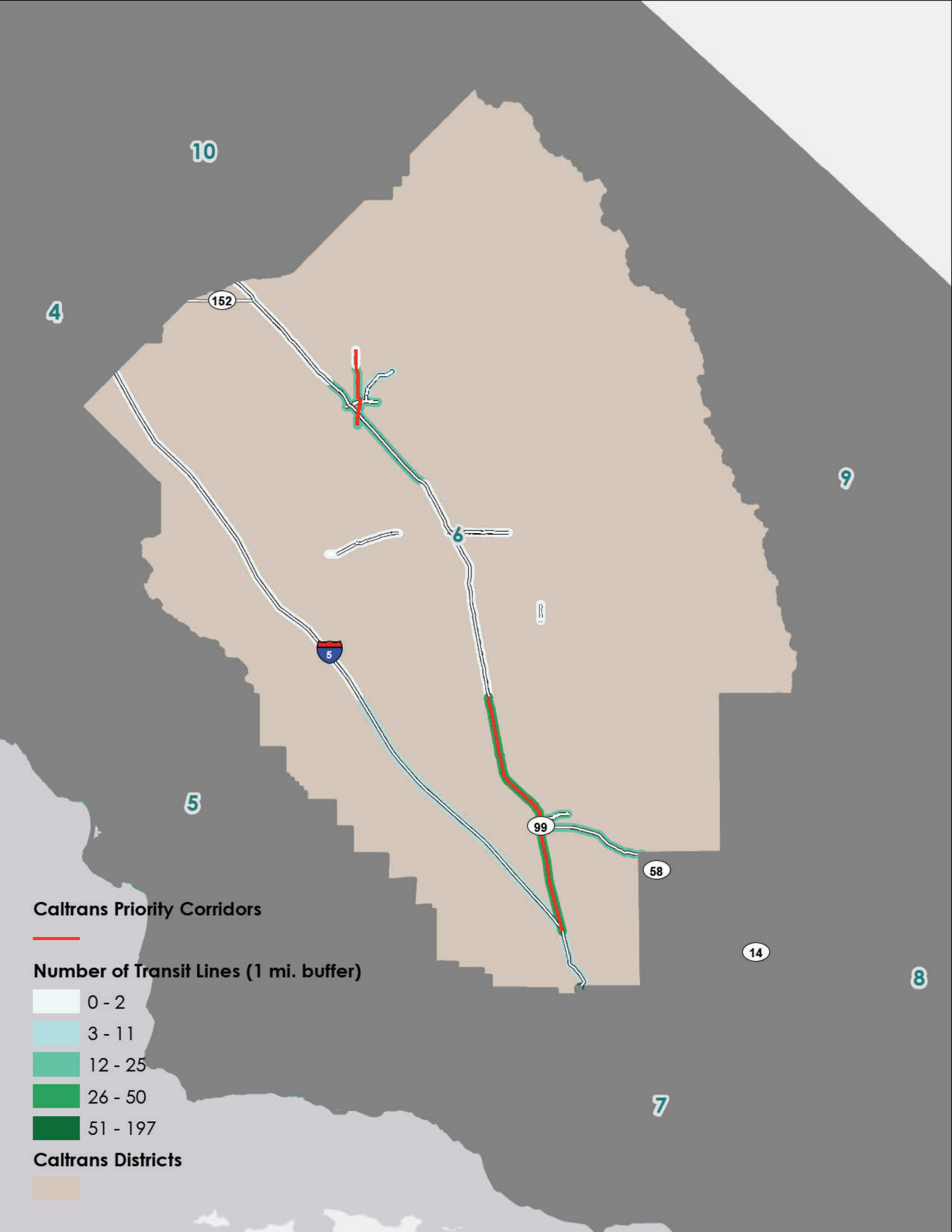
12 - 25
26 - 50
51 - 197
Caltrans Districts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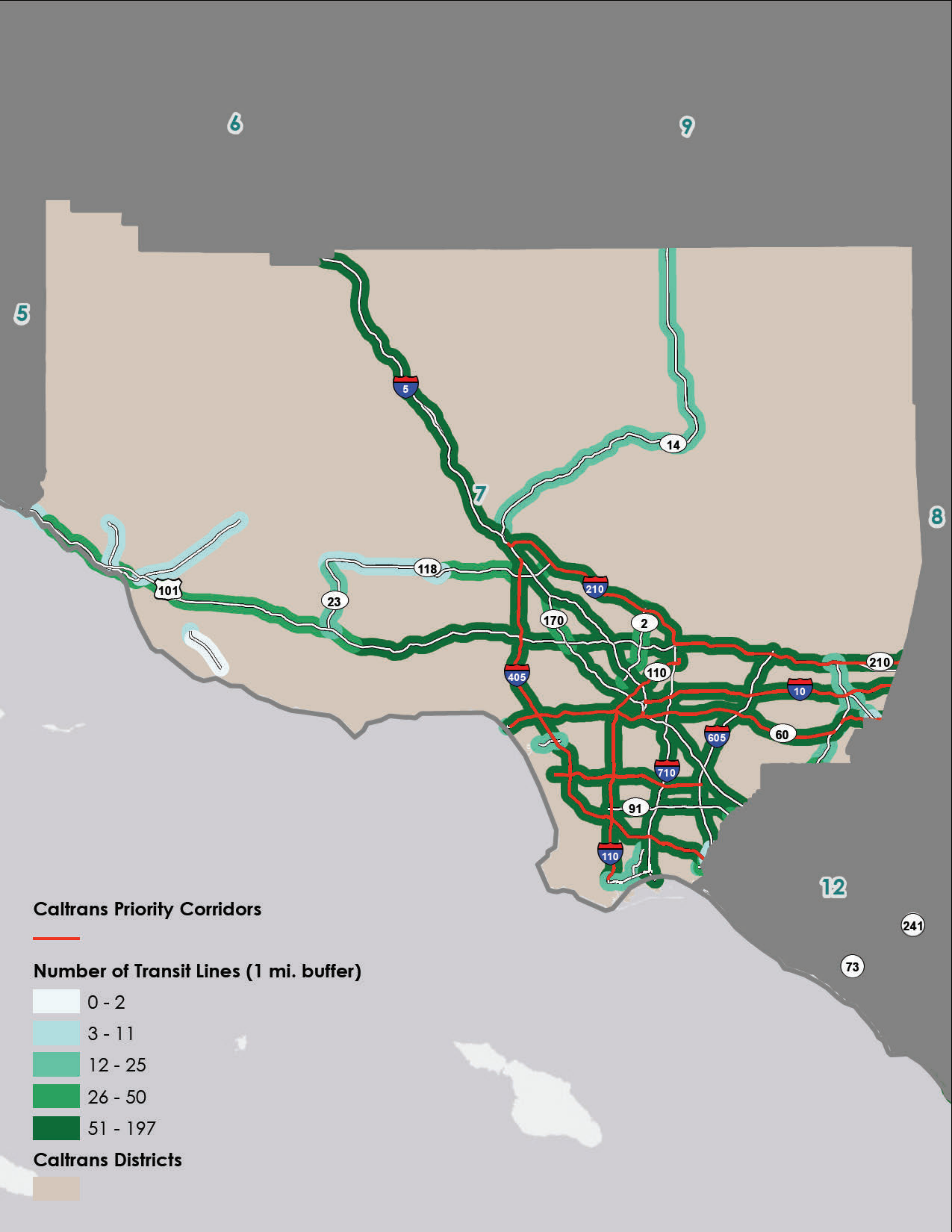
51 - 197
Caltrans Districts



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Caltrans Priority Corridors
Number of Transit Lines (1 mi. buffer)
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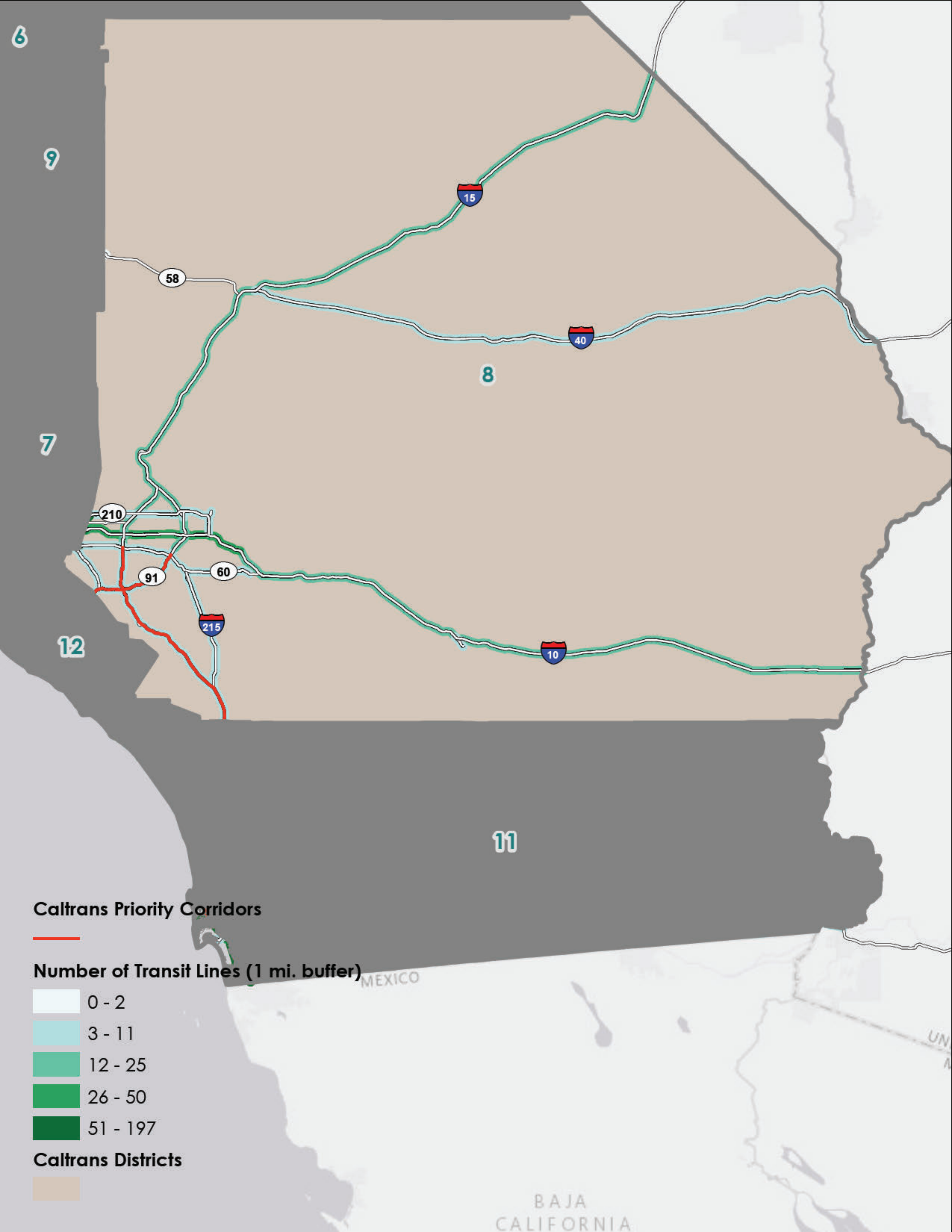
12 - 25
26 - 50
51 - 197
Caltrans Districts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MEXICO
BAJA CALIFORNIA
Caltrans Priority Corridors
Number of Transit Lines (1 mi. buffer)
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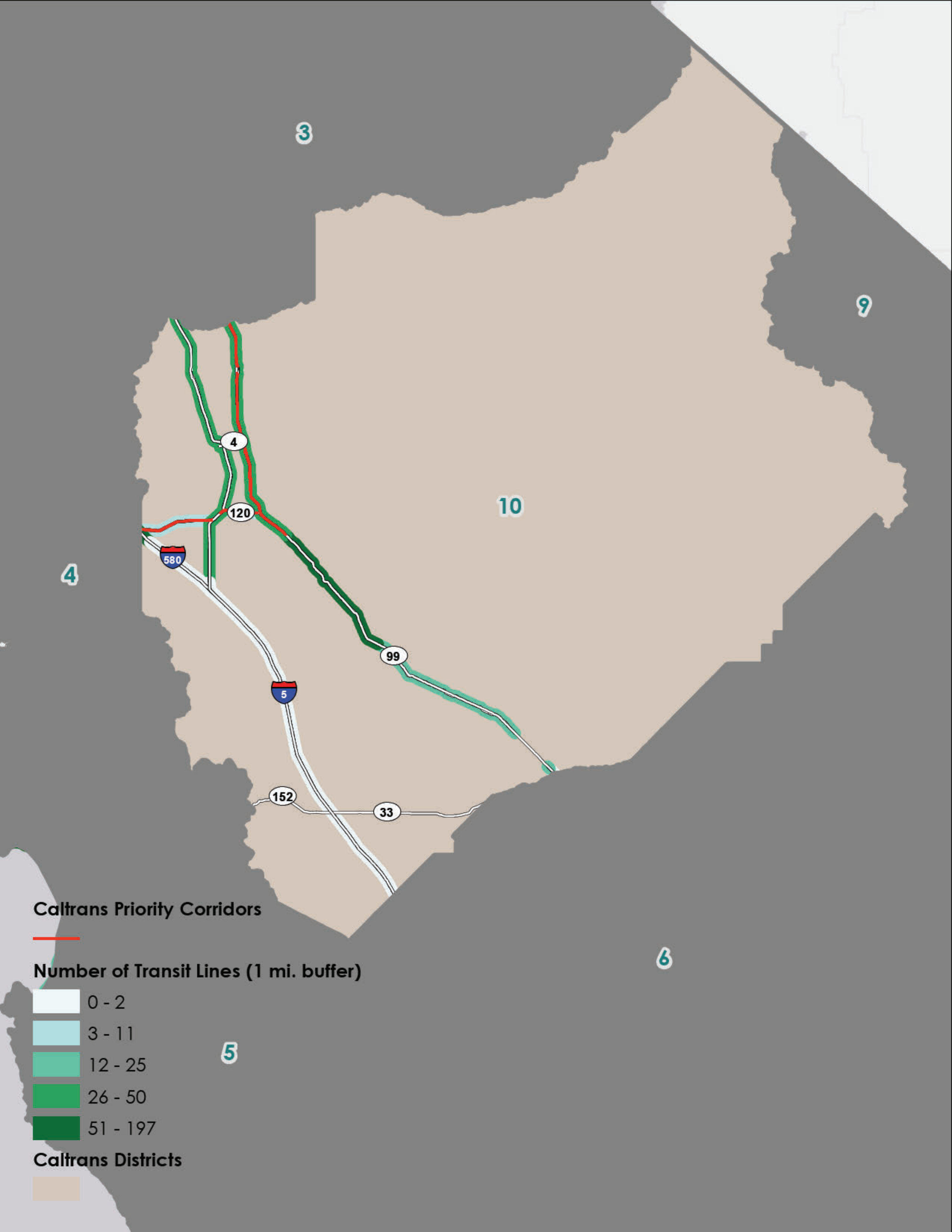
12 - 25
26 - 50
51 - 197
Caltrans Districts



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Caltrans Priority Corridors
Number of Transit Lines (1 mi. buffer)
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3 - 11
12 - 25
26 - 50
51 - 197
Caltrans Districts


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Caltrans Priority Corridors
Number of Transit Lines (1 mi. buffer)
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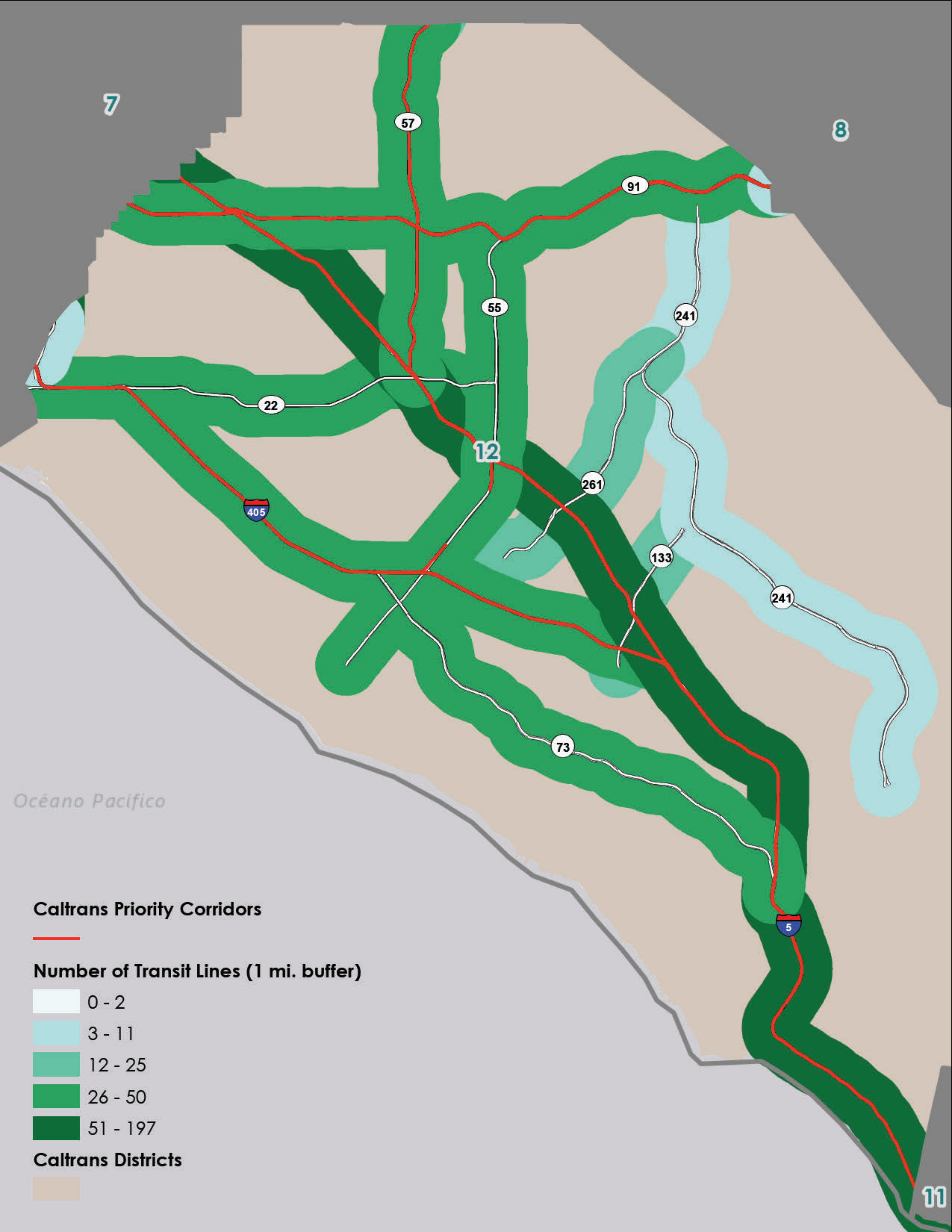
Caltrans Districts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Océano Pacífico
Caltrans Priority Corridors
Number of Transit Lines (1 mi. buffer)
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12 - 25
26 - 50
51 - 197
Caltrans Districts

Appendix B: Map Series 2 – Transit Mode and HOV/HOT Lanes by District


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Transit Mode
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HOV Lanes
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HOT Lanes
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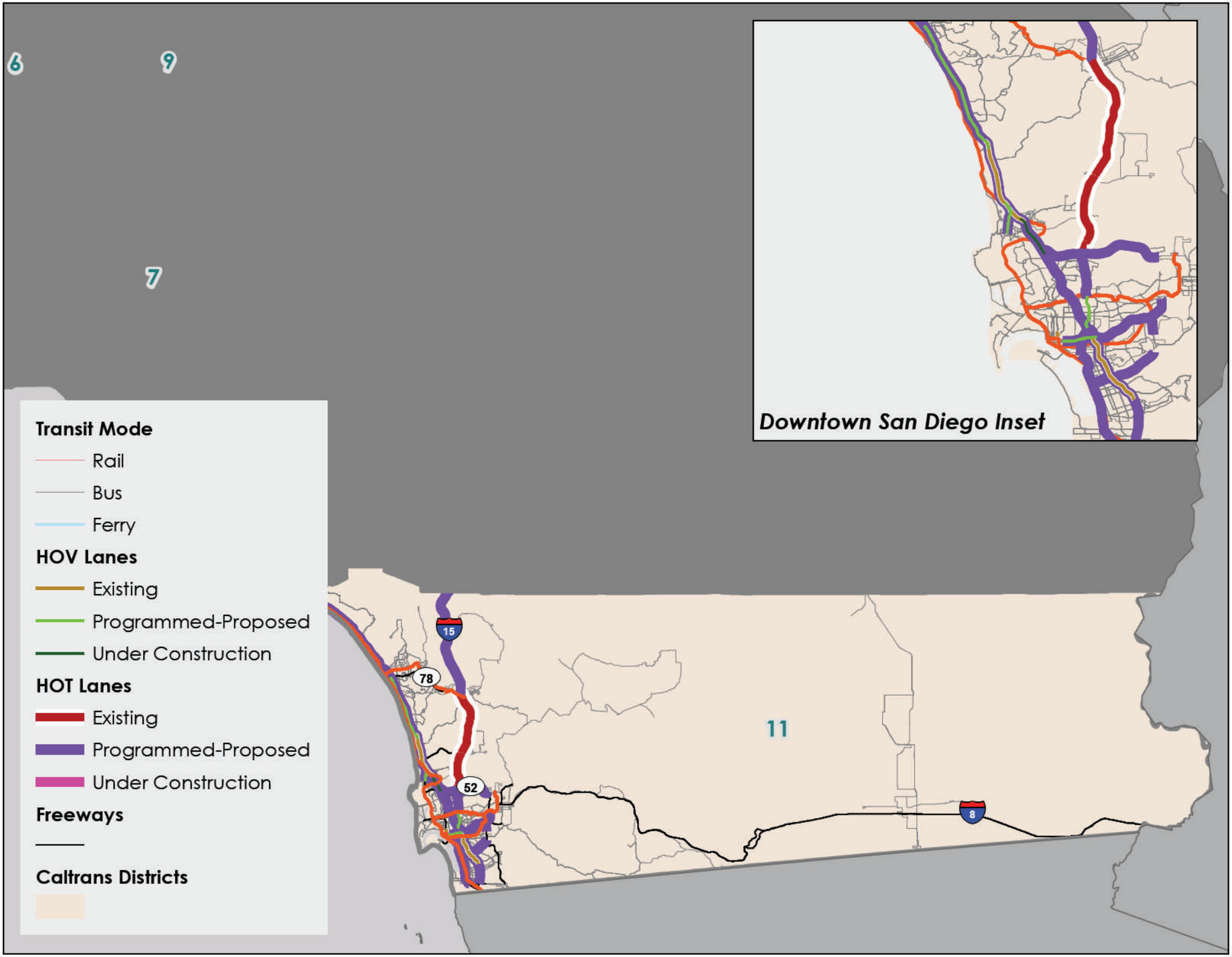
Programmed-Proposed
Under Construction
Freeways
Caltrans Districts



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Downtown San Diego Inset
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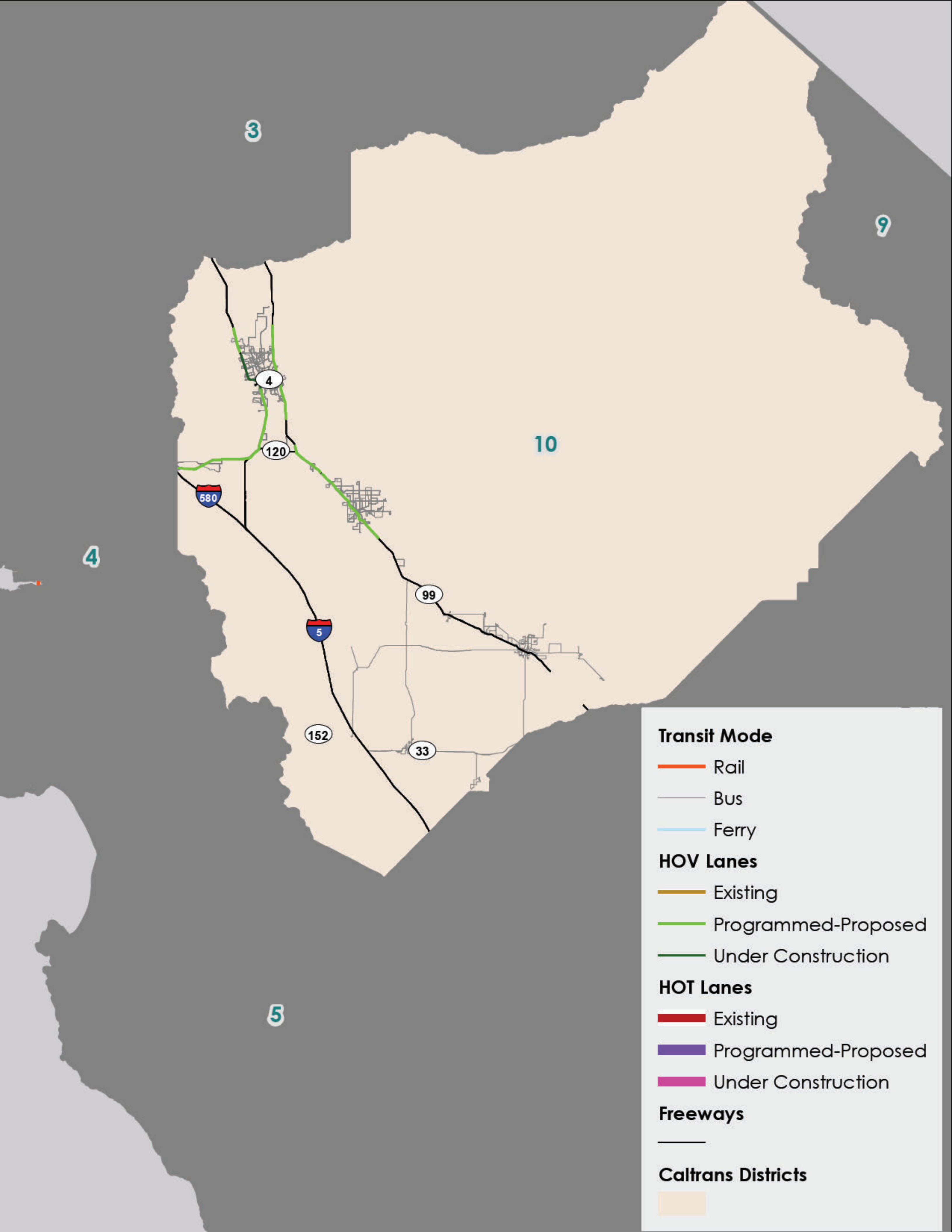
Freeways
Caltrans Districts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HOT Lanes
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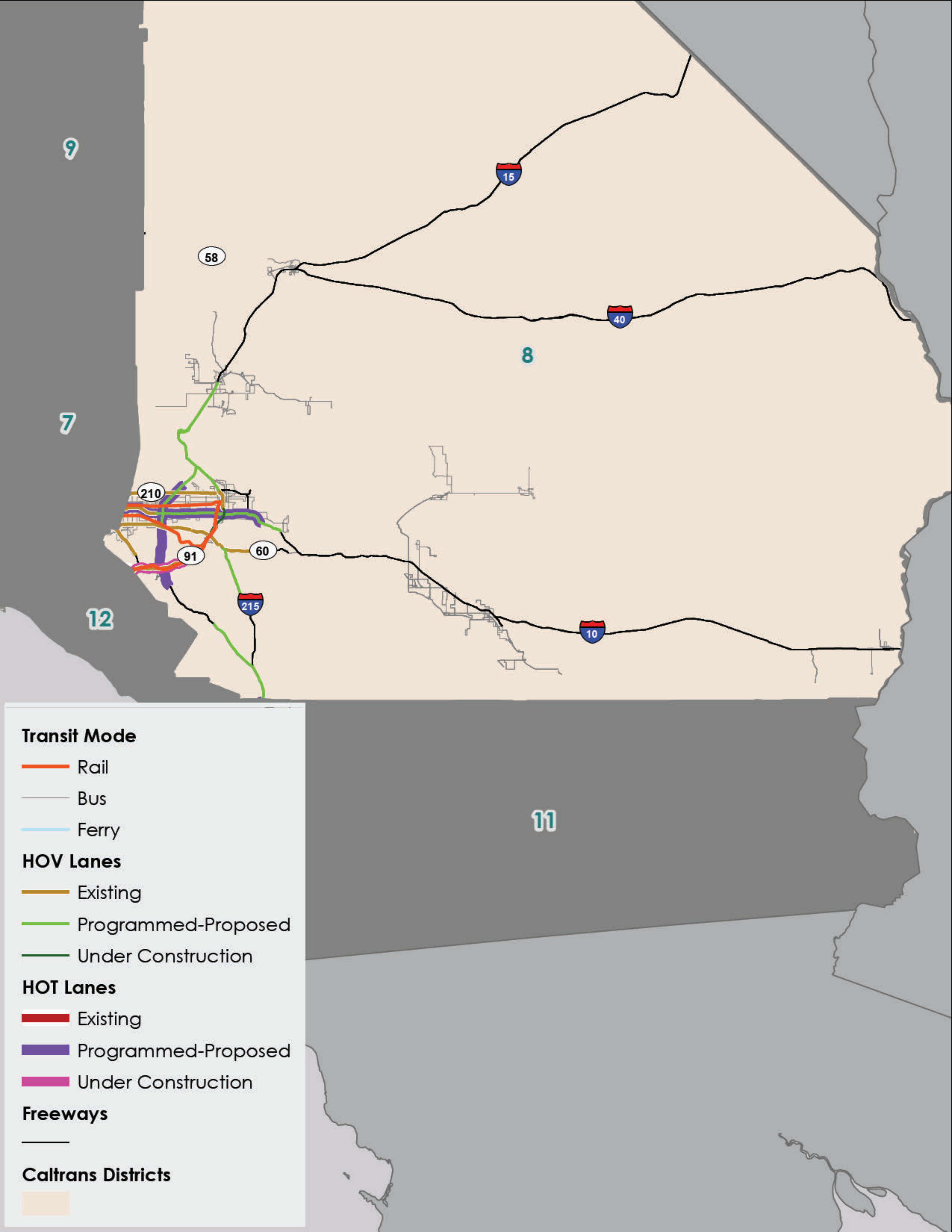
Freeways
Caltrans Districts



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Caltrans Districts


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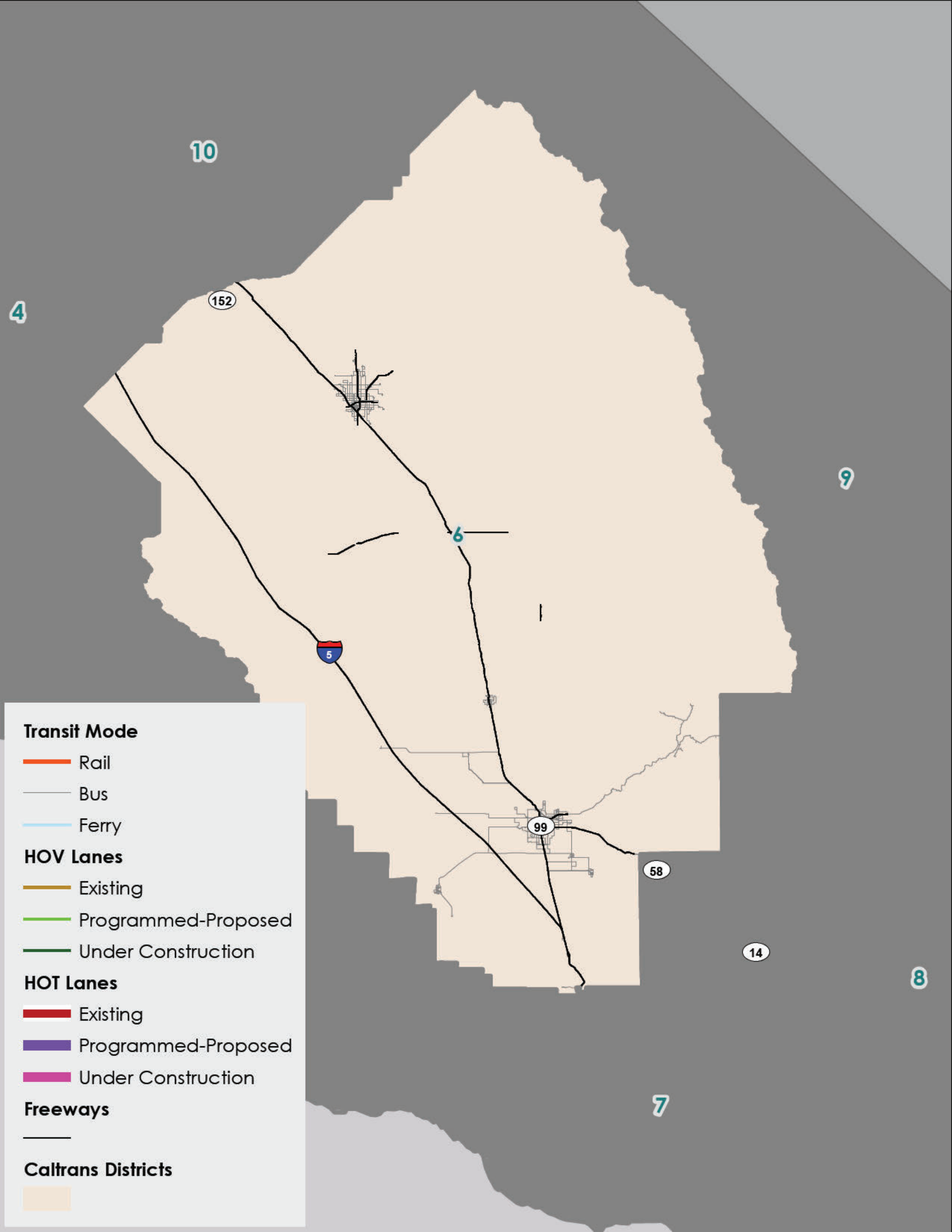
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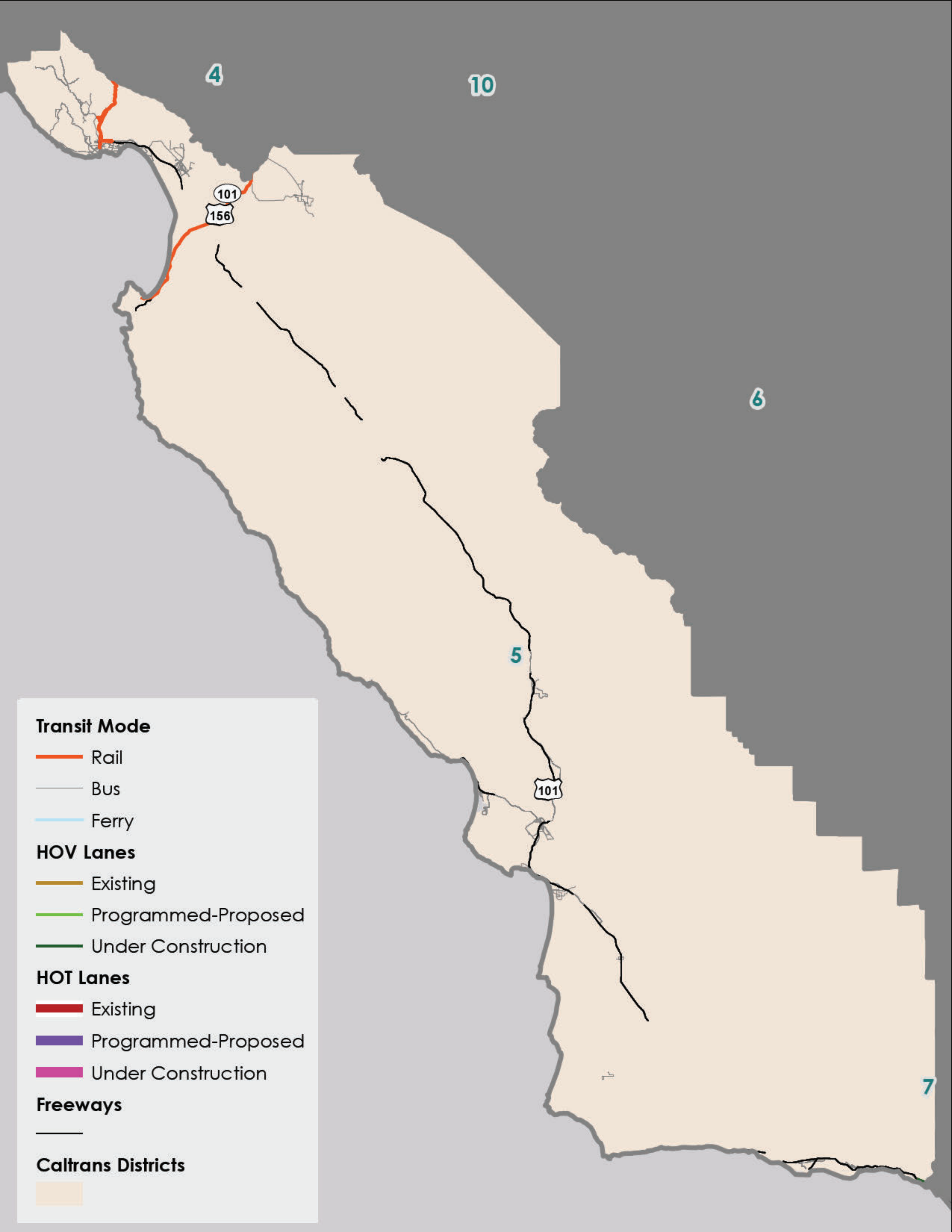

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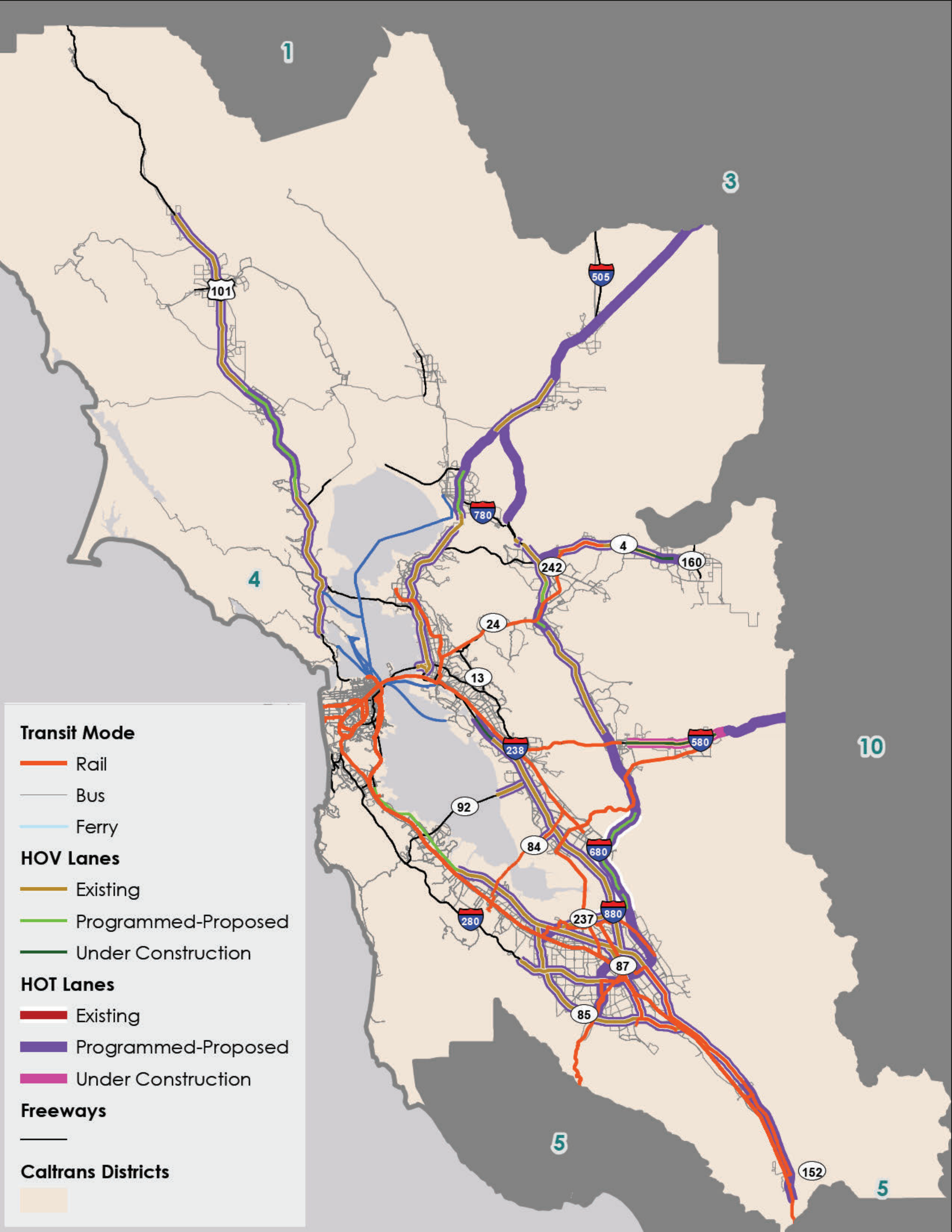

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Caltrans Districts


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Caltrans Districts

Appendix C: Caltrans priority ICM corridors

			List Compiled with Priorities from each District Traffic Operations Deputy									
Caltrans Strategic Management Plan (SMP) - System Performance - Objective 4	District	District Rank	Route	County	Vehicle Hours of Delay (at 35 mph) 2013*	Post Mile Limits	Number of Incidents 2013*	VMT 2013	Incidents/ Day*	Incidents/ million VMT*	District Traffic Operations and Transportation Planning Contact:	District Deputy for Traffic Operations and Transportation Planning:
CT SMP System Performance Goal, TMS BCP Corridor & Connected Corridor Priority 1	7	1	I-210	Los Angeles	2,789,943	24.7-33.5 (Connected Corridors Segmt 1); 7-LA-210 PM R22.283 – R36.411	10,032	3,113,364,581	27.48	3.22	Sam Esquenazi, Sheik Moinuddin	Ali Zaghari, Gary Slater
CT SMP System Performance Goal, TMS BCP Corridor Priority 2	4	1	I-80	Alameda	2,065,218	4-ALA/CC-80 CC 14.139 – Ala 1.939 (WB -AM)	3,546	499,810,971	9.72	7.09	Julianna Gum, Cesar Pujol	Sean Nozarri, Jean Finney
CT SMP System Performance Goal & Connected Corridor Priority 3	12	1	SR-57	Orange	869,170	12-Ora-57 PM 10.734R – R22.551 (NB - PM)	2,508	945,456,088	6.87	2.65	Bassem Barsoum, Fedrico Hormozi	James Pinhiero, Xiaolan (Lan) Zhou
CT SMP System Performance Goal & Connected Corridor Priority 4	7	2	I-110	Los Angeles	2,987,933	7-LA-110-PM 0.7 – PM 25.57 (NB - AM)	11,429	1,939,421,592	31.31	5.89	Sam Esquenazi, Sheik Moinuddin	Ali Zaghari, Gary Slater
CT SMP System Performance Goal (ICM only) & Connected Corridor Priority 5	12	2	SR-91	Orange	1,518,164		6,934	1,608,166,242	19.00	4.31	Bassem Barsoum, Fedrico Hormozi	James Pinhiero, Xiaolan (Lan) Zhou
Priority 2 Group (Yellow) 6	8	1	SR-91	Riverside	1,550,721	0.0-21.7	7,769	1,469,417,281	21.28	5.29	Thomas Ainsworth	Catalino Pining
7	12	3	I-5	Orange	2,895,529		12,805	3,827,923,497	35.08	3.35	Bassem Barsoum, Fedrico Hormozi	James Pinhiero, Xiaolan (Lan) Zhou
8	12	4	I-405	Orange	2,575,837		7,097	2,056,568,888	19.44	3.45	Fedrico Hormozi	James Pinhiero, Xiaolan (Lan) Zhou
9	4	2	I-580	Alameda	1,472,155	30.81-46.46	9,620	2,179,049,718	26.36	4.41	Julianna Gum	Sean Nazzari, Jean Finney
10	11	1	5	San Diego	2,190,818		9,863	3,991,828,286	27.02	2.47	Gary Vettese	Marcelo Peinado
11	4	1	101	San Mateo	1,086,010	0.0-26.2	4,828	1,497,390,946	13.23	3.22	Julianna Gum	Sean Nozarri
12	7	3	405	Los Angeles	7,810,420		20,371	4,317,842,401	55.81	4.72	Abdolhossein Saghafi	Ali Zaghari, Gary Slater
13	4	3	880	Alameda	1,871,778		8,954	2,089,172,019	24.53	4.29	Julianna Gum	Sean Nozzari, Jean Finney
14	8	2	15	Riverside	766,358		5,940	2,669,820,020	16.27	2.22	Thomas Ainsworth	Catalino Pining
15	11	2	805	San Diego	1,020,001		5,417	1,411,488,179	14.84	3.84	Gary Vettese	Marcelo Peinado
16	7	5	10	Los Angeles	5,526,908		16,900	3,517,712,013	46.30	4.80	Abdolhossein Saghafi	Ali Zaghari, Gary Slater
17	7	5	60	Los Angeles	2,293,018		9,216	2,340,949,033	25.25	3.94	Abdolhossein Saghafi	Ali Zaghari, Gary Slater
18	3	3	50	Sacramento	365,219		5,197	1,372,708,228	14.24	3.79	Jim Calkins, Nieves Castro	Andrew Brandt, Marlon Flournoy
19	6	1	41	Fresno	21,068		1,178	410,403,856	3.23	2.87	John Liu	John Liu
20	5	1	17	Santa Clara	170,824		1,797	233,915,267	4.92	7.68		Sara von Schwind, Aileen Loe
21	3	2	80	Sacramento	134,925		3,543	891,196,671	9.71	3.98	Jim Calkins, Nieves Castro	Andrew Brandt, Marlon Flournoy
22	3	1	99	Sacramento	326,175		3,736	1,121,057,919	10.24	3.33	Jim Calkins, Nieves Castro	Andrew Brandt, Marlon Flournoy
23	7	4	105	Los Angeles	1,566,071		5,407	1,231,554,439	14.81	4.39	Abdolhossein Saghafi	Ali Zaghari, Gary Slater
24	10	1	99	San Joaquin	97,571	I-5 (PM 12.6 to 40.0) and SR 99 (PM 6.3 to PM 29.3)	2,524	1,010,058,398	6.92	2.50	Sam Haack, Ken Baxter	Sam Haack
25	10	2	I-205, SR 120 West	San Joaquin	86,596, 139,062	I-205 (PM 0.00 to PM R13.4) and SR 120 West (PM 0.0 to PM R6.9)	766, 385	496,076,438 241,947,179	2.10 1.05	1.54 1.59	Sam Haack, Ken Baxter	Sam Haack
26	6	2	99	Kern	61,185		524	625,350,033	1.44	0.84	John Liu	John Liu

* Delay and incidents are from PeMS for the entire corridor in the county (not the post mile limits of the Connected Corridors Candidate)

INTEGRATED CORRIDOR MANAGEMENT: CASE STUDIES

Deliverable 3

Investigating Relationships Between Highway System Performance and Transit System Management

Agreement Number 65A0528
Task Order Number TO 011 A01

December 21, 2016

Prepared for Caltrans

UCLA Institute of Transportation Studies

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Contents

1.0 Introduction and Overview

This document presents several case studies of ICM corridors (and one UPA project) whose implementation is already under way. These projects show how transportation agencies and departments are poised to use ICM and UPAs to improve highway performance. It is important to note that as of the date of this research there were no publicly available data on the effect of transit provision on an ICM freeway corridor.

The corridors chosen as case studies for discussion in this document were selected for their similarity in both context and goals to the "top priority corridors" identified in Deliverable 2, specifically the priority segments of the I-80 in District 4 and the I-110 and CA-210/I-210 in District 7. These corridors are in urban areas with endemic congestion and, as discussed in Task 2, have adjacent transit services that will facilitate the full benefits of ICM for corridor travelers.

The corridors discussed in this paper are Dallas, Minneapolis, and San Diego, the three ICM "stage 1" demonstration project sites. This paper focuses on aspects of these sites' plans that relate both to the Caltrans "top priority" corridors and the relationship of adjacent transit service to ICM corridors' full potential being realized.

2.0 Dallas US-75 Corridor

Dallas' US-75 ICM corridor spans a distance of approximately 28 miles, from downtown Dallas to SH-121 (USDOT, 2010). The corridor is noteworthy as a case study for its having, in the same corridor, both transit and a tollway in addition to arterials: Running north to south, the US-75 is flanked by the North Dallas Toll Way to the west, and arterials and light rail to the east. Each of these facilities is managed by a different agency: TxDOT operates the US-75, the North Texas Tollway Authority operates the North Dallas Tollway, DART operates the light rail lines, and the Cities of Dallas, Richardson, Plano, University Park, and Highland Park maintain the many arterials in the corridor (USDOT, 2010).

2.1 Coordinated Operations and Data Sharing

Operations are coordinated among the five operating agencies that would respond to major incidents or closures on US-75. Responses that the corridor partnership has made possible include using dynamic message signs (DMS), 511 service to advise travelers to use alternate routes, and DART light rail. In addition, the cities' coordinated signal operations mean that changing signal timing along arterials to move traffic around the incident or closure is possible (USDOT, 2010).

Information on corridor performance is managed at the DalTrans facility, which houses TxDOT, Dallas County, and DART. The co-location of these ICM partners facilitates easy information exchange, especially during active incident management (USDOT, 2010).

2.2 Traveler Information

The Dallas ICM corridor's advanced traveler information system (ATIS) uses three platforms for disseminating information about travel conditions: a 511 automated phone system (the state's first), a website, and a mobile app (Spiller et al., 2014). The website's "My511DFW" function allows travelers to personalize the pre-trip information they receive about both traffic and transit conditions on their pre-selected routes. For corridor users, this information gives individual travelers more choices as to when, via what route, and by what mode they will make a trip. A mobile app also serves the corridor and further supports trip choice making: in addition to having a transit trip planner, the app allows users to view DMS messages, traffic speeds, HOV speeds, as well as traffic camera feeds, parking information, traffic incidents, transit incidents, traffic construction, transit construction, special events, and finally weather (DART, 2016).

While these pre-trip information services are not limited to the corridor, their use in the corridor serves several ICM goals, such as improving trip time reliability (by better managing information and enabling travelers to choose their routes based on conditions).

2.3 Decision Support System

Some of the key functions of ICM are facilitated by a Decision Support System (DSS) which is a rules-based system that scans real-time data from detectors and inputs and compares current conditions with norms to determine when an incident is occurring that might warrant an ICM response (Spiller et al., 2014).

Dallas' DSS concept for the US-75 involves monitoring for congestion on US-75 and when a response is required—as defined by specified deviations from the norm—taking the following successive steps: 1) diverting to a frontage road; 2) diverting to frontage road and a nearby arterial; 3) diverting to the frontage road, arterial, and the DART Red Line (Koorash, 2013). The concept is based on the idea of "overflow" from one facility to another, so following an incident, traffic is directed to "spill out" in a controlled fashion.

DSS plans are highly context-specific and there is no DSS template. Dallas' DSS concept relegates diversion to transit as a last resort in an incident (only after the frontage road and arterial have filled), and transit appears to be a more-or-less passive receiver in such cases (although plans to incorporate automated passenger count (APC) on transit vehicles and station parking occupancy data into the ICM were announced in 2013) (Olyai, 2013).

2.4 California Take-Aways

What could future projects in California learn from the Dallas case study? On other corridors, such as California's I-80, I-110 or CA-210/I-210, transit service could play a more primary and active role such that choosing between mode could be on par with choosing what route to take. For example, with better data about both current traffic and traffic conditions, ICM corridor managers could coordinate to increase the supply of transit service when and where it is needed. It is conceivable that financial incentives to travelers either in toll incentives or fare credits could also be effective in steering corridor travelers to transit where and when more transit ridership would improve corridor throughput. As an example, the Los Angeles County Metropolitan Transportation Authority has such an incentive in place; people who ride transit frequently on certain (UPA) highway routes receive toll credits to use on the same highway corridor when they are not riding transit (LA Metro, n.d.).

3.0 Minneapolis

Minneapolis is the site of both ICM and UPA projects. These are discussed separately below.

3.1 I-394 ICM Project

Minneapolis' I-394 corridor is a heavily-used commuter route in a dense urbanized area where physical freeway expansion is constrained. The ICM corridor extends approximately 25 miles from the central business district to western suburbs (Spiller et al., 2014). Highway 55 on the north and Highway 7 on the south parallel the I-394. Few arterials run completely through the corridor.

The state department of transportation, MnDOT, oversees the freeway and emergency incident management from its operations center. MnDOT's traffic signal group coordinates with the local city and traffic departments on ICM corridor arterials to develop scenarios and plans for changing signal timing in the corridor when warranted (Spiller et al., 2014).

MnDOT operates a 511 service that allows traveler to receive real-time information on weather-related road conditions, roadwork, restrictions, closures, and other travel-affecting incidents (MnDOT, n.d.).

The I-394 corridor is the site of several major improvements. In addition to its Express Lanes facility, the I-394 features bus stations that serve freeway-running bus routes currently and will soon serve the under-construction Metro Orange Line, a BRT route (Spiller et al., 2014). The enhanced transit service in the corridor will expand its capacity and improve the potential for ICM to increase throughput and reduce travel time variability.

The development of I-394 as a facility and corridor, from its addition of HOT lanes to its integration with ICM and finally the imminent arrival of its BRT line, underscores the need for ICM frameworks to be flexible and "modular" such that new facilities or services can be integrated without disruption or rework.

3.2 I-35 UPA Project

Minneapolis is also home to the I-35 Urban Partnership Agreement project, an initiative to reduce traffic congestion on the corridor which serves downtown Minneapolis. A number of ITS technologies and strategies were deployed as part of the UPA initiative, including HOT lanes across a 16 mile-segment of I-35W, intelligent lane control signals (ILCS), a priced dynamic shoulder lane (PDSL), and real-time traffic and next bus arrival information (Turnbull et al., 2013).

Other UPA transit projects or improvements included (Turnbull et al., 2013):

- Five new and one expanded park-and-ride facilities, providing 2,347 new parking spaces, and new service to those lots, resulting in an increase in bus ridership of 13 percent.
- 27 new buses
- "MARQ2" Contraflow bus lanes in downtown Minneapolis that resulted in increased operating speeds in downtown by 31 to 72 percent (depending on the route), and facilitated an increase in the number of buses able to operate in the corridor, from 475 to 586 buses daily (a 23.4 percent increase)
- A bus bypass lane/highway ramp at the Highway 77/Highway 62 intersection, which was determined to save 60-90 seconds for each of 52 bus runs that use it daily
- Freeway shoulder running buses, facilitated by a driver assist system
- Digital messaging signs displaying real-time transit and traffic travel times to encourage people traveling by car to divert to park-and-ride lots and take transit.

Transit ridership on the UPA project sites increased, despite the backdrop of record high unemployment at the time following their opening. Transit routes operating on the I-35 increased 13 percent and express buses operating on the MARQ2 lanes saw increases of 9 percent, compared to 2 percent for non-MARQ2 operating routes (Turnbull et al., 2013).

3.2.1 Corridor Performance

Analyses indicated that travel speeds generally increased in the corridor, with some variations. Peak-period median end-to-end corridor travel times improved as did peak-period travel time reliability and median travel speeds. However, because the UPA involved several concurrent projects (HOV-to HOT conversion, new HOT lanes, PDSL, active traffic management, and speed harmonization), the effects cannot be attributed to a single projects or service. In addition, assessing the effect of UPA and transit improvements as a whole is somewhat complicated by the concurrent (non-UPA) expansion of a nearby freeway (Crosstown Commons) (Turnbull et al., 2013).

One of the most significant improvements observed in the wake of the project is in safety. Preliminary results indicate that, after adjusting for changes in VMT, crashes declined by 22 percent in the corridor after implementation (Turnbull et al., 2013).

3.2.2 Transit Performance on UPA Facilities

The effect of UPA projects on transit performance varied. Following the conversion of HOV to HOT lanes (which transit vehicles can use) and the reduction in lane drops and merge points, bus speeds increased by 29 mph in one segment, and by 10.5 mph in another. Bus speeds decreased slightly (1.9-3.2 mph) on the PDSL segment once the shoulder had been opened to toll-paying vehicles (Turnbull et al., 2013).

3.2.3 Transit Effects on Freeway Facility

A study conducted in 2011 (Hourdos et al., 2013) determined that at freeway speeds of 45 mph and higher, the transit bus lane changes (necessary for serving freeway median stations on the I-35) had no apparent effect on traffic flow. Minimal effects were noted in moderate congestion. In heavy congestion (or where the receiving lane is experiencing low speeds), a bus' lane change was observed as having a "disturbance" on downstream traffic that lasted approximately one minute before dissipating.

The authors note that although bus lane changes can generate a "shockwave" on the receiving lane, "the disturbance is not strong enough to cause a flow breakdown" although they note that "in some special cases where the conditions of the receiving lane are already nearing capacity and therefore unstable, the bus lane change may instigate a flow breakdown," though this was not observed and the authors add that action is not warranted and "at near capacity the action of any vehicle can tip over the scale anyway" (Hourdos et al., 2013).

4.0 San Diego

San Diego's I-15 ICM project is a 21-mile corridor; it was a demonstration project that was launched, after some delays in system development, in March 2014 (Dion, Skabardonis, 2015).

4.1 Traveler Information

The San Diego I-15 ICM primarily uses the regional 511 service as its ATIS strategy for disseminating pre-trip information to travelers. In addition to providing real-time information on traffic conditions, incidents, and driving times, 511SD has information on current (dynamic) toll rates for the I-15 Express Lanes, traffic camera image feeds, transit schedules and fare information, carpool and vanpool referrals, and bicycling information (bike map, bike parking, and bikes on transit information). A mobile app includes this information as well and additionally offers text-to-speech spoken alerts for drivers to receive traffic information en route.

4.2 Decision Support System

Similar to Dallas' DSS, San Diego's system monitors corridor conditions for deviations from norms to identify incidents that may require a diversion strategy. Unlike Dallas' system which selects pre-set plans based on condition thresholds and response rules, San Diego's DSS uses a dynamic real-time model to generate and select response plans as conditions warrant. Data feeds include corridor traffic signal systems, ramp meters, loop detectors for both speed and volume, video cameras, and transit vehicle location and passenger counts (Spiller, 2014).

When conditions trigger a response plan (e.g., freeway speeds fall below a threshold), San Diego's DSS generates response plans and then provides 15, 30, 45, and 60 minute forecasts on the impacts of each response plan on level of service, volume-to-capacity ratio and speed. Each response plan is assessed and scored using an assessment of delay by *traveler*, not vehicle, and the generated response plan with the best score (i.e., providing the most congestion reduction) is recommended for implementation. Implementation can be automatic or set for approval; response plans could include, for example, traveler information alerts, corridor ramp metering and arterial signal coordination (Spiller, 2014).

Although San Diego's DSS generates response plans dynamically and in an ad hoc manner, its set of possibilities is governed by business rules agreed upon in advance by ICM partners, and constrained by localized operational considerations that, for example, restrict traffic from being directed through school zones at certain hours of day (Spiller et al., 2014).

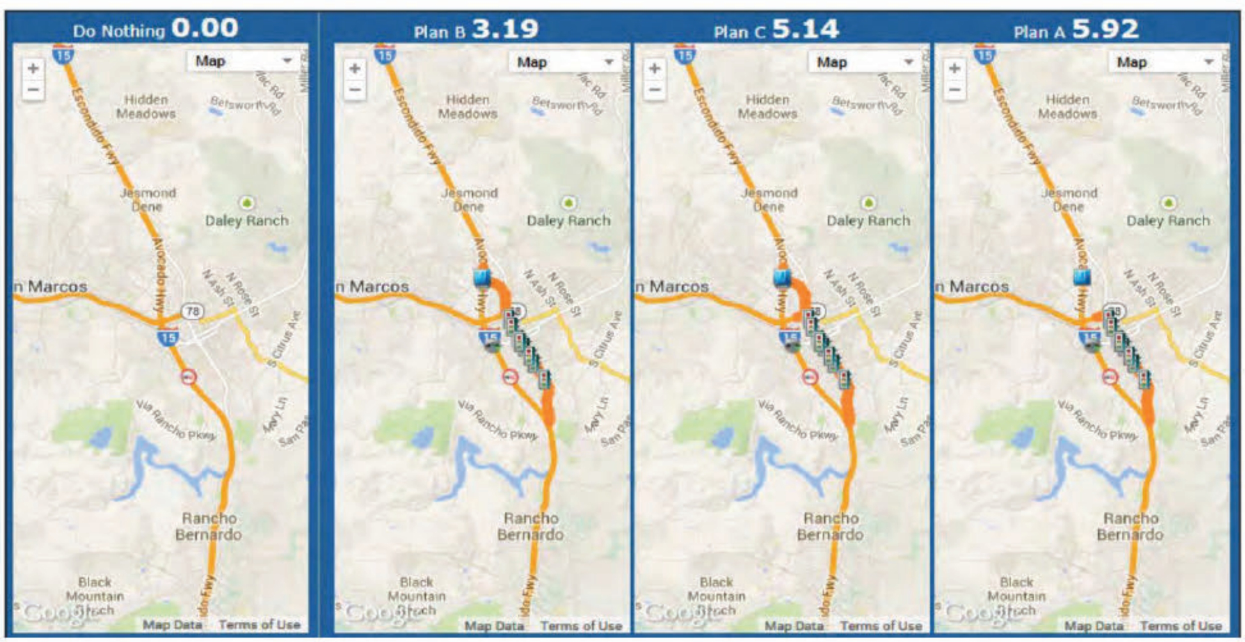

Figure 1: San Diego DSS Dynamic Response Plan Scenario Examples

4.3 Implications and Takeaways

San Diego's DSS appears to maximize the benefits of ICM with its capability of optimizing traveler routing in response to incidents or closures. Its ability to forecast the effects of delay caused by each of its proposed responses (and to select the least impactful) means the system can use ICM to its fullest potential.

San Diego's focus on *traveler* delay as opposed to vehicular delay has implications for transit use throughout the corridor. As transit vehicles can carry more passengers than single occupancy vehicles, the model could take into account this capacity and plans that incorporate transit vehicles could rank higher in the model's selection algorithm. With live automated passenger count data, transit vehicles' actual real-time capacity could be monitored and managed as carefully as freeway and arterial traffic. Passengers could, for example, be advised that the next bus or train is full but a vehicle coming in two minutes is empty. For transit operators, this capability would mean less system delay from the time-consuming boarding of already-full vehicles, which, for transit vehicles that serve a corridor, translates into greater corridor throughput.

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AT THE INTERSECTION OF HIGHWAYS AND PUBLIC TRANSIT: POTENTIAL PERFORMANCE MEASURES

Deliverable 4

Investigating Relationships Between Highway System Performance and Transit System Management

Agreement Number 65A0528
Task Order Number TO 011 A01

December 21, 2016

Prepared for Caltrans

UCLA Institute of Transportation Studies

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Contents

1.0 Introduction

At its most basic level, any transportation system can be broken down into three essential components: ways, vehicles, and terminals. Ways are the system's connective tissue—the highways, streets, rail lines, alleys, paths, and even rivers that allow movement of people and goods from one place to another. Vehicles provide a means of traversing these ways. Automobiles, buses, trains, ships, bicycles, and people (when pedestrians) are some of the most obvious examples of the vehicles. Terminals are the places where most trips begin and end, and are where most transfers occur. A garage attached to a private home, a parking lot at a grocery store, a bicycle rack in front of a school, airports, and seaports are all examples of terminals in transportation networks.

While every travel mode involves some combination of ways, vehicles, and terminals, the roles played by individual, commercial, and governmental actors vary significantly. For example, with private automobiles, governments plan, build, operate, regulate, and maintain the way; private travelers purchase, insure, operate, and maintain the vehicles; and property owners and renters primarily (off-street parking) and governments secondarily (on-street parking), build, insure, operate, and maintain the terminals. For public transit, by contrast, other government agencies plan, build, operate, regulate, and maintain the way (for buses) while the public transit agency itself is often responsible for rail; the transit agency purchases, insures, operates, and maintains the vehicles; other government agencies typically (stops and stations) control the terminals, while transit agencies typically control the vehicle storage yards.

Which actors control which domains of these systems of way, vehicles, and terminals affect how subsets of transportation networks are bounded and defined, and how the performance of these subsets is measured. Consider the two examples of automobile travel and public transit described above: the traveler plays a central role in the ownership and operation of the vehicle, while s/he simply purchases passage on public transit. Likewise, the government agencies responsible for planning, building, operating, regulating, and maintaining streets and roads, do not typically control the vehicles that drive on them or the terminals (save on-street parking) at the beginning and end of trips.

The result is a cacophony of performance measures operationalized mostly to reflect the span of control of the operating entity; making multi-modal, multi-domain performance measures difficult to implement. So while the government operator of a street network may monitor detailed information on the processing of vehicles on links and through intersections on a road network, less attention is typically paid to the people in those vehicles, or where they park at the beginning and end of a trip.

As a result, the greatest gaps in performance measurement are not found from agency to agency, but rather between transportation modes within a single system. Those responsible with managing a given mode generally have access to data specific to that mode, and thus develop assessment metrics consistent with such data. Likewise, the components of the transportation system that an agency controls—be they ways, vehicles, and/or terminals—are generally highly dependent on the mode under their purview. Consequently, agencies use performance metrics geared toward the components over which they have direct influence.

This inter-modal measurement gap is substantial when you compare the typical metrics used to assess roadway performance with those that are used to evaluate public transportation systems. Despite significant jurisdictional diversity across the United States, roadway assessment metrics share remarkable similarities among cities, regions, and states.

Likewise, public transit performance indicators are highly compatible regardless of the size or location of the agency doing the assessment. When performance metrics are compared between modes, however—for example, when the methods used to assess roadway performance are compared to the methods used to assess public transit performance—the results reveal apples and oranges; this adage may even prove to be too similar in this particular comparison. Even within the same jurisdiction, differences in performance measurement across modes are often striking.

Having modally-specific measures that are incompatible or inconsistent makes it difficult for planners, engineers, and public officials to meaningfully evaluate the "big picture." As a result, public funds dedicated to "fixing" the problems of a single mode without regard for how this fix might affect other modes may result no net impact (or perhaps even a detrimental one) on the entire transportation network.

Ideally, staff and policy makers within transportation agencies would have access to universal metrics. These metrics should be comparable across modes, and provide insight as to how effectively the full transportation network is moving people and goods from place to place.

Since the 1990s, several professional planners and planning scholars made great strides in identifying the shortcomings of traditional performance measurement, and independently worked towards the creation of a more unified, more coherent transportation assessment paradigm (Khisty, 1994; Kittleson & Roess, 2001; NCHRP, 2008; Roess et al., 2010).

In this vein, this report examines transportation performance metrics and the challenges to developing cross-mode, cross-domain measures of transportation system analysis. First, the current state of performance measurement is explored. The development of both roadway and transit performance indicators is discussed, and the metrics most commonly used in current practice are reviewed. With this as a background, some of the shortcomings and challenges of current measurement practices are considered, and alternative measurement structures are examined.

2.0 Roadway Performance Measures

The performance of America's roadway network is an issue that, to some degree, affects nearly everyone in the nation. Almost 90 percent of daily travel in the United States takes place in private automobiles (USDOT, 2009), meaning an enormous range of activities—from a simple trip to the supermarket to logistically complex delivery of cargo—are often heavily dependent on the conditions of streets and highways. Congestion, delays, and travel time instability are not only frustrating for individual travelers, but can cause severe economic consequences as well. As such, professional planners and transportation agencies arduously searched and attempted to develop roadway performance indicators as a means of assessing the quality and effectiveness of an area's roads. Throughout their history, roadway operators have used these metrics to identify problematic segments of the roadway network, as well as point out effective planning and management practices that might be replicated in other jurisdictions (Homberger et al., 2007; Baerwald, 1965; Homberger et al., 1982).

While there is great diversity in the types of roadways that comprise America's automobile transportation system, the manner in which planners and engineers assess the performance of these thoroughfares is actually quite similar from city to city, region to region, and state to state. A good deal of this uniformity results from the obligations of state and federal data reporting requirements. For example, the requirements of the Highway Performance Monitoring System (HPMS) provide one prominent illustration of how such data collection uniformity arises. In order to receive federal highway funding, all state departments of transportation must submit reports containing an array of roadway performance indicators for publication in the HPMS database. Although the data required by HPMS and most other governmental agencies are quite diverse, these reporting demands encourage a significant degree of measurement homogeneity amongst transportation agencies across the nation.

2.1 Levels of Service

One of the most salient aspects of this measurement homogeneity is that, for the most part, roadway performance indicators use the relative presence or absence of congestion on a given segment of a motorway as a means of assessing its performance. The volume of traffic and the speed at which this traffic can pass through the identified segment are thus the main determinants of roadway performance. Levels of Service (LOS), a measure developed in the 1960s, is perhaps the most widely used congestion-based performance metric by planning and engineering agencies (NCHRP, 2003).

When evaluating a road's performance using an LOS measure, free-flowing traffic conditions have long been the gold standard. An early edition of *The Traffic Engineering Handbook* (Baerwald, 1965) tasks the traffic engineer not with managing demand or influencing driving patterns, but with providing roadways that deliver an acceptable standard of automotive mobility to an area's drivers. In other words, a successful roadway is one that allows motorists to travel freely, at their preferred speed and along their preferred path (Homberger et al., 1982). Still today, traffic engineers and planners follow a similar rubric, ranking a given roadway using an "A" to "F" grading scale. Sections of road that exhibit free-flowing traffic and impediment-free driving are assigned a grade of "A," with grades being progressively lowered as a road's congestion grows.

With its simple and easy to understand interpretation of complex traffic situations, LOS has proven extremely durable, and continues to be the preferred method of disseminating roadway performance information (Roess and Prassas, 2014). Table 1 shows the six levels of service as defined by the *Highway Capacity Manual* (HCM) (TRB, 2010), and provides a description of each service level for multilane highways. While the descriptions in this table are specific to multilane highway performance, similar LOS measures exist for virtually every category of roadway, including local streets, rural highways, and an array of intersection types.

Table 1 Levels of Service for Multilane Highways

Level of Service (LOS)	Description
A	Free flow, low volumes and densities, high speeds. Drivers can maintain their speeds with little or no delay and are unaffected by other vehicles.
B	Reasonably free flow, operating speeds beginning to be restricted somewhat by traffic conditions. Drivers still have reasonable freedom to select their speed.
C	Speed remains near free-flow, but freedom to maneuver is noticeably restricted.
D	Speed begins to decline with increasing volume. Freedom to maneuver is further reduced, and the traffic stream has little space to absorb disruption.
E	Unstable flow with volume at or near capacity. Freedom to maneuver is extremely limited, and level of comfort afforded to the driver is poor.
F	Breakdown in flow. Both speeds and volumes can drop to zero.

Source: *Highway Capacity Manual* (TRB, 2010)

2.2 Other Common Performance Metrics

The vast majority of the other commonly used metrics for highway performance are similarly based on traffic volumes or congestion, in that they assess either the degree of vehicular travel on a section of roadway, or the extent of delay caused by this volume. A National Cooperative Highway Research Program survey of 39 major transportation agencies across the country found that, of the ten most commonly used performance metrics, nine of them were either volume- or congestion-based (NCHRP, 2003). Aside from LOS, the most commonly used performance metrics included the following:

- traffic volume
- vehicle-miles traveled
- travel time
- speed
- crash incidents
- duration of congestion
- percent of system congested
- percent of travel congested.

The report also highlights volume-to-capacity (V/C) as another congestion-based metric that is widely used to assess the performance of the nation's roads (NCHRP, 2003). Table 2 shows several common roadway performance metrics, along with a basic description of how each metric is calculated.

Table 2 Common Roadway Performance Metrics

Roadway performance metric	Description
Level of service (LOS)	Qualitative assessment of traffic flow on a highway segment or system ranging from A (best) to F (worst)
Traffic volume	Average daily, peak-hour, or peak-period traffic
Volume-to-capacity ratio (V/C)	Traffic volume divided by road capacity
Vehicle-miles traveled (VMT)	Traffic volume times distance
Travel time	Distance traveled divided by speed
Speed	Distance traveled divided by time
Incidents	Number of traffic interruption caused by a crash or unscheduled event
Duration of congestion	Hours of congested travel
Percent of system congested	Percent of miles congested (usually defined as an LOS of E or F)
Percent of travel congested	Percent of vehicle-miles traveled in congested conditions (usually defined as an LOS of E or F)

Source: *Performance Measures of Operational Effectiveness for Highway Segments and Systems* (NCHRP, 2003)

2.3 Caltrans Performance Measurement System (PeMS)

Like most motorway performance measurement throughout the United States, roadway performance indicators used in California focus predominantly on assessing traffic volume and speed. The state's most expansive roadway evaluation system, Caltrans' Performance Measurement System (PeMS), provides real-time, web-based data on several traffic indicators, including vehicle-miles traveled, vehicle-hours traveled, vehicle-hours of delay, LOS, and derived indictors such as hours of lost productivity per lane mile.

Since its launch in the early 2000s, PeMS has been particularly effective in identifying bottlenecks, accurately determining highway segment LOS, and evaluating the impact of traffic incidents (Choe et al., 2002). Similar to the statewide PeMS database, metropolitan planning organizations (MPOs) in the state focus on evaluating roadway performance via vehicle volume and speed. A summary of California MPO transportation performance monitoring systems carried out by the San Diego Association of Governments (SANDAG) identified a range of congestion measures that serve as common performance metrics among MPOs. The most common include vehicle-miles traveled, LOS, and commute time to job centers (SANDAG, 2013).

Of course, not all roadway performance indicators are based on measures of traffic and delay. Transportation planners and engineers are also concerned with limiting roadway collisions and protecting motorists. As such, a separate range of metrics are used to evaluate the safety of a roadway segment or system. Furthermore, in recent decades, as policy makers and the general public are becoming more aware of the detrimental environmental impacts of acute automobile dependence, measures of fuel consumption and estimates of carbon emissions are becoming quite common in the roadway performance measurement mix. These attendant measures, while providing analysts with a more complete picture of the health of streets and highways, remain secondary in their importance. Measurements of vehicle volume and travel speed are, by far, the most commonly used performance metrics, and continue to be the indictors upon which most roadway planning and engineering decisions are based (NCHRP, 2003).

3.0 Public Transportation Performance Measures

Despite the great deal of diversity in planning and engineering agencies across the United States, metrics used to measure roadway performance are quite comparable regardless of location or size of jurisdiction. Similarly, the indicators with which public transit agencies assess performance also show little variation despite vast differences in local transit systems' size and structure.

Part of this similarity stems from the data reporting requirements of two important federal grant programs: the Urbanized Area Formula Program and the Rural Area Formula Program. In order to receive grant money through one of these programs, transit agencies are required to report a range ridership, revenue, and expenditure data to the National Transit Database (NTD). Since many transit districts are heavily dependent upon federal assistance for both operations and capital outlays, these grant programs produce a good deal of reporting continuity between agencies (Mineta Transportation Institute, 2016).

In addition to this level of uniformity created by NTD reporting requirements, the operational mandates of public transit agencies—in other words, the parts of the transportation system that public transit managers can influence and control—also engender a degree of similarity among transit performance metrics. Just as roadway managers developed assessments based on what they control (generally a portion of the road system), transit planners have largely focused on assessing aspects of public transit that lie within their purview.

For example, most public transit agencies are charged with providing service either on infrastructure that they do not directly control (i.e., bus service on city streets) or on infrastructure that is relatively free of congestion (i.e., rail rapid transit on exclusive rights-of-way). Therefore, rather than being concerned with measuring the speed and volume of vehicles moving over the "way," (as is the case with many roadway metrics), transit planners instead tend to focus on the performance of the vehicles themselves, and the ability of these vehicles to move individual passengers.

This attention to vehicle- and passenger-level measurements as opposed to roadway congestion measurements allows transit planners and managers to develop far more flexible performance metrics than roadway planning and engineering agencies. Since transit agencies own and operate the vehicles that provide public transportation, they are easily able to track three key transit-related dimensions (Fielding, 1987):

1. Service inputs: the costs associated with providing transit service
2. Service outputs: the quantity of transit service provided
3. Service consumption: the degree to which the public uses a given transit service

Using service input, output, and consumption data, transit planners can employ a range of commonly used indicators to assess transit performance, which have evolved over time. In the interest of simplicity and consistency, planners, engineers, and scholars have labeled these measures as falling into one of three categories: efficiency measures, effectiveness measures, and overall measures (Fielding 1992; Fielding, 1987; Fielding et al., 1978).

Efficiency measures illustrate the relationship between service inputs and outputs. Simply put, these measures assess how much it costs a transit agency to produce a given amount of service. While a range of efficiency measures are collected by transit agencies, only two are required in the NTD:

1. Operating expenses per vehicle revenue mile
2. Operating expenses per vehicle revenue hour

Efficiency indicators are important performance metrics because they can assess the quality of a transit agency's management rather accurately. As Fielding (1987) points out, the inputs of a transit system (its costs) and the outputs of the system (its service) are, to a large degree, under the direct control of transit agency staff. Consequently, failure to produce a satisfactory degree of service at a given cost may very well reflect ineffective and/or wasteful administration.

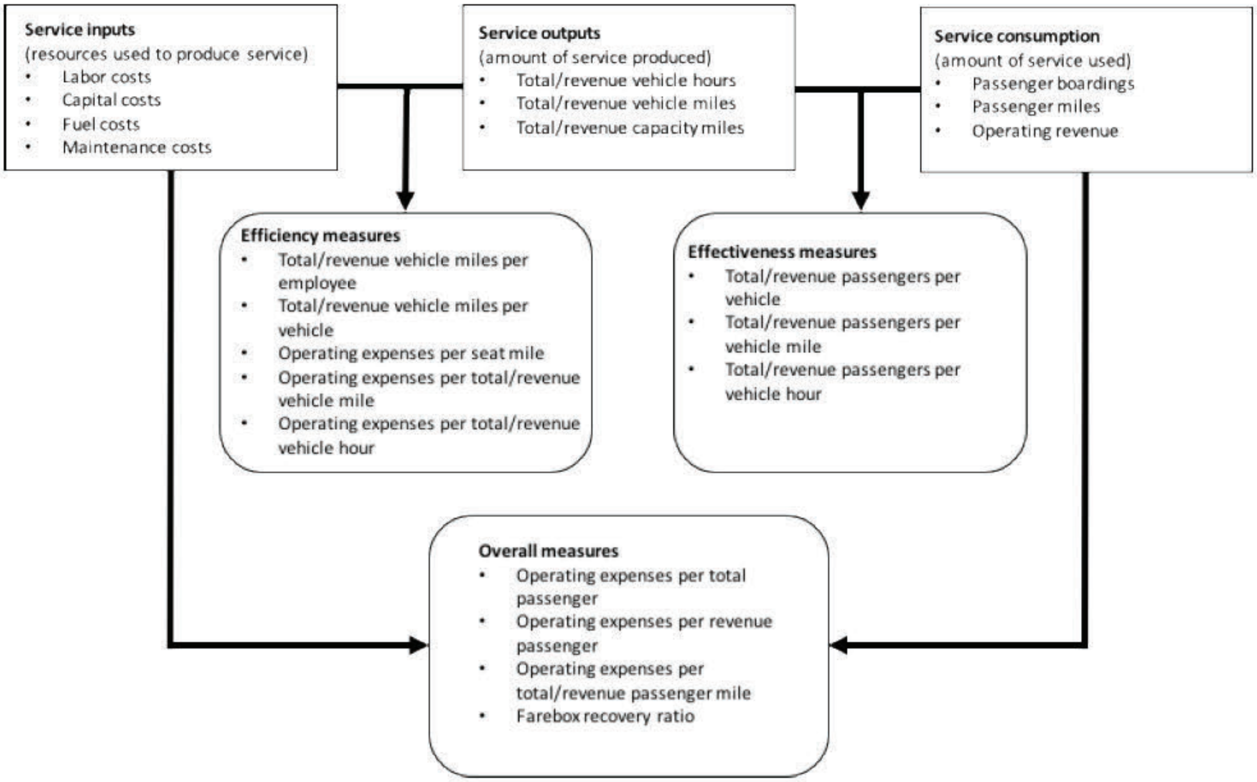
While efficiency indicators evaluate the relationship between inputs and outputs, effectiveness measures assess the link between outputs and consumption—in other words, how many people are riding the transit service that is being provided. Total passengers per revenue vehicle mile and total passengers per revenue vehicle hour are two commonly reported effectiveness indicators, both of which must be submitted to the NTD to receive federal funding.

Unlike efficiency indicators, effectiveness measures are, to a certain degree, beyond the control of transit system managers (Fielding, 1987). Because they are partially determined by ridership levels, effectiveness measures are often heavily influenced by contextual factors such as population density, income levels, and built environment characteristics. Therefore, unfavorable locational characteristics may drive down the ridership levels of even the most efficiently-managed transit system, resulting in low levels of effectiveness through no fault of the transit agency itself.

Overall performance indicators measure the association between service inputs and service consumption. Because they provide a direction connection between cost and ridership, these measures are often of keen interest to the planners and the public alike. Federal requirements mandate the reporting of two overall measures: operating expenses per passenger mile; and operating expenses per unlinked passenger trip.

Below, Figure 1 provides an illustration of the relationship between the three main dimensions of public transit (service inputs, outputs, and consumption) and the three main performance measurement metrics (efficiency, effectiveness, and overall). Several commonly used indicators for each type of measurement metric are also listed.

Figure 1 Dimensions and Performance Measurement Metrics for Public Transit Systems



Sources: Fielding (1987); Fielding et al. (1978)

The practices of public transit agencies illustrate the centrality of these efficiency and effectiveness measures in transit performance evaluation. In California, for example, an analysis of the state's MPOs reveals that, in addition to ridership statistics, financial performance measures—which, the authors define to include cost effectiveness and cost efficiency metrics—are by far the most commonly reported data (Mineta Transportation Institute, 2016). While the authors also examine other areas of transit performance such as service availability, safety and security, and community impact, they find that these non-financial indicators are not widely collected, and in each instance are measured by less than one-fifth of the state's transit agencies.

Similar analyses of other states reveal parallel findings. A review of Florida's transit agencies by the state's Department of Transportation uncovered a similar focus on effectiveness and efficiency measures (Elefteriadou et al., 2012). Of the seven most commonly reported transit indicators, six dealt with either service inputs (total operating expense, total capital expense, and fuel expense) or service outputs (revenue miles, vehicle miles, and vehicle hours).

By focusing on measures of efficiency, effectiveness, and overall performance, engineers, planners, and scholars have developed a diverse array of measurement tools to assess public transit performance. Since transportation agencies control the vehicles that comprise the public transit system, they can collect a vast amount of information regarding both the cost of providing service and the degree to which that serviced is consumed. These data, while valuable in the information they provide to transit managers, are unfortunately somewhat limited, in that they make cross-modal evaluation difficult. Roadway managers, for example, have access to far less data regarding cost and consumption, since vehicle costs and ridership are largely features of the private sector. Thus, while transit performance metrics may be more varied than their automobile counterparts, they are equally limited in their ability to be applied across modes.

4.0 Closing the gap

As discussed in the previous sections, there is a gap between the metrics used to assess the performance of roadways and those used to assess the performance of public transit systems. For the most part, planning and engineering agencies across the country rely on traffic and delay measures to determine the performance of roadways. Roadway performance metrics focus on the speed and the volume of traffic that can pass over a given segment of road in a set amount of time. Public transit performance measurement, on the other hand, is carried out in a far different manner. Instead of focusing on congestion, transit metrics combine efficiency, effectiveness, and overall measures that allow planners to assess a wider range of performance characteristics than their roadway counterparts. Table 3, on the following page, gives a summary of the many differences between roadway and public transit assessment that give rise to this performance measurement gap.

Table 3: Comparison of roadway and transit performance measures

Transportation mode	Roadway	Public Transit
Primary unit of analysis	• Way (road, intersection, highway)	• Vehicle (bus, train)
Primary performance measurement metrics	• Outputs (roadway capacity) • Consumption (vehicle volume)	• Inputs (capital/operating costs) • Outputs (vehicle miles/vehicle hours of service) • Consumption (passenger trips)
Operating costs	• Generally omitted from performance measurement; e.g Level-of-Service considers nothing about the roadway O&M costs	• Both publicly (local, state, and federal funds) and privately (fares, advertising) funded • Generally considered in performance measurement
Ownership of way	• Mixed—streets and highways controlled by a range of entities, including transportation agency • Way costs generally omitted from performance measurement	• Bus transit: way not controlled by transit agency • Rail transit: way often controlled by transit agency • Way costs sometimes considered in performance measurement
Ownership of vehicle	• Largely private • Vehicle costs generally omitted from performance measurement	• Largely public • Vehicle costs generally considered in performance measurement
Ownership of terminal	• Largely private (garages, parking lots) • Terminal costs generally omitted from performance measurement	• Largely public • Terminal costs generally considered in performance measurement

Perhaps the biggest problem caused by this performance measurement gap is that it makes assessing the effectiveness of the transportation system as a whole extraordinarily difficult, particularly for systems which include both roadway and public transit components. Because the value of a transportation system rests in its overall ability to move people and goods from origins to destinations quickly, safely, sustainably, and cost effectively, performance metrics should ideally be designed to evaluate these objectives.

Unfortunately, when these performance measures lack uniformity across modes or are overly narrow, they may create perverse incentives that favor upgrades to one transportation mode at the expense of all others. In such a situation, improving the performance of one aspect of the transportation system might entail a diminution in performance of the system.

5.0 Alternatives to the Norm: Multimodal performance measures

To address the problems caused by these measurement gaps, various researchers, transportation engineers, and planning professionals have developed alternative means of assessing transportation system performance. Most these alternative assessment methods focus on the creation of multi-modal metrics—measures that can be applied to a number of modes and provide an understanding of how efficiently and effectively an entire transportation system is functioning. Some of these new metrics represent an expansion of traditional measures like LOS to include non-automotive modes, an effort that—as critiques of the 2010 Highway Capacity Manual (HCM) show—has had somewhat mixed results. Other measures are broader in scope, and seek take performance indicators beyond an assessment of inputs and outputs, and toward a focus on broader outcomes that transportation systems might affect.

5.1 Improving and Expanding Traditional Measures

In their examination of multimodal performance measures, Pratt and Lomax (1996) draw upon the broad shift towards integrated transportation planning that took hold with the passage of the Intermodal Surface Transportation Efficiency Act (ISTEA) in 1991. The authors highlight how an overdependence on traditional, single-mode metrics might produce behavior that is at odds with the goals of the entire transportation system. Typical roadway congestion measures like V/C ratios or LOS, they argue, when viewed in isolation, can lead to an inefficient use of resources. By focusing on moving *vehicles* through a portion of the *system*, V/C ratios or LOS measures divert attention from the movement of *people* to their *destinations*.

Consequently, this vehicle-centric view might encourage costly roadway expansion to increase vehicle capacity when simpler, more cost effective methods might do far more to improve overall passenger throughput. For example, converting one or more conventional lanes on a congested multilane highway to bus-only traffic could potentially lead to a dramatic increase overall passenger capacity. Effective multimodal performance metrics would be able to accurately capture the benefits of this relatively inexpensive change. Unfortunately, however, traditional single-mode metrics such as LOS prioritize only vehicle capacity and movement. Thus, adding additional highway lanes—while far more expensive and far less effective in terms of passenger movement—may seem like the more expedient choice when evaluated using traditional means.

Instead of these narrow performance indicators, the authors encourage the use of broader measures that can be applied to several different transportation modes. They propose a range of potential metrics such as speed of person movement or travel time differences among modes that might allow the performance of different modes to be directly compared. However, the authors are careful to point out that no one metric (or combination of metrics) will serve as a magic bullet for the assessment of multiple modes. Instead, they emphasize that a number of key points must be considered by planners, engineers, and managers—including a strong focus on the movement of people and goods—in order to ensure a more comprehensive understanding of a transportation network's performance. While the authors convincingly outline the necessity of a new approach to performance measurement, a discussion of the substantial institutional obstacles that might prevent the implementation of alternative metrics is, unfortunately, somewhat lacking.

5.2 Multimodal Levels of Service

A report by the National Cooperative Highway Research Program (NCHRP) (2008) expands upon the issues raised by Pratt and Lomax by proposing an array of original multimodal performance measures. Recognizing the dominance of LOS among roadway performance metrics, the report, rather than suggesting LOS be replaced, proposes LOS indices for a range of modes. LOS measures for transit, cycling, and walking are all developed using an A through F measurement scale to match that of the standard roadway LOS scale.

While these multimodal levels of service (MMLOS) indicators give agencies the ability to assess several modes of travel, they unfortunately do little to make intermodal, system-wide evaluation possible. With MMLOS, multiple modes can be assessed, but these modes are still evaluated in isolation, and cannot be combined to represent a more comprehensive understanding of system performance. For example, a traditional automobile LOS measure would likely respond positively to policies allowing for increased speed and traffic flow on a given road. At the same time, these policies might cause MMLOS metrics for cyclists and pedestrians on that same road to suffer a decline. How, then, do these divergent trends affect the overall performance of the transit system in this example? MMLOS indicators, unfortunately, offer no insight into this important question. While they may be able to capture LOS changes to several different modes, MMLOS measures do little to clarify how certain changes affect the overall quality of the transportation system.

The 2010 *Highway Capacity Manual* (HCM) (TRB, 2010) faces a similar problem in terms of its inability to assess system-wide performance. Echoing the NCHRP's 2008 study, the 2010 HCM proposes LOS metrics for transit vehicles, cyclists, and pedestrians. Unfortunately, like the NCHRP study, it too fails to address how these performance measurements fit into a larger evaluation of a transportation network. Roess and Prassas (2014) highlight this problem, and argue that as more and more performance measures have become available, the HCM's overreliance on segment or point metrics like LOS is ill advised. They contend that facility-level or system-level measures, such as travel time reliability, should supplement these traditional indices, giving planners and analysis a more complete understanding of transportation performance. Perhaps most saliently, Roess and Prassas maintain that the current usage of LOS as a catch-all metric to cover multiple modes and multiple units of analysis needs to be rethought. While LOS certainly has a place in assessing transportation performance, it should not, in Roess and Prasaas's opinion, be the end-all, be-all evaluation tool.

5.3 Creating New, More Holistic Measures

While the above efforts are notable for their movement away from existing metrics, other studies have sought to address inter-modal measurement issues by pressing for new metrics that are more inclusive and more reflective of larger societal goals. This trend marks an important shift away from an assessment of transportation inputs and outputs as the ultimate goal, and toward a focus on the actual outcomes that transportation systems produce. Instead of strictly measuring costs, capacities, or volumes, this new research instead concentrates on assessing how effectively the transportation system aids in creating safe, equitable, and ecologically sustainable communities in a more holistic manner.

Central to this holistic assessment is, not surprisingly, the development of measurement tools that can estimate how individual transportation modes combine to have a larger, cumulative effect on the regions which they serve. Traditional analyses of single modes are often characterized by a focus on the data available to planners of that mode, and the ability of those planners and engineers to influence policy outcomes (DeRobertis et al., 2014). As such, these metrics might ignore factors which may be essential to the health of the overall transit system, or to the health of the surrounding community.

New research, however, instead of relying upon single-mode indicators such as LOS, looks to place transportation assessment in a larger social context. Florida's *Expanded Transportation Performance Measures to Supplement Levels of Service (LOS)* (Elefteriadou et al., 2012), for example, urges planners to first define the specific transportation-related goals of their community—be they reduced ecological impact, increased transit ridership, or enhanced safety—and then select multi-modal performance measures that are designed to support the pursuit of these objectives. The authors argue that this process will help planners and policy makers craft a transportation system that supports broader public aims, rather than seeking to maximize the performance of a single transportation mode.

Similarly, Caltrans' Smart Mobility Framework document (Caltrans, 2010) speaks to challenges such as a growing population, climate change, and social equity concerns, and lays a foundation for Caltrans and other agencies to understand the interaction of transportation and land use decisions on these issues, and make decisions that support goals much broader than merely providing transportation: specifically a safe, accessible transportation system that uses land and resources responsibly, and serves disadvantaged communities.

Black et al. (2002) argue for a similarly broad view of transportation planning. Based on existing research, the authors develop sustainable transportation indicators—including measurements of economic, social, and environmental sustainability—and use a case study of Sydney, Australia to illustrate its analytical utility. The authors point out that their individual metrics allow planners to concretely assess how transportation policies contribute to the larger goal of urban sustainability.

Levine et al. (2012) add an important dimension to the performance measurement discussion by focusing on accessibility—as opposed to mobility—when assessing transit system performance. While a good deal of commonly used performance metrics measure how far and fast people move through a transportation network (mobility), Levine et al. argue that what really must be evaluated is the ability of the network to connect people with their destinations (accessibility). The authors examine the connection between speed, destination proximity, and urban form in order to demonstrate that low speeds and high volumes—outcomes that, using traditional metrics, might signify poor performance—may actually result in higher levels of accessibility. Such accessibility calculations are particularly important not only because they have the potential to account for all modes within a single metric, but also because they more accurately assess the ultimate purpose of a transportation system: moving people from origins to destinations.

5.4 Multimodal Performance Measures: Obstacles to Implementation

Given the limitations of traditional transportation performance measurement, the case for implementing multimodal performance measures is a strong one. The above research has demonstrated that transportation performance assessment all too often focuses on a single mode. This narrow focus provides planners, engineers, and public officials with an incomplete picture of overall system performance, and can lead to decisions that prioritize the performance of one mode at the expense of all others.

Yet while the benefits of multimodal performance assessment have been well documented, their implementation has been slow to catch hold. To be sure, a central factor in this tendency to use single-mode metrics rests with the dominance of the private automobile in many communities across the country. As Elefteriadou et al. (2012) point out, because transit and pedestrian travel account for a relatively small transportation mode share in many jurisdictions, officials have little incentive to integrate non-roadway performance measures into their current planning practices. Consequently, car-centric evaluation methods continue to dominate, cross-agency cooperation remains limited, and transportation systems continue to be evaluated largely by their individual parts.

Another factor which makes implementing new performance assessment schemes difficult is the nature of public funding for transportation systems. In many cases, both state and federal funding for transportation is tied to the collection and dissemination of “traditional” performance data. Just as roadway operators are required to report volume and capacity data to the Highway Performance Monitoring System, transit agencies are similarly obligated to provide service input, service output, and service consumption data to the National Transit Database. Therefore, because transportation budgets are so closely intertwined with data collection and performance assessment requirements, agencies have little incentive to put their fiscal wellbeing at risk by implementing unfamiliar, unproven, and potentially costly measurement policies.

This disincentive to implement more holistic transportation performance metrics is exacerbated by the extraordinary complexity of both transportation systems themselves, and the towns, cities, and regions in which they operate. As was discussed in the Introduction section, transportation networks—and even individual modes—are often constructed, maintained, and operated by a variety of different agencies. A single trip in a car, on a bus, or on a train will almost certainly have been made possible by the management and financial outlays of numerous parties. Because these groups have access to divergent resources and generally have different (and in many cases competing) interests, marshalling the cooperation necessary to implement unfamiliar multimodal performance measures is a daunting task.

Adding to the difficulties posed by the numerous agencies responsible for a transportation network is the fact that virtually every transportation system, in one way or another, traverses multiple jurisdictional boundaries. Whether it is a rural highway crossing a county line, or a metropolitan transit authority operating in numerous independent cities, transportation planning inevitably involves cooperation between political entities. The concerns raised by the need for inter-jurisdictional cooperation are the same as those faced by efforts to cooperate across agencies. Resources may be unequally distributed, knowledge may be dissimilar, and most importantly, objectives may be different—or potentially at conflicting—between jurisdictions served by the same transportation network.

The magnitude of these inter-agency and inter-jurisdictional challenges is highlighted in a National Cooperative Highway Research Program (NHCRP) report entitled *Multimodal Corridor and Capacity Analysis* (1998). In an effort to ultimately close the performance measurement gap between modes, four case studies investigate how the various agencies and jurisdictions in a given area might work together to improve transportation performance measurement. In doing so, they also demonstrate the complexity of such an effort. Each case study outlines numerous financial, logistical, and political obstacles that must be overcome in order to establish a multimodal assessment scheme—obstacles that local participants may or may not be willing to address. Additionally, each of the case studies address a *single corridor* in a given transportation network. The cooperation necessary to address the multimodal assessment needs of the entire area's transportation network would undoubtedly be a far more complex undertaking than those described in this report.

6.0 Implications for Integrated Corridor Management

As discussed, multimodal performance measures are problematic and there is no single, unified measurement for performance that works well in assessing both freeway and transit operating together as in an ICM context. It may be that such single performance measures are not necessarily desirable for ICMs in any case; as ICMs have a number of individual but interrelated goals, a single measurement would not accurately capture or reflect the performance of the corridor as measured against those goals. Instead, the effectiveness of ICM can be measured through individual metrics relating to their safety, congestion, speeds, and (transit) passenger counts.

7.0 ICM-oriented performance measures

FHWA guidance indicates performance measures should be user-facing, i.e., "include metrics that users of the transportation system experience directly, such as travel time between points." (FHWA, 2006)

Characteristics of good performance measures, as defined by FHWA, include the following (FHWA, 2006):

- Clearly understood
- Measurable
- Sensitive to modes (person-based)
- Time-based (traveltime or speed, not volume-to-capacity ratio)
- Link- or trip-based (to provide system monitoring)
- Sensitive to time period (at least hourly)
- Not too difficult or costly to collect
- Can be forecast into the future
- Sensitive to the impact of congestion mitigation strategies (on people and/or goods)

The following are select performance measures that have the characteristics described above, have been used in previous ICM projects, and are applicable to the Caltrans projects described in Deliverable 2: List of Selected Highway Corridors. The performance measures are categorized by the goals outlined in Deliverable 1: Literature Review.

7.1 Reduce travel time

7.1.1 Average and Maximum Travel Time

Measuring maximum and average travel times for users of the corridor is a fundamental metric for determining how conditions are changing over time, in response to changes in transit service, transit interfacing, or other ICM corridor improvements. Average travel time is a performance measure corridor users are likely to intuitively understand, although travel time reliability (discussed below) is even more important for perceptions of service quality. Travel times are also inputs to delay and variability performance measures (US DOT, 2008a).

7.1.2 Vehicle/person Hours Traveled

Vehicle hours traveled is a commonly used volume-based metric based on distance and travel times. Person hours traveled is a similar mode-neutral measure that can account either for transit occupancy (when those data are available) or average vehicle occupancy. Person hours better captures the utility of the corridor for moving people.

7.1.3 Delay

Delay is defined as the "total observed travel time less the travel time under non-congested conditions" (US DOT, 2008a). Delay can be reported in units of vehicle-hours or person-hours. The threshold for delay is usually considered to be 35 mph on freeways (or the 85th percentile of travel speed or the speed limit on arterials) and is calculated with the formula (US DOT, 2008a):

(Vehicles affected per hour) x (distance) x (duration) x $\left[\frac{1}{congested\ speed} - \frac{1}{35\ mph}\right]$

7.2 Reduce Travel Time Variability (Increase Reliability)

"Results from the ICM AMS effort indicate that corridors that implement ICM can expect greater travel-time reliability and corridor network productivity along with reduced emissions. Travelers can expect improved predictability of their travel within the corridor and lower fuel consumption." (FHWA, 2012).

7.2.1 Buffer Index

A buffer index accounts for the amount of extra time travelers need to be on time 95% of the time they take trips on the corridor (equivalent to one late day per month). This measure of reliability is distance and time neutral; travelers can multiply by their average trip time by the index to arrive at the amount of time that will ensure an on-time arrival 95% of the time (US DOT, 2008a). The index is a useful measure for reliability: a lower index score indicates greater reliability in travel time, which commuters perceive as more important than average travel time (US DOT, 2008b).

7.2.2 Transit Schedule Adherence

The measure of what percent bus transit vehicles or rail transit vehicles are late within the corridor is an indicator of how both traffic conditions and transit operations independent of traffic are affecting travel time reliability in the corridor. This is an important measure next to the buffer index and delay for assessing corridor users' experience.

7.3 Increase Corridor Throughput

7.3.1 Person Miles Traveled

Similar to vehicle-miles traveled (VMT), person-miles traveled (PMT) is a volume-based measure based on distance and travel time (US DOT, 2008b). Unlike VMT, PMT can account for transit, carpool, and vanpool passengers where occupancy data (or averages) are available. PMT gives a more complete picture of corridor usage especially when presented with data on speeds or delay, because they are not necessarily correlated: PMT volumes can be higher when speeds are lower and vice versa.

7.3.2 Travel Time Index

The travel time index, a ratio of travel times in the peak period to a target, free-flow, or acceptable travel time standard, indicates how much longer trips can be expected to take in the peak period (US DOT, 2008a; US DOT 2010).

7.3.3 Queue Wait Time

The amount of time vehicles (including transit vehicles) are stopped at intersections as a measure can help identify where bottlenecks are occurring and/or where throughput and transit throughput could be improved.

7.3.4 Ridership

Transit ridership on the corridor is an important measure for determining to what extent transit service is contributing to corridor throughput and how well ICM initiatives to enable intermodal travel decisions are working.

7.4 Improve Incident Management

Through the active monitoring of corridor traffic and transit conditions, one of ICM's benefits is that, with proper coordinated traffic incident management (TIM), collisions can be responded to quickly, and traffic can be expeditiously slowed down, diverted, or otherwise managed, thus preventing secondary collisions that would cause further delay. Because collisions are a major source of congestion, reducing their number not only improves safety but also average corridor speeds, travel reliability, and throughput. Therefore, incidents and clearance times are an important performance measure for ICM corridors (Brewster et al., 2016).

7.4.1 Incident Detection Time

The time between when an incident occurs and it is detected is a useful measure of how well deployed ICM technology and processes are working.

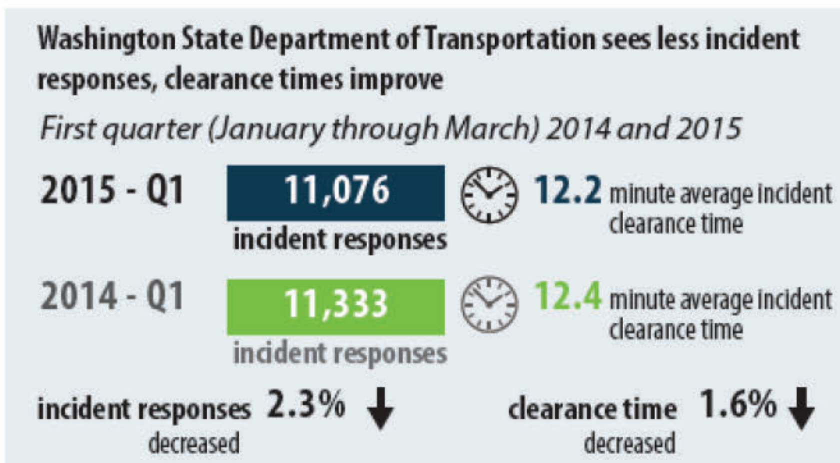


Figure 2: Incident and response time measures from WSDOT Gray Notebook (Brewster et al., 2016)

7.4.2 Incident Response Time

The time between when an incident is detected and responders are on the scene is a useful measure of ICM communications technology and deployment strategies.

7.4.3 Incident Clearance Time

The time between when responders are at the incident site and when it has been cleared is an important measure since crashes are a significant cause of recurrent congestion and a cause of secondary crashes (Brewster et al., 2016).

7.4.4 Number of Secondary Crashes
The number of secondary crashes that occur upstream in proximity of a primary accident is a measure that can help identify where incident clearance could be improved.

7.4.5 Incident Impact on Capacity
Related to response times and secondary crashes, the observed effect of incidents on upstream traffic as observed through roadway sensors is a useful measure for determining the effects of incidents on traffic and what is recurrent traffic as opposed to incident traffic. These data are potentially valuable inputs to ICM Decision Support Systems (see Deliverable 3).

7.4.6 Time-To-Traveler Notification
Collecting data on the percentage of closures and incidents for which information on alternative modes and routes is disseminated, and the time elapsed in issuing such alerts, is useful for assessing how effective ICM communications capabilities are being deployed.

7.5 Enable intermodal decisions
7.5.1 Boardings At Park And Ride Stations
Information on the number of transit boardings at park and ride stations is a measure that can indicate how well the ICM corridor is communicating intermodal decisions and facilitating them.

7.5.2 Average Parking Availability at Park and Ride Stations
Information on the number of parking spaces available or occupied at park and ride stations is a useful measure for determining the appeal and effectiveness of transit service in the corridor. If occupancy data are available in real-time, they can be used to manage capacity.

7.5.3 Travel Times by Mode
Comparing travel times for the general purpose lanes, HOV/HOT lanes, corridor bus transit, corridor rail transit provides a systems-level performance measure of intermodal opportunities available to corridor travelers.

7.5.4 Percentage of Drivers Changing Mode
As a performance measure, the extent of mode shift to transit that is occurring would indicate the effectiveness of an ICM corridor's ATIS system and successful coordination between modes, whether by service improvements, useful station locations, and well-placed park and ride lots. Measuring mode shift is done by using simulation modeling with inputs of transit travel times (calculated by network segment) at key decision points in the corridor. A "pivot-point mode shift model" has been developed that allows a corridor-level analysis of transit in an ICM setting and accounts for "the interrelation of impacts with the traffic operations in the corridor" (Alexiadis et al., 2009).

7.6 Environmental Metrics

Although emissions and fuel consumption do not relate to the major goals identified in Deliverable 1, they are notable as measures because they were metrics in San Diego's I-15 ICM project, for example (Brewster et al., 2016) and measured for all three demonstration ICM projects (San Diego, Minneapolis, and Dallas)(Alexiadis, 2012). Tons of total mobile emissions saved annually is another environmental metric that is sometimes presented as an ICM performance measurement (Mortensen, 2012).

8.0 Conclusion

This deliverable discussed the complications involved in using metrics for multiple modes, and outlined performance measures used in ICM and UPA corridors, as they apply to goals identified in Deliverable 1.

In Deliverable 5, the performance measures in this document are presented as a matrix and performance measures with interactions between highway and transit modes are discussed.

Although it is important that performance measures be chosen carefully, given their role in assessing performance and their attention-focusing effects, performance measurements may change over time, due to the "evolving process" of corridor operations, changes in organizational arrangements, technical implementations, and shifts in policy (Urbanik et al., 2006).

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COMPARING HIGHWAY AND TRANSIT PERFORMANCE MEASURES: VARIABLE MATRIX

Deliverable 5

Investigating Relationships Between Highway System Performance and Transit System Management

Agreement Number 65A0528
Task Order Number TO 011 A01

December 21, 2016

Prepared for Caltrans

UCLA Institute of Transportation Studies

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Contents

1.0 Performance Measure Matrix

The matrix in this deliverable outlines performance measures for both highway and transit modes as described in Deliverable 4; they are grouped by the goals identified in Deliverable 1. Performance measures in italics are measures with some interaction between transit and highway performance and are discussed in Section 2.0.

Goal	Highway	Transit
Reduce travel time/costs	Maximum travel times experienced by travelers[1] Average travel time[2] Vehicle hours traveled[5] Delay (observed travel time – normal travel time)[6]	Maximum travel times experienced by travelers[1] Average travel time[2] Person hours of delay (PHD)[6]
Reduce travel time variability	Buffer index – amount of time travelers need to ensure they are on time 95% of the time[2]	*Transit schedule adherence*[1] Number of transit vehicle breakdowns in corridor[4]
Increase corridor throughput/efficiency	Person miles traveled[6] *Travel time index*[7] Queue wait time at intersections	Person miles traveled[6] Ridership[6] Vehicle capacity utilization[5] Queue wait time at intersections or freeway ramps[6]

Goal	Highway	Transit
Improve incident management	Number of closures when drivers are informed of alternate routes[1] Incident detection time[2] Incident response time[2] Incident clearance time[2] Number of primary crashes[3] Number of secondary crashes[3] Incident impact to capacity[6]	Time-to-traveler notifications for transit riders across the system
Enable intermodal travel decisions	Percent of routes with real-time information reported[1] Average capacity utilization[1]	Boardings at P&R stations *Average parking availability per P&R facility per facility, time of day*[1,2] *Comparison of transit, HOV/HOT, freeway, arterial corridor travel times*[1] Percentage of routes and modes' information reported in real time[1] Percentage of drivers changing mode estimated by survey[1,2] Ridership[5]

[1] "Concept of Operations for the I-394 Corridor in Minneapolis, Minnesota." US DOT, March 31, 2008.
[2] "Concept of Operations for the I-270 Corridor in Montgomery County, Maryland." US DOT, March 31, 2008.
[3] "Interstate 80 Integrated Corridor Mobility Project Concept of Operations." DKS Associates, October 14, 2010.
[4] "Concept of Operations for the I-880 Corridor in Oakland, California." US DOT, March 31, 2008.
[5] "Concept of Operations for the I-15 Corridor in San Diego, California." US DOT, March 31, 2008.
[6] "Concept of Operations – Dallas Integrated Corridor Management (ICM) Management Project." US DOT, December 2010.
[7] "Integrated Corridor Management Analysis, Modeling, and Simulation Results for the Test Corridor." US DOT, June 2008.

2.0 Performance measures with mode interplay

2.1 Transit Schedule Adherence

Poor transit schedule adherence scores correlating *with* highway delay suggest congestion is largely to blame and indicate that solutions such as TSP at ramps, HOT lane access, better lane entry strategies, or bus-only lanes may be warranted.

Poor transit schedule adherence scores *without* corresponding congestion or delay (or at different times) could suggest more operational issues, such as breakdowns, driver/vehicle shortages, excessive dwell times, or “upstream” traffic conditions outside of the corridor that may need investigating.

2.2 Travel Time Index

A high travel time index indicates recurrent congestion delays are significant and opportunities to increase mode shift are likely available; use of dynamic messaging signs comparing HOT lane travel time (if applicable), and transit travel times to freeway travel times may be warranted.

2.3 Average Parking Availability

When data are available in real-time, parking availability can be used to balance corridor capacity. When parking spaces are available, changeable messaging sign (CMS), 511, and other ICM communications technology for pre-trip and en-route traveler information systems can be used to inform drivers of the spaces available and encourage them to change their mode of travel.

2.4 Comparison of Transit, HOV/HOT, Freeway, Arterial Corridor Travel Times

Comparing travel times for the general purpose lanes, HOV/HOT lanes, corridor bus transit, corridor rail transit provides a systems-level performance measure of intermodal opportunities available to corridor travelers.

POLICY BRIEF

Deliverable 6

Investigating Relationships Between Highway System Performance and Transit System Management

Agreement Number 65A0528
Task Order Number TO 011 A01

December 21, 2016

Prepared for Caltrans

UCLA Institute of Transportation Studies

1.0 Problem Statement

This document gives an overview of the process undertaken to evaluate the latest practice in accounting for transit service in freeway planning and concept reports. The main objective was to identify measures that are appropriate for assessing the performance of multimodal transportation corridors. Deliverables from this process are briefly described; select recommendations from the Statewide Transit Strategic Plan are then reviewed and presented with new information uncovered from this undertaking.

2.0 Summary

Although the relative newness of Integrated Corridor Management (ICM) projects and Urban Partnership Agreements (UPAs) means that there is limited publicly available data on program results, the principles, goals, strategies, and performance measures that were developed for the demonstration sites and initial projects are instructive. Their planning and Concept of Operations reports outline many considerations in integrating the modes of transit and highways into one multi-modal, multi-jurisdictional corridor, whose management as a system rather than as separate facilities offers better and more reliable transportation to travelers and goods.

As noted in Deliverable 1, all "pioneer" ICM sites had at least fixed route bus service; some had BRT, commuter rail, light rail, and subway service, too. Transit's high capacity and relative space-efficiency make bus and particularly rail service valuable characteristics in urbanized corridors where travel demand is high and existing land use constrains or complicates further freeway expansion. By emphasizing transit, planners can increase the corridor's throughput while also improving travel time reliability for all corridor users.

The analysis in Deliverable 2 found that many urban corridors in California have existing transit adjacent to congested freeways with sufficient "service density" to warrant integration into a corridor management scheme. Three were found to be especially suitable and were labeled as "top priority." In other less urbanized and rural areas, there was not enough existing transit service to incorporate into ICM; therefore new service in those areas is not likely to be cost-effective and is not recommended.

Having identified where transit would be most easily integrated, the question of how transit is incorporated into ICMs and UPAs was approached in Deliverable 3's examination of three ICM case studies in Dallas, San Diego, and Minneapolis, and one UPA site in Minneapolis. Levels of integration varied: Dallas' ICM Decision Support System (DSS) directs travelers to transit only after shifting them to a frontage and then an arterial road, perhaps due to the relatively small capacity of the light rail system. (Dallas' Concept of Operations Report notes that a (simulated) transit emergency that shut down the rail line in both directions had little effect on freeway traffic.) San Diego's ICM seems to have transit slightly more integrated in the response plans that its DSS generates dynamically when traffic conditions warrant. Minneapolis' UPA project is (as a UPA project) more focused on recurrent congestion than incident-induced traffic; transit is a large part of the project, with contraflow lanes, bypass ramps, expanded park and ride facilities, and freeway running buses. The range of transit integration among these projects is considerable, and indicates there is wide latitude for transit integration in corridors; agency goals and context considerations have more weight than standards (of which there are few). Results from a study of Minneapolis' UPA project indicated transit bus lane changes (to reach freeway median stations) had no significant impact on freeway traffic in free-flowing and moderate traffic conditions, and no lasting impact (over a minute) on freeway traffic in heavily congested lanes.

How well corridors with both transit and freeways are performing as a system is difficult to assess with a single metric. Deliverable 4 describes why unitary measures are problematic and explains that instead measures need to be chosen carefully for the goals and facility context involved. Performance measures that were proposed for ICM and UPA projects are categorized by goal and outlined. Deliverable 5, a matrix, puts these performance measures in relation to prevalent ICM goals and calls out a few specific measures whose use precipitates certain responses, underscoring the need to choose performance measures carefully. For example, the availability of spaces at park and ride lots is a performance measure (that requires the installation of equipment that can report parking occupancy in real-time); these data could be used to on changeable message signs to encourage travelers to switch modes as spaces are available, thereby balancing capacity. But these data could also potentially precipitate pressure to expand park and ride capacity, which may not be a desirable outcome due to possible increase in high-polluting short trips and opportunity costs of these lands. Performance measures can steer decisions and outcomes, so they should be chosen carefully.

3.0 Recommendations relating to the Statewide Transit Strategic Plan

3.1 Re-Purpose Underutilized Space to Transit

As described in the STSP, traffic congestion is costly to transit operators: it drives away riders, increases the ratio of vehicle hours to miles and the cost of each run along a route, and requires more vehicles operating to maintain headways under reduced speed conditions. ICM facilities would improve travel time reliability but may or may not improve travel time. At the same time, transit represents an efficient way to use valuable space in congested contexts, and slow vehicle speeds in congested segments represent substantially reduced vehicle throughput and underutilized traffic lane space. The STSP argues that limiting access to some general-purpose lanes (through HOV, HOT, or transit-only) increases vehicle speeds and the lane's effective vehicle capacity, with the added benefit of increasing people throughput. HOV and tolled lanes are common ICM and UPA strategies (HOT lanes are used in 5 of the 8 pioneer ICM sites) and represent a cost-effective way to increase transit capacity in a corridor that also promotes transit use (through a comparative time-savings advantage to driving in general purpose lanes and cost savings to driving in HOT lanes).

The STSP also recommends allowing transit bus-on-shoulder operations as a highly cost-effective strategy to reduce travel times and increase capacity. A mid-2000s pilot study in San Diego County indicated that this strategy improved travel times, increased customer satisfaction, and led to 99% on-time performance. As discussed in Deliverable 1, Minneapolis' ICM site makes extensive use of shoulder-running transit, with specially-equipped buses that have a lane-keeping driver assist system (DAS).

3.2 Support Local Efforts to Implement Congestion Pricing

UCLA researchers found "conditional support for congestion pricing as a locally-administered policy used in limited applications" per the STSP. Congestion pricing has the benefits of reducing or eliminating traffic congestion on segments, increasing the speed of transit vehicles operating on those segments, and making transit more attractive by giving travelers the option of a quick and reliable journey without paying a toll. Congestion pricing is also a potential revenue source for transit capital and operations funding, which could then be used to support greater corridor throughput.

3.3 Understand the Implications of a Changing Transit Market

As discussed in Caltrans' Statewide Transit Strategic Plan (STSP), deciding how to expand transit use calls for an understanding of the market segments involved. On one end of the spectrum, existing high-propensity transit users who comprise people lacking viable substitutes for transit and some "choice riders" with similar needs; this group is less costly to acquire and maintain. On the other end, low-propensity transit users might use transit occasionally when it is difficult to park or for special events but usually drive; these riders are potentially very expensive to acquire. The STSP notes one of the "growth categories" of riders is a market segment of people drawn by "psychographic motivation," to take transit; this group may be willing to pay for premium services if they are reliable and frequent. One of ICM's signature effects is making travel times more reliable, including for bus services using the corridor. For this market segment, this increase may be an inducement to ride transit on the corridor.

3.4 Work with Other Agencies to Improve the Perception of Transit

STSP recommends a Caltrans-led state-wide campaign to promote transit in the way *Flex Your Power* promotes energy conservation. Targeting high-propensity users—especially the psychographically-motivated—has high potential. ICM corridors are multi-agency endeavors and present an opportunity for Caltrans to pursue such campaigns on a regional level tied to the ICM corridor. ICM ATIS communications systems (e.g., 511, websites, apps, changeable messaging signs) present ready "platforms" for promoting transit.

4.0 Conclusion

Space and capacity have always come at a premium in congested urban corridors. Seeking to provide more reliable travel times and effective capacity, decision makers have turned to technology and improved management techniques since the advent of intelligent transportation systems and the case study results suggest that ICM appears to be effective at improving travel time reliability, a major factor in travelers' perceptions of their trips. Though advanced traveler information system technology, ICM also can provide useful ways to improve information about available transit service. Signal synchronization and transit signal priority can improve bus transit operations at the margin. To significantly improve both transit capacity and corridor throughput, however, additional approaches such as those recommended in the STSP are needed. As noted above and in the literature review (deliverable 1), most pioneer sites have an ICM implementation in conjunction with HOT lanes or tolling to achieve capacity, travel time, and revenue benefits. The demand for travel will continue to increase in California's urbanized areas. Decision makers should work to incorporate improvement management techniques alongside cutting edge technology to meet this growing demand.